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# THE INFLUENCE OF INDOOR ENVIRONMENT IN RESPIRATORY HEALTH AND QUALITY OF LIFE OF OLDER PEOPLE LIVING IN ELDERLY CARE CENTERS

Tese de Candidatura ao grau de Doutor em Ciências Biomédicas, submetida ao Instituto de Ciências Biomédicas Abel Salazar da Universidade do Porto.

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This work was supported by the Portuguese Foundation for Science and Technology (FCT) under the grant SFRH/BD/72399/2010, under the QREN - POPH - Type 4.1 - Advanced Training, subsidized by the European Social Fund and national funds from the Ministry of Education and Science (MEC). This work was also supported by GERIA Project PTDC/SAU-SAP/116563/2010 through Operational Competitiveness Program (COMPETE) as part of the National Strategic Reference Framework.

**‘A goal without a plan is just a wish.’**

*Antoine de Saint-Exupery*

## ACKNOWLEDGMENTS

To my supervisor, Professor João Paulo Teixeira, for the guidance, support and the opportunity to start my research career.

To Professor Beatriz Porto, my co-adviser, for the availability and all the accurate comments.

To Professor Stuart Batterman, for all the support in the early stage of this work.

Per il Professor Stefano Bonassi e il suo team di Epidemiologia Clinica e Molecolare per tutto il supporto nell'analisi statistica dei dati. Inoltre, l'IRCCS San Raffaele Pisana per avermi accolto durante il mio lavoro a Roma.

To Professor Ana Luísa Papoila and Dr. Pedro Martins for all the cooperation, availability and commitment in the statistical analysis and review of the papers.

I especially want to thank the support and collaboration of all my colleagues working in the Unit of Air and Occupational Health that cooperate closely with this project, particularly to Paula Neves, Cristiana Pereira, Susana Silva, Fátima Brandão, Diana Mendes and Luís Guimarães who supported the field monitoring and questionnaires, as well as, the immense amount of laboratory work, calculation and planning.

A special recognition to Lívia Aguiar for all the work putting together the biological contamination article.

To Iolanda, Teresa, Professor Amália Botelho and Professor Nuno Neuparth for all the work and precious knowledge throughout this project, particularly enabling the data quality of the health and quality of life questionnaires.

To all the co-authors, of the articles included in this thesis, I appreciate their cooperation and availability.

To all in the GERIA Project research team, Institute of Public Health of the University of Porto (ISPUP), Nova Medical School and Faculty of Sciences and Technology from Nova University of Lisbon and National Laboratory for Civil Engineering, for technical cooperation in the field of health, buildings and ventilation assessment.

To Fundação para o Desenvolvimento Social do Porto, FP, known as Fundação Porto Social, for welcoming our project ideas and enable the contacts with all the participant institutions in Porto city.

I am indebted to all of the participants in the GERIA Project as well as to the professionals and older people living in the elderly care centers and the authorities from which they depend.

To Joana Madureira for sharing her know-how and perform the review of technical contents.

To Solange Costa and Carla Costa for all the advices and encouragement.

Finally, but always in the first place, a very special and warm acknowledgment to my family, for always be there, for always believe in my work and for always remember me the true values of life.

Dedicado ao Rui, à Beatriz e aos meus pais, esta tese também é vossa…

Ana Sofia Mendes
Porto, Janeiro de 2016

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## LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, which will be referred to in the text by their Roman numerals:

**I.** Ana Mendes, Cristiana Pereira, Diana Mendes, Lívia Aguiar, Paula Neves, Susana Silva, Stuart Batterman, João Paulo Teixeira. Indoor Air Quality and Thermal Comfort - Results of a Pilot Study in Elderly Care Centers in Portugal. Journal of Toxicology and Environmental Health. Part A: Current Issues, 76:4-5, 333-344, 2013.

**II.** Ana Mendes, Stefano Bonassi, Lívia Aguiar, Cristiana Pereira, Paula Neves, Susana Silva, Diana Mendes, Luís Guimarães, Rossana Moroni, João Paulo Teixeira. Indoor Air Quality and Thermal Comfort in Elderly Care Centers. Urban Climate 14 (2015) 486-501.

**III.** Lívia Aguiar, Ana Mendes, Cristiana Pereira, Paula Neves, Diana Mendes, João Paulo Teixeira. Biological Air Contamination in Elderly Care Centers: GERIA Project. Journal of Toxicology and Environmental Health, Part A: Current Issues, 77:14-16, 944-958, 2014.

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**V.** Ana Mendes, Ana Luísa Papoila, Pedro Martins, Lívia Aguiar, Álvaro Silva Ribeiro, Stefano Bonassi, Iolanda Caires, Teresa Palmeiro, Amália Botelho, Nuno Neuparth, Cristiana Pereira, Paula Neves, João Paulo Teixeira. The Influence of Thermal Comfort on the Quality of Life of Nursing Home Residents. Submitted to Indoor and Built Environment (2016).

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The present work also contains techniques and/or data also presented in the following scientific papers:

- Pedro Carreiro-Martins, Joana Gomes-Belo, Ana Luísa Papoila, Iolanda Caires, Teresa Palmeiro, João Gaspar- Marques, Paula Leiria-Pinto, Ana Sofia Mendes, João Paulo-Teixeira, Maria Amália Botelho, Nuno Neuparth. Chronic Respiratory Diseases and Quality of Life in Elderlies. Chronic Respiratory Disease (2016). DOI: 10.1177/1479972316636990.

- Aelenei, D., Nogueira, S., Viegas, J., Mendes, A., Cano, M., Cerqueira, F. Caracterização Experimental das Taxas de Renovação Horária em Residências para Pessoas Idosas - Resultados Preliminares do Projeto GERIA. PATORREB 2015 - 5ª Conferência sobre Patologia e Reabilitação de Edifícios, 26-28 de Março de 2015.

- A. Mendes, A. L. Papoila, P. Martins, I. Caires, T. Palmeiro, L. Aguiar, C. Pereira, P. Neves, S. Costa, J. Teixeira. Health Impact of Indoor Air quality on Elderly living in Care Centres located in Porto city. Eurotox 2015 - 51st Congress of the European Societies of Toxicology. 13-16 September 2015, Porto, Portugal. Toxicology Letters 10/2015; 238(2):S125-S126. DOI:10.1016/j.toxlet.2015.08.398.

- Ana Mendes, Ana Luísa Papoila, Pedro Martins, Iolanda Caires, Teresa Palmeiro, Lívia Aguiar, Cristiana Pereira, Paula Neves, Amália Botelho, Nuno Neuparth, João Paulo Teixeira. O Impacto do Ambiente Interior na Saúde Respiratória dos Idosos - Resultados Preliminares do Projeto GERIA. Boletim Epidemiológico Observações, Nº temático 4 - Saúde Ambiental. 2014. ISSN 2182-8873.

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- Ana Mendes, Lívia Aguiar, Cristiana Pereira, Paula Neves, Susana Silva, João Paulo Teixeira. 2014. Qualidade do ar interior em lares de idosos em Portugal, Projeto GERIA. Boletim Epidemiológico Observações, Volume 3 - Número 9, Julho - Setembro 2014. Instituto Nacional de Saúde Doutor Ricardo Jorge, IP. ISSN: 0874-2928 | ISSN: 2182-8873.

- Ana Mendes, Daniel Aelenei, Ana Luísa Papoila, Pedro Martins, Lívia Aguiar, Cristiana Pereira, Paula Neves, Susana Azevedo, Manuela Cano, Carmo Proença, João Viegas, Susana Silva, Diana Mendes, Nuno Neuparth, João Paulo Teixeira. 2014. Environmental and Ventilation Assessment in Children Day Care Centers in Porto: The ENVIRH Project. Journal of Toxicology and Environmental Health, Part A. ISSN: 1093-7404. DOI:10.1080/15287394.2014.911134.

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- Ana Mendes, Pedro Martins, Ana Luísa Papoila, Iolanda Caires, Teresa Palmeiro, Lívia Aguiar, Cristiana Pereira, Paula Neves, Amália Botelho, Nuno Neuparth and João Paulo Teixeira. Quality of Life. In: J. P. Teixeira *et al*. (Eds), Geriatric Study in Portugal on Health Effects of Air Quality in Elderly Care Centers. Instituto de Saúde Pública da Universidade do Porto, September 2015, ISBN: 978-989-98867-7-3 (ebk).

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- Taylor & Francis Book Awards - Oral Presentation: Ana Mendes, Lívia Aguiar, Diana Mendes, Cristiana Pereira, Susana Silva, Luís Guimarães, Maria P. Neves, João P. Teixeira. The effects on health of Indoor Air Quality and Thermal Comfort in elderly care centers. International Conference on Occupational & Environmental Toxicology (ICOETox 2013). 16th & 17th September. Porto. Portugal (2013).

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## LIST OF ABBREVIATIONS

ASHRAE - American Society of Heating Refrigerating and Air-Conditioning Engineers

BOLD - Burden of Obstructive Lung Disease

BRI - Building-related illnesses

$CO_2$ – Carbon dioxide

CO - Carbon monoxide

COPD - Chronic obstructive pulmonary disease

CT – Conforto Térmico

ECC – Elderly care centers

ERPI - Equipamentos residenciais para pessoas idosas

ETS - Environmental tobacco smoke

EU - European Union

GDP - Gross Domestic Product

HVAC - Heating, ventilation, and air conditioning

IAQ - Indoor air quality

IEQ - Indoor environmental quality

LTC - Long-Term Care

$NO_2$ - Nitrogen dioxide

PM - Particulate matter

$PM_{2.5}$ - Particulate matter with an aerodynamic diameter smaller than 2.5 µm

$PM_{10}$ – Particulate matter with an aerodynamic diameter smaller than 10 µm

PMV – Predicted mean vote

PPD - Predicted percentage dissatisfied

ppm - Parts per million

PSSI - Private Social Solidarity Institution

QoL - Quality of life

QV – Qualidade de Vida

SBS - Sick building syndrome

SCMP - Santa Casa da Misericórdia do Porto

$SO_2$ - Sulphur dioxide

TC - Thermal comfort

TVOC - Total volatile organic compounds

VOC - Volatile organic compounds

WHO - World Health Organization

WHOQOL-BREF - WHO Quality of Life-BREF

WHOQOL Group - World Health Organization Quality of Life Group

## ABSTRACT

The mean age of the European population is rising and percentage of adults aged 65 years and older is projected to increase from 16% in 2000 to 20% in 2020. It has been estimated that older subjects spend approximately 19 to 20 h/day indoors. Older individuals may be particularly at risk for detrimental effects from pollutants, even at low concentrations, due to reduced immunological defenses and multiple underlying chronic diseases.

This cross-sectional study explored environmental variables and buildings characteristics in 22 elderly care centers (ECC) out of a total of 58 institutions in Porto, Portugal. Indoor environmental parameters were measured twice during summer and winter from November 2011 to August 2013 at a total of 141 sampling sites within dining rooms, drawing rooms, medical offices, and bedrooms (including the bedridden). Each site was assessed for $PM_{10}$, $PM_{2.5}$, total volatile organic compounds (TVOC), formaldehyde, CO, $CO_2$, total bacteria and fungi. Thermal comfort (TC) parameters were measured according to ISO 7730:2005 and a building characterization was performed. Mean radiant temperature, predicted mean vote (PMV) and predicted percent of dissatisfied people (PPD) indices and the respective measurement uncertainties were calculated by Monte Carlo Method.

To evaluate the influence of indoor environment parameters on older people's respiratory health and quality of life (QoL), 21 of the former ECC accepted to participate in the health and QoL questionnaire administered by an interviewer to older residents able to participate (n=143). The standardized and validated Portuguese versions of BOLD and WHOQOL-BREF questionnaires were conducted from September 2012 to April 2013, along the winter season sampling campaign.

Mixed effects logistic regression models were used to study the association between the health, QoL questionnaire results and the monitored indoor environmental parameters. In this sense, 135 rooms were considered to study the association between the health questionnaire results and the indoor variables, adjusted for age, smoking habits, gender and number of years living in the ECC, and 130 rooms were acknowledged to study the influence of TC in older people QoL.

The leading indoor environment results showed overall $PM_{2.5}$ mean and median concentration of the 22 ECC above international reference levels in summer and winter seasons. TVOC, bacteria, CO and $CO_2$ showed significantly higher indoor levels compared to outdoor, in both seasons. Indoor $PM_{10}$, TVOC, bacteria and $CO_2$ present

significant differences between seasons and peak values exceeded the reference levels, compromising indoor air comfort. TVOC, bacteria and $CO_2$ show significant variation between ECC rooms. In winter, mean fungi concentration exceeded reference values, while bacteria concentrations were within the new Portuguese standards in both seasons. The main fungi species found indoors were *Cladosporium* (73%) in summer and *Penicillium* (67%) in winter. *Aspergillus fumigatus*, *Aspergillus niger*, and *Aspergillus flavus*, known potential pathogenic/toxigenic species, were also identified. Although the overall rate and mean values of bacteria and fungi found in ECC indoor air met Portuguese legislation, some concern is raised by the presence of pathogenic microorganisms. The winter PMV index showed a 'slightly cool' thermal sensation scale which may potentiate respiratory tract infections. The PPD and PMV indices also showed significant differences by season. The building variables 'Insulation', 'Heating Ventilation' and 'Windows frames' were significantly associated to chemical, biological and TC parameters. 'Bacteria', 'Fungi', 'Temperature', Relative Humidity', and 'PPD index' are the mostly affected by building characteristics.

Cough (23%) and sputum (12%) were the major respiratory symptoms, and allergic rhinitis (18%) the main self-reported illness among the interviewed elderly living in the ECC. Older people exposed to $PM_{10}$ above the reference levels demonstrated higher odds of allergic rhinitis (OR=2.9, 95% CI: 1.1–7.2). Therefore, high levels of $PM_{10}$ were associated with 3-fold odds of allergic rhinitis. No association was found between indoor air chemical and biological contaminants and respiratory symptoms.

The influence of winter season TC in older people QoL results showed that values of PMV above -0.7 had higher mean score of QoL (coefficient estimate: 11.13 units) when compared with values of PMV below -0.7.

The results suggest a need to improve the balance between indoor air quality (IAQ) and TC in ECC, a critical environment housing a susceptible population. Simple measures, like opening windows and doors to promote air exchange and renewal, may improve effectiveness in enhancing IAQ. Insulating ceilings, walls, and windows could improve winter season TC, providing health benefits to ECC residents.

## RESUMO

Os idosos representam uma população suscetível apresentando um sistema imunológico mais enfraquecido e uma maior prevalência de doenças crónicas e de problemas respiratórios. Estudos indicam que esta faixa etária da população passa cerca de 19-20 h/dia em ambientes fechados tornando-se mais vulneráveis a complicações de saúde associadas à poluição do ar interior. Para além da qualidade do ar interior (QAI) também o ambiente térmico é um fator chave que pode afetar o conforto, a saúde e o bem-estar dos ocupantes. Esses efeitos podem resultar no aumento do uso de medicação e visitas ao médico, bem como, no acréscimo de admissões em hospital e mortes prematuras.

Nesse sentido, o objetivo principal deste estudo transversal consistiu na avaliação da relação entre a qualidade do ambiente interior e a saúde respiratória em populações suscetíveis, promovendo a qualidade de vida (QV) nos idosos residentes em equipamentos residenciais para pessoas idosas (ERPI). A seleção da amostra a estudar na cidade do Porto foi efetuada por conveniência, sendo convidadas a participar todas as ERPI inscritas na 'Carta Social'. De um total de 58 instituições aceitaram participar no estudo n=22. A recolha dos dados nas instituições decorreu entre novembro 2011 a agosto 2013. Cada lar de idosos foi estudado nas seguintes componentes: (i) visita de caraterização do edificado e ventilação; (ii) avaliação de parâmetros ambientais em duas estações do ano (verão e inverno), incluindo agentes químicos [partículas suspensas no ar $PM_{10}$ e $PM_{2.5}$, dióxido de carbono ($CO_2$), monóxido de carbono (CO), formaldeído e compostos orgânicos voláteis totais (COVT)] e agentes biológicos (bactérias e fungos). Em cada lar foram efetuadas amostragens em espaços interiores (sala de convívio, sala de refeição, quartos e gabinete médico) e no exterior para comparação. A avaliação dos índices do conforto térmico (CT) [voto médio previsto (PMV) e percentagem prevista de insatisfeitos (PPD)] foi realizada de acordo com a norma ISO 7730:2005. O cálculo da temperatura média radiante, dos índices PMV e PPD e respetivas incertezas foi efetuado pelo método de Monte Carlo.

Os questionários de saúde respiratória (BOLD) e de QV (WHOQOL-BREF) aplicados decorreram entre setembro de 2012 e abril de 2013, durante a fase de inverno do estudo. As versões portuguesas validadas dos questionários foram aplicadas, por entrevista, a todos os idosos residentes (n=143), que deram o seu consentimento informado e que cumpriam os critérios de inclusão do estudo.

Modelos mistos de regressão logística foram utilizados para estudar a associação entre os resultados de saúde, qualidade de vida e os parâmetros ambientais. Neste sentido, 135 áreas avaliadas foram consideradas para estudar a associação entre os resultados dos questionários da saúde e as concentrações dos poluentes do ar interior, ajustado para idade, tabagismo, sexo e o número de anos a residir nos ERPI. Para estudar a influencia dos parâmetros de CT na QV dos idosos foram consideradas 130 áreas estudadas.

A monitorização ambiental nas ERPI apresenta os seguintes resultados: (i) concentrações médias e medianas de $PM_{2.5}$ acima dos valores de referência da legislação nacional e internacional, em ambas as estações analisadas; (ii) COVT, bactérias, CO e $CO_2$ apresentam concentrações interiores significativamente mais altas que no exterior, nos dois períodos avaliados; (iii) $PM_{10}$, COVT, bactérias e $CO_2$ apresentam diferenças significativas entre o verão e o inverno e mostram valores máximos acima das referências nas duas estações; (iv) COVT, bactérias e $CO_2$ mostram variações significativas entre os vários espaços avaliados em cada instituição; (v) as concentrações de fungos no período de inverno não cumprem com as condições de referência estabelecidas e foram identificadas algumas espécies de *Aspergillus* potencialmente toxigénicas nos ERPI estudados; (vi) o índice PMV na estação de inverno, apresenta resultados entre -1 (ligeiramente fresco) e -2 (fresco) na escala de sensação térmica, o que pode potenciar infeções do trato respiratório, particularmente em populações suscetíveis como os idosos. De referir também que vários estudos mostram que os idosos preferem ambientes cerca de 2ºC mais quentes que a restante população, e que a temperatura de conforto para esta população idosa sedentária se encontra acima dos 25ºC; (vii) os índices PPD e PMV mostram também diferenças significativas entre o inverno e verão; (viii) foram encontradas associações significativas entre as caraterísticas do edificado ‘Isolamento Térmico’, ‘Aquecimento’ e ‘Caixilharias Janelas’ e a concentração ambiental interior dos seguintes parâmetros avaliados: ‘bactérias’, ‘fungos’, ‘temperatura’, ‘humidade relativa’ e ‘índice PPD’.

Entre os idosos inquiridos, a tosse (23%) e expetoração (12%) foram os sintomas respiratórios mais comuns e a rinite alérgica (22%) a principal doença reportada. As pessoas idosas expostas a $PM_{10}$ acima dos níveis de referência apresentaram 3 vezes maior probabilidade de ter rinite alérgica (OR=2.9, IC 95%: 1.1-7.2). Para cada aumento de grau na temperatura há uma diminuição de 20% na probabilidade de ter rinite alérgica (OR = 0.8, 95%: 0.6-1.0). Nenhuma associação foi encontrada entre o ambiente interior e sintomas respiratórios.

O estudo da influência do CT na estação de inverno na QV dos idosos mostrou que valores de PMV acima de -0.7 (na direção do zero e, portanto, menos negativos) têm, em média, valores de QV superiores em 11.13 unidades, quando comparados com valores de PMV abaixo de -0.7 (na direção de -3 e, portanto, mais negativos).

Tendo em vista a melhoria da QAI dos ERPI, sugere-se a implementação de medidas adequadas, tais como, sistemas de exaustão local perto de cozinhas e dispositivos de queima de gás, bem como, a limpeza diária ligeiramente humedecida das superfícies dos diversos locais avaliados, por forma a reduzir a acumulação e ressuspensão de partículas. Para uma melhoria da QAI no que diz respeito aos agentes microbiológicos, o controlo da humidade relativa no interior é essencial, de forma a eliminar/diminuir toda a humidade e bolores existentes nas paredes, tetos e superfícies. O número de ocupantes e os seus hábitos são também aspetos importantes para a proliferação de microrganismos. As baixas temperaturas interiores e respetivo desconforto associado, especialmente no inverno, poderá ser evitado por medidas simples, tais como a implementação de isolamento no teto, paredes e janelas, mantendo a ventilação natural e passiva dos espaços, contribuindo assim para a prevenção de efeitos adversos na saúde induzidos pela QAI nesta população suscetível.

# 1. INTRODUCTION

Human health and well-being are intimately linked to environmental quality. The quality of the environment in Europe has improved considerably over recent decades with benefits to human health. European Union (EU) citizens live longer than in many other parts of the world, but health challenges of the ageing population may increase due to lifestyle changes and environmental megatrends (climate change, depletion of natural resources and the disruption of ecosystems services) [1].

One of the major challenges to urban sustainability is the threat posed by exposure to air pollutants, which is associated with various health problems [2]. Air pollution has wide-ranging and deleterious effects on human health and is a major issue for the global community. Among the extended number of chemicals emitted by road traffic sources, hazardous air pollutants require special attention due to growing international recognition of their link with a variety of adverse effects on human health and the need for action to minimize these risks [3]. Recently, the International Agency for Research on Cancer classified outdoor air pollution as carcinogenic to humans [4].

The Global Burden of Disease study has described the worldwide impact of air pollution with as many as 3.1 million of 52.8 million all-cause and all-age deaths being attributable to ambient air pollution in the year 2010 [5]. Moreover, ambient air pollution ranked ninth among the modifiable disease risk factors, being listed above other commonly recognized factors, such as low physical activity, a high-sodium diet, high cholesterol, and drug use. Finally, air pollution accounts for 3.1% of global disability-adjusted life years, an index that measures the time spent in states of reduced health. Although it is intuitive that air pollution is an important stimulus for the development and exacerbation of respiratory diseases, such as asthma, chronic obstructive pulmonary disease, and lung cancer, there is also generally less public awareness of its substantial impact on cardiovascular disease.

Outdoor air pollution is a complex mixture of thousands of components. From a health perspective, important components of this mixture include airborne particulate matter (PM) and the gaseous pollutants ozone, nitrogen dioxide ($NO_2$), volatile organic compounds (VOC) (including benzene), carbon monoxide (CO), and sulphur dioxide ($SO_2$) [6]. Primary pollutants, such as soot particles, and oxides of nitrogen and sulphur, are emitted directly into the air by combustion of fossil fuels. Major sources of $NO_2$ are motorized road traffic, power generation, industrial sources, and residential heating. Secondary pollutants are formed in the atmosphere from other components. An important example is ozone, which is formed through complex photochemical reactions of nitrogen oxides and volatile organic components. Outdoor air pollution varies in time and space. Air pollution shows substantial variability both between areas (higher in Southern Europe) and within areas. Spatial variation is mostly related to the presence of local and regional scale sources. $PM_{2.5}$ concentrations at traffic sites were on average 14% higher than at urban background locations in a large European study [7]. Larger urban-rural differences are found for soot particles (average 38% higher), $NO_2$ (63% higher), and ultrafine particle numbers. Temporal variation of daily average air pollution concentrations is mostly related to weather conditions affecting the dispersion of pollution and less so to variations in the strength of pollutant sources. Important factors include wind direction, wind speed, atmospheric stability, temperature and sunlight. Air pollution concentrations also vary within a day.

Although people in Western societies spend about 90% of their time indoors, predominantly in their own homes, outdoor air pollution (especially $PM_{2.5}$) infiltrates buildings and most of the exposure typically occurs indoors. Even though household pollution is an especially prominent problem in low-income countries where solid fuels are used for cooking and heating, indoor air quality (IAQ) in homes, schools, working places, and other community sites is not a trivial problem in Europe. For instance, the increasing use of biomass burning to heat homes is creating major air quality problems in many Northern European cities. Concerns have also been raised about the emerging contribution of synthetically engineered nanoparticles to indoors air pollution exposure. The INDEX project, performed on behalf of the EU, emphasized the negative role on health played by environmental tobacco smoke (ETS), organic compounds (polycyclic aromatic hydrocarbons, volatile organic substances, formaldehyde, naphthalene), CO and benzo(a)pyrene [8]. Consequently, the World Health Organization (WHO) and the European Commission have drafted guidelines for IAQ risk assessment and management [9-11].

The air one breathes inside buildings dominates overall inhalation exposure of most air pollutants, whether of indoor or outdoor origin [12]. As levels of outdoor ambient pollution have decreased in many areas, the relative impact of indoor air pollution has grown, and thus IAQ has increasingly gained importance. Since levels of pollutants in indoor air are often higher than in outdoor air, the study of exposure of individuals to air pollution is a subject of vital importance. Concern should be focused not only on ambient air contaminant levels, but also on IAQ [13]. Globally, 4.3 million deaths were attributable to household air pollution in 2012, almost all in low and middle income countries. The South East Asian and Western Pacific regions bear most of the burden with 1.69 and 1.62 million deaths, respectively. Almost 600’000 deaths occur in Africa, 200’000 in the Eastern Mediterranean region, 99’000 in Europe and 81’000 in the Americas. The remaining 19’000 deaths occur in high income countries. Although women experience higher personal exposure levels than men and therefore higher relative risk to develop adverse health outcomes due to their greater involvement in daily cooking activities, the absolute burden is larger in men due to larger underlying disease rates in men [14].

Exposure to indoor chemicals, PM, dust and dampness, molds and other biological agents, has been linked to increased prevalence of respiratory symptoms, allergies and asthma as well as perturbation of the immunological system. With the EU 2020 strategy, and particularly its focus on smart growth and resource efficiency, European environment and health policy moves into a more systemic direction. As human demand for the world's natural resources increases and the environmental consequences become more and more manifested, it is imperative that we increase our understanding of the intricate links between environmental conditions and human health and well-being.

# 2. REVIEW OF THE LITERATURE

## 2.1 Indoor Environment Quality and Health

Indoor environments should safeguard and enhance occupant's health, comfort, and productivity, as people spend around 90% of their lives indoors. There is still limited knowledge regarding the causes of symptoms observed in nonindustrial indoor settings such as office buildings, recreational facilities, schools and residences. Indoor environmental quality (IEQ) is influenced by multifactor parameters such as IAQ, thermal comfort (TC), and psychosocial issues (Figure 1). Additionally, the acoustic and visual comfort also influences the IEQ occupant's perception [15] (Figure 2).

There are many indoor parameters (e.g. thermal factors, lighting aspects, moisture, mold, noise and vibration, radiation, smell, chemical compounds and particulates) that can cause their effects additively or through complex interactions (synergistic or antagonistic). It has been shown that exposure to these parameters can cause both short-term and long-term effects. Nevertheless, IEQ is still described with quantitative dose-related indicators, expressed in number and/or ranges of numbers assumed to be acceptable and healthy for people [16].

There is an increasing amount of scientific evidence indicating that a range of health problems and complaints are associated with poor IEQ. The problems range from transient sensory irritation of the respiratory tract to life-threatening diseases. These problems can be generally divided into two categories: Sick building syndrome (SBS) and Building-related illnesses (BRI).

A syndrome is defined by the WHO as 'a collection of signs and symptoms fitting a recognizable pattern'. SBS has been acknowledged by WHO since 1986 and it is defined as 'a syndrome of complaints covering nonspecific feelings of malaise, the onset of which is associated with occupancy of certain modern buildings' [17]. Most researchers agree that SBS describes a group of symptoms that have no clear etiology and are attributable to exposure to a particular building environment. SBS is related to both personal and environmental risk factors and affect building occupants over an indefinite period being directly connected with the building itself. In the office environment, SBS may have important economic implications. More focus is needed on the indoor environment in schools and day care centers, hospitals and nursing homes for elderly. Improvements of the home environment may be the most cost-effective way to reduce the burden of indoor exposure. The link between indoor and outdoor air pollution should not be neglected, and the role of energy saving and climate changes will be an important future issue [18].

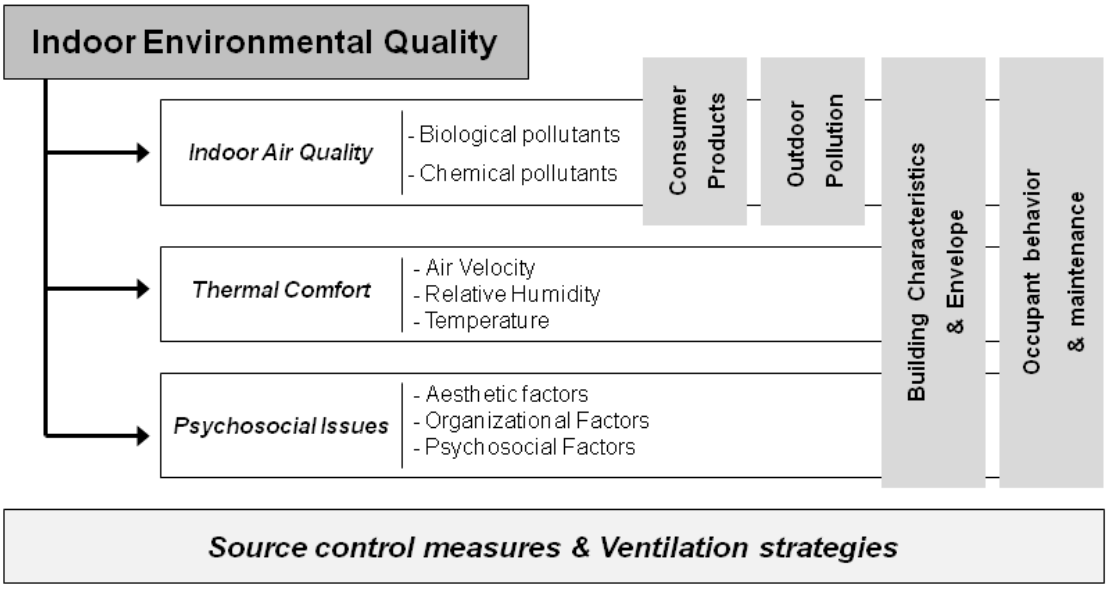


Figure 1. IEQ and its influencers' multifactor parameters [19]

Differing from SBS, BRI, refer to a pathological condition, harmful not only to the regular, everyday occupants, but also to visitors and passers-by. BRI includes sicknesses such as Legionnaires disease, which may be contracted as a direct result of entering a building and, unlike SBS, continues to have an effect after the sufferer has vacated the building. In opposite to SBS, BRI can be specifically diagnosed and can be classified into three groups: airborne infectious diseases, hypersensitivity diseases, and toxic reactions. Some building-related infectious diseases are transmitted through indoor air; for example, Pontiac fever, Legionnaires' disease, histoplasmosis, tuberculosis, measles, rubella, chickenpox, influenza, and the common cold caused by adenoviruses and some rhinoviruses. With the exception of Pontiac fever and Legionnaires' disease, which are spread from environmental sources, the risk of transmitting these diseases increases as building occupant densities increase.

The symptoms characterizing SBS, first noted in the 1950s, appeared to be correlated with the development of post-war, energy efficient, airtight buildings, at a time when the architects' main brief was to keep costs low.

The reported common symptoms of SBS compiled by WHO include eye, nose and throat irritation; sensation of dry mucous membranes; dry, itching, and red skin; headaches, mental fatigue and loss of concentration; high frequency of airway infections and cough; hoarseness and wheezing; nausea and dizziness; and unspecific hypersensitivity. These symptoms may occur singly or in combination with each other and have a characteristic periodicity increasing in severity over the working shift and resolving rapidly on leaving the building in the evening. Most manifestations, therefore, with the exception of some cutaneous symptoms, improve over weekends and all symptoms usually disappear on holiday.

The diagnosis of SBS requires a demonstration of an elevated complaint or symptom prevalence associated with a particular building. The term SBS should be restricted to multi-factorial problems, where no single cause factor exceeds the level of generally accepted recommendations. Many possible causes of SBS have been suggested, with the majority of explanations focusing on air quality (Figure 2) within the building and the systems that are used to ventilate the building. Other factors that have been implicated are artificial lighting, noise, TC (Figure 2), occupant's activities, stress and psychological effects, workplace maintenance and workstation layout (Figure 1).

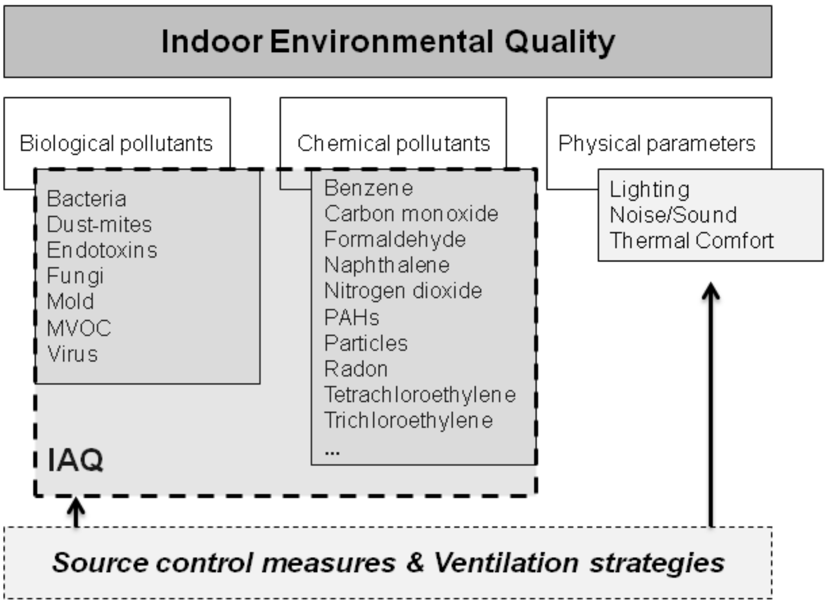


Figure 2. Relations between IAQ and IEQ [19]

A susceptible and aging population brings with it all of the older people diseases, such as cancer, immunological disorders, cardiovascular problems, bone frailty, and skeletal and muscular structure degeneration. Therefore, the people who are generally least aware of the risks posed to their health are also the ones most vulnerable to hazards. This situation is further exacerbated by the increased amount of time elders spend indoors [20]. It has been estimated that older persons spend approximately 19–20 h/day indoors [21], and many spend all their time indoors in elderly care centers (ECC). To the extent of that the workforce is also aging, IEQ and safety should continue to become more important in the design and construction of facilities.

## 2.2 INDOOR PARAMETERS SOURCES AND HEALTH EFFECTS

The quality of air inside homes, offices, schools, day care centers, public buildings, health care facilities or other private and public buildings where people spend a large part of their life is an essential determinant of a healthy life and well-being. Hazardous substances emitted from buildings, construction materials and indoor equipment or due to human activities indoors, such as combustion of fuels for cooking or heating, lead to a broad range of health problems and may even be fatal [9].

According to the United Nations estimates, the total number of people aged 65 years and older was 506 million in 2008 and is anticipated to double to 1.3 billion by 2040, accounting for the 14 percent of total global population. This trend explains the increasing demand of long-term care services [22] such as ECC. Furthermore, considering that persons who are 65 years or older, often spend a considerable portion of their lives indoors, it is clear that the possibility of adverse indoor climate influencing their health status cannot be ignored. Moreover, older persons may be particularly at risk of adverse health effects from pollutants, even at low exposures, due to multiple underlying chronic diseases. Therefore, the study of IAQ among the elderly is becoming an important research issue.

Indoor air could contain outdoor air pollutants as well as those generated indoors by the occupants and their activities including carcinogens, biological and chemical contaminants. The pollutants released by the building occupants include carbon dioxide ($CO_2$), VOC, microbiological organisms and PM. The indoor air contaminants which can be hazardous to health (Table 1) include CO, dust and fibbers from carpets, ETS - currently narrowed by the indoor smoking ban laws in several developed countries - formaldehyde especially from urea formaldehyde insulation, radon, VOC emanating from solvents, paints, varnishes, adhesives used for furniture and sticking carpets causing long-term and short-term illnesses. Biological contaminants like bacteria, viruses and fungi (due to presence of high humidity) also directly affect the health of the occupants. In a conditioned space, without fresh air intake, free passage of air is limited, thus pollutants tend to accumulate resulting in higher concentration of some contaminants than outdoor ambient air.

Many different factors influence how indoor air pollutants impact occupants. Some pollutants, like radon, are of concern because exposure to high levels of the pollutant over long periods of time increases risk of serious, life threatening illnesses, such as lung cancer. Other contaminants, such as CO at very high levels, can cause “silence death” within few minutes. Some pollutants can cause both short and long-term health problems. Prolonged exposure to ETS can cause lung cancer, and short-term exposures can result in irritation and significant respiratory problems. Table 2 lists a number of environmental and personal factors that directly impact the levels of pollutants to which people are exposed and also affecting how people perceive IAQ.

Table 1. Main indoor air contaminants, their sources and possible health effects. Based on the published literature review performed by [23]

| | **Exposures** | | | | | |
|---|---|---|---|---|---|---|
| **Health Effects** | Combustion Particles | CO | Dampness, mold, dust mites, bioaerosols | ETS | Radon | VOC Indoor Chemistry Products |
| Allergic and Asthma Symptoms | ● | | ● | ● | | ● |
| Lung Cancer | ● | | | ● | ● | |
| Chronic Obstructive Pulmonary Disease | ● | | ● | ● | | |
| Airborne Respiratory Infections | ● | | ● | ● | | |
| Cardiovascular Morbidity and Mortality | ● | ● | | ● | | |
| Odor and Irritation | ● | | ● | ● | | ● |
| **Causes & Sources** | | | | | | |
| Outdoor Air | ● | ● | ● | | | ● |
| Building/Equipment/Ventilation | ● | ● | ● | ● | ● | ● |
| Consumer Products | ● | | | | | ● |
| Occupant behavior & maintenance | ● | ● | ● | ● | ● | ● |

Table 2. Environmental factors affecting the levels of pollutants and perceptions of IAQ

| |
|---|
| **A**ir velocity and movement - too drafty or stuffy |
| **F**eelings about physical aspects of the workplace (location, work environment, availability of natural light, and the aesthetics of office design, such as color and style) |
| **F**urniture crowding |
| **G**lare from ceiling lights, especially on monitor screens |
| **H**eat or glare from sunlight |
| **N**oise and vibration levels |
| **O**dors |
| **S**election, location and use of office equipment |
| **S**tress in the workplace or at home |
| **T**emperature - too hot or cold |
| **W**orkspace ergonomics, including height and location of computer, and adjustability of keyboards and desk chairs |

### 2.2.1 CHEMICAL PARAMETERS

Sources of chemical pollutants include tobacco smoke, emissions from products used in the building, and gases such as CO and $NO_2$, which are products of combustion. Indoor sources of CO include vehicle exhaust from attached garages, gas stoves, furnaces, woodstoves, fireplaces and cigarettes and incense burning. Symptoms of CO poisoning, such as headache, nausea and fatigue, may be mistaken for the flu. ETS is a cause of premature mortality. Living with a smoker is associated with an estimated 20%–30% increased risk of lung cancer [24]. ETS is also associated with a 25%–35% increased risk of coronary artery disease [25]. $NO_2$ is an airway irritant that is emitted mainly during the combustion of fossil fuels. The $NO_2$ indoor sources include combustion appliances such as gas or oil furnaces and stoves. $NO_2$ may move from outdoors to indoors; however, if from an outdoor source, it will be at a lower concentration indoors than if it were generated from an indoor source. Whether chronic exposure to low concentrations of $NO_2$ from indoor sources increases the risk of respiratory illnesses is still unclear [26]. This is shown by the observation that short-term inhalation of high concentrations of $NO_2$ increases bronchial responsiveness to inhaled allergens in sensitized asthmatics. In addition to the direct release of nitrogen oxides, indoor combustion sources emit various co-pollutants including ultrafine particles related with decrease of respiratory function and increase of cardiovascular diseases. Also, secondary reactions, such as the production of nitrous acid from surface chemistry involving $NO_2$, can contribute to indoor pollutant concentrations that directly affect health.

High indoor air VOC levels have also been associated with SBS and low productivity at workplaces [27, 28]. Furthermore, interventions to reduce such levels by increased fresh air exchange, case by case, have been studied to reduce the symptoms and improve performance.

Formaldehyde is a proven airway irritant and is classified by the International Agency for Research on Cancer as a human carcinogen (Group 1) [29, 30]. In indoor environments, formaldehyde is mainly produced by off-gassing from wood-based products assembled using urea-formaldehyde resins (plywood, particle board, medium-density fiberboard). Other sources include cigarette smoke, certain paints, varnishes and floor finishes, or candle or incense burning. Secondary formation of formaldehyde occurs indoors through chemical reactions between, for example, ozone and terpenes. Greater concentrations of formaldehyde were associated with lower fresh air exchange and with painting, varnishing and acquiring new wooden or melamine furniture in the previous 12 months. Associations between residential and school exposure to formaldehyde and respiratory symptoms have been reported in observational epidemiologic studies [9, 23].

PM consists of particles from a wide variety of sources that differ in size and composition. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, carbon, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. Particles are often classified into three major size groups: coarse particles (diameter < 10 and ≥ 2.5 mm), fine particles (diameter < 2.5 and ≥ 0.1 mm), and ultrafine particles (< 0.1 mm) [5]. In regulations, and consequently most monitoring networks, particles are represented by the mass concentration of particles with an aerodynamic diameter smaller than 2.5 mm ($PM_{2.5}$) and 10 mm ($PM_{10}$) (Figure 3). $PM_{10}$ thus includes the fine particles and coarse particle fraction with $PM_{2.5}$ generally representing 50–70% of the total mass of $PM_{10}$. Ultrafine particles are included in $PM_{2.5}$ and $PM_{10}$ as well, typically contributing with a minimal fraction to the mass concentrations, whereas they dominate in particle numbers. Resuspension of soil and road dust by wind or moving vehicles, as well as construction work and industrial emissions, result in coarse particles ($PM_{10}$). Important sources of other primary particles typically include motorized road traffic, power plants, and industrial and residential heating using oil, coal, or wood. These combustion processes result in fine particles ($PM_{2.5}$) composed of elemental carbon, transition metals, complex organic molecules, sulphate, and nitrate, with the latter components being formed in the atmosphere from VOC, $SO_2$ and $NO_2$. Fine particles can travel large distances (> 100 km) resulting in the potential for high background concentrations over a wide area [5].

PM affects more people than any other pollutant [31, 32]. $PM_{2.5}$ are more dangerous since, when inhaled, they may reach the peripheral regions of the bronchioles, and interfere with gas exchange inside the lungs (Figure 4). The effects of PM on health occur at levels of exposure currently being experienced by most urban and rural populations in both developed and developing countries. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer [31].

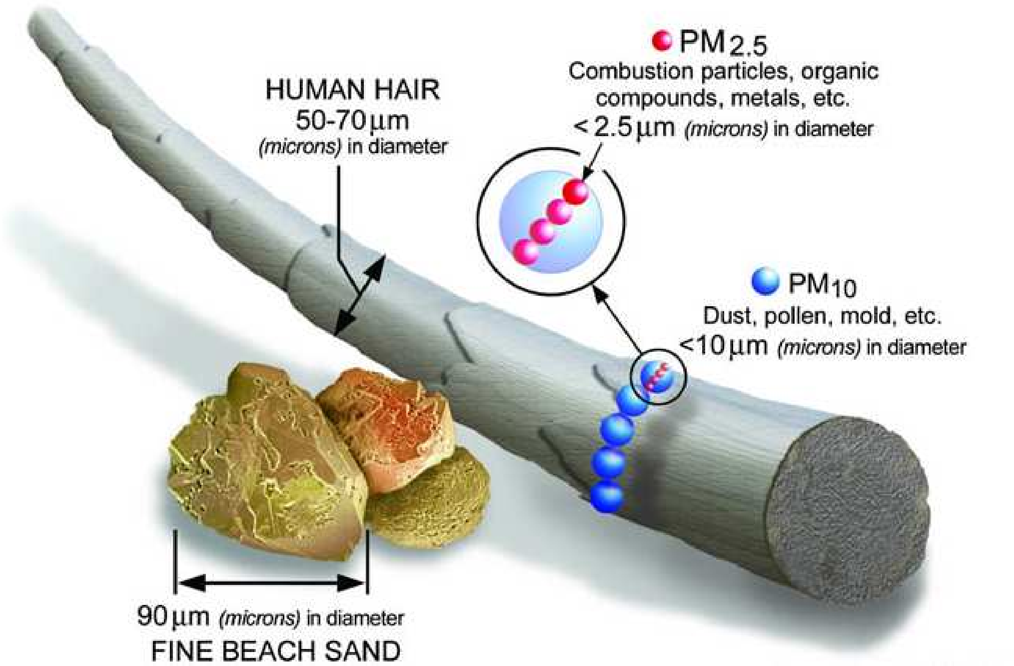


Figure 3. Aerodynamic diameter of difference sizes of PM [33]

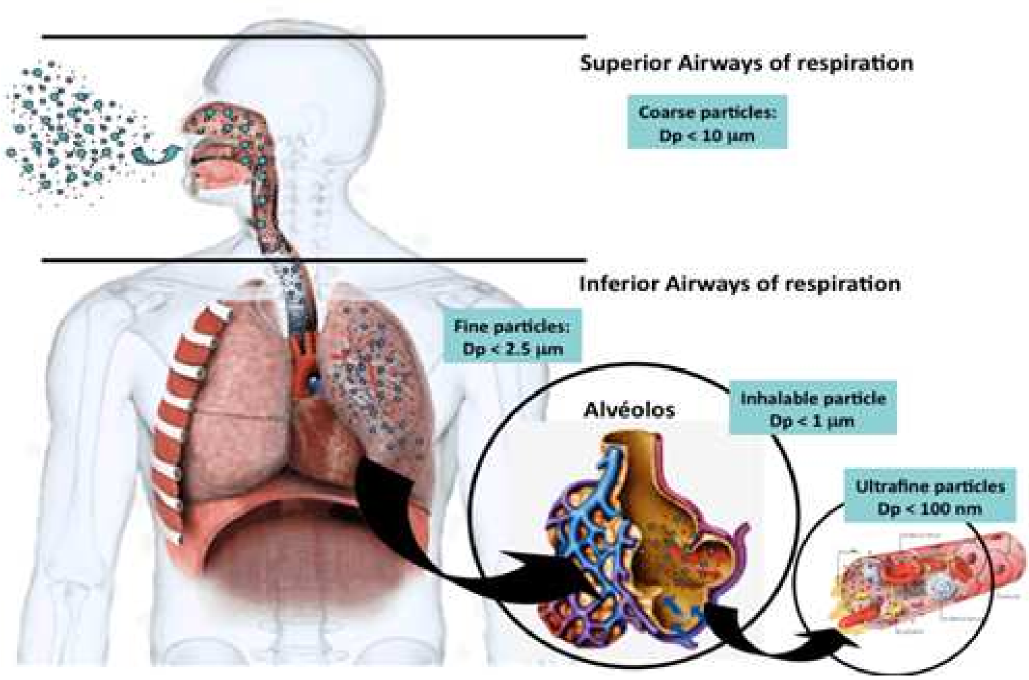


Figure 4. Lungs penetration of difference sizes of PM: Represents the areas where particulate material from incomplete combustion processes is deposited in the body [34]

### 2.2.2 Biological Parameters

The microbial indoor air pollutants (bioaerosols) of relevance to health are widely heterogeneous, ranging from pollen and spores of plants coming mainly from outdoors, to bacteria, fungi, algae and some protozoa emitted outdoors or indoors. They also include a wide variety of microbes and allergens that spread from person to person. Excessive concentrations of bacteria, viruses, fungi (including molds), dust mite allergen, animal dander, and pollen may result from inadequate maintenance and housekeeping, water spills, inadequate humidity control, condensation, or may be brought into the building by occupants, infiltration, or inadequate ventilation. Moreover, the improper operation and maintenance of heating, ventilation, and air conditioning (HVAC) systems in controlling the humidity in air-conditioned buildings is one of the most common causes for microorganisms' distribution and proliferation [35-37].

Allergic responses to indoor biological pollutant exposures cause symptoms in allergic individuals and also play a key role in triggering asthma episodes. Endotoxins (lipopolysaccharide components of the outer membranes of gram-negative bacteria) are associated with contaminated humidifiers, lower ventilation rates, presence of cats and dogs, storage of food waste and increased amounts of settled dust. Increased levels of endotoxins in indoor dust have been associated with increases in asthma symptoms and with reduced lung function in people with atopy [38].

Apart from floods, there are four major sources of mold growth in indoor rooms: leaks in building fabric, condensation, unattended plumbing leaks and household mold (e.g., mold growth on kitchen and bathroom surfaces, hidden food spills, garbage's, defrost pans). A large number of cross-sectional and case-control studies from several countries have found an association between mold and dampness indoors and health complaints [39]. Exposure to microbial contaminants is clinically associated with respiratory symptoms, allergies, asthma and immunological reactions. The most important means for avoiding adverse health effects is the prevention (or minimization) of persistent dampness and microbial growth on interior surfaces and in building structures.

Both fungi and fungi like bacteria produce allergenic spores. Although the most commonly encountered spores in IAQ are mold spores, other fungal spores and bacteria spores can and frequently contribute to the total airborne spore count [35]. The epitopes of the mold, spores and growth structures that promote sensitization are thought to be located in the outer protective surface. Sections of the growth structures can be allergenic as well.

The most common airborne spore is *Cladosporium*. Beyond *Cladosporium* there is some variation, based on geographic region and the time of the year (Table 3). The consensus appears to be for *Alternaria* as the second-largest contributor, and many include *Aspergillus* and *Penicillium*. Most of these molds are reputed to cause exacerbations in mold-sensitized individuals.

Table 3. Most common airborne allergenic molds from 19 random surveys, In [35], page 51 by Al Doory, Y., and J. F. Domson. Mould Allergy. Lea & Febiger, Philadelphia, Pennsylvania (1984).

| Genera | Prevalence (%) | Natural Habitats |
|---|---|---|
| *Cladosporium* | 29.2 | Wordwide: soil, textiles, foodstuffs, and stored crops<br>Region dependent: woody plants and paints |
| *Alternaria* | 14.0 | Worldwide: decaying plant matter, foodstuffs, soil, and textiles |
| *Penicillium* | 8.8 | Region dependent: soil, decaying vegetation, foods cereals, textiles, and paints<br>Occasional occurrences: compost piles, animal feces, paper/paper pulp, stored temperature foods, cheeses, and rye bread |
| *Aspergillus* | 6.1 | Region dependent: soil, stored cereal products, soil, foodstuffs, dairy products, textiles, compost, and house dust |
| *Fusarium* | 5.6 | Worldwide: soil and plants |
| *Aureobasidium* | 4.7 | Worldwide: soil, decaying pears and oranges, paint wood, and paper |

Bacteria are single-celled organisms usually less than 1 micron in diameter, but they can be as large as 5 microns. The actinomycetes are filamentous bacteria that can produce structures that have an appearance similar to small mold spores and can contribute to the total allergenic spore count. Their spores are also allergenic. Actinomycetes are spherical or oval in shape and range in diameter from 0.8 to 3 microns, similar to that of *Aspergillus* or *Penicillium*. However, their nutrient requirements are complex. They grow best in rich organic material and tolerate extreme in temperature. Extensive growth of actinomycetes may be seen on building materials in damp crawlspaces. Bacilli are rod-shaped, spore-forming bacteria. They are generally associated with food spoilage and are not likely to be airborne.

### 2.2.3 PHYSICAL PARAMETERS

One of the main purposes of buildings is to provide healthy and comfortable environments for human activities. A building must accommodate the activities it is built for and provide floor space, room volume, shelter, light and amenities for working, living, learning, curing, processing etc. Furthermore, the building must supply a healthy and comfortable indoor climate to the people using it. In meeting these basic requirements, the building should not cause harm to its occupants or the environment and must, for example, be structurally stable and fire safe. Sustainable development requires that the building does not cause unnecessary load or risk to the environment, for example in the form of energy use [40].

Among physical agents, the most important health risk factor is represented by radon. Radon exposure in houses and other buildings is estimated to be responsible for a remarkable proportion of the lung cancers occurring in the population (5 to 15% depending on the local radon level in soil) [41]. Since radon is a genotoxic carcinogen for man, there is not a radon level to be considered “safe” in absolute and the desirable level should follow the “ALARA” principle (As Low As Reasonably Achievable). Long term health risk associated with exposure to continuous low level electromagnetic fields is still debated. Although countries or organizations have adopted regulatory or recommended values based on the precautionary principle, there is no scientific consensus as to the validity and justification of such values. At the moment there are no specific target values recommendable.

The environmental parameters which constitute the thermal environment are: temperature (air, radiant, surface), humidity, air velocity and the personal parameters: clothing together with activity level. The thermal comfort (TC) is one of the indoor environment factors that affect health and human performance. Thus chiefly determined by temperature, humidity and air movement it has a very significant impact on the general well-being and daily performance of building occupants. Poor thermal environment can also aggravate the impact of air pollutants on occupant’s health [19].

The human body produces heat, exchanges heat with the environment, and loses heat by diffusion and evaporation of body liquids. During normal activities these processes result in an average core body temperature of approximately 37ºC [42]. The body’s temperature control system tries to maintain these temperatures even when thermal disturbances occur. The human body should meet a number of conditions in order to perceive thermal comfort. According to Fanger in 1970 [43], these requirements for steady-state thermal comfort are: (i) the body is in heat balance, (ii) mean skin temperature and sweat rate, influencing this heat balance, are within certain limits, and (iii) no local discomfort exists. Local discomfort to be avoided includes draughts, radiant asymmetry, or temperature gradients (vertical temperature difference between head and ankles). Moreover, high frequency of temperature fluctuation should be minimized as well.

The most commonly used model for evaluating general or whole-body thermal comfort is the PMV (predicted mean vote) model by Fanger [44, 45]. The PMV model was created by climate chamber research involving college – age students. It was validated later, for older people with 128 subjects. The model expresses thermal sensation by PMV, a parameter that indicates how occupants judge the indoor climate. PMV is expressed on the ASHRAE 7-point scale of thermal sensation (Table 4). The outcome of the model is a hypothetical thermal sensation vote for an average person, i.e., the mean response of a large number of people with equal clothing and activity levels, who are exposed to identical and uniform environmental conditions [46]. The PMV model is adopted by the international standards ISO 7730 [47], ANSI/ASHRAE Standard 55 [48] and EN 15251 [49]. These standards aim to specify the conditions that provide comfort to the majority of healthy building occupants, including older adults.

Table 4. Seven-point thermal sensation scale

| | |
|---|---|
| +3 | Hot |
| +2 | Warm |
| +1 | Slightly warm |
| 0 | Neutral |
| -1 | Slightly cool |
| -2 | Cool |
| -3 | Cold |

The Predicted Percentage Dissatisfied (PPD) result as function of PMV and predicts the number of thermally dissatisfied persons among a large group of people. The PMV and PPD indices express warm and cold discomfort for the body as a whole. But thermal dissatisfaction may also be caused by unwanted cooling (or heating) of one particular part of the body (local discomfort).

The ability to regulate body temperature tends to decrease with age and there is a reduction in the sweating activity of aged men compared to younger age groups [50].

These differences are even more pronounced in aged women. Tsuzuki and Iwata (2002) [51] found that the evaporative water loss does not significantly increase with metabolic rate in older adults taking light exercise. In general, elderly seem to perceive TC differently from the young due to a combination of physical ageing and behavioral differences [46, 50]. The effects of gender and age can be accounted for by model parameters such as activity and clothing level [43]. On average, older adults have a lower activity level, and thus metabolic rate, than younger which is the main reason why they require higher ambient temperatures [52]. Elderly have reduced (i) muscle strength, (ii) work capacity, (iii) sweating capacity, (iv) ability to transport heat from body core to skin, (v) hydration levels, (vi) vascular reactivity, and (vii) lower cardiovascular stability [53]. Tsuzuki and Ohfuku (2002) [54] also found that older adults have reduced warmth sensitivity in cold seasons, and similarly reduced cold sensitivity in hot seasons. Physiologically older adults preferred a warmer environment (+ 2ºC) than younger people. Several studies [50, 52, 55, 56] on older people suggested that, also psychologically, the 20 - 24ºC comfort zone is not warm enough for older adults and found an optimum temperature around 25.3ºC for sedentary elderly, which is within the current comfort range. Moreover, measures of indoor operative temperatures (what humans experience thermally in a space) in Portuguese ECC [56] ranged between 16ºC and 25ºC in winter and 22ºC and 31ºC in summer. Elderly preferred a higher temperature in comparison with the young adults [57].

Individual differences are too large to draw an unequivocal conclusion on the requirements of older adults regarding their preferred thermal environment. Nevertheless, self-reported poor health was significantly associated with poor thermal comfort [58]. Exposure to cold has often been associated with increased incidence and severity of respiratory tract infections. The data available suggest that exposure to cold, either through exposure to low environmental temperatures or during induced hypothermia, increases the risk of developing upper and lower respiratory tract infections and dying from them; in addition, the longer the duration of exposure the higher the risk of infection [59].

There is a constant increase in hospitalizations and mortality during winter months; cardiovascular diseases as well as respiratory infections are responsible for a large proportion of this added morbidity and mortality. Although not all studies agree, most of the available evidence from laboratory and clinical studies suggests that inhaled cold air, cooling of the body surface and cold stress induced by lowering the core body temperature cause pathophysiological responses such as vasoconstriction in the respiratory tract mucosa and suppression of immune responses, which are responsible for increased susceptibility to infections. Research on thermal preferences of older adults is needed through field studies in which older adults are given personal control options over their thermal environment. TC for all can only be achieved when occupants have effective control over their own thermal environment [43].

## 2.3 Indoor Environment Quality Control Strategies

Poor IAQ could be associated with improperly managed HVAC systems and inadequate ventilation. For each of the two effects of poor health and loss of productivity, adequate amounts of fresh air and appropriate ventilation can address the problem adequately. There may be an increased risk of multifactor symptoms in buildings with air-conditioning systems compared to naturally or mechanically ventilated buildings. One of the other areas that could cause concern is the cleanliness of the air conditioning system during installation. Dirty ducts that are not cleaned prior to commissioning will cause the dirt to be circulated throughout the building. There is evidence from field studies that buildings with the lowest symptoms reporting rates are those whose ventilation characteristics most closely match the original design intent. This suggests that well-defined goals clearly communicated to all relevant parties throughout the building design and construction process is a potentially important key to achieving good IEQ.

$CO_2$ has been recognized by ASHRAE as the surrogate ventilation index [60]. $CO_2$ levels both in natural and air-conditioned rooms are a good indicator of occupancy and ventilation rate within a space. $CO_2$ by itself is not considered an indoor air contaminant. Humans are the major source of $CO_2$. As people exhale $CO_2$, they also exhale and give off a wide range of bioeffluents. These bioeffluents include bacteria, gases, odors, particulate and viruses. When these bioeffluents are allowed to build up in space, due to poor ventilation, occupants complain of fatigue, headache and general discomfort. The assumption is that if there is sufficient ventilation to remove/dilute the human generated contaminants, there will be no discomfort [61].

Outside levels of $CO_2$ are relatively constant and range between 350 to 600 parts per million (ppm). Therefore, the concentration of $CO_2$ in a space can provide an indication of the actual ventilation rate per person within the space. If the $CO_2$ levels are higher than 1000 ppm (1830 mg/m$^3$), then it is an indication that not enough outdoor air is coming in to dilute the $CO_2$ level. For that reason, the indoor air is being re-circulated and the levels of the other pollutants in the enclosed space must be high. $CO_2$ itself does not create indoor air related symptoms but elevated $CO_2$ concentrations will often occur at the same time other pollutant levels build up. The real value of $CO_2$ in IAQ control is a very good indicator of ventilation rates within a space. The Finnish Society of Indoor Air Quality suggests 1300 for ‘very good’, 1650 for ‘good’, and 2200 mg/m$^3$ for ‘satisfactory’ IAQ. At these concentrations, $CO_2$ is not harmful; however, it is an indicator of other airborne pollutants and ventilation rate [38, 62].

The existing literature offers evidence that characteristics of buildings and indoor environments significantly influence prevalence’s of respiratory disease, allergy and asthma symptoms. IAQ related symptoms are influenced by multifactor parameters therefore a combined approached of measures along all variables is recommended. From the regulatory point of view, several ways to control the effect or possible effect on exposure to indoor pollutants are available [23]:

- Establishing minimum allowable emission rates of pollutants from a source;
- Banning the use of certain pollutants in products or in general (e.g. asbestos, smoking);
- Requiring a minimum ventilation rate, taking in account the activities and occupation rate of the indoor area;
- Defining a maximum allowable concentration level (exposure level) (e.g. formaldehyde);
- Implementing preventive measures such as design approaches, maintenance activities to prevent growth of Legionella or strict procedures of intended use of a space or product.

The ventilation can contribute by reducing the concentration of contaminants from building materials and processes inside the building and also heat produced in it, nevertheless the most important measure to reduce such contaminants remains source control. Notwithstanding, building ventilation is one important factor affecting the relationship between airborne transmission of respiratory infections and the health.

## 2.4 Susceptible Populations Health and Indoor Environment Quality

IAQ has increasingly gained importance for maintaining a health status. As levels of outdoor ambient pollution have decreased in many geographic areas, the relative impact of indoor air pollution has grown. Residents of developed countries spend most of their time indoor, thus are more likely to be exposed [1]. At the same time, changes in home and office building construction have resulted in decreased air exchange rates, increasing personal exposure to indoor pollutants [63].

The mean 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 [64]. According WHO it has been estimated that older persons spend most of their time indoors. Therefore, the study of IAQ and TC in the elderly 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 and multiple underlying and misdiagnosed chronic diseases.

It is often thought that indoor environments are among the healthiest and safest places for people to be particularly for older persons, who can have unique health needs and environmental sensitivities. Several health-related effects may be caused (or worsened if already present) by exposure to poor IAQ, including immediate effects such as eye irritation, nausea, upper respiratory complications, cognitive impairment, asthma, and long-term effects as respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease and cancer [65]. For residents in ECC, IAQ is a special concern and a critical component of their health and quality of life (QoL). Older persons may present reduced immunological defense and concurrent age-related pathophysiological modifications, making them particularly vulnerable to health complications due to indoor air pollution. Moreover, the risk assessment process is often difficult in older persons, involving the identification of multiple factors potentially affecting health and QoL, the quantification of human exposure to pollutants, and the evaluation of the individual's response to these stimuli.

These older population risk assessments may require the design of a specific strategy and intervention plan with specific recommendations for controlling, mitigating and/or solving these risk factors. Policies should be focused on indoor exposures to identify, control, and eliminate the indoor sources of pollution, including outdoor air and adequate ventilation levels. Such intervention cannot be uniquely focused on IAQ, but they should consider a wide spectrum of policies related to the subjects' health and to the environment. Health effects of indoor air pollutants have been addressed in recent studies on susceptible populations such as children [13, 66-68]. Nevertheless, current evidence suggests the existence of an association between low concentrations of indoor pollutants with increased morbidity and mortality in particular, related to respiratory and cardiovascular disease. In this sense, there is still a clear need for more studies on indoor pollution and health specifically targeting adults and older persons. Specifically tailored studies should address both short-term and long-term health-related effects due to indoor air pollutants. Identification of subgroups among older persons who are especially susceptible to adverse effects of air pollutants is particularly important to provide the basis to design adequate preventive interventions [69-72]. Moreover, evidence is still sparse about the role of indoor pollutants in determining the prognosis of pre-existing diseases. Studies on this specific topic represent an important area of research, taking into account that older persons often present multiple diseases and live in restricted indoor environments at increased risk of exposure to indoor pollutants.

## 2.5 Influence of Indoor Environments in the Respiratory Health and Quality of Life in Older People

Problems of IEQ are recognized as important risk factors for human health in low, middle and high income countries. Indoor air and TC are also important because people spend a substantial proportion of their time in buildings. In households, day-care centers, retirement homes (ECC) and other special environments, indoor environment pollution affects population groups that are particularly vulnerable owing to their health status or age [9]. The main debate on different shares of psychosocial and environmental factors goes on with results depending largely on specific characteristics of samples such as subjects and buildings envelope [73].

QoL, according to the World Health Organization Quality of Life Group (WHOQOL Group), is defined as the individual's perception of their position in life in the context of the culture and the value system they inhabit, in relation to expectancies, patterns and concerns [74]. This concept is based on the definition of health itself, as proposed by WHO, interpreted as the individual's perception of their overall wellbeing, both mental and social, rather than simple absence of disease. Assuming that the concept of QoL goes beyond symptoms and beyond the effects of diseases on functional status a good number of questionnaires have been developed and used to assess the health related QoL of patients and general population.

In this study, the Portuguese version of the World Health Organization Quality of Life WHOQOL-BREF questionnaire was applied [73, 75, 76] as presented in appendix A. This instrument is a 26-item version of the WHOQOL-100 assessment. Its psychometric properties were analyzed using cross-sectional data obtained from a survey of adults carried out in 23 countries. It is focused around the definition of QoL advocated by WHO, which includes the culture and context which influence an individual's perception of health.
Sick and well respondents were sampled from the general population, as well as from hospital, rehabilitation and primary care settings, serving patients with physical and mental disorders and with respect to quotas of important socio-demographic variables. The first two questions evaluate self-perceived QoL and satisfaction with health. The remaining 24 questions represent each of the twenty-four facets of which the original instrument is composed (WHOQOL-100), divided into four domains: physical, psychological, social relationships and environment. The mean score in each domain

indicates the individuals' perception of their satisfaction with each aspect of their life, relating it with QoL. The higher the score, the better this is perceived to be.
According the WHOQOL Group [77] 12.0 should be used as the scale midpoint where QOL is judged to be neither good nor poor. The scores are transformed on a scale from 0 to 100 to enable comparisons to be made between domains composed of unequal numbers of items, being 50 the midpoint.
Questionnaires, such as the one developed and validated by WHO, measure relatively broad domains and can be used to conduct comparisons across different diseases, ethnicities, and cultures. A large number of studies have confirmed the association of air pollution with human diseases, which was not confined to respiratory illnesses, but also involved many other conditions with the highest impact on cancer and cardiovascular diseases. Of note, the World Health Report 2002 by WHO estimated that, each year, about 800,000 premature deaths are due to air pollution worldwide [78].

The BOLD (Burden of Obstructive Lung Disease) questionnaire is applied by researchers to gather information on chronic respiratory diseases and symptoms and has been used in multi-national studies [79]. Individuals are asked to complete a questionnaire covering respiratory symptoms, health status, activity limitation, and exposure to potential risk factors such as tobacco smoke, and previous work in dusty environments. The intent is to obtain information about respiratory symptoms (cough, sputum, wheezing, shortness of breath), exposure to potential risk factors, occupation, respiratory diagnoses (asthma, chronic obstructive pulmonary disease, chronic bronchitis, and allergic rhinitis), co-morbidities, health care utilization, medication use, activity limitation, and health status. The Portuguese version [80] of the respiratory health questionnaire BOLD [79, 81] was administered in this study and is part of appendix A.

# 3. RATIONALE, MOTIVATION AND AIMS

## 3.1 RATIONALE AND MOTIVATION

The world is aging. Globally, the number of persons aged 60 and above is expected to more than double by 2050 and more than triple by 2100, increasing from 901 million in 2015 to 2.1 billion in 2050 and 3.2 billion in 2100. The number of persons aged 80 or over is projected to more than triple by 2050 and to increase more than seven-fold by 2100. Globally, the number of persons aged 80 or over is projected to increase from 125 million in 2015 to 434 million in 2050 and 944 million in 2100. In 2015, 28% of all persons aged 80 and over lived in Europe, but that share is expected to decline to 16% by 2050 and 9% by 2100 as the populations of other major areas continue to increase in size and to grow older themselves [82].

These demographical trends are likely to change the sociodemographic composition of society, and pose major challenges to social and health care systems. The number of cases of conditions such as cancer and diabetes are expected to increase as this population segment grows [83, 84]. Demands and costs for social services and health care are also expected to grow [85, 86]. For instance, estimations indicate that the public expenditures for Long-Term Care (LTC) for EU/OECD countries may increase at a rate of 1% a year above the growth of the real Gross Domestic Product (GDP) per working member of the population. By 2050 the LTC expenditure parts of the GDP for EU/OECD countries may grow to either 2.2% or 2.7% [84].

In Europe, 24% of the population is already aged 60 years or over and that proportion is projected to reach 34% in 2050 and 35% in 2100 [82]. Portugal is the 8th oldest country in the world and the 6th in Europe, with 23% of population with more than 60 years old (Figure 5 and Figure 6). Moreover, in Portugal, the number of ECC increased 49% between 1998 and 2010 [87].

Nevertheless, no matter how old, older citizens can still play part in society and enjoy a better QoL. The challenge is to make the most of the enormous potential that older people harbor even at a more advanced age [88]. Health declines as people grow old, but a lot can be done to cope with this decline. And quite small changes in our environment can make a great difference to people suffering from various health impairments and disabilities.

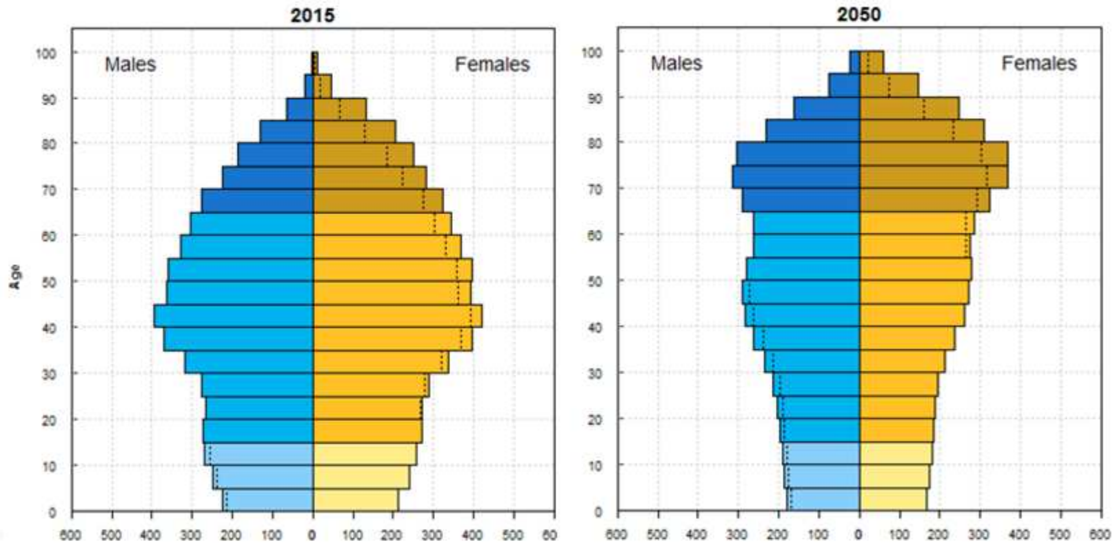


Figure 5. Portuguese demographic profiles: Population pyramids. The dotted line indicates the excess male or female population in certain age groups. The data are in thousands or millions [82].

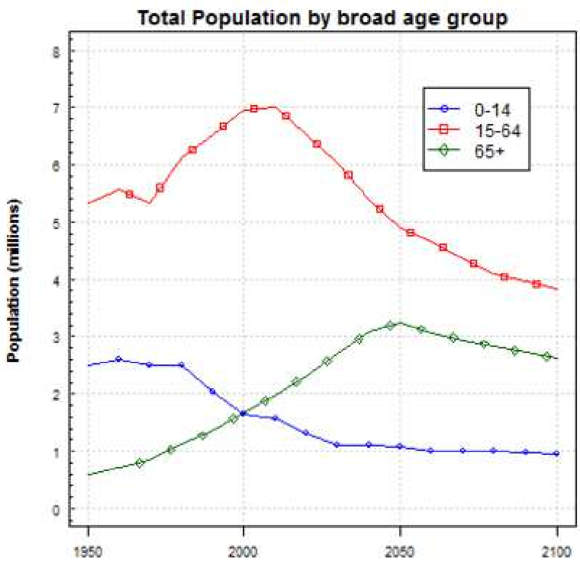


Figure 6. Portuguese demographic profiles: Line Charts [82].

Active ageing means growing old in good health and as a full member of society, feeling more fulfilled, more independent in daily life and more involved as citizens. In 2012 the topic of World Health Day was Ageing and health with the theme "Good health adds life to years". Also, that year was the 'European Year for Active Ageing and Solidarity between Generations'. Accordingly, this project aim was to integrate these initiatives and to ensure greater recognition of what older people bring to society and create more supportive conditions for them. To our knowledge, this is the first study in Portugal to assess effects of indoor air contaminants on health status and quality of life in older persons living in ECC.

ECC is considered a facility where users of 65 years or older reside permanently in a substitute environment and are offered shelter and elderly care, due to an increased dependency. In order to study the ECC and their population, a cross-sectional study according to a preceding characterization of the Porto ECC and their residents was performed. The elderly population living in Porto ECC is divided into 7 different parishes with about 1.327 older citizens lived in these institutions in 2012 [87]. Those ECC have different typologies (Figure 5) indicating if their financial source is private or public.

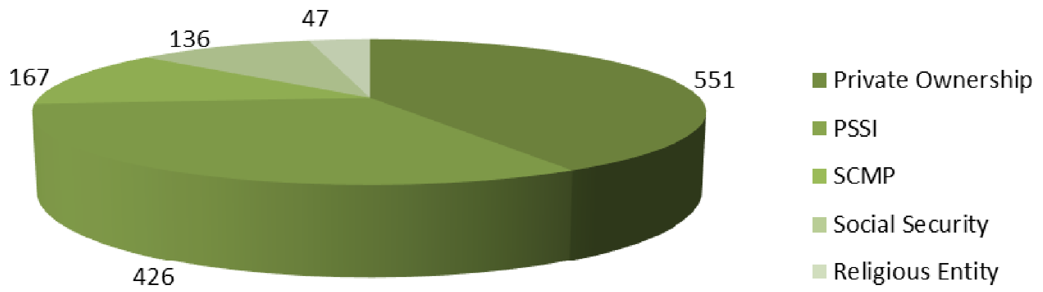


Figure 7. Porto elderly population (No.) living in ECCs, by typology [87].
(PSSI: Private Social Solidarity Institution; SCMP: Santa Casa da Misericórdia do Porto)

This PhD study was involved in a more comprehensive project (GERIA: PTDC/SAU-SAP/116563/2010) also supported by Fundação para a Ciência e Tecnologia (FCT) through Operational Competitiveness Program (COMPETE) as part of the National Strategic Reference Framework, which enriched the outcomes of this work.

### 3.2 Aims

The main outcome of this study was to draw conclusions about health status and QoL of older persons living in ECC and to correlate it with IAQ, TC and ECC building characteristics. A set of recommendations was produced towards ECC, focusing on health care, QoL, and household behaviors. In order to accomplish the main goal, the following specific objectives were set along the work.

Scientific objectives

i. Review critically and collate international and national research on the most relevant indoor air health related QoL indicators applicable to ECC;
ii. Assess buildings characteristics, ventilation and the patterns of the everyday use of the selected social equipment's;
iii. Monitor chemical and biological indoor and outdoor air contaminants and TC parameters in ECC;
iv. Assess respiratory health and QoL questionnaires outcomes;
v. Study the influence of indoor environmental parameters on elderly respiratory health and QoL.

Technological objectives

i. Apply to ECC residents the standardized and validated versions of respiratory health and QoL questionnaires.

Policies and environmental education objectives

i. Produce guidelines on remedial measures and recommendations in ECC;
ii. Raise society's awareness and sensibility to IEQ issues, especially those of susceptible individuals;
iii. Contribute with data to assist stakeholders and decision makers to improve health policies and take health related QoL prevention measures.

### 3.3 Brief paper description and interconnection

In order to accomplish the previous established aims, this project was designed as a cross-sectional study according to a preceding characterization of the Porto ECC and their residents. This study explored environmental variables and buildings characteristics in 22 ECC conducted during summer and winter from November 2011 to August 2013, within dining rooms, drawing rooms, medical offices and bedrooms, as well as, health related QoL outcomes in the residents of these institutions.

The first article was the pilot study where six urban area ECC, housing a total of 425 older persons, were studied to assess IAQ [$PM_{10}$, $PM_{2.5}$, total volatile organic compounds (TVOC), formaldehyde, CO, $CO_2$, total bacteria and fungi] and TC in the two seasons. This paper presented the preliminary results in 36 ECC rooms, all naturally ventilated and compare the IEQ results with the former Portuguese legislation for the IAQ [89] and international standard for TC parameters. Ambient air samples were also collected for comparison to the indoor measurements.
In this stage of the project a building characterization of the ECC was performed including the following assessment (appendix B): (i) type of building construction (concrete, masonry, etc.); (ii) thermal isolation of the building; (iii) characteristics of building envelope (structural type of the windows and doors – with weather-strip or not, sliding windows or casement windows, etc.); (iv) ventilation system (natural, mechanical, hybrid, etc.); (v) materials used for finishing; (vi) use of gas burning appliances that could influence the IAQ; (vii) evidences of dampness and mold at the building envelope; (viii) ventilation practices of the occupants (opening windows or not). Additionally, the inside and outside temperatures, the internal and external air humidity, and the $CO_2$ concentration in private and community rooms were also monitored. These measurements provided additional objective information about the studied indoor environment. This collected delivered a description of the construction characteristics and household behaviors.

The second article present the complete indoor environmental parameters assessment measured twice for a total of 141 sampling sites in all studied ECC (n = 22). The IAQ and TC assessment results were compared to international reference levels, since the national reference levels were being updated at that time to reflect recent changes [90] (Table 5 and 6). This paper also presents a complete analysis regarding classical statistical methods to estimate means, medians and frequencies in order to obtain insight into the ECC characteristics and environmental monitoring results within and between buildings. The variables were tested for normality with Shapiro–Wilk test generally revealing a non-normal distribution, except for the parameters air temperature. Nonetheless it was decided to use the mean for descriptive purposes. Mann–Whitney (U) test and Kruskal–Wallis (H) for independent samples were conducted for seasonal effects assessment, indoor/outdoor and within buildings location differences.

Table 5. Portuguese and International reference levels for chemical and biological parameters

| | Portugal | Source | International | Source |
|---|---|---|---|---|
| $PM_{10}$ (µg/m$^3$) | 50 | a) | 150 | c) |
| $PM_{2.5}$ (µg/m$^3$) | 25 | a) | 35 | c) |
| TVOC (µg/m$^3$) | 600 | a) | 200 | d) |
| Formaldehyde (µg/m$^3$) | 100 | a) | 100 | e) |
| CO (mg/m$^3$) | 10 | a) | 10 | e) |
| $CO_2$ (mg/m$^3$) | 2250 | a) | 1300 | f) |
| Bacteria (CFU/m$^3$) | < outdoor (until 350 CFU/m$^3$ more) | a) | - | - |
| Fungi (CFU/m$^3$) | < outdoor | a) | 500 | g) |

a) [90]; c) [91]; d) [92]; e) [9]; f) [38]; g) [36].

Table 6. Portuguese and International reference levels for physical parameters

| | Portugal | Source | International | Source |
|---|---|---|---|---|
| Air Temperature (ºC) | [18-22] up to 25 | b) | Winter [20.0 – 23.6]<br>Summer [22.8 – 26.1] | j) |
| | 25 in Summer<br>18 in Winter | (i.1)<br>(i.2) | - | - |
| Relative Humidity (%) | [50-70] | b) | 30 - 65 | k) |
| Air Velocity (m/s) | - | - | 0.25 | k) |
| PMV | - | - | Class A [-0.2; 0.2]<br>Class B [-0.5; 0.5]<br>Class C [-0.7; 0.7] | h) |
| PPD (%) | - | - | Class A < 6<br>Class B < 10<br>Class C < 15 | h) |

b) [93]; h) [47]; i1) [94]; i2) [94]; j) [48]; k) [95].

The third paper aimed to further explore the impact of indoor biological agents (total bacteria and fungi identification) in the 22 ECC located in Porto. The results obtained were compared with the recently revised Portuguese standards. It was characterized the main fungi species found indoors, including some known potential pathogenic and toxigenic.

The fourth and the fifth paper provided a different approach including statistical models between the IEQ and the health related QoL outputs. These articles analyzed the IEQ of 21 ECC, due to the decline of one ECC into participate in the health questionnaires survey. The older residents who gave their informed consent (appendix C) and were able to participate were 143 with ≥ 65 years old and living in the ECC for more than 2 weeks. An exploratory analysis was carried out for all variables. Categorical data were presented as frequencies and percentages, and continuous variables as median and inter-quartile range (25th percentile-75th percentile) or range (min-max). Due to the fact that most of the sampling points were not the same in both seasons, the two samples were considered to be independent. Mann–Whitney and Kruskal–Wallis tests were used to compare seasonal effects assessment because of the existence of outliers, high variability and skewed distributions. Main health outcomes were wheezing, cough, sputum, asthma and allergic rhinitis. Mixed effects logistic regression models were used to study the association between the BOLD questionnaire results and the monitored environmental parameters, adjusted for age, smoking habits, gender and number of years living in the ECC. The outcome QoL variables were the physical health, psychological health, social relationships and environment WHOQOL-BREF domains in a 0-100 scale. Furthermore, mixed effects linear regression models were used to study the association between the QoL domains and winter season PMV index.

The findings presented may prove useful in modelling future by developing environments responsive to the aspirations of older people. Policies and programs directed at achieving “age-friendly” communities are considered to require a wide range of interventions, including actions at the level of the social and physical environment [96]. In this sense, our results were presented to the stakeholders by a formal IEQ report (appendix D) and an e-book from GERIA Project [97]. These instruments contributed with guidelines on remedial measures and recommendations to ECC and older people QoL and respiratory health. The e-book chapter related to quality of life is presented in appendix E [98].

# 4. MATERIAL AND METHODS, RESULTS AND DISCUSSION

# I. Indoor Air Quality and Thermal Comfort – Results of a Pilot Study in Elderly Care Centers in Portugal


**Journal of Toxicology and Environmental Health, Part A: Current Issues**
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uteh20

# Indoor Air Quality and Thermal Comfort—Results of a Pilot Study in Elderly Care Centers in Portugal

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Version of record first published: 20 Mar 2013.

**To cite this article:** Ana Mendes , Cristiana Pereira , Diana Mendes , Lívia Aguiar , Paula Neves , Susana Silva , Stuart Batterman & João Paulo Teixeira (2013): Indoor Air Quality and Thermal Comfort—Results of a Pilot Study in Elderly Care Centers in Portugal, Journal of Toxicology and Environmental Health, Part A: Current Issues, 76:4-5, 333-344

**To link to this article:** http://dx.doi.org/10.1080/15287394.2013.757213

*Journal of Toxicology and Environmental Health, Part A*, 76:333–344, 2013

ISSN: 1528-7394 print / 1087-2620 online
DOI: 10.1080/15287394.2013.757213



# INDOOR AIR QUALITY AND THERMAL COMFORT—RESULTS OF A PILOT STUDY IN ELDERLY CARE CENTERS IN PORTUGAL

**Ana Mendes[1], Cristiana Pereira[1], Diana Mendes[1], Lívia Aguiar[1], Paula Neves[1], Susana Silva[1], Stuart Batterman[2], João Paulo Teixeira[1]**

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**The age of the European population is rising and percentage of adults aged 65 years and older is projected to increase from 16% in 2000 to 20% in 2020. It has been estimated that older subjects spend approximately 19 to 20 h/d indoors. Older individuals may be particularly at risk for detrimental effects from pollutants, even at low concentrations, due to reduced immunological defenses and multiple underlying chronic diseases. Six Porto, Portugal, urban area elderly care centers (ECC), housing a total of 425 older persons, were studied to assess indoor air quality (IAQ) and thermal comfort (TC) in two seasons. This study presents the IAQ and TC results in 36 rooms and constitutes part of a wider and ongoing study. The study areas were all naturally ventilated, and indoor concentrations in winter were within Portuguese reference values. However, 42% of the participants were dissatisfied with indoor thermal conditions, rating it "slightly cool." In summer, the index rate of dissatisfied individuals was lower (8%). Significant differences were found between seasons in predicted percent of dissatisfied people (PPD) and predicted mean vote (PMV) indices. Fungal concentrations frequently exceeded reference levels (>500 colony-forming units [CFU]/m$^3$). In addition, other pollutants occasionally exceeded reference levels. To our knowledge, this is the first study in Portugal to assess effects of indoor air contaminants on the health status and quality of life in older subjects living in ECC. Although IAQ and TC parameters were mostly within reference values, the results suggest a need to improve the balance between IAQ and TC in ECC, a critical environment housing a susceptible population.**

The air one breathes inside buildings dominates overall inhalation exposure of most air pollutants, whether of indoor or outdoor origin (Corsi et al., 2012). As levels of outdoor ambient pollution have decreased in many areas, the relative impact of indoor air pollution has grown, and thus indoor air quality (IAQ) has increasingly gained importance. 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. In addition to IAQ, thermal comfort (TC) is a key indoor factor that might affect comfort, health, and performance. TC is chiefly determined by temperature, humidity, and air movement. Although the thermal environment found in residential settings does not usually produce serious adverse health effects, this atmosphere exerts a significant impact on the general well-being and daily performance of building occupants. Poor thermal environments might also

Our current research is supported by Fundação para a Ciência e Tecnologia (FCT) through GERIA Project PTDC/SAU-SAP/116563/2010 and a PhD grant (SFRH/BD/72399/2010).
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aggravate the impact of air pollutants on health (Mendes and Teixeira, 2012).

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 et al., 2006). Older individuals spend approximately 19–20 h/d indoors (WHO, 2003). Elderly care centers (ECC) and homes have the potential to influence people's lives socially, physically, and psychologically (Bradshaw et al., 2012). Older subjects may be particularly at risk of detrimental effects from air pollutants, even at low concentrations, due to their reduced immunological defenses and multiple underlying chronic diseases. Exposure to poor IAQ may produce or exacerbate eye irritation, nausea, upper respiratory complications, cognitive impairment, asthma, respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease, and cancer (Ferng and Lee, 2002). Thus, IAQ is a special concern for ECC residents, important for both health and quality of life.

Risk assessment processes inadequately address susceptibility of older populations. Many factors may affect health and quality of life, pollutant exposure, and an individual's response to these stimuli. While considerable evidence indicates that low concentrations of air pollutants are associated with increased risks of morbidity and mortality, particularly for respiratory and cardiovascular disease and cancer (Pope and Dockery, 2006; Miller et al., 2007; Krewski et al, 2004; Samet and Krewski, 2007), information on the elderly in indoor settings is limited. Adverse health effects associated with indoor air pollutants were investigated among some susceptible populations, especially children (Neas et al., 1994; Nafstad et al., 1996; 1997; Bruce et al., 2000; Jaakkola et al., 2001; Jaakkola and Jaakkola, 2002; Foos et al, 2008; Selgrade et al, 2008; Madureira et al., 2009). However, few studies evaluated adults and older people (Xu and Wang, 1993; Moran et al., 1999; Pilloto et al., 1999; Venners et al., 2001; Simoni et al., 2003). No apparent study was identified that jointly considered IAQ and TC among the elderly. Further, evidence remains sparse regarding the role of indoor pollutants on preexisting diseases common among the elderly, such as particulate matter (PM), bioaerosols, and volatile organic compounds (VOC). Thus, a need exists to examine IAQ, TC, and the health of older persons. The identification of subgroups that are susceptible to pollutants and TC is particularly important for designing appropriate and efficient interventions aimed at maintaining a healthy and comfortable environment.

Active aging implies growing old in good health and as a full member of society, feeling fulfilled, independent in daily life, and more involved as citizens. No matter how old, the elderly still play an active part in society and enjoy a better quality of life. The challenge is to make the most of the enormous potential that older citizens harbor even at an advanced age (European Union [EU], 2012). Health declines as people grow old, but much can be done to cope with this decline. Further, rather small changes in the environment may make a great difference to individuals suffering from health impairments and disabilities. Research to understanding such effects, especially taking into account that older individuals often have multiple diseases and live in restricted indoor environments that place them at increased risk of exposure to indoor pollutants, is an important endeavor and a natural shift in the focus of IAQ and TC studies.

## OBJECTIVES AND STUDY DESIGN

This study characterizes effects of IAQ and TC among older individuals residing in Portugal. Ultimately, this ongoing study called GERIA—Geriatric Study in Portugal on Health Effects of Air Quality in Elderly Care Centers—will examine 20 ECC among 60 selected in Porto and Lisbon, the two largest cities in Portugal, and will include measures of cardio-respiratory health and quality of life. Table 1 presents the information used to calculate the sample size required for the study. To our knowledge, this is the first such study in Portugal, and one of the first with these objectives and study design. The GERIA study uses a prospective cohort design.

**TABLE 1.** Study Design Estimates

| | |
|---|---|
| Porto elderly population living in ECCs (number)[a] | 1574 |
| ECCs in Porto (number)[a] | 57 |
| Lisbon elderly population living in ECCs (number)[a] | 3646 |
| ECCs in Lisbon (number)[a] | 95 |
| Estimated elderly dementia (%)[b] | 53 |
| Estimated sample size population with 95% CI in Porto (number)[c] | 309 |
| Estimated sample size population with 95% CI in Lisbon (number)[c] | 348 |

*Note.* Sources: *a*, Carta Social, 2010 [http://www.cartasocial.pt]; *b*, estimated based on data provided by the ECCs managers; *c*, OpenEpi, Version 2.3.1, 2011 [www.OpenEpi.com] (Dean et al., 2001).

This investigation presents measurements of IAQ and TC in 36 rooms in 6 ECC in 2 seasons. Our main aim is to present the overall results of environmental monitoring and TC assessment in these ECC.

The following data sets and samples were collected at each ECC: (1) building characteristics; (2) environmental parameters, such as formaldehyde, particulate matter up to 10 μm in size ($PM_{10}$), total volatile organic compounds (TVOC), carbon monoxide (CO), carbon dioxide ($CO_2$), total bacteria, fungi, temperature, relative humidity (RH), and air velocity; and (3) predicted mean vote (PMV) and predicted percent of dissatisfied people (PPD).

## MATERIAL AND METHODS

### Walk-Through Survey

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).

### Indoor Air Monitoring and Thermal Comfort Assessment

IAQ parameters were measured twice, during winter 2011 (November–December) and summer 2012 (May–June), and included chemical parameters ($CO_2$, CO, formaldehyde, TVOC, $PM_{10}$), and biological contaminants (bacteria and fungi). TC parameters determined at the same time (following ISO 7730:2005) included the PMV index, which predicts the mean response of a larger group of people according to a 7-point thermal sensation scale (ISO 7730:2005), and the PPD index as a quantitative measure of the TC of a group of subjects at a particular thermal environment relative humidity (RH), temperature, and air velocity. The monitoring was performed in dining rooms, drawing rooms, medical offices, and bedrooms. Ambient air samples were also collected for comparison to indoor measurements. All active sampling and associated analytical measurements were performed in replicate and duplicate. This investigation was performed by the Environmental Health Department of the National Health Institute using methodologies accredited by NP EN ISO/IEC 17025:2005, "General requirements for the competence of testing and calibration laboratories."

### Sampling Schedule and Locations

The 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.

### Suspended Particle Matter (PM10)

$PM_{10}$ samples were collected using polytetrafluoroethylene (PTFE) filters on 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" (Winberry et al., 1993). Pumps were calibrated and checked prior and after each sample using a Gillian Gilibrator-2 air flow calibrator. Before sampling, filters were stored in a desiccator for equilibration. At least one field blank per sampling event was used. Exposed and unexposed filters were transported, protected from dust and sunlight, and kept away from air in a closed filter holder. Each filter was weighed under controlled temperature (20 ± 1°C) and RH (50 ± 5%) before and after sampling using an electronic microbalance. Static charges were eliminated using a nonradioactive, ionizing air blower (EXAIR, model number 7907). Concentrations were calculated from the difference in filter weight and sample air volume.

### TVOC and Formaldehyde

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. These pumps were calibrated and checked daily prior to and after each sample using a Gilian Gilibrator-2 air flow calibrator. Before sampling, each tube was conditioned at 250, 300, and 330°C for 30 min consecutively using helium carrier gas flow. 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, and an internal method (ECA, 1997). TVOC was quantified using the toluene response factor, and concentrations were calculated as the sum of identified and unidentified compounds eluting between hexane and hexadecane (included), expressed as toluene.

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 (calibrated and checked daily prior to and after each sampling with Gilian Gilibrator-2 air flow calibrator). Concentrations were determined by high-performance liquid chromatography (HPLC) using the methods described by Levin et al. (1986) and the National Institute for Occupational Safety and Health (NIOSH) 2016:2003. This method is well established in the lab and meets the quality criteria defined by it and accepted by independent audit entities. Each analysis used certified reference standards as well as duplicate and recovery samples.

### Carbon Dioxide, Carbon Monoxide, and Thermal Comfort Parameters

$CO_2$ and CO concentrations 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.

TC parameters (temperatures, RH, and air velocity) were measured using a Delta Ohm HD 32.1 data logger. After stabilization (25 min) in each room, 10-min measurements were recorded using the software just described. According to ISO 7730 and confirmed by observation, elderly occupants' daily activity was considered to have a metabolic rate of 1 met, and their clothing a thermal insulation of 1 clo in summer and 1.3 clo in winter.

### Bacteria and Fungi

Microorganism air sampling was conducted following NIOSH Method 0800, Bioaerosol Sampling (Indoor Air), 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 and 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$^3$).

### Data Analysis

Descriptive analyses were used to obtain insight into the ECC characteristics and environmental monitoring results. Uncertainty was reported as 95% confidence intervals (CI) based on error propagation of multiple samples and instrumental uncertainty. Paired *t*-tests were used to test for indoor/outdoor differences and Spearman's correlation for seasonal effects. A .05 level of significance was used for all analyses. All data were analyzed using SPSS 16.0.

## RESULTS

### Characterizations of Elderly Care Centers

The 6 ECC were located in an urban area of Porto and housed a total of 425 aged individuals with a range of 7 to 136 occupants per building. Table 2 presents selected building characteristics of the ECC sampled. Most ECC (78%) were in older buildings (up to 60 years old) using stone masonry construction and single pane windows. All buildings had been adapted for the purpose of ECC. Only 33% had insulation on the roof and walls. Most of the buildings presented leaks (67%) and condensation (56%) in interior walls and ceilings. The studied rooms were naturally ventilated with a mean floor area of 30 m$^2$. Floor coverings were mainly wood, tile/stone, or polyvinyl chloride (PVC). The ECC were all equipped with heating systems (30% central heating and 70% gas and electric heaters). None of the buildings had cooling systems apart from the natural ventilation and some passive measures, such as blinds and curtains on the windows. Occupancy rates per room during monitoring were 3.8 persons in dining rooms, 7.2 in drawing rooms, 1.5 in medical offices, and 0.4 in bedrooms. All ECC were smoke free and 89% were near roads with heavy traffic.

**TABLE 2.** ECC Building Characteristics, Expressed as Percentage

| | |
|---|---|
| Heating systems | |
| Central | 30 |
| Gas and oil heaters | 70 |
| Interior conditions | |
| Condensation | 56 |
| Leaks | 67 |
| Insulation | 33 |
| Power supply | |
| Electricity | 56 |
| Gas | 67 |
| Proximity to traffic | 89 |
| Single pane glass | 78 |
| Stone masonry | 78 |
| Window frames (wood) | 67 |

### TVOC, Formaldehyde, and CO

Table 3 summarizes results of the environmental monitoring at the six ECC. The mean TVOC concentration was within Portuguese and international reference values in both winter and summer seasons, although maximal levels (0.5 mg/m$^3$) considerably exceeded the WHO (2010) reference value of 0.2 mg/m$^3$. On average, indoor TVOC levels were approximately threefold higher than outdoor levels, indicating the presence of indoor sources, such as emissions from construction materials, furniture, cleaning products, and cosmetics (Spengler et al. 2001; Martínez and Gómez, 2007).

Of the 66 indoor formaldehyde samples collected, 60 were below the method limit of quantification (LOQ; 0.0002 mg/m$^3$). These findings were consistent with the age of the buildings, old furniture, and absence of plywood, carpets and environmental tobacco smoke (ETS), all known formaldehyde sources. The elderly do not appear to be hypersensitive to formaldehyde (Paustenbach et al., 1997); rather, these subjects may be generally less sensitive to sensory irritation (WHO, 2010).

Outdoor CO levels exceeded indoor levels by approximately 1.3-fold, reflecting traffic pollution and absence of indoor CO sources. Apart from cooking restricted to the kitchens with proper exhaust and some gas heaters, there were no other combustion sources in the buildings. Maximal summer CO level (10.4 mg/m$^3$) exceeded the WHO reference

**TABLE 3.** Overall IAQ Chemical and Biological Parameters Results (Indoor and Outdoor) and Reference Levels

| Parameter | Season | Indoor Average | Indoor SD (range) | Outdoor Average | Outdoor SD (range) | Indoor reference levels Portuguese[a] | Indoor reference levels International |
|---|---|---|---|---|---|---|---|
| Formaldehyde (mg m$^{-3}$) | Summer | <0.0002 | — | — | — | 0.1 | 0.1[b] |
| | Winter | <0.0002 | — | — | — | | |
| TVOC (mg m$^{-3}$) | Summer | 0.07 | 0.09 (0.03–0.5) | 0.04 | 0.01 (0.02–0.06) | 0.6 | 0.2[c] |
| | Winter | 0.08 | 0.07 (0.02–0.32) | 0.02 | 0.01 (0.01–0.03) | | |
| $PM_{10}$ (mg m$^{-3}$) | Summer | 0.074 | 0.04 (0.02–0.2) | 0.08 | 0.02 (0.05–0.11) | 0.15 | 0.05[b] |
| | Winter | 0.064 | 0.071 (0.01–0.43) | 0.05 | 0.03 (0.02–0.12) | | |
| CO (mg m$^{-3}$) | Summer | 1.3 | 2.47 (0.01–10.4) | 1.2 | 1.61 (0.01–4.8) | 12.5 | 7[b] |
| | Winter | 0.5 | 0.68 (0.01–4.08) | 0.8 | 0.81 (0.01–2.56) | | |
| $CO_2$ (mg m$^{-3}$) | Summer | 996 | 436 (512–3568) | 669 | 91 (512–951) | 1800 | 1080[d] |
| | Winter | 1196 | 512 (512–3842) | 712 | 344 (457–3751) | | |
| Bacteria (CFU m$^{-3}$) | Summer | 397 | 237 (6–830) | 166 | 126 (68–336) | 500 | 500[b] |
| | Winter | 329 | 280 (32–996) | 52 | 20 (30–84) | | |
| Fungi (CFU m$^{-3}$) | Summer | 525 | 533 (6–2224) | 476 | 726 (20–1314) | 500 | 300[e] |
| | Winter | 296 | 263 (90–1218) | 225 | 146 (114–478) | | |

[a]DL 79/2006, 4 April 2006 (Decree-Law 2006a).
[b]WHO (2010).
[c]ECA (1997).
[d]Burton (1995).
[e]Robertson (1997).



value of 7 mg/m$^3$ at one site. This value was measured in a bedroom with an open window next to a road with heavy traffic, which likely influenced results for this room.

### Particulate Matter and $CO_2$

The mean indoor summer (0.074 mg/m$^3$) and winter (0.064 mg/m$^3$) $PM_{10}$ concentration were within the Portuguese reference concentration of 0.15 mg/m$^3$, but above the 24-h average interim WHO guideline of 0.05 mg/m$^3$, which is intended as a target for outdoor air but which generally relates to both acute and chronic adverse health effects. Of the 93 $PM_{10}$ measurements in both seasons, 54% exceeded the WHO guidelines. Maximal concentrations measured (0.43 mg/m$^3$) occurred in winter in a busy drawing room.

The mean indoor $CO_2$ winter (1196 mg/m$^3$) and summer (996 mg/m$^3$) concentrations fell below the Portuguese reference level (1800 mg/m$^3$), but the winter concentration was numerically above the international reference level of 1080 mg/m$^3$ (Burton, 1995). Indoor levels exceeded outdoor levels in both seasons. These concentrations of $CO_2$ are not harmful, but are indicators of occupancy and ventilation in the study areas. Some guidance is given by the Finnish Society of Indoor Air Quality and Climate, suggesting 1300 mg/m$^3$ for "very good," 1650 mg/m$^3$ for "good," and 2200 mg/m$^3$ for "satisfactory" indoor air quality (Säteri, 2002).

### Bioaerosols

Table 3 shows that average airborne levels of bacteria and fungi fell below reference levels (500 CFU/m$^3$). In summer, fungi concentrations reached 2224 CFU/m$^3$. All of the highest indoor levels (10% of samples exceeded 1000 CFU/m$^3$) were associated with high outdoor levels (38% of samples above reference levels). The most prevalent mold species were *Cladosporium* species (found in 41% of the samples), *Penicillium* species (24%), and *Aspergillus fumigatus* (8%). The last species produces mycotoxins (Ayanbimpe et al., 2010), may induce invasive lung infections, and is a potential cause of morbidity and mortality in susceptible and immunodeficiency individuals, including the elderly. The outdoor main species were *Cladosporium* species and *Penicillium* species in both seasons.

Figures 1a and 1b represent the distribution of the bioaerosols by room and season. The total bacteria concentration was below the reference level, but indoor levels were twofold higher than levels outdoors. Bacteria concentrations were highest in the dining room (467 CFU/$m^3$) in the winter; in contrast, drawing-room levels were highest in the summer (509 CFU/$m^3$). Fungi showed a wider distribution in all areas analyzed in the summer season (Figure1b). Figure 1c presents bacteria and $CO_2$ levels by season and by room. Although bacteria and $CO_2$ concentrations show some similar trends by room, the correlation coefficient was not significant (Figure 1c).

### Thermal Comfort

During monitoring, the mean daily ambient air temperatures in Porto ranged from 16 to 28°C in summer, and from 4 to 14°C in winter. In the ECC, temperatures ranged between 16 to 30°C in summer and 12 to 16°C in winter.

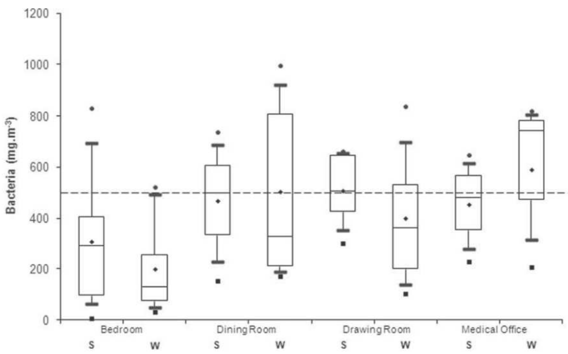


**FIGURE 1a.** Bacteria concentration distribution by room and season (● Max; ■ Min; S – summer; W – winter; — high reference level).

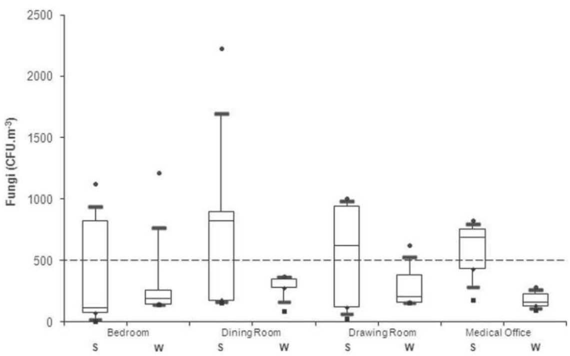


**FIGURE 1b.** Fungi concentrations distribution by room and season (● Max; ■ Min; S – summer; W – winter; — high reference level).

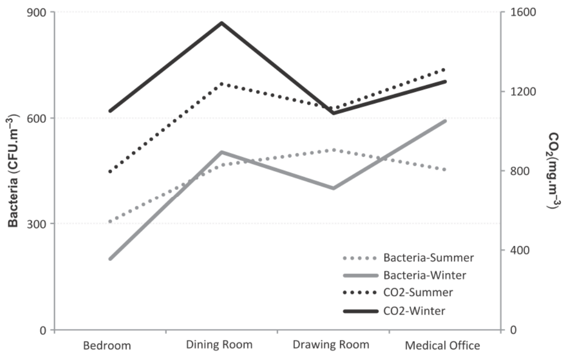


**FIGURE 1c.** Bacteria and $CO_2$ concentrations by room and season.

Both PPD and PMV varied significantly by season. In winter, 42% of residents were dissatisfied (PPD) with indoor TC, rating it "slightly cool" (PMV = –1.2) (Figure 2). As noted earlier, only 33% of the ECC buildings were insulated, 30% had central heating, and visible inspection suggested leaks and condensation problems were common. In summer, the dissatisfaction index presented a lower rate of (PPD = 8%), reflecting a "neutral" PMV index (PMV = –0.03). Analysis of PPD by room (Figure 3) showed that medical offices (winter: 49%; summer: 10%) and bedrooms (winter: 47%; summer: 9%) were the areas with the highest percent of dissatisfied residents in both seasons. Dining and drawing rooms had the lowest PPD, likely due to higher occupancy rates in these rooms that may disguise the lack of insulation present in most of the buildings. Our results indicate that maintenance of a comfortable indoor environment with good IAQ for elderly populations living in ECC in Portugal may be a substantial challenge, especially in winter.

## DISCUSSION

The indoor environment has special significance for elderly persons, who are particularly susceptible to TC concerns as well as adverse

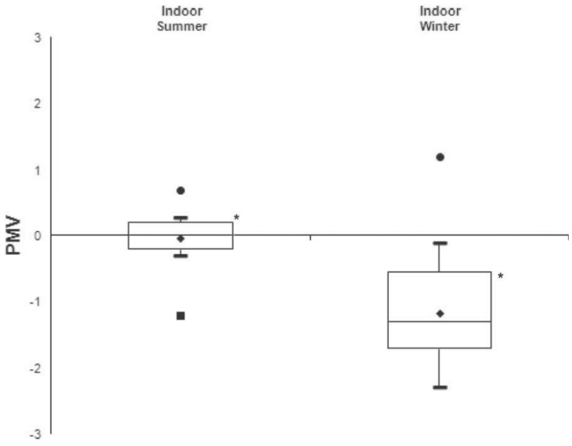


**FIGURE 2.** Overall PMV indexes (*$P < 0.05$) (• Max; ■ Min).

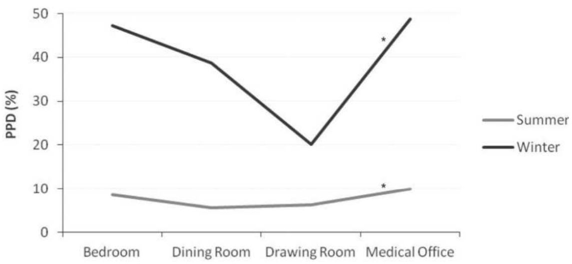


**FIGURE 3.** PPD by room and season (*$P = 0.013$).

respiratory and cardiovascular effects associated with IAQ pollutants, and who are likely to spend most of their day indoors. Currently, few reports have addressed IAQ and TC concerns among older subjects or in elderly care centers (ECC). Simoni et al. (2002) showed an association of relatively low levels of indoor pollutants, such as PM, with acute respiratory symptoms and reduced peak expiratory flow in an older population. Later, Simoni et al. (2003) suggested the need for further studies on indoor pollutants and health in the elderly, including a focus on improved exposure assessment, various short-term and long-term health outcomes, and identification of those characteristics potentially associated with susceptibility of adverse effects. The indoor environment may also affect the development of preexisting diseases in the elderly, an unstudied and potentially important research area.

Air quality monitoring in a small set of Portuguese ECC showed that $PM_{10}$, TVOC, formaldehyde, CO, bacteria, and fungi levels were often, but not always, within reference values. These pollutants have been associated with a variety of effects, where airborne bacteria are confirmed or presumed causative agents of several infectious diseases, and also with the development and exacerbation of chronic respiratory illness, including asthma (Peccia et al., 2008). The same concern was reported in a review by Tang (2009) for fungi and their spores, which may trigger hypersensitivity reactions such as rhinitis, sinusitis, or asthma, and also for viruses such as the severe acute respiratory syndrome-associated coronavirus with a 50% fatality rate for those over 65 years old. Further, the role of human occupancy as a source of indoor biological aerosol is poorly understood. Size-dependent particle behavior often might be associated with specific chemical and biological components of PM. The strong signal of human microbiological contaminants as far as airborne PM is concerned in an occupied room demonstrates that the inhalation route might be a source of exposure to microorganisms emitted from the skin, hair, nostrils, and mouths of their occupants (Qian et al., 2012).

In our study, while the total bacterial concentration was almost always below the reference level, indoor levels were twofold greater than those outdoors, due to a result of occupancy (e.g., direct human shedding), or resuspension (e.g., from carpet, and potentially other sources (Hospodsky et al. 2012). The similar trends of bacteria and $CO_2$ concentrations by room in our study indicate possible human source of the bacteria. Low ventilation rates and crowded conditions increase $CO_2$ levels, and bioeffluent concentrations, potentially including bacteria, gases, odors, PM, and viruses (Mendes and Teixeira, 2012). With respect to bacteria, inhalation of infectious microorganisms from individuals and animals is a primary mechanism of contagion for most acute respiratory infections. Such risks may increase in indoor environments that have low ventilation rates and use untreated and recirculated air (Franchi et al., 2006).

In general, the elderly seem to perceive TC differently from the young due to a combination of physical aging and behavioral differences (Hoof and Hensen, 2006). Our findings show a PPD index of 42% dissatisfied residents in winter, a high rate that may partially be explained by cooler outdoor temperatures found (average of 13°C) and the ECC building characteristics, including use of natural ventilation, stone masonry, and lack of insulation. Several investigators found that older adults have a lower activity level and metabolic rate than younger persons, and thus require higher ambient temperatures (Havenith, 2001; Tsuzuki and Iwata, 2002). Further, the ability to regulate body temperature tends to decrease with age (Hoof and Hensen, 2006). Tsuzuki and Ohfuku (2002) also found that older adults have reduced warmth sensitivity in cold seasons, and similarly reduced cold sensitivity in hot seasons. Physiologically older adults preferred a warmer environment (+2°C) than younger people. Enomoto-Koshimizu et al. (1997) suggested that a 20– 24°C comfort zone is not warm enough for older adults, and specified an optimal temperature of 25.3°C for sedentary older adults.

The IAQ and TC measurements suggest the difficulty of maintaining indoor environmental conditions in ECC that are suitable to this susceptible population, especially in winter. Individual differences among older persons may be large with respect to the requirements and preferences of TC parameters, and more research is needed on this topic, for example, using studies allowing older adults personal control over their thermal environment (Hoof and Hensen, 2006). Further, Raymann and Van Someren (2008) presented temperature and TC as major issues for the elderly population where cardio-mortality was associated with (1) ambient temperature (Halonen et al., 2010) and (2) indoor climate with low temperatures due to poor insulated houses (Bøkenes et al., 2009).

### Strengths and Limitations of the Study

This study investigated both IAQ and TC parameters in occupied ECC in both in summer and winter seasons. Sampling could not be conducted simultaneously in the ECC due to equipment and logistical limitations; thus, temporal variation in outdoor pollutant levels and weather over the measurement period may have affected indoor results. In addition, measurements were short-term in nature, and only a subset of rooms within ECC and a small number of ECC in one city were studied. This limitation will be addressed in further research in which 20 ECC will be studied in two cities, and the larger data set will allow a number of additional analyses.

## CONCLUSIONS

IAQ and TC have been rarely evaluated in ECC. Characterization of IAQ and TC in six ECC in Portugal revealed several concerns. Not surprisingly, concentrations of $CO_2$, TVOC, and bacteria were above outdoor levels, indicating indoor sources, and these and other pollutants ($PM_{10}$, CO and fungi) sometimes exceeded reference levels. Perhaps most significantly, TC PPD index was classified as "slightly cool" in the winter season. Although these results suggest that indoor concentrations of most parameters were generally within reference values, the results suggest the need to improve the balance between IAQ and TC parameters. Potentially, simple measures could provide health benefits to ECC residents and workers, such as insulating ceilings, walls, and windows, without giving up natural and passive ventilation solutions that are common in Portugal due to the advantage of the country's generally mild weather. The present study suggests that further study is needed to analyze the interaction between TC and IAQ variables in order to improve the well-being of our elderly population.

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# II. Indoor Air Quality and Thermal Comfort in Elderly Care Centers

Urban Climate 14 (2015) 486–501

Contents lists available at ScienceDirect

Urban Climate

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

# Indoor air quality and thermal comfort in elderly care centers

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A R T I C L E   I N F O

*Article history:*
Received 2 December 2013
Revised 11 July 2014
Accepted 15 July 2014

*Keywords:*
Indoor air quality
Thermal comfort
Building assessment
Elderly care centers
Older people

A B S T R A C T

This study explored environmental variables and buildings characteristics in 22 elderly care centers (ECCs) in Portugal. Indoor environmental parameters were measured twice for a total of 141 sampling sites. Each site was assessed for $PM_{10}$, $PM_{2.5}$, total volatile organic compounds (TVOC), formaldehyde, CO, $CO_2$, total bacteria and fungi. Thermal comfort (TC) parameters were measured according to ISO 7730:2005 and a building characterization was performed. The overall $PM_{2.5}$ mean concentration of the 22 ECC was above international reference levels in summer and winter seasons. TVOC, bacteria, CO and $CO_2$ showed significantly higher indoor levels compared to outdoor, in both seasons. Indoor $PM_{10}$, TVOC, bacteria and $CO_2$ present significant differences between seasons. TVOC, bacteria and $CO_2$ show significant variation between ECC rooms and 4% of fungi samples were positive for pathogenic *Aspergillus species*. The winter predicted mean vote (PMV) index showed a 'slightly cool' thermal sensation scale which may potentiate respiratory tract infections. The predicted percent of dissatisfied people (PPD) and PMV indices show significant differences by season. The building variables 'Insulation', 'Heating Ventilation' and 'Windows frames' were significantly associated to chemical, biological and TC parameters. 'Bacteria', 'Fungi', 'Temperature', Relative Humidity', and 'PPD index' are the mostly affected by building characteristics. Insulating ceilings, walls, and

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http://dx.doi.org/10.1016/j.uclim.2014.07.005

windows could improve winter season TC, providing health benefits to ECC residents.



## 1. Introduction

According to the United Nations estimates, the total number of people aged 65 years and older was 506 million in 2008 and is anticipated to double to 1.3 billion by 2040, accounting for the 14 percent of total global population. By 2050, Europe will continue to be the world's oldest region with its elder population increasing more than fivefold from 40 million to 219 million (Bentayeb et al., 2013). These demographic changes result in new patterns of morbidity and mortality, such as the increasing number of patients simultaneously affected by different chronic diseases. Healthcare organizations throughout the world have an increasing concern about how to cope with a quickly aging population (Caley and Sidhu, 2011). This trend explains the increasing demand of long-term care services (Damiani et al., 2009) such as elderly care centers (ECCs). Furthermore, considering that persons who are 65 years or older often spend a considerable portion of their lives indoors it is clear that the possibility that adverse indoor climate can influence their health status cannot be ignored.

As levels of outdoor air pollution have been reported to decrease in many areas, indoor air quality (IAQ) has increasingly gained importance. It is estimated that in developed countries people spend 80% to 90% of their day indoor (Kembel et al., 2012), and this figure is likely to be higher in elderly. This prolonged exposure to indoor air pollutants of this age-group – even at low concentrations – may induce health damage more likely than occasional exposure to outdoor pollutants (Corsi et al., 2012). In addition to IAQ, also thermal comfort (TC) is a key factor that might affect comfort, health, and occupants' performance (Mendes et al., 2013). Thermal comfort is influenced by a range of environmental and individual factors, both objective and subjective, including air temperature, the temperature of the surrounding surfaces, the air movement, the relative humidity, and the rate of air exchange (ventilation) (Ormandy and Ezratty, 2012).

Living in a ECC may induce exposure to chemical compounds through their release from building materials, household furnishings, and a wide range of consumer products (Spengler and Adamkiewicz, 2009). Furthermore, indoor habitat has been found to harbor microbial taxa not commonly found outdoors, and it has been reported that air temperature and relative humidity, as well as the source of ventilation air and occupant density, can influence the abundance and transmission of some pathogenic microbes (Kembel et al., 2012). Inadequate air-conditioning systems, low ventilation rate, and overcrowding can increase these risks (Wan et al., 2011).

Fine particulate matter, with diameter 2.5 µm or less ($PM_{2.5}$), can penetrate deeply into lung tissue and be associated with reduced lung function in children and adults, lung inflammation, respiratory symptoms, adverse cardiovascular effects, and increased prevalence of chronic obstructive pulmonary disease (COPD) (Wang et al., 2006). $PM_{2.5}$ exposure can also cause oxidative stress to human DNA (Sørensen et al., 2003). The quality of indoor climate is affected equally by the building equipment and operation and maintenance. However, critical conditions may originate from the buildings themselves, or actions of the occupants or operation and maintenance of the buildings (Seppänen et al., 2004). Although housing standard is important for indoor climate, knowledge on different aspects of individual daily behavior patterns, especially those related to thermoregulatory behavior and home heating habits, is a critical piece of information (Bokenes et al., 2011). In general elderly energy expenditure decreases with increasing age because of a reduction in basal metabolic rate and also because elderly tend to be less active (Antunes et al., 2005). Due to this mechanism, elder population has an average comfort zone/thermal neutrality (where the body is able to maintain a balance between heat production and heat loss) higher than the general population (25 °C in summer and 23 °C in winter) (Hwang and Chen, 2010; Schellen et al., 2010), and is more sensitive to respiratory infections in the winter (Ormandy and Ezratty, 2012; Mourtzoukou and Falagas, 2007) and heat-related mortality during the summer heat waves (Kovats and Hajat, 2008). Poor thermal environment can also aggravate the impact of air pollutants on occupant's health.

However, Indoor environmental conditions vary in space and time, and health risk may depend on factors such as the time pattern of exposure, as well as on individual features such as age, gender, genetic heritage, and underlying state of health. More studies on indoor pollutants and health in the elderly are needed, with an improved exposure assessment, evaluation of short-term and long-term outcomes, identification of susceptible subgroups (Simoni et al., 2003).

This paper presents results which have been produced within the GERIA ongoing project 'Geriatric study in Portugal on Health Effects of Air Quality in Elderly Care Centers', by measuring and characterizing IAQ and TC in 22 ECCs out of 58 (with an overall number of 1355 residents), in Porto, Portugal. Aim of the study was to evaluate (1) the indoor air quality and thermal comfort in a representative sample of ECCs in Porto as compared with national and international standards, (2) to study the variability among different spaces within single ECCs, and (3) how buildings characteristics may affect the extent of indoor air pollution or thermal regulation.

## 2. Material and methods

All ECCs located within the Porto urban area and included in the '*Portuguese Social Charter*' where invited to participate in our study. Out of a total of 58 ECCs located in Porto urban area, 38% ($n = 22$) accepted to participate in this study. Data were collected for each ECC in two seasons (i.e. summer and winter), and the following parameters were measured: (i) building and ventilation characteristics; (ii) environmental, chemical, biological and thermal comfort parameters; (iii) index of thermal comfort, i.e., predicted mean vote (PMV) which predicts the mean response of a larger group of people according to the seven point thermal sensation scale (ISO 7730:2005), and predicted percent of dissatisfied people (PPD) as a quantitative measure of the TC of a group of people at a particular thermal environment.

The city of Porto (41N11.8W36) is located along the Douro river estuary in northern Portugal, featuring the Mediterranean climate (Köppen climate classification = Csb) with moderate temperatures and rainy weather in the winter season, and milder summers due to the nearby presence of cold ocean currents that bring fog but prevent rain. The research team considered that all the ECCs included in the study were exposed to the same climate.

### *2.1. Buildings walk-through survey*

The building characterization included the following information: type of building construction (concrete, masonry, etc.); thermal isolation of the building; characteristics of building envelope (type of windows and doors, presence of weather stripping, etc.); ventilation system (natural, mechanical, hybrid, etc.); types of indoor materials; use of gas burning appliances; evidence of dampness or mold; ventilation practices (opened windows). All ECCs were smoke-free.

### *2.2. Indoor air monitoring and thermal comfort assessment*

IAQ parameters were measured twice, during winter and summer seasons, starting from November 2011 till August 2013, and included chemical parameters [carbon monoxide (CO), carbon dioxide ($CO_2$), formaldehyde, total volatile organic compounds (TVOC), particulate matter up to 10 and 2.5 micrometers in size ($PM_{10}$ and $PM_{2.5}$)], and biological contaminants (total bacteria and fungi). TC parameters were measured at the same time (following ISO 7730:2005) including the PMV and PPD indices, relative humidity (RH), temperature and air velocity. The monitoring was performed in each ECC in the following spaces: dining rooms, drawing rooms, medical offices and bedrooms, including the bedridden subgroup. A total of 141 areas were evaluated. Ambient air samples were also collected for comparison to the indoor measurements. All active sampling and the associated analytical measurements were performed in replicate (in the same room) and duplicate (in the same sampling point). This work was performed by the Environmental Health Department of National Health

Institute using methodologies accredited by NP EN ISO/IEC 17025:2005 "General requirements for the competence of testing and calibration laboratories".

*2.2.1. Sampling schedule and locations*

The monitoring phase included daytime air sampling (starting at 10 am and continuing for at least 4 h to 8 h during normal activities) conducted discretely to minimize nuisance to normal resident's activities. Samplers were placed at a height of 0.6–1.5 m above the floor, approximately at the breathing zone level, and as close as possible to the center of the room. Sampling points were always located more than 1 mt. from walls, windows, doors or an active heating system.

*2.2.2. Suspended particle matter ($PM_{10}$ & $PM_{2.5}$)*

$PM_{10}$ and $PM_{2.5}$ samples were collected using polytetrafluoroethylene (PTFE) filters on SKC Personal Environmental Monitors (PEM), Gilian personal pumps, and a sample flow rate of 2.0 L $min^{-1}$ following US Environmental Protection Agency (EPA) Method 10-A, 'Determination of Respirable Particulate Matter in Indoor Air Using Size Specific Impaction' (Winberry et al., 1990). Pumps were calibrated and checked prior and after each sample using a Gillian Gilibrator-2 Air Flow Calibrator. Before sampling, filters were stored in a desiccator for equilibration. At least one field blank per sampling event was used. Exposed and unexposed filters protected from dust and sunlight during transportation, and kept away from air in a closed filter holder. Each filter was weighed under controlled temperature (20 ± 1 °C) and relative humidity (50 ± 5%) before and after sampling using an electronic microbalance (Sartorius M5P with 0.001 mg of precision). Static charges were eliminated using a non-radioactive, ionizing air blower (EXAIR, Model No. 7907). Concentrations were calculated from the difference in filter weight and the sample air volume.

*2.2.3. TVOC and formaldehyde*

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 $min^{-1}$ for a period of 45 min. These pumps were calibrated and checked daily prior and after each sample using a Gilian Gilibrator-2 Air Flow Calibrator. Before sampling, each tube was conditioned at 250 °C, 300 °C and 330 °C for 30 min consecutively in the helium carrier gas flow. Analysis of volatile organic compounds (VOCs) was performed by automatic thermal desorption coupled with capillary gas chromatography 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 (International Organization for Standardization, 2004), and an internal method following ECA Report 19 (European Commission Joint Research Centre Environment Institute, 1997). TVOC was quantified using the toluene response factor, and concentrations were calculated as the sum of identified and unidentified compounds eluting between hexane and hexadecane (included), expressed as toluene.

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 $min^{-1}$ (calibrated and checked daily prior and after each sampling with Gilian Gilibrator-2 Air Flow Calibrator). Concentrations were determined by high-performance liquid chromatography (HPLC) using the methods reported by Levin et al. (1996) and the National Institute for Occupational Safety and Health (NIOSH) 2016:2003 (National Institute for Occupational Safety and Health, 2003). Each analysis used certified reference standards as well as duplicate and recovery samples.

*2.2.4. Carbon dioxide and carbon monoxide*

$CO_2$ and CO concentrations 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.

*2.2.5. Bacteria and fungi*

Microorganism air sampling was conducted following NIOSH Method 0800 – Bioaerosol Sampling (Indoor Air) (National Institute for Occupational safety and Health (NIOSH), 1998) and ISO 16000-18:2011 (International Organisation for Standardization, 2011), using a microbiological air sampler

(Merck Air Sampler MAS-100), an air flow rate of 100 L $min^{-1}$, and two 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 and 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 (International Organisation for Standardization, 2003). Bacteria were incubated at 37 °C. Results were expressed as colony-forming units per cubic meter of air (CFU/$m^3$).

*2.2.6. Thermal comfort parameters*

ECCs rooms 'homogeneous' and steady-state environment were tested according ISO 7726:1998 (International Organisation for Standardisation, 1998) specifications with TSI 8386A-M-GB thermo-anemometer. Moderate environments (class C – comfort standard) were considered. Objective physical data, including air temperature, relative humidity and air velocity were collected by Delta Ohm HD 32.1 – Data logger, placed at a height of 0.60 m above the floor (sitting – abdomen level). All monitoring data were collected as close as possible to the center of the room, with the sampling points no closer than 1 m to a wall, a window, a door or an active heating system. After 25 min equipment stabilization in each room, the measurements were recorded during 10 min. The data for each room was obtained using the software DeltaLog10 version 1.30. According to ISO 7730:2005 (International Organisation for Standardisation, 2005) and confirmed by observation, elderly occupants' daily activity was considered to have a metabolic rate of 1.0 met (seated, relaxed) and their clothing a thermal insulation of 1 *clo* (underwear with short sleeves and legs, shirt, trousers, jacket, socks and shoes) in summer, and 1.3 *clo* (underwear with long sleeves, long trousers, long shirt, jersey, thermo-jacket, socks and shoes) in winter. PMV and PPD indices, mean radiant temperature ($tr$) and their measurement uncertainties were calculated by Monte Carlo Method using MatLab software.

*2.3. Calculation & data analysis*

The IAQ and TC assessment results were compared to international reference levels, since the national reference levels are currently being updated to reflect recent changes. To characterize and rate the overall IAQ of the ECCs included in this study, the concentration of chemical and biological parameters was ranked from 1 to 3. The '1' score was attributed when the mean concentration of each parameter in all ECCs was under the lower value within national (Ordinance 353-A/2013 of 4th December, 2013) and international references (see Table 2), the score '2' when the concentration levels were between the national and the international references, the score '3' when concentration values were higher than both reference levels and an intervention is required. For the purpose of this classification all chemical and biological parameters were considered to have the same influence on the IAQ. Classical statistical methods were used to estimate means, medians 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 and generally revealed a non-normal distribution, except for air temperature. Nonetheless it was decided to use the mean for descriptive purposes. Mann–Whitney ($U$) test and Kruskal–Wallis ($H$) for independent samples were conducted for seasonal effects assessment, indoor/outdoor and within buildings location differences. It was also performed a student $t$-test for the variable 'air temperature'. A 0.05 level of significance was used for all analyses. Expanded uncertainty was evaluated for 95% confidence interval based on probability distributions propagation of measurements obtained by multiple samples and considering instrumental uncertainty obtained from traceable calibrations. All data were analyzed using IBM SPSS 21.0.

## 3. Results

*3.1. Buildings characteristics*

The 22 ECCs are located in the urban area of Porto city, most of them ($n$ = 17) in heavy traffic areas. A total of 716 elderly lived in these centers with a range of 7–136 occupants per building (generally three-storey houses with a little garden in front or in the back of the household). As regards construction characteristic, 53% of ECCs are separate from surrounding buildings, 66% are an adaptation to ECC of an existing residential building, and 40% ECCs are also developing activities of day care centers for elderly in separate facilities (due to technical and logistic reasons from the centers and to promote an effective and better service to those diverse care giving realities). The mean age of ECCs buildings is 111 years, ranging from 8 to 313 years. Retrofit average is 7 years.

Table 1 presents the main buildings characteristics. Most of them are built in stone masonry construction (49%) with single pane windows (87%). Only 30% have roof and walls insulation, while 61% of the sampled presented condensations and infiltrations along walls and roofs inside the buildings. The ceramic tile is the common roof lining (87%) and the indoor floor is typically (48%) covered by Vinyl (PVC). Twelve buildings (53%) have central heating while the others have autonomous devices (one ECC had both installations), equally fueled with electricity or gas (39%). 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. Environmental assessment*

During monitoring, the mean daily ambient air temperature in Porto was 17 °C [11–23 °C], with 49% [18–80%] RH in the winter, and 24 °C [17–34 °C] with 47% [18–76%] RH in the summer. Table 2 shows the overall ECC indoor air quality analysis. $PM_{2.5}$ mean concentration of the 22 ECC was above the reference levels in both seasons. The other chemical and biological parameters concentration 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 indoor air comfort. 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. Table 2 also reports significantly higher levels of TVOC, bacteria, CO and $CO_2$ when compared to outdoors, in both seasons. Indoor $PM_{10}$, TVOC, bacteria and $CO_2$ show significant differences between seasons. Furthermore, 4% of fungi samples were positive for *Aspergillus flavus* (52% in summer) that often infect patients with reduced or compromised immune systems, *Aspergillus*

**Table 1**
Distribution of ECCs by building characteristics.

| Building characteristics | *n* | % |
|---|---|---|
| ADAPTED To ECC | 14 | 66 |
| WALLS | | |
| Brickwork | 6 | 30 |
| Stone masonry | 11 | 49 |
| Both | 5 | 22 |
| WITH Roof & Walls INSULATION | 6 | 30 |
| VENTILATION TYPE | | |
| Natural (only) | 3 | 13 |
| Mixed ventilation | 19 | 87 |
| HEATING | | |
| Central heating (CH) | 12 | 53 |
| Autonomous devices (AD) | 9 | 43 |
| CH + AD | 1 | 4 |
| WINDOWS | | |
| With sealants | 13 | 43 |
| Double-pane glass | 3 | 13 |
| Single-pane glass | 19 | 87 |
| BUILDING PATHOLOGIES | | |
| Condensations + infiltrations | 13 | 61 |
| Clear | 9 | 39 |

**Table 2**
Elderly care centers indoor/outdoor air quality and thermal comfort: descriptive statistics by season.

| | Indoor | | Outdoor | | Reference | *p* |
|---|---|---|---|---|---|---|
| | *N* | Mean [Min–Max] | *N* | Mean [Min–Max] | | |
| $PM_{10}$ ($mg/m^3$) | | | | | | |
| SUMMER | 139 | 0.066 [0,02–1.73] | 24 | 0.05 [0.02–0.25] | 0.15[a] | 0.01* |
| WINTER | 138 | 0.067 [0.02–0.43] | 24 | 0.06 [0.02–0.21] | | |
| $PM_{2.5}$ ($mg/m^3$) | | | | | | |
| SUMMER | 120 | 0.09 [0.02–2.12] | 20 | 0.05 [0.02–0.18] | 0.035[a] | – |
| WINTER | 119 | 0.06 [0,02–0.86] | 20 | 0.05 [0.02–0.29] | | |
| TVOC ($mg/m^3$) | | | | | | |
| SUMMER | 129 | 0.11 [0.01–2.53] | 22 | 0.17 [0.01–2,6] | 0.2[b] | 0.01* |
| WINTER | 137 | 0.13 [0.01–0.93] | 20 | 0.04 [0.01–0.3] | | 0.001** |
| Formaldehyde ($mg/m^3$) | | | | | | |
| SUMMER | 77 | <0.042 [<0.042–0.06] | – | | 0.1[c] | – |
| WINTER | 84 | <0.042 [<0.042–0.32] | | | | |
| CO ($mg/m^3$) | | | | | | |
| SUMMER | 137 | 0.7 [0.1–7.1] | 24 | 1.3 [0.1–7.7] | 10[c] | 0.03** |
| WINTER | 137 | 0.6 [0.1–3.0] | 24 | 0.9 [0.1–3.5] | | |
| $CO_2$ ($mg/m^3$) | | | | | | |
| SUMMER | 137 | 786 [538–2313] | 24 | 590 [384–893] | 1300[d] | 0.001* |
| WINTER | 137 | 1125 [541–2697] | 24 | 609 [516–879] | | 0.001** |
| Bacteria ($CFU/m^3$) | | | | | | |
| SUMMER | 137 | 329 [6–2282] | 23 | 162 [24–616] | 500[e] | 0.01* |
| WINTER | 133 | 258 [14–996] | 23 | 89 [8–368] | | 0.001** |
| Fungi ($CFU/m^3$) | | | | | | |
| SUMMER | 132 | 305 [6–2224] | 23 | 531 [20–3454] | 500[f] | – |
| WINTER | 130 | 260 [18–2812] | 22 | 208 [62–676] | | |
| Air temperature (°C) | | | | | | |
| SUMMER | 137 | 23.5 [14.0–32.0] | 24 | 24.8 [17.0–34.0] | Summer [22,8–26,1] | 0.001* |
| Winter | 137 | 19.7 [13.0–27.0] | 24 | 17.2 [11–23.0] | Winter [20,0–23,6][g] | |
| Relative humidity (%) | | | | | | |
| SUMMER | 137 | 52.8 [21.0–75.0] | 24 | 47.4 [18–76] | [30–65][h] | – |
| WINTER | 137 | 49.7 [24.0–75.0] | 24 | 49.0 [18–80] | | |
| Air velocity (m/s) | | | | | | |
| SUMMER | 71 | 0.07 [0.01–0.75] | – | – | <0.25 [h)] | – |
| WINTER | 79 | 0.12 [0.01–1.26] | | | | |
| PMV | | | | | | |
| SUMMER | 71 | −0.4 [−3.0–2.3] | – | – | Class A [−0.2; 0.2][i] | |
| WINTER | 65 | −1.7 [−3.0–(−0.3)] | | | Class B [−0.5; 0.5] | 0.001* |
| | | | | | Class C [−0.7; 0.7] | |
| PPD (%) | | | | | | |
| SUMMER | 71 | 27.3 [5.0–99.1] | – | – | Class A < 6[i)] | |
| WINTER | 65 | 58.9 [6.8–99.2] | | | Class B < 10 | 0.001* |
| | | | | | Class C < 15 | |

[a] Environmental Protection Agency (2012).
[b] European Collaborative Action (1997).
[c] World Health Organization (2010).
[d] Finnish Society of Indoor Air Quality in 'The Thade Report' (2004).
[e] Decree-Law No. 79/2006 of April 4th, Annex VII.
[f] World Health Organization (2009).
[g] ASHRAE 55.
[h] IAQA 01-2003.
[i] ISO 7730:2005.
* Significant differences in indoor measurements by season (summer/winter).
** Significant differences by indoor/outdoor (overall measurements).

*fumigatus* (32% in summer; 19% in winter) that can cause invasive lung infections in susceptible individuals and *Aspergillus niger* (2% in summer; 59% in winter) with toxigenic properties which some strains have been reported to produce mycotoxins and if large amounts of spores are inhaled cause aspergillosis. However the most predominant fungi species were *Cladosporium* and *Penicillium species* (Fig. 1), which are common in indoor and outdoor environments in all seasons.

A breakdown of IAQ and TC parameters by room and season is presented in Table 3. All the concentrations are within the reference levels except $PM_{2.5}$. Higher levels of this parameter were found in all indoor samples collected, with a peak in the drawing rooms. $CO_2$, bacteria and fungi presented the highest mean levels in the rooms with the highest occupancy rate, i.e., dining room and drawing room. There are significant differences between rooms and season for the following chemical and biological indoor air parameters, TVOC, bacteria and $CO_2$ ($p < 0.01$).

A distribution of all ECCs according to the overall quality rating described in the methods is reported in Fig. 2. The 14% of the studied ECCs have a 'Good' IAQ with all the values under the national and international reference levels. All the other ECCs are classified as 'Acceptable' IAQ, and no center requires immediate intervention.

As regards TC parameters there are significant differences between season of air temperature, PMV, and PPD indices ($p = 0.001$), as shown in Table 2. PMV and PPD indices were measured and calculated only indoors, while air temperature was measured both indoors and outdoors. The lack of significant difference between indoor and outdoor measurements suggests a lack of insulation (Table 1).

The winter season PMV index for all ECCs shows results in the 'slightly cool' [$\leqslant -1$] thermal sensation scale [$-3$ to 3], condition that may increase the risk of respiratory tract infections. The winter PMV ($-1.7$) and PPD (58.9%) overall means are clearly out of the interval reference level showing discomfort in all the areas evaluated. Similarly, minimum winter and summer indoor air temperatures are out of the comfort levels (Table 2). Analyzing the TC parameters by room and season (Table 3) it is clear that in all the areas investigated the PMV winter index is below references and between the 'slightly cool' and 'cool' ($-2$) points in the thermal sensation scale (Fig. 3). Summer PMV indices indicates the bedrooms as the area closer to the 'slightly cool' point. The PPD indices, are not within references in any monitored room both in winter and summer season. The highest dissatisfaction is presented by the winter PPD index in the dining rooms probably because is a temporary place to stay and the heating system is not privileged in this area. The medical office is the area showing the

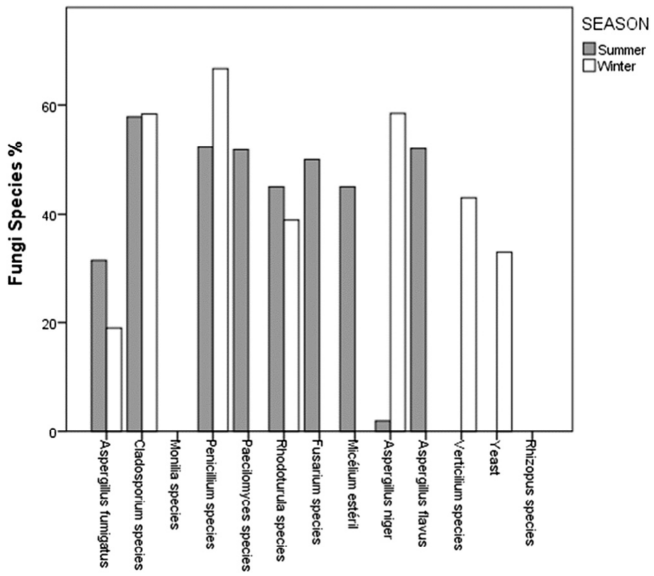


**Fig. 1.** ECCs indoor fungi species (mean percentage of the main identified species) by season.

**Table 3**
Indoor air quality and thermal comfort parameters: descriptive statistics by room & season [Kruskal–Wallis (*H*) Test].

| | | Mean [Min–Max] | | | | |
|---|---|---|---|---|---|---|
| | | Dining Room | Drawing Room | Bedroom | Bedridden | Medical office |
| $PM_{10}$ (mg/m$^3$) | | | | | | |
| | SUMMER | 0.14 [0.02–1.7] | 0.06 [0.02–0.32] | 0.05 [0.02–0.35] | 0.05 [0.02–0.17] | 0.03 [0.02–0.05] |
| | WINTER | 0.07 [0.02–0.3] | 0.07 [0.02–0.43] | 0.07 [0.02–0.37] | 0.05 [0.02–0.2] | 0.05 [0.02–0.09] |
| $PM_{2.5}$ (mg/m$^3$) | | | | | | |
| | SUMMER | 0.06 [0.02–0.3] | 0.11 [0.02–1.39] | 0.05 [0.02–0.26] | 0.2 [0.02–2.1] | 0.3 [0.02–0.6] |
| | WINTER | 0.06 [0.02–0.2] | 0.08 [0.02–0.6] | 0.06 [0.02–0.9] | 0.03 [0.02–0.11] | 0.04 [0.02–0.13] |
| TVOC (mg/m$^3$)* | | | | | | |
| | SUMMER | 0.1 [0.03–0.7] | 0.13 [0.01–2.5] | 0.12 [0.02–0.9] | 0.04 [0.02–0.08] | 0.06 [0.03–0.15] |
| | WINTER | 0.14 [0.01–0.7] | 0.15 [0.03–0.9] | 0.13 [0.02–0.8] | 0.09 [0.03–0.3] | 0.15 [0.02–0.2] |
| Formaldehyde (mg/m$^3$) | | | | | | |
| | SUMMER | <0.042 | <0.042 [<0.042–0.06] | <0.042 | <0.042 [<0.042–0.03] | <0.042 |
| | WINTER | <0.042 | <0.042 [<0.042–0.32] | <0.042 [<0.042–0.3] | <0.042 | <0.042 |
| CO (mg/m$^3$) | | | | | | |
| | SUMMER | 0.7 [0.1–4.4] | 0.6 [0.1–5.4] | 0.8 [0.1–7.1] | 0.9 [0.1–5.3] | 0.5 [0.1–1.2] |
| | WINTER | 0.6 [0.1–2.3] | 0.6 [0.1–2.6] | 0.7 [0.1–3.0] | 0.47 [0.1–1.9] | 0.3 [0.1–0.8] |
| $CO_2$ (mg/m$^3$)* | | | | | | |
| | SUMMER | 938 [595–2313] | 833 [553–1583] | 728 [538–1221] | 689 [543–984] | 718 [640–842] |
| | WINTER | 1323 [563–2374] | 1157 [541–2009] | 1001 [579–2697] | 1143 [678–1590] | 1243 [581–2113] |
| Bacteria (CFU/m$^3$)* | | | | | | |
| | SUMMER | 427 [92–1414] | 411 [36–2282] | 252 [6–1386] | 269 [58–1052] | 342 [84–650] |
| | WINTER | 298 [14–996] | 293 [44–838] | 210 [20–630] | 262 [40–618] | 343 [30–820] |
| Fungi (CFU/m$^3$) | | | | | | |
| | SUMMER | 412 [8–2224] | 269 [38–1010] | 290 [6–1128] | 251 [34–640] | 387 [36–824] |
| | WINTER | 366 [38–2812] | 259 [26–784] | 241 [18–1218] | 218 [18–502] | 171 [80–284] |
| Air Temperature (°C)* | | | | | | |
| | SUMMER | 24.0 [17.0–31.0] | 23.6 [16.0–32.0] | 23.2 [14.0–32.0] | 23.6 [20.0–27.0] | 24.2 [21.0–27.0] |
| | WINTER | 20.0 [15.0–24.0] | 19.5 [16.0–24.0] | 19.5 [13.0–27.0] | 20.6 [16.0–24.0] | 20.3 [15.0–23.0] |
| Relative humidity (%) | | | | | | |
| | SUMMER | 53.1 [23.0–72.0] | 52.9 [28.0–72.0] | 53.3 [28.0–75.0] | 54.9 [32.0–67.0] | 41.3 [21.0–59.0] |
| | WINTER | 50.8 [31.0–75.0] | 49.8 [25.0–68.0] | 49.2 [24.0–72.0] | 51.2 [28.0–73.0] | 46.3 [32.0–58.0] |
| Air Velocity (m/s) | | | | | | |
| | SUMMER | 0.05 [0.01–0.11] | 0.11 [0.01–0.8] | 0.06 [0.01–0.48] | 0.04 [0.01–0.2] | 0.1 [0.1] |
| | WINTER | 0.09 [0.01–0.5] | 0.15 [0.01–1.17] | 0.08 [0.01–0.89] | 0.23 [0.01–1.26] | 0.05 [0.01–0.13] |
| PMV* | | | | | | |
| | SUMMER | −0.06 [(−2.5)–0.9] | −0.3 [(−2.5)–2.3] | −0.7 [(−3.0)–2.0] | −0.2 [(−1.3)–0.8] | 0.4 [0.2–0.6] |
| | WINTER | −1.9 [(−2.8)–(−1.0)] | −1.7 [(−2.9)–(−0.3)] | −1.7 [(−3.0)–(−0.3)] | −1.6 [(−2.5]–(−0.8)] | −1.3 [(−1.7)–(−1.0)] |
| PPD (%)* | | | | | | |
| | SUMMER | 23.1 [5.1–93.8] | 26.3 [5.2–93.2] | 33.9 [5.0–99.1] | 17.3 [5.2–41.4] | 8.8 [5.6–11.9] |
| | WINTER | 69.5 [26.7–98.0] | 59.8 [7.4–98.6] | 58.9 [6.8–99.2] | 57.6 [17.8–92.9] | 38.0 [26.4–60.6] |

* Significant differences by room and season (summer/winter) $p < 0.01$.

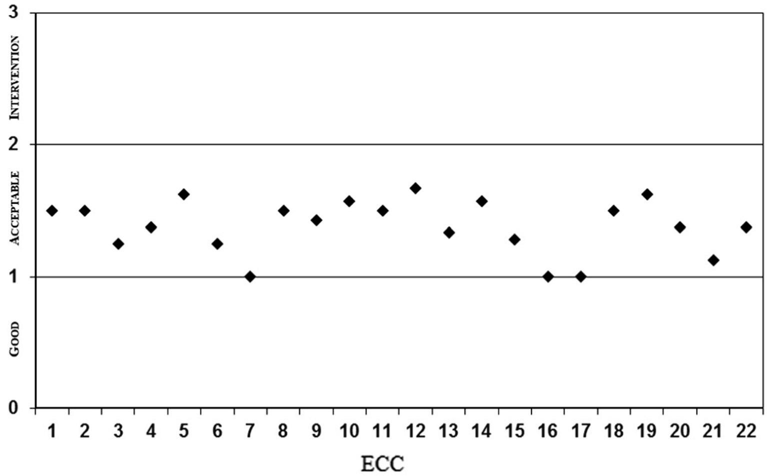


**Fig. 2.** Overall rating of ECCs indoor air quality.

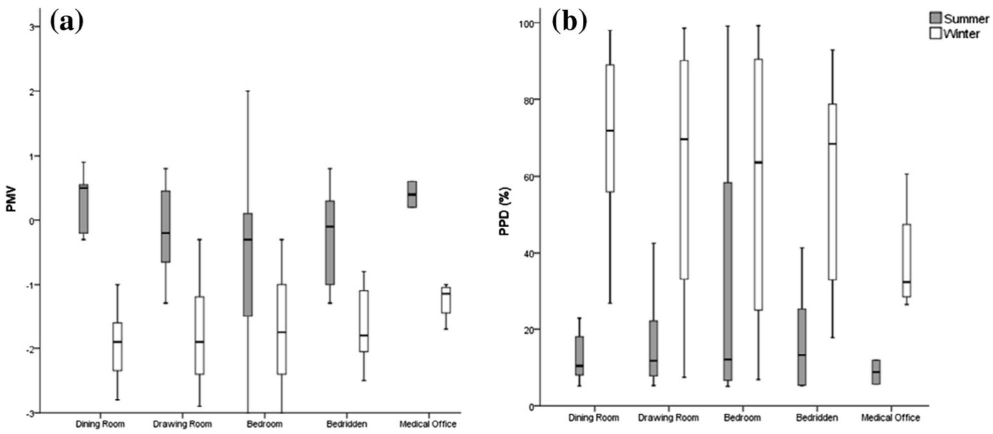


**Fig. 3.** (a) PMV index by room and season, (b) PPD index (%) by room and season (mean of the 22 ECCs).

minimal variability of PPD and PMV, both in winter and summer, suggesting a more accurate control of temperature. In general, PPD and PMV indices largely differ by room and by season ($p < 0.01$). These differences are clearly shown by Fig. 3a (PMV index) and Fig. 3b (PPD index).

### 3.3. Building characteristics vs. environmental assessment

This section explore the possible influence of building characteristics on the indoor environmental quality. A summary view of the association between these variables is reported in Table 4. The building characteristics 'Insulation', 'Heating Ventilation' and 'Windows frames' appear to be the most influential parameters on IAQ and TC. The environmental parameters most commonly affected by building characteristics are the 'Bacteria', 'Fungi', 'Temperature', Relative Humidity', and 'PPD index'.

Regarding the indoor air suspended particles, $PM_{10}$ presents significant differences depending on windows characteristics, whereas $PM_{2.5}$ is also affected by ventilation characteristics, type of roof lining and insulation, and by the presence of architectural modification to adapt the building to the use as

**Table 4**
Building characteristics in the indoor environmental evaluation.

| | Parameters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Buildings Variables** | *$PM_{10}$* | *$PM_{2.5}$* | *TVOC* | *HCHO* | *Bacteria* | *Fungi* | *CO* | *$CO_2$* | *Temp.* | *RH* | *Air Vel.* | *PPD* | *PMV* |
| Adapted to ECC | | $p < 0.001$ | | $p < 0.01$ | | $p < 0.001$ | $p < 0.01$ | | $p < 0.001$ | $p < 0.01$ | | $p < 0.01$ | $p < 0.01$ |
| Building occupancy | | | | | $p < 0.01$ | | | | $p < 0.001$ | $p < 0.001$ | | $p < 0.001$ | $p < 0.001$ |
| Sources of pollution | | | $p < 0.01$ | $p < 0.001$ | | $p < 0.001$ | | | $p < 0.001$ | | | | |
| Walls | | | $p < 0.01$ | | $p < 0.05$ | | | | $p < 0.05$ | $p < 0.05$ | | | |
| Insulation | | $p < 0.05$ | $p < 0.01$ | $p < 0.001$ | | $p < 0.01$ | $p < 0.01$ | | $p < 0.001$ | $p < 0.001$ | | $p < 0.001$ | $p < 0.01$ |
| Roof lining | | | | | $p < 0.05$ | $p < 0.01$ | $p < 0.001$ | | $p < 0.001$ | $p < 0.001$ | | $p < 0.05$ | $p < 0.01$ |
| Ventilation type | | $p < 0.05$ | | | $p < 0.05$ | $p < 0.05$ | | | | $p < 0.001$ | | | |
| Heating ventilation | | $p < 0.01$ | $p < 0.01$ | $p < 0.01$ | $p < 0.001$ | | $p < 0.01$ | | $p < 0.001$ | $p < 0.001$ | | $p < 0.001$ | $p < 0.001$ |
| Building pathologies | | $p < 0.001$ | | | $p < 0.001$ | $p < 0.001$ | $p < 0.05$ | | | | | | |
| Windows type | $p < 0.01$ | | | | $p < 0.05$ | $p < 0.001$ | | | $p < 0.001$ | $p < 0.001$ | | $p < 0.05$ | $p < 0.001$ |
| Sealants | | | | | $p < 0.001$ | | | $p < 0.001$ | | | | | |
| Type sealants | $p < 0.01$ | | $p < 0.001$ | | $p < 0.001$ | $p < 0.05$ | | $p < 0.001$ | | | | | |
| Windows frames | $p < 0.01$ | | $p < 0.01$ | $p < 0.01$ | | $p < 0.01$ | $p < 0.05$ | $p < 0.05$ | $p < 0.001$ | | | $p < 0.05$ | $p < 0.05$ |
| Glass type | | | $p < 0.01$ | | | | | | $p < 0.001$ | | | $p < 0.01$ | |
| Flooring | | $p < 0.001$ | $p < 0.001$ | $p < 0.01$ | | $p < 0.05$ | | | $p < 0.001$ | $p < 0.001$ | $p < 0.05$ | | |

Significant differences by building variable and environmental evaluation: $p < 0.001$; $p < 0.01$; $p < 0.05$

ECC ('adapted to ECC'). TVOC is higher if the building is close to sources of pollution, and depends also by building insulation, ventilation characteristics, windows, walls and floor characteristics. Formaldehyde is significantly affected by the condition of 'adapted to ECC', by 'insulation' and type of flooring. Similarly, CO is higher in building 'adapted to ECC' and is modified by insulation and roof lining characteristics. $CO_2$ shows differences also depending upon the presence of windows sealants and the type of these sealants. The presence of bacteria depends on heating/ventilation or the presence of building pathologies. Fungi concentrations is associated to 'adapted to ECC', 'sources of pollution', 'insulation', roof and windows characteristics, and building pathologies such as infiltrations and condensations.

Concerning the TC, temperature is modified by essentially all building characteristics except by the type of ventilation, the building pathologies, and the windows sealant characteristics. RH varies according to the building purpose and occupancy, the insulation and ventilation characteristics, and roof, walls, floor and windows features. These findings are overlapping those of PMV and PPD indices, with the exception of the glass-type variable for PPD.

## 4. Discussion

Aging is associated with a decline in immune defense and respiratory function, and predisposition to respiratory infections (Boita et al., 2006). Due to these conditions, elderly are more susceptible to the effects of air pollution, and since they spend the large majority of their time indoors, monitoring IAQ and TC in elderly centers is a public health priority (Bentayeb et al., 2013). With this purpose the GERIA project aims to characterize the ECC indoor environment and explore the influence of building characteristics on IAQ parameters. Our study found higher levels of $PM_{2.5}$ in all ECC spaces in both seasons, compared to the international reference levels, revealing that particle matter concentrations is a critical parameter of air quality, both for its sensitivity and for its possible influence on human health. The findings which showed as this parameter is strongly depending to season, filter usage, relative humidity, air exchange ratios, number of occupants, outdoor PM levels, sweeping/dusting, and presence of a central air conditioner, reported a number of critical issue for any programs aimed at preventing exposure to inhalable toxic agents of the elderly population (Batterman et al., 2012).

Our mean overall indoor $PM_{2.5}$ evaluations were about 3 times above the US EPA (Environmental Protection Agency, 2012) reference levels, with the highest values in the bedridden subset and medical office. This might be due to combination of outdoor contamination, occupancy rate and the accelerated particle resuspension in spaces dedicated to indoor activities (Hospodsky et al., 2012). Other studies (Wang et al., 2006; Bentayeb et al., 2013) have found, high levels of $PM_{2.5}$ in similar indoor environments, and the link with lung function (Lee et al., 2007) and respiratory diseases such as COPD (Osman et al., 2007; Liu et al., 2007) has been quite demonstrated. Weather generated by indoor or outdoor pollution the $PM_{2.5}$ is acknowledged by WHO and by EPA as a known cause health risk for lung and heart diseases (including asthma) (World Health Organization, 2006).

Although all the other indoor air pollutants were within the reference levels peak values of $PM_{10}$, TVOC, $CO_2$, bacteria and fungi exceeded the reference levels, compromising indoor air comfort and worsening the already existent respiratory chronic diseases. A VOC study in the elderly French dwellings show statistically significant associations between breathlessness and living in dwellings with elevated concentrations of toluene and o-xylene in elderly population (Bentayeb et al., 2013).

When TVOC, bacteria, CO and $CO_2$ indoor levels are compared with ambient air they were higher in both seasons, suggesting as indoor pollution is the most important source of exposure, at least in this population. Indoor ECCs activities influence pollution levels, especially in the winter season. Seasonality is a critical parameter affecting the level of exposure to $PM_{10}$, TVOC, bacteria and $CO_{2,}$ and simple behaviors such as opening and closing windows may dramatically change these values. Dining rooms and drawing rooms are expected to have the highest mean and maximum levels of $PM_{10}$, $CO_2$ and bacteria concentration due to higher occupancy rate in these room areas when compared to bedrooms and medical offices. An inadequate ventilation can increase exposure not bringing in enough outdoor air to dilute emissions from indoor sources and allowing indoor air pollutants out of the rooms (Annesi-Maesano et al., 2013). Similar conditions may explain significant differences between rooms and season for TVOC, bacteria and $CO_2$.

Although the most predominant airborne fungi species found in the ECCs were *Cladosporium* and *Penicillium species*, which are common in indoor and outdoor environments, we also found samples positive for the genotoxic and pathogenic species of *Aspergillus*. These species may infect patients with reduce or compromised immune systems and may cause invasive lung infections in susceptible individuals such as elderly. The lack of building insulation causes ECC rooms to have similar temperature and humidity of outdoors, while the high rate of building pathology, e.g., condensations and infiltrations, may influence positive results, since the environmental parameter 'Fungi' was strictly associated to the building characteristics 'Insulation' and 'Building pathologies' (Sandstrom and Viegi, 2003; Hulin et al., 2012). Temperature and humidity levels can also increase the concentration of some pollutants.

In an overall perspective this study shows reassuring results about IAQ in the ECCs evaluated. More than 1/3 of the studied ECCs reported excellent results, regarding the control of chemical and biological pollutants. However, although no ECC requires immediate intervention according to international and national reference levels, these thresholds may not be appropriate for susceptible populations, and specifically for elderly, which besides the increased biological sensitivity to the effect of air pollution spend nearly the 100% of their time in indoor spaces. Dedicated exposure/effect models should be developed for this population (United States Environmental Protection Agency (US EPA), 2011).

Thermal environmental comfort is another major issue for the elderly population (Raymann and Van Someren, 2008). Several studies demonstrated the effect of ambient temperature on cardio-respiratory mortality (Halonen et al., 2010) and these findings were replicated with indoor climate (Bokenes et al., 2011). In general, elderly perceive TC differently from the young due to a combination of physical ageing and behavioral differences (Hoof and Hensen, 2006; van Hoof, 2008). Studies show that older adults prefer a warmer environment (+2 °C) than younger people (Hoof and Hensen, 2006). The standard 20–24 °C comfort zone may be not warm enough for older adults, which reported an optimum temperature above 25 °C for sedentary older adults (Hwang and Chen, 2010). The TC results or our study showed significant differences between room and season for air temperature, especially for PMV and PPD indices, suggesting that the building and heating characteristics may affect indoor variance in the winter/summer temperature and RH. Moreover, thermal comfort depends also by individual parameters such as the degree of activity, the clothing worn by the individual, the age, health status, gender, and the adaptation to the local environment and household. Other factors like rooms crowding or under-occupancy may have an influence, and so is for the variability during the day and over time (Ormandy and Ezratty, 2012). However, the results of the winter season PMV index in our study show that thermal sensation scale in all analyzed rooms ranged between the 'slightly cool' (−1) and 'cool' (−2), while minimum winter and summer indoor air temperatures were constantly out of the comfort levels. Colder environments may potentiate elderly respiratory tract infections and also increase hospital consultations (Hajat et al., 2004). Among the other results also the inflammation caused by respiratory syncytial virus may be modified by the biologically active contaminants of indoor air (Foster et al., 2003). The prevalence in our study group of buildings built in stone masonry with poor insulation and a limited availability of double-pane glass may explain this low thermal sensation scale index (PMV) and the high percentage of PPD (59%) index in the winter season, and pave the way for the most urgent structural interventions. To be noted that the presence of diverse heating systems in the ECCs evaluated did not significantly affect average indoor temperature in the winter season (19.7 °C), which constantly stay below reference values for neutral/comfort temperature.

The present study investigated a large selection of indoor air pollutants and TC parameters in ECCs both in summer and winter season. Several significant differences were found for IAQ and TC parameters when compared by season, when indoor parameters were compared with outdoor, when differences between the 22 ECCs or their internal spaces were tested. Although the reliability of $p$ values associated to hypothesis testing is limited – as in this case – by the presence of multiple comparison, these data provide a comprehensive view on the quality of IAQ and TC in this setting, and especially on the relative importance of building characteristics and ECCs daily life activities in determining indoor conditions in the ECCs. Our findings which are in keeping with our project preliminary results (Mendes et al., 2013), provide remarkable information to assess housing structure and function along with lifestyle decisions determinants to IAQ. This research will contribute to the understanding of the health effects due to IAQ variables and their potential to improve the health of our elderly population.

In conclusion, these results provided critical data on how maintaining comfortable indoor temperatures and good IAQ for susceptible populations living in ECCs, suggesting a high priority to intervention regarding insulation devices, such as, roof, walls and windows insulation.

## 5. 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 host factors like age, gender, genetic heritage, and underlying state of health. Our study focused on the assessment of indoor environmental variables (IAQ and TC) in the ECCs that might influence elderly comfort and wellbeing and interact with their already existent chronic diseases. Our study suggested that the IAQ in the ECCs of the Porto area is acceptable and no immediate intervention is required. Attention is needed to peak concentrations and fungi species that might compromise IAQ comfort. The concentration reduction of indoor air pollutants, in particular, particle matter and its health effects range from regulatory measures (stricter air quality standards, limits for emissions from various sources), structural changes (such as reducing energy consumption, especially that based on combustion sources, changing modes of transport, land use planning) as well as behavioral changes by individuals by, for example, using cleaner modes of transport or household energy sources. Nevertheless, adequate measures, such as, local exhaust ventilation systems near cooking and gas burning devices, as well as, daily slightly moist cleaning of the rooms surfaces would reduce particle accumulation and re-suspension. To prevent low indoor temperatures and discomfort, especially on winter season, simple measures could provide health benefits to ECC residents and workers, such as insulating ceilings, walls, and windows, maintaining natural and passive ventilation, solutions that are common in Portugal due to the advantage of the country's generally mild weather. More studies on indoor pollutants and health in the elderly are needed, with focus on exposure assessment, providing a better understanding of the adverse health effects induced by indoor air pollution in elderly.

## Acknowledgments

We are indebted to all of the participants in the GERIA Project as well as to the professionals and elderly residents in the ECCs and the authorities from which they depend. Our current research is supported by GERIA Project (www.geria.webnode.com): PTDC/SAU-SAP/116563/2010 and a PhD Grant (SFRH/BD/72399/2010) from Foundation for Science and Technology (Fundação para a Ciência e Tecnologia – FCT). SB and RM work was supported by a grant funded by AIRC (Associazione Italiana per la Ricerca sul Cancro).

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# III. Biological Air Contamination in Elderly Care Centers: GERIA Project


**Journal of Toxicology and Environmental Health, Part A: Current Issues**

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uteh20

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Published online: 29 Jul 2014.

**To cite this article:** Lívia Aguiar, Ana Mendes, Cristiana Pereira, Paula Neves, Diana Mendes & João Paulo Teixeira (2014) Biological Air Contamination in Elderly Care Centers: Geria Project, Journal of Toxicology and Environmental Health, Part A: Current Issues, 77:14-16, 944-958, DOI: 10.1080/15287394.2014.911135

**To link to this article:** http://dx.doi.org/10.1080/15287394.2014.911135

*Journal of Toxicology and Environmental Health, Part A*, 77:944–958, 2014

ISSN: 1528-7394 print / 1087-2620 online
DOI: 10.1080/15287394.2014.911135

Taylor & Francis
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# BIOLOGICAL AIR CONTAMINATION IN ELDERLY CARE CENTERS: GERIA PROJECT

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**Indoor air quality (IAQ) affects health particularly in susceptible individuals such as the elderly. It has been estimated that the older population spends approximately 19–20 h/d indoors, and the majority of the elderly spend all of their time indoors in elderly care centers (ECC). Older individuals may be particularly at risk of exposure to detrimental effects from pollutants, even at low concentrations, due to common and multiple underlying chronic diseases that increase susceptibility. This study, aimed to assess the impact of indoor biological agents in 22 ECC located in Porto, was conducted during summer and winter from November 2011 to August 2013 at a total of 141 areas within dining rooms, drawing rooms, medical offices, and bedrooms (including the bedridden). Air sampling was carried out with a microbiological air sampler (Merck MAS-100) and using tryptic soy agar for bacteria and malt extract agar for fungi. The results obtained were compared with the recently revised Portuguese standards. In winter, mean fungi concentration exceeded reference values, while bacteria concentrations were within the new standards in both seasons. The main fungi species found indoors were *Cladosporium* (73%) in summer and *Penicillium* (67%) in winter. *Aspergillus fumigatus, Aspergillus niger*, and *Aspergillus flavus*, known potential pathogenic/toxigenic species, were also identified. Although the overall rate and mean values of bacteria and fungi found in ECC indoor air met Portuguese legislation, some concern is raised by the presence of pathogenic microorganisms. Simple measures, like opening windows and doors to promote air exchange and renewal, may improve effectiveness in enhancing IAQ.**

According to United Nations estimates, the total number of people aged 65 yr and older was 506 million in 2008 and is anticipated to double to 1.3 billion by 2040, accounting for 14% of total global population. By 2050, Europe will continue to be the world's oldest region with its elder population increasing more than 5-fold from 40 million to 219 million (Bentayeb et al., 2013). These demographic changes result in new patterns of morbidity and mortality, such as increasing number of patients simultaneously affected by different chronic diseases. Globally, health care organizations displayed an elevated concern regarding mechanisms to cope with an aging population (Caley and Sidhu, 2011). This trend explains the increasing demand of long-term care services (Damiani et al., 2009) such as elderly care centers (ECC) (Kembel et al., 2012). It has been estimated that older persons spend approximately 19–20 hr/d indoors, and many spend all their time indoors in ECC. Adverse health effects are produced by biological agents found in the ECC, and with the fact that the susceptible population spends the bulk of time indoors in the ECC, it is thus extremely important to assess these people's exposure to biological pollutants.

Portugal is the 8th oldest country in the world and the 6th in Europe, with 23% of

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population being more than 60 yr of age. In Portugal, the number of ECC rose 49% between 1998 and 2010. Further, considering that elders often spend a considerable portion of their lives indoors, enhanced by reduced independence, it is clear that the possibility that adverse indoor climate might influence their health status cannot be ignored (Silva-Almeida et al., 2014).

Biological air contaminants are basically constituted with bacteria, fungi, and viruses, and their distribution may vary according to environment, area within the environment, and location within a given area. The numbers may also vary depending upon the source of microorganisms, such as speech, cough, sneeze, or breathing (Grigorevski-Lima et al., 2006). Kembel et al. (2012) reported that air temperature and relative humidity (RH), as well as the source of ventilation air and occupant density, influence the abundance and transmission of some pathogenic microbes. Inadequate air-conditioning systems, low ventilation rate, and overcrowding enhance exposure risks (Wan et al, 2011). In addition, environments with problems of RH or infiltration generally have a microbial population larger than acceptable (Grigorevski-Lima et al., 2006).

Airborne bacteria in indoor air are potential causative agents of several infectious diseases, and their components are linked to development and exacerbation of chronic respiratory illness including asthma (Hospodsky et al., 2012). Further, fungal exposures have been documented to induce allergic diseases, toxicoses, irritation, and infections (Chao et al., 2002). Dampness and mold in buildings are also associated with increased incidence of upper-respiratory-tract (nasal and throat) symptoms, cough, wheeze, and asthma symptoms in sensitized asthmatic persons (Lee et al., 2006; Niemeier et al., 2006). Exposure to fungi indoors is particularly hazardous for individuals with underlying respiratory disease, such as the elderly (Ayanbimpe et al, 2010), namely, exposure to fungi of the *Aspergillus* species, which for the most part fail to trigger an infection in a healthy person; however, these fungi constitute a threat predominantly to subjects with immunity disorders.

*Aspergillus fumigatus* exerts most significant clinical relevance for humans. This fungal species may produce acute and chronic inhaled respiratory-tract infections (aspergillosis, aspergilloma), as well as infections of the hematopoietic system, digestive system, genitourinary tract, skeletal muscles, and nervous system. Another pathogenic species that produces infections of the respiratory system and that also may induce allergic aspergillosis is *Aspergillus flavus*. This fungus is also responsible for cases of chronic invasive sinusitis as well as deep fungal infections. *Aspergillus niger* may also produce infections of the inner and outer ear, as well as pulmonary aspergillosis (Gniadek, 2012).

This study presents results that have been produced within the GERIA ongoing project "Geriatric study in Portugal on Health Effects of Air Quality in Elderly Care Centers," by measuring and characterizing indoor biological environments in 22 ECC in Porto, Portugal, out of 58 (with an overall number of 1355 residents). The study aims were to (1) assess total bacteria and fungi concentrations in a representative sample of ECC in Porto as compared to current national standards, (2) examine the variability of these biological parameter among different spaces within ECC, (3) identify the main fungi species found in the evaluated areas, (4) determine possible correlations between biological contamination and other indoor air quality (IAQ) parameters, and (5) examine how buildings characteristics may affect indoor air biological pollutants.

## MATERIAL AND METHODS

All ECC located within the Porto urban area and included in the *"Portuguese Social Charter"* were invited to participate in our study. Out of a total of 58 ECC located in Porto urban area, 38% ($n$ =22) agreed to participate in this study. Data were collected for each ECC in two seasons (i.e., summer and winter), and the following parameters were measured: building and ventilation characteristics; biological parameters such as total bacteria count, fungi count, and identification; the chemical parameter carbon dioxide ($CO_2$); and the physical parameters relative humidity (RH) and air temperature. The city of Porto (41N11.8W36) is located along the Douro river estuary in northern Portugal, featuring the Mediterranean climate (Köppen climate classification = Csb) with moderate temperatures and rainy weather in the winter season, and milder summers due to the nearby presence of cold ocean currents that bring fog but prevent rain. The research team considered that all ECC included in the study were exposed to the same climate.

### Buildings Walk-Through Survey

The building characterization included the following information: type of building construction (concrete, masonry, etc.); thermal isolation of the building; characteristics of building envelope (type of windows and doors, presence of weatherstripping, etc.); ventilation system (natural, mechanical, hybrid, etc.); types of indoor materials; use of gas-burning appliances; evidence of dampness or mold; and ventilation practices (opened windows).

### Indoor Air Quality (IAQ) Monitoring

IAQ parameters were measured twice, during winter and summer seasons, from November 2011 until August 2013. The monitoring was performed in each ECC in the following spaces: dining rooms, drawing rooms, medical offices, and bedrooms, including the bedridden subgroup. In total, 141 areas were evaluated. Ambient air samples were also collected for comparison to indoor measurements. All active sampling and associated analytical measurements were performed in duplicate (in the same sampling point). This investigation was performed by the Environmental Health Department of the National Health Institute using methodologies accredited by NP EN ISO/IEC 17025:2005, "General requirements for the competence of testing and calibration laboratories."

### Sampling Schedule and Locations

The monitoring phase included daytime air sampling starting at 10 a.m. and conducted discretely to minimize nuisance to normal resident's activities. Samplers were placed at a height of 0.6–1.5 m above the floor, approximately at the breathing zone level and as close as possible to the center of the room. Sampling points were always located more than 1 m from walls, windows, doors, or an active heating system.

### Carbon Dioxide ($CO_2$), RH, and Air Temperature

During normal occupancy conditions, $CO_2$ concentrations, RH, and air temperature were determined using a portable IAQ monitor (GasData, model PAQ). Short-term measurements (30 min average) were collected in each room. After equipment stabilization, measurements were recorded continuously and transferred to an informatics system using PCLogger 32 V3.0 software.

### Bacteria and Fungi

Microorganism air sampling was conducted following NIOSH Method 0800: Bioaerosol Sampling (Indoor Air) (National Institute for Ocupational Safety and Health [NIOSH], 1998), and ISO 16000-18:2011 (International Organization for Standardization, 2011), using a microbiological air sampler (Merck Air Sampler MAS-100), an airflow rate of 100 L/min, and two 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 and with one field blank per culture medium per day. To quantify fungi, samples were incubated at 25°C over 3 d. Identification of fungal colonies was based upon phenotypic characteristics and followed standard mycological procedures (International Organization for Standardization, 2003). Bacteria were incubated at 37°C for 2 d. Quantification of bacteria and fungi was performed by naked eye count, following the methodologies expressed in ISO 4833:2013 (International Organization for Standardization, 2013) and CSN EN 13098, respectively. Results were expressed as colony-forming units per cubic meter of air ($CFU/m^3$).

### Calculation and Data Analysis

The biological assessment results were compared to the revised Portuguese reference levels. Classical statistical methods were used to estimate means, medians, and frequencies (%) in order to obtain insight into ECC characteristics and environmental monitoring results within and between buildings. Descriptive statistics such as boxplots, scatterplots, and bar charts were also applied. The variables were tested for normality with the Shapiro–Wilk test and generally revealed a non-normal distribution except for air temperature. Nonetheless, it was decided to use the mean for descriptive purposes. The Mann–Whitney ($U$) test and Kruskal–Wallis ($H$) test for independent samples were conducted for seasonal effects assessment, indoor/outdoor, and within buildings location differences. Spearman's rank correlation coefficient ($r_S$) was performed to assess possible relationships between some variables in study. A $p < .05$ level of significance was used for all analyses. Expanded uncertainty was evaluated for the 95% confidence interval based on probability distributions propagation of measurements, obtained by multiple samples and considering instrumental uncertainty obtained from traceable calibrations. All data were analyzed using IBM SPSS 21.0.

## RESULTS

### Buildings Characteristics

The 22 ECC are located in the urban area of Porto city, most of them ($n = 17$) in heavy traffic areas. In total, 716 elderly persons lived in these centers with a range of 7 to 136 occupants per building (generally three-story houses with a little garden in front or in the back of the household). As regards construction characteristic, 53% of ECC were separated from surrounding buildings, 66% were an adaptation to an ECC of an existing residential building, and 40% were also developing activities of day care centers for elderly. The mean age of ECC was 111 yr, ranging from 8 to 313 yr. Retrofit average was 7 yr.

Table 1 presents the main buildings characteristics. Most of them were built in stone masonry construction (49%) with single-pane windows (87%). Only 30% have roof and walls insulation, while 61% of the sampled buildings presented condensation and infiltration along walls and roofs inside the buildings. Ceramic tile is the common roof lining (87%), and the indoor floor is typically (48%) covered by vinyl (PVC). Twelve buildings (53%) have central heating, while the others possess autonomous devices (one ECC had both installations), equally fueled with electricity or gas (39%). All ECC 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.

### Biological Assessment

During monitoring, the mean daily ambient air temperature in Porto was 17°C (11–23°C), with 49% (18–80%) RH in the winter, and 24°C (17–34°C) with 47% (18–76%) RH in the summer. The mean biological parameters concentrations found between all ECC assessed were within the Portuguese reference levels with exception of fungi concentration in winter (Table 2). It is important to note that regarding bacteria concentration, maximal levels detected indoors are much higher than the maximal levels found outdoors, enhanced by the significant difference between indoor and outdoor bacteria concentration. These values might compromise indoor air comfort. Table 2 also reported significant differences between bacteria concentrations in both seasons, as well

**TABLE 1.** Distribution of ECCs by Building Characteristics

| Building characteristics | *n* | % |
|---|---|---|
| Adapted to ECC | 14 | 66 |
| Walls | | |
| Brickwork | 6 | 30 |
| Stone masonry | 11 | 49 |
| Both | 5 | 22 |
| With roof and walls insulation | 6 | 30 |
| Ventilation type | | |
| Natural (only) | 3 | 13 |
| Mixed ventilation | 19 | 87 |
| Heating | | |
| Central heating (CH) | 12 | 53 |
| Autonomous devices (AD) | 9 | 43 |
| CH + AD | 1 | 4 |
| Windows | | |
| With sealants | 13 | 43 |
| Double-pane glass | 3 | 13 |
| Single-pane glass | 19 | 87 |
| Building pathologies | | |
| Condensations + infiltrations | 13 | 61 |
| Clear | 9 | 39 |

as for $CO_2$ concentrations. $CO_2$ was within Portuguese reference levels; however, maximal levels recorded are important to notice. Statistical differences between fungi concentration in summer and winter were tested without significant results.

A breakdown of biological parameters by room and season is presented in Table 3. Once again, bacteria and $CO_2$ concentrations are within the Portuguese reference levels, but indoor fungi concentrations in winter are higher than fungi concentrations outdoors in all areas evaluated with the exception of the "medical office." $CO_2$, bacteria, and fungi presented the highest mean levels in the rooms with the highest occupation rate, that is, the dining room and drawing room, in both seasons. There were significant differences between rooms and season for bacteria.

Figure 1 illustrates the fungi concentration values in all bedrooms assessed. These are predominantly distributed below the 400 CFU/m$^3$ and, although mean fungi concentration indoors in winter is above the fungi concentration outdoors, it is in summer that fungi concentrations in bedrooms register higher levels. Figure 2 displays median bacteria concentrations at higher levels in summer for all evaluated areas with exception of "bedridden." This figure concurs and illustrates the values of this parameter in both seasons and by area established in Table 3. Outdoor bacteria concentrations are also higher in summer than

**TABLE 2.** Elderly Care Centers Indoor/Outdoor: Descriptive Statistics by Season

| | Indoor | | Outdoor | | | |
|---|---|---|---|---|---|---|
| | N | Mean [Min-Max] | N | Mean [Min-Max] | Reference | *p* |
| $CO_2$ (mg/m$^3$) | | | | | | |
| Summer | 137 | 786 [538–2313] | 24 | 590 [384–893] | 2250[a] | 0.001*(1) |
| Winter | 137 | 1125 [541–2697] | 24 | 609 [516–879] | | 0.001**(1) |
| Bacteria (CFU/m$^3$) | | | | | | |
| Summer | 137 | 329 [6–2282] | 23 | 162 [24–616] | Indoor < Outdoor + 350 CFU/m$^3$[a] | 0.01*(1) |
| Winter | 133 | 258 [14–996] | 23 | 89 [8–368] | | 0.001**(1) |
| Fungi (CFU/m$^3$) | | | | | | |
| Summer | 132 | 305 [6–2224] | 23 | 531 [20–3454] | Indoor < Outdoor[a] | — |
| Winter | 130 | 260 [18–2812] | 22 | 208 [62–676] | | |
| Air temperature (°C) | | | | | | |
| Summer | 137 | 24 [14–32] | 24 | 25 [17–34] | [18–22][b] | 0.001*(2) |
| Winter | 137 | 20 [13–27] | 24 | 17 [11–23] | | |
| Relative humidity (%) | | | | | | |
| Summer | 137 | 53 [21– 75] | 24 | 47 [18–76] | [50-70] [b] | — |
| Winter | 137 | 50 [24–75] | 24 | 49 [18–80] | | |

*Note.* (1) Mann–Whitney (*U*) test. (2) Paired *t*-test (t).
[a]Ordinance no. 353-A/2013 of December 4th
[b]Decree-Law no. 243/86 of August 20.
*Significant differences in indoor measurements by season (summer/winter).
**Significant differences by indoor/outdoor (overall measurements).

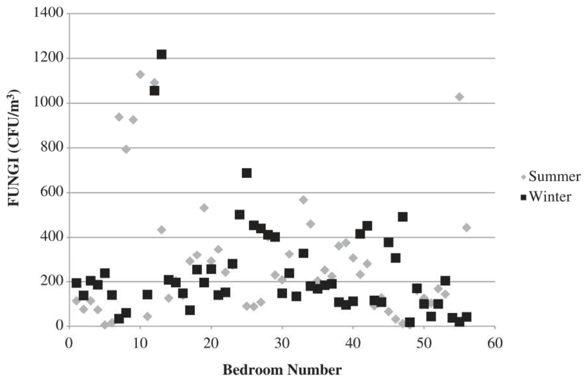


**FIGURE 1.** Fungi concentration along bedrooms assessed, in summer and winter.

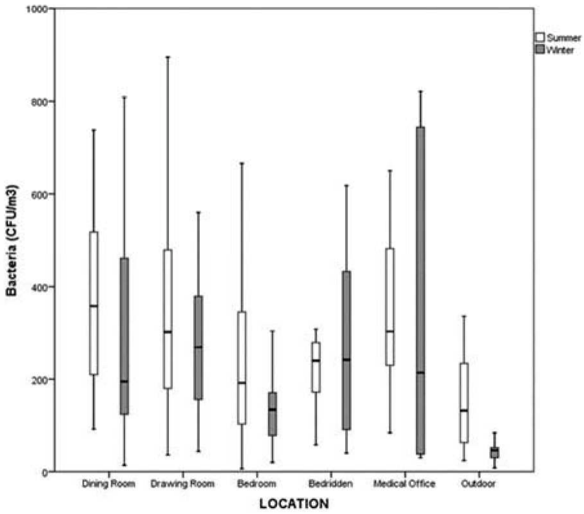


**FIGURE 2.** Bacteria concentration by area, summer and winter.

winter. The maximal values found for bacteria concentration were higher in winter for the areas of "dining room," "bedridden," and "medical office." For the other two areas evaluated, "drawing room" and "bedroom," maximal values were consistent with median values, indicating they were also higher in summer.

## Fungi Identification

The predominant fungi species found inside the studied ECC were *Cladosporium* (73%) in summer, followed by *Penicillium* (52%), *Paecilomyces* (52%), and *Aspergillus flavus* (52%). In winter, *Penicillium* (67%) was the prevalent fungi species identified, followed by *Cladosporium* (58%) and *Aspergillus niger* (57%) the other two main species (Figure 3). Table 4 presents mean isolates number of colonies of each prevalent species identified in summer and winter, as well as mean isolates number of *Aspergillus* species identified in our study.

Both *Penicillium* and *Cladosporium* are considered to be common in indoor and outdoor environments in all seasons. On the other hand, all *Aspergillus* species identified are

**TABLE 3.** Indoor Air Quality Parameters: Descriptive Statistics by Room and Season [Kruskal–Wallis (*H*) Test]

| | Mean [Min-Max] | | | | | |
|---|---|---|---|---|---|---|
| | Dining Room | Drawing Room | Bedroom | Bedridden | Medical Office | Outdoor |
| $CO_2$ (mg/m$^3$)* | | | | | | |
| Summer | 938 [595–2313] | 833 [553–1583] | 728 [538–1221] | 689 [543–984] | 718 [640–842] | 590 [384–893] |
| Winter | 1323 [563–2374] | 1157 [541–2009] | 1001 [579–2697] | 1143 [678–1590] | 1243 [581–2113] | 609 [516–879] |
| Bacteria (CFU/m$^3$)* | | | | | | |
| Summer | 427 [92–1414] | 411 [36–2282] | 252 [6–1386] | 269 [58–1052] | 342 [84–650] | 162 [24–616] |
| Winter | 298 [14–996] | 293 [44–838] | 210 [20–630] | 262 [40–618] | 343 [30–820] | 89 [8–368] |
| Fungi (CFU/m$^3$) | | | | | | |
| Summer | 412 [8–2224] | 269 [38–1010] | 290 [6–1128] | 251 [34–640] | 387 [36–824] | 531 [20–3454] |
| Winter | 366 [38–2812] | 259 [26–784] | 241 [18–1218] | 218 [18–502] | 171 [80–284] | 208 [62–676] |
| Air temperature (°C)* | | | | | | |
| Summer | 24 [17–31] | 24 [16–32] | 23 [14–32] | 24 [20–27] | 24 [21–27] | 25 [17–34] |
| Winter | 20 [15–24] | 20 [16–24] | 20 [13–27] | 21 [16–24] | 20 [15–23] | 17 [11–23] |
| Relative humidity (%) | | | | | | |
| Summer | 53 [23–72] | 53 [28–72] | 53 [28–75] | 55 [32–67] | 41 [21–59] | 47 [18–76] |
| Winter | 51 [31–75] | 50 [25–68] | 49 [24–72] | 51 [28–73] | 46 [32–58] | 49 [18–80] |

*Significant differences by room and season (summer/winter), $p < .01$.

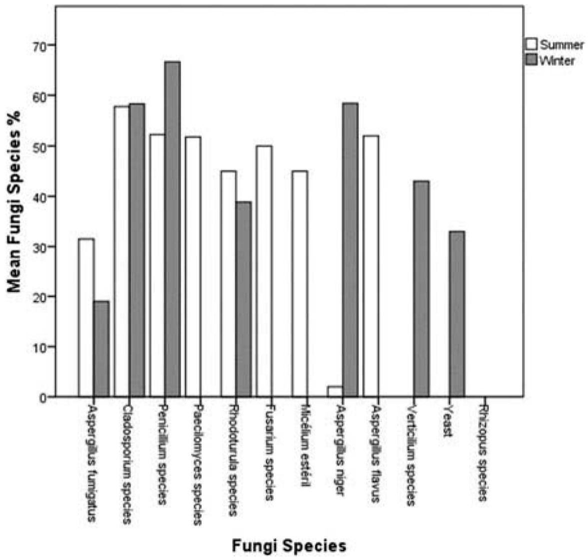


**FIGURE 3.** ECC main indoor fungi species by season.

**TABLE 4.** Fungi Species Isolates Number in Summer and Winter

| Fungi species | CFU: Mean [min–max] Summer | Winter |
|---|---|---|
| *Cladosporium* | 221 [14–528] | 117 [6–576] |
| *Penicillium* | 108 [14–304] | 222 [45–856] |
| *Paecilomyces* | 32 [1–262] | 4 [1–15] |
| *Aspergillus flavus* | 5 [1–21] | 1 [1–1] |
| *Aspergillus fumigatus* | 21 [1–62] | 17 [1–49] |
| *Aspergillus niger* | 7 [1–14] | 31 [1–218] |

considered to be toxigenic: *Aspergillus flavus* often infects patients with reduced or compromised immune systems; *Aspergillus niger* possesses toxigenic properties, with some strains being reported to produce mycotoxins, and if large amounts of spores are inhaled induces aspergillosis. *Aspergillus flavus* was only identified in summer and *Aspergillus niger* was only prevalent in winter. However, *Aspergillus fumigatus* that produces invasive lung infections in susceptible individuals was found in four ECC both in winter (19%) and summer (32%), and was the prevalent species identified in the majority of evaluated areas of one ECC during summer. During summer assessment, this three pathogenic *Aspergillus* species were found in one ECC.

### Correlation Between Chemical, Physical, and Biological Parameters

The mean bacteria concentrations along with the mean number of persons found in the areas evaluated in both seasons are presented in Figure 4. To assess whether the bacteria concentration was higher as more elderly people were present in a room evaluated, Spearman's rank correlation coefficient was applied. The correlation result was not statistically significant.

$CO_2$ concentration is an indicator of human presence and contamination, allowing one to evaluate whether ventilation is effective. In this sense, correlation between the concentrations found indoors of this gas and bacteria by area in summer and winter was also tested. There seems to be no apparent relationship between bacteria and $CO_2$ concentrations, as illustrated in Figure 5. This result was supported by Spearman's rank correlation coefficient. Data indicate that in our study high concentrations of $CO_2$ were not markedly associated with high levels of bacteria.

Regarding fungi concentration, it is known that a room with high levels of RH is more likely to also possess high concentrations of fungi. The values found for these two parameters between the ECC evaluated in summer and winter are shown in Figure 6. Once again the correlation was not statistically significant.

### Building Characteristics Versus Environmental Assessment

This section explores the possible influence of building characteristics on biological indoor air parameters. A summary of the association between these variables is reported in Table 5. Data show that the most significant differences between building variable and biological parameter are that the presence of bacteria in an ECC depends on heating/ventilation or presence of building pathologies, and the dependence upon presence of window sealants and the type of these sealants. On the other hand, fungi concentrations are associated with building adaption to ECC, existing sources of pollution, insulation, roof and windows

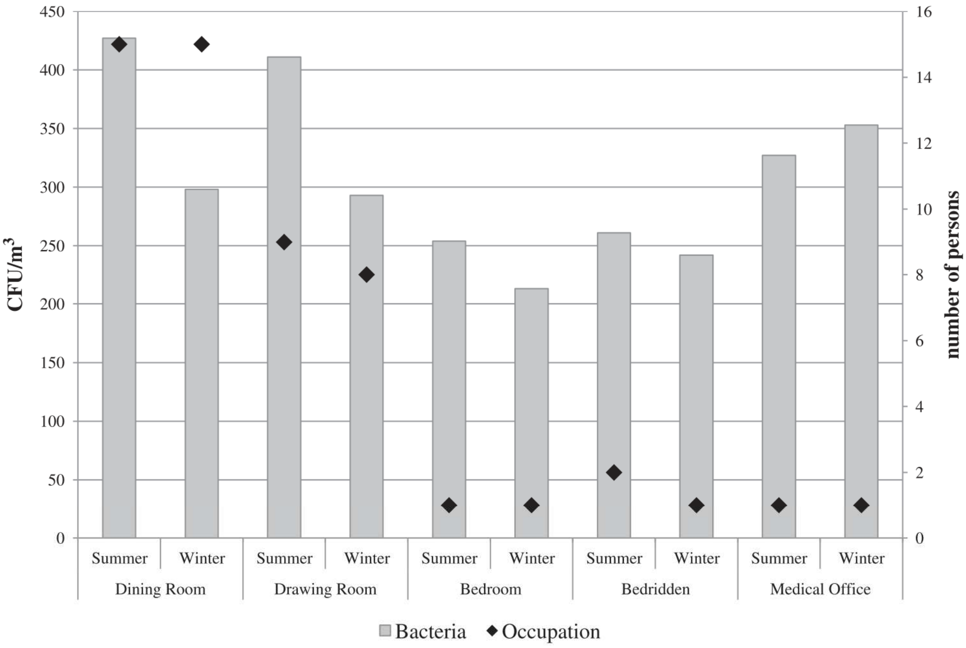


**FIGURE 4.** Bacteria concentration and occupancy by area, summer and winter.

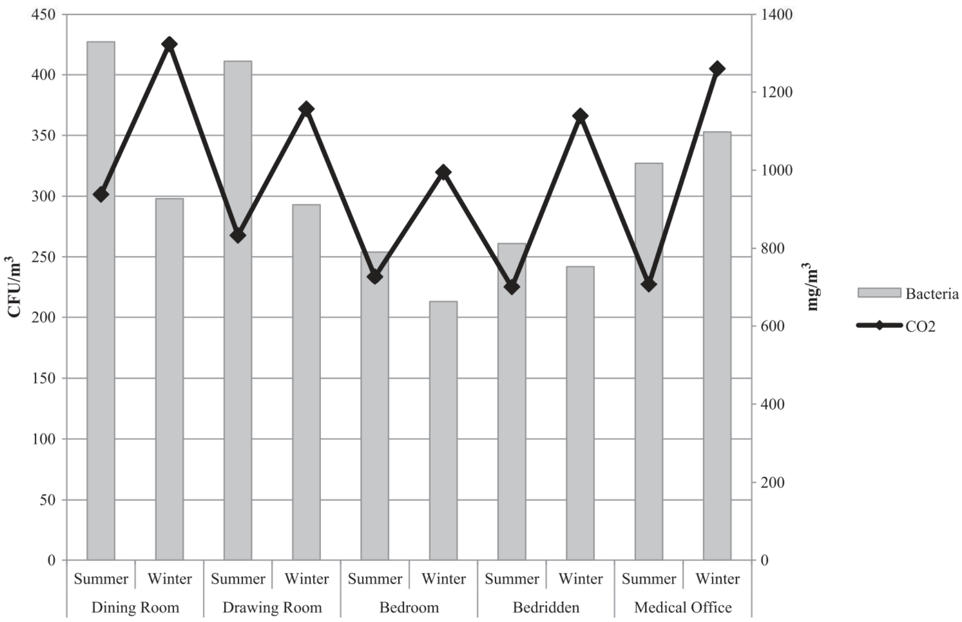


**FIGURE 5.** Concentrations of bacteria and $CO_2$ by area, in summer and winter.

characteristics, and building pathologies such as infiltrations and condensations.

## DISCUSSION

### Biological Assessment

The Portuguese legislation regarding indoor air quality parameters has undergone a recent modification (December 4, 2013), with reference values for biological agents altered from an established value of 500 CFU/m$^3$ for both bacteria and fungi in indoor air to conformity assessed through comparison of concentration of these parameters indoors with outdoors. In the present study, 22 ECC had an average bacteria concentration within the actual

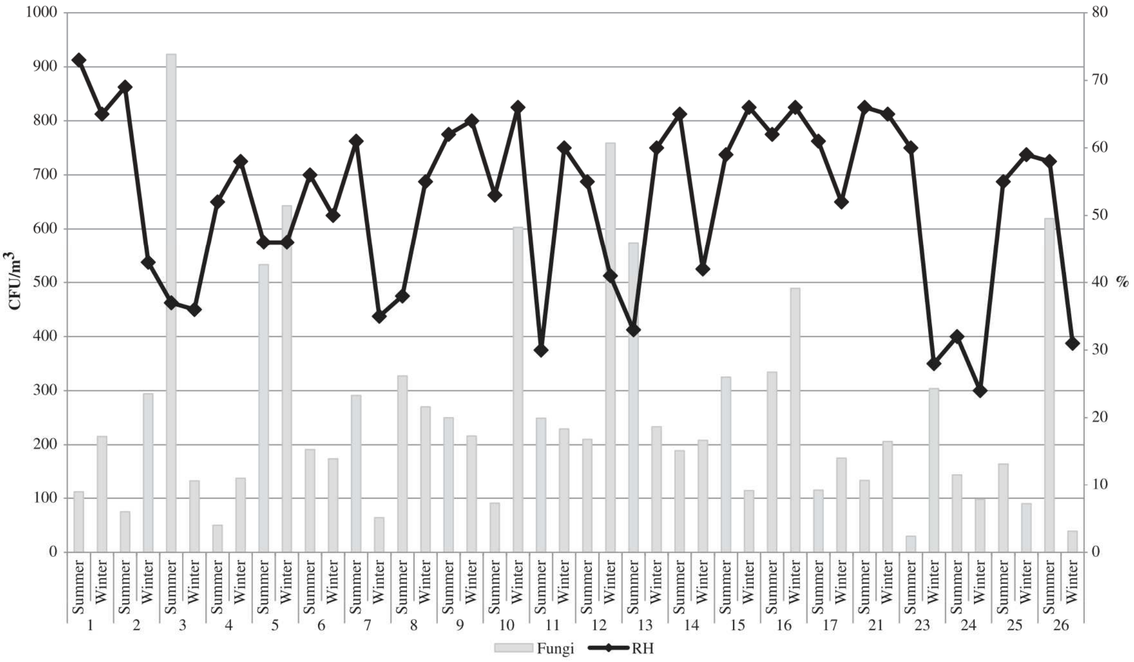


**FIGURE 6.** Fungi concentration and levels of Relative Humidity by ECC, summer and winter

reference terms in both seasons and in all evaluated rooms. By past legislation, these values would also be considered in conformity within the limit value. With respect to fungi concentration in summer, ECC and rooms mean concentrations found were all in accordance with the recommendations. However, in winter this was not observed. For the ECC mean and also in four of the five areas where the assessment took place, indoor fungi concentrations were above the outdoor concentrations. If the previous legislation were still in effect, fungi concentration would be considered to be within the reference value for ECC mean and for concentrations found in evaluated areas. Chao et al. (2002) reported low fungal concentrations in the buildings studied (median = 22 CFU/$m^3$) according to commonly used standards/guidelines with the maximal fungal count at 618 CFU/$m^3$, which is not indicative of serious indoor contamination. However, Flannigan (1997) noted that the number of viable spores of individual fungi may be below the limit of detection (LOD) by established methods and still the total is sufficient to induce respiratory problems.

Significant differences between bacteria concentrations in both seasons were found (Table 2). Rintala et al. (2008) demonstrated that in a study of indoor air of 20 homes in Chicago, total concentrations of cultivable bacteria were highest in summer, which is in agreement with our study result that bacterial concentrations were also higher in summer than winter. In another study cited by Rintala et al. (2008), airborne bacteria did not exhibit an equally clear seasonal pattern.

Statistical differences between fungi concentration in summer and winter did not show significant results. Ayanbimpe et al. (2010) reported that the rate of isolation of fungi was not significantly varied in the wet and dry months of the year. However, Tang (2009) noted a seasonal variation of airborne fungal and spore concentrations attributed to seasonal changes in environmental factors such as temperature, RH, rainfall (precipitation), and wind speed. Fungal spore counts seem to be highest in summer, both indoors and outdoors. Lee et al. (2006) corroborated these findings that indoor fungi concentrations measured in spring were higher than those in fall, and this may be

**TABLE 5.** Building Characteristics in the Indoor Environmental Evaluation

| Buildings variables | Bacteria | Fungi |
|---|---|---|
| Adapted to ECC(1) | | $p < .001$ |
| Building occupation(1) | $p < .01$ | |
| Sources of pollution(2) | | $p < .001$ |
| Walls(2) | $p < .05$ | |
| Insulation(1) | | $p < .01$ |
| Roof lining(2) | $p < .05$ | $p < .01$ |
| Ventilation type(2) | $p < .05$ | $p < .05$ |
| Heating ventilation(2) | $p < .001$ | |
| Building pathologies(2) | $p < .001$ | $p < .001$ |
| Windows type(2) | $p < .05$ | $p < .001$ |
| Sealants(1) | $p < .001$ | |
| Type sealants(2) | $p < .001$ | $p < .05$ |
| Windows frames(2) | | $p < .01$ |
| Glass type(1) | | |
| Flooring(2) | | $p < .05$ |

Significant differences by building variable and biological evaluation: $p < .001$; $p < .01$; $p < .05$. (1) Mann–Whitney (*U*) test. (2) Kruskal–Wallis (*H*) test.

attributed to the fact that the residents were more likely to use their air conditioning systems and, therefore, to keep their windows closed.

Certainly if the buildings are air conditioned, or if windows and doors are kept closed, the indoor biological concentration might be expected to be lower (Flannigan, 1997). In contrast, in the evaluated ECC indoor fungi concentrations in winter were higher than outdoors. Our results are contrary to those obtained by Robertson (1998), where outdoor concentrations ranged from 3 to 71% higher on average (CFU/m$^3$) with respect to indoor ones. Data are consistent with referenced literature indicating that indoor and outdoor fungal contaminants may be similar, with indoor concentrations being lower than outdoors (Robertson, 1998). Niemeier et al. (2006) suggested that indoor levels were most likely higher due to the presence of visible mold in housing. Lee et al., (2006) examined indoor concentrations of total fungal spores and found that they were related with outdoor concentration, and the outdoor levels were usually greater than indoors. In this study, the increase of outdoor concentrations resulted in a corresponding rise of indoor concentrations in most houses. Biological sources are often located outdoors. Therefore, the influence of these sources on human exposure largely depends on the fraction of outdoor bioaerosol, which is subjected to indoor penetration (Lee et al., 2006).

Bacteria concentrations were higher in summer for all ECC evaluated areas. Studies of indoor air from Europe demonstrated that Gram-positive cocci (*Micrococcus, Staphylococcus* species) are the most commonly found bacteria in indoor air environments, although some gram-negative bacteria (*Pseudomonadaceae* family, *Aeromonas* species) are also often present (Tang, 2009).

### Fungi Identification

Both in summer and winter, the main fungi species identified indoors were *Cladosporium, Penicillium*, and *Aspergillus*. Indoor versus outdoor fungi species identification comparison showed that fungi species indoors were the same as outdoors: *Cladosporium* in the majority, followed by *Penicillium*. Our results follow these trends. For Rao et al. (2007) *Penicillium* and *Aspergillus* were the most commonly cultured fungal genera found indoors and they identified six *Aspergillus species*. Flannigan (1997) identified *Cladosporium species* predominating in both outdoor and indoor air, with outdoor concentrations being higher than those indoors. Flannigan (1997) emphasized the perceived role of spores infiltrating from outdoors to determine indoor air spore levels. Niemeier et al. (2006) found that *Aspergillus, Penicillium*, and *Cladosporium* spores were the most common types of fungi. Tang (2009) indicated that *Penicillium, Aspergillus, Cladosporium*, and *Alternaria* were found worldwide, in varying mixtures in both indoor and outdoor environments, where airborne levels of fungi varied seasonally, usually highest in autumn and summer and lowest in winter and spring. In temperate climates, *Cladosporium* species is the predominant fungus, followed by *Penicillium* species, *Aspergillus* species, *Alternaria* species, yeasts, and mycelia sterilia. The order of these last five groups varies with location (type of climate, if rural or urban) but they are always in the minority in relation to *Cladosporium* species (Cabral, 2010).

The more pathogenic fungi, *Aspergillus* and *Penicillium* species, may be hazardous to humans in high concentrations owing to an ability to produce mycotoxins (Tang, 2009; Cabral, 2010). *Penicillium* may also be a source of volatile organic compounds and was implicated in asthma symptoms in children (Araujo et al, 2008). Studies showed that both species are present in air both indoors and outdoors, although typically at lower concentrations than *Cladosporium* and *Alternaria* (Tang, 2009; Araujo et al., 2008). *Cladosporium* and *Alternaria* might induce or exacerbate hypersensitivity reactions including asthma. The indoor and outdoor concentrations of *Aspergillus* and *Penicillium* species may vary considerably in both winter and summer, as well as in urban or more suburban environments, with higher temperature and RH, and with suburban areas being generally more favorable to generate higher airborne spore concentrations (Tang, 2009).

In our study, prevalence of *Aspergillus fumigatus* in one ECC raises concern. However, this species is not the only one that exerts influence on human health: *Alternaria, Cladosporium, Penicillium*, and *Stachybotrys* have frequently been associated with adverse health effects in humans (Solomon et al., 2006). The presence of toxin-producing fungi like *Aspergillus fumigatus* indoors is a cause for concern, considering the potential risk of mycotoxicosis. Adverse health effects on residents of fungal presence in indoor environments cannot be overemphasized (Ayanbimpe et al., 2010). *Aspergillus* species (*Aspergillus flavus* and *Aspergillus fumigatus*), are well-known potentially life-threatening airborne contaminants when they are blown in through the windows of wards containing immunocompromised patients (Tang, 2009) like the elderly. Even in otherwise healthy individuals working in other indoor environments such as offices and schools, as well as at home, fungi and their spores may trigger hypersensitivity reactions such as rhinitis, sinusitis, or asthma (Tang, 2009).

## Correlation Between Chemical, Physical, and Biological Parameters

Bacterial concentrations and occupancy showed a relationship in our study. During occupancy, resuspension and direct shedding of microorganisms from humans are potential sources of bacterial aerosol particles. The origin of many of the airborne bacteria is from human skin, hair, nostrils, and the oral cavity. Desquamated human skin cells are an important contributor to particles in indoor air, and there is evidence that bacteria are associated with these skin cells. Overall, these data suggest that relative contribution of human-associated bacteria is variable and environment dependent (Hospodsky et al., 2012). Bacterial infections, such as tuberculosis, are known to be transmitted primarily by an airborne route. There is increasing evidence that airborne transmission may play a role in the dissemination of many opportunistic pathogens responsible for a range nosocomially acquired infections. In particular, airborne transmission was implicated in nosocomial outbreaks of *Staphylococcus aureus*, including methicillin-resistant strains (MRSA) (Noakes et al., 2006).

Testing the possible relationship between the $CO_2$ and bacteria concentrations in the evaluated areas, it was concluded that these two variables were not related. Chao et al. (2002) also measured $CO_2$ concentration at each sampling location and, similar to our study, significant temporal variation of $CO_2$ levels was not found. Continuing to relate more IAQ parameters, RH and fungi concentrations showed no relationship between them. Similar to our study, Chao et al. (2002) measured RH and temperature at each sampling site to examine correlations with airborne fungal counts, and observed significant seasonal variation for RH, highest in summer (50%) and lowest in winter (15%). Similar results were noted in our study: RH higher in summer (53%) than in winter (20%). Tang (2009) observed in several studies that spore concentrations were higher with higher RH levels, although at least one study demonstrated opposite findings. It is also well established that there are positive correlations between high indoor RH and certain respiratory pathologies, an expected result considering that high indoor RH usually leads to high indoor fungal concentrations that induce adverse reactions in the human body (Cabral, 2010).

## Building Characteristics

In our study, evidence indicated that ECC bacteria concentration depended on several building characteristics (Table 5). The influence of building characteristics including ventilation on the spread of viral respiratory infections has received increased attention from the public, government, media, and scientists, after some studies showed (1) a relationship between lower ventilation rates and more frequent tuberculosis infections among hospital workers, (2) association between sick leave of employees and outdoor air supply rate, and (3) detecting airborne rhinoviruses being positively associated with weekly average $CO_2$ concentration in an office (Sun et al., 2011).

Regarding fungi concentration and building characteristics, our study indicated factors such as existing sources of pollution, insulation, roof and windows characteristics, and building pathologies such as infiltrations and condensations, affect indoor air contamination by fungi. It is now well established that there is a positive correlation between water infiltrations in walls, indoor dampness, and proliferation of indoor fungi. Cabral (2010) showed that indoor fungi grown in culture media or building materials, and subjected to an air current, release groups of spores, individual spores, and fungal fragments. An Institute of Medicine (IOM) committee concluded in 2004 that there is sufficient evidence of a causal link between indoor dampness and upper-respiratory-tract symptoms, cough, wheeze, asthma symptoms in sensitized people, and hypersensitivity pneumonitis in susceptible subjects. Although the IOM report did not ascribe all of these health effects to mold, the committee noted that dampness and mold are highly intercorrelated (Solomon et al., 2006). However, investigators indicated fungal presence in damp houses as well as in homes without apparent dampness problems (Ayanbimpe et al., 2010). Niemeier et al. (2006) reported that exposure to visible mold, or excessive moisture, which promotes mold growth, leads to an increase in allergic symptoms, and toxicity produced by exposure to metabolites of certain molds has also been linked to adverse health effects (Fisk et al., 2010).

The adverse health effects of damp building materials and fungal growth in homes, institutions, and workplaces have been reported in World Health Organization (WHO) guidelines "Dampness and Mould," which concluded that there is sufficient epidemiological evidence to demonstrate that occupants of damp or moldy buildings are at increased risk of respiratory problems, respiratory infections, and exacerbation of asthma. The symptoms reported by occupants in moldy buildings are many and diverse, as are the fungal species found on moldy building materials. The fact that some individuals are hypersensitive to fungi while others do not react at all further complicates the issue (Andersen et al., 2011).

## Study Limitations

Although identification to species level is always recommended, in order to know the existent fungal diversity, in our study, we were only able to identify some species to genera level. Identification to species level is important from a health perspective, since several fungal genera contain species capable of producing species-specific metabolites, mycotoxins, and allergens (Andersen et al., 2011). The diversity of species in genera such as *Penicillium* and *Aspergillus*, and the differences in the ecological, allergenic, and toxigenic characteristics between species in these genera, clearly call for reliable identification (Flannigan, 1997).

Our study was conducted by air sampling. As the health effects of biological parameters are mainly respiratory, air sampling is believed to be adequate to represent exposure. However, biological aerosols have been found to exhibit varying patterns in their release into the air depending on several environmental factors (Niemeier et al., 2006). Nevertheless, air sampling might favor growth of fungi that produce large quantities of small, dry spores, and might discriminate against fungi that generate small amounts of spores, large spores, or spores in slime. Air sampling alone may give an incorrect picture of the biological diversity actually present in a building (Andersen et al., 2011). Currently, there are numerous sampling methods available to measure biological concentrations in the environment. Source sampling, which includes methods such as swab, tape, bulk, and dust, is commonly used to identify indoor fungi and bacteria (Niemeier et al., 2006). For a better understanding and identification of which microorganisms exists in ECC indoor air, a specific and focused approach needs to be applied in further studies.

According to Rintala et al., (2008), based on the results of cultivation methods, gram-positive and gram-negative bacteria are common in indoor air of residential settings, office buildings, and hospitals. There are several frequently encountered taxa: gram-positive *cocci, corynebacteria*, and *bacilli*, in addition to gram-negative species, such as *Acinetobacter* and *Pseudomonas*. Certain gram-positive bacteria with potent immunogenic properties or potential toxin producers, such as *mycobacteria, streptomycetes*, or *Nocardiopsis* spp., were also found to be present in indoor environments. It is not possible to discuss these findings, as in our study only total bacteria were assessed. In future developments of this study, bacterial identification needs to be determined.

Portuguese recent legislation, only fungi concentrations in winter did not accomplished the reference levels. Nevertheless, maximum bacteria concentrations were very high in both seasons. It is important to notice that, although biological concentrations were considerable acceptable, in light of Portuguese references, it doesn't assure that there is no risk for people who spend most of the day, or even consecutive days, inside these areas. Especially the elderly people: a group that is known for their impaired immune system and therefore ability to develop diseases, such as respiratory illnesses or airborne.infections.

Most of the evaluated ECC presented condensations and infiltrations along walls and roofs inside the buildings. Although fungi main species found were *Cladosporium* and *Penicillium*, considered to be common in indoor air, *Aspergillus flavus, Aspergillus fumigatus*, and *Aspergillus niger* were also identified, species that produce mycotoxins and therefore may produce several adverse health effects.

For an improvement of IAQ regarding biological agents, control of indoor RH is essential, eliminating all dampness and mold present in walls, roofs, and surfaces. Number of occupants and their habits are also contributors to the proliferation of microorganisms. Ventilation is a crucial factor that provides healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it through supply of outdoor air into a building or a room, and distribution within it. Ventilation systems require good maintenance in order for the required air change rate to be achieved and sustained, and otherwise it serves as a source of several microorganisms with harm to health. Opening windows or other sources of fresh and clean air, when the room is empty, is another effective and cheap measure that improves IAQ by removing biological agents from its composition.

## CONCLUSIONS

A total of 141 areas within 22 ECCs located in Porto urban area were assessed to evaluate the impact of indoor biological agents in elderly daily lives. Comparing the results with

## FUNDING

Our current research is supported by the GERIA Project (www.geria.webnode.com), PTDC/SAU-SAP/116563/2010, and a PhD grant (SFRH/BD/72399/2010) from the Foundation for Science and Technology (Fundação para a Ciência e Tecnologia–FCT).

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# IV. The Impact of Indoor Air Quality and Contaminants on Respiratory Health of Older People Living in Long-Term Care Residences in Porto

*Age and Ageing* 2016; **45:** 136–142
doi: 10.1093/ageing/afv157
Published electronically 11 November 2015



# The impact of indoor air quality and contaminants on respiratory health of older people living in long-term care residences in Porto

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## Abstract

**Background:** persons who are 65 years or older often spend an important part of their lives indoors thus adverse indoor climate might influence their health status.
**Objective:** to evaluate the influence of indoor air quality and contaminants on older people's respiratory health.
**Design:** cross-sectional study.
**Setting:** 21 long-term care residences (LTC) in the city of Porto, Portugal.
**Subjects:** older people living in LTC with ≥65 years old.
**Methods:** the Portuguese version of BOLD questionnaire was administered by an interviewer to older residents able to participate ($n = 143$). Indoor air contaminants (IAC) were measured twice, during winter and summer in 135 areas. Mixed effects logistic regression models were used to study the association between the health questionnaire results and the monitored IAC, adjusted for age, smoking habits, gender and number of years living in the LTC.
**Results:** cough (23%) and sputum (12%) were the major respiratory symptoms, and allergic rhinitis (22%) the main self-reported illness. Overall particulate matter up to 2.5 micrometres in size median concentration was above the reference levels both in winter and summer seasons. Peak values of particulate matter up to 10 micrometres in size ($PM_{10}$), total volatile organic compounds, carbon dioxide, bacteria and fungi exceeded the reference levels. Older people exposed to $PM_{10}$ above the reference levels demonstrated higher odds of allergic rhinitis (OR = 2.9, 95% CI: 1.1–7.2).
**Conclusion:** high levels of $PM_{10}$ were associated with 3-fold odds of allergic rhinitis. No association was found between indoor air chemical and biological contaminants and respiratory symptoms.

**Keywords:** *allergic rhinitis, long-term care residences, indoor air quality, older people, respiratory health*

## Introduction

The health effects of urban air pollution in the general population are well-documented. Each year, 500,000 deaths due to pneumonia, chronic obstructive pulmonary disease (COPD) and all causes combined are attributed to outdoor air pollution worldwide [1]. Particulate air pollution has been associated with cardiovascular morbidity and mortality, but it remains unclear which time windows and pollutant sources are most critical [2]. Cardiopulmonary conditions are highly prevalent, multifactorial, and associated with multiple comorbidities and poor outcomes, such as increased disability and decreased quality of life [3]. Older individuals spend approximately 19–20 h/day indoors [4] and have reduced physical activities, outings and commuting [5], so being particularly at risk of detrimental effects from air pollutants, even at low concentrations, due to their reduced immunological defences and multiple underlying chronic diseases. Portugal has the 8th oldest population in the world and the 6th in Europe, with 23% of the population with more than 60 years old [6]. Furthermore, between 1998 and 2010, the number of long-term care residences (LTC) increased 49% in our country [7]. The GERIA project 'Geriatric study in Portugal on Health Effects of Air Quality in LTC' aims to provide insights into the association between respiratory health and indoor air quality (IAQ) at elderly settings, with the purpose of contributing to health improvement for the older population. This paper presents results of a substudy within the GERIA project, in Porto city LTC.

## Research aim

This study focused on respiratory health of older people living in LTC. The aims of this paper were to evaluate the influence of IAQ and contaminants on older people's respiratory health and to assess the issue in order to discuss strategies that could provide benefits.

## Data collection and methods

All LTC located within the Porto urban area and included in the 'Portuguese Social Charter' were invited to participate in our study. These institutions provide assistance in activities of daily living with medical and nursing services when required. Out of a total of 58 LTC, 36% ($n = 21$, with 668 residents) accepted to participate. All the participants were ≥65 years old, live in the LTC for more than 2 weeks and possessed cognitive and interpretative skills in order to receive the questionnaire. Environmental data were collected for each LTC in two seasons (summer and winter) starting from November 2011 till August 2013. Moreover, in each LTC the Portuguese version [8] of the respiratory health questionnaire BOLD (Burden of Obstructive Lung Disease) [9, 10] was administered by a trained interviewer to the older people who gave their informed consent and were able to participate ($n = 143$); it was conducted from September 2012 to April 2013, along the winter season indoor air sampling. This study was approved by the Ethics Committee and the Portuguese Data Protection Authority.

### Indoor air monitoring

Indoor air assessment strategy took into account building and ventilation characteristics. Indoor air chemical and biological contaminants were measured. Carbon monoxide (CO), carbon dioxide ($CO_2$), formaldehyde, total volatile organic compounds (TVOC), particulate matter up to 10 micrometres in size ($PM_{10}$) and particle matter up to 2.5 micrometres in size ($PM_{2.5}$) were evaluated. The biological contaminants were assessed for total bacteria and fungi, including fungi identification and were expressed as colony-forming units per cubic metre of air ($CFU/m^3$). The monitoring was performed in each LTC in the following spaces: dining rooms, drawing rooms, medical offices and bedrooms, including the bedridden subgroup (residents confined to bed because of illness or infirmity for a long or indefinite period). A total of 135 areas were evaluated. Outdoor samples were also collected for comparison to the indoor measurements. The monitoring phase included daytime air sampling (starting at 10 am and continuing for at least 4 h during normal activities) conducted discretely to minimise nuisance to normal residents' activities. National and international reference levels were presented pointing the maximum recommended safe levels.

### Respiratory health

The BOLD questionnaire was used to gather information on chronic respiratory diseases and symptoms [9]. Individuals were asked to complete a questionnaire covering respiratory symptoms, health status, activity limitation, and exposure to potential risk factors such as tobacco smoke, and previous work in dusty environments. The intent was to obtain information about respiratory symptoms (cough, sputum, wheezing, shortness of breath), exposure to potential risk factors, occupation, respiratory diagnoses (asthma, emphysema, chronic bronchitis and allergic rhinitis), co-morbidities, health care utilisation, medication use, activity limitation, and health status.

### Statistical methods

An exploratory analysis was carried out for all variables. Categorical data were presented as frequencies and percentages, and continuous variables as median and inter-quartile range (25th percentile–75th percentile) or range (min-max). Due to the fact that most of the sampling points were not the same in both seasons, the two samples were considered to be independent. Mann–Whitney and Kruskal–Wallis tests were used to compare seasonal effects assessment because of the existence of outliers, high variability and skewed distributions. Main health outcomes were wheezing, cough, sputum, asthma and allergic rhinitis. Mixed effects logistic regression models were used to study the association between these health outcomes and indoor air contaminants (IAC) (categorised above and below the reference values [11]), adjusted for age, smoking habits, gender and the number of years living in the LTC. The 95% confidence intervals (CI) were also calculated whenever appropriate. A 0.05 level of significance was used for all analyses. Data were analysed using IBM SPSS 21.0 (SPSS, Inc., Chicago, IL, USA) and STATA 12.0. (StataCorp LP, Stata Statistical Software; TX, USA).

## Results

### Environmental assessment scenario

The 21 LTC were located in the centre of Porto city and 78% of them in areas of heavy traffic. A total of 668 older people lived in these centres with a range of 7–136 occupants per building. As regards to construction characteristics, 64% were an adaptation to LTC of an existing residential building, and 42% also had a day centre activities for non-residents older people. Most of them were built in stone masonry construction (46%) with single pane windows (87%). Only 31% had roof and walls insulation and half of the sampled buildings presented condensations and infiltrations along walls and roofs inside the buildings. All LTC were smoke-free. Regarding the ventilation type, 91% had mixed ventilation (natural ventilation in the rooms along with exhaustion systems in the kitchen and bathrooms) while 9% had only natural ventilation in all the indoor areas.

Table 1 presents the LTC indoor environmental quality descriptive statistics by season. The overall $PM_{2.5}$ median concentration of the 21 LTC was above national references (25 μg/m$^3$) [11] in both seasons. When inhaled, $PM_{2.5}$ may reach the peripheral regions of the bronchioles, and interfere with gas exchange inside the lungs [12]. These findings showed how this parameter is critical for air quality for its possible influence on human health particularly to older people with previous lung or heart disease [13]. Although all the other indoor air pollutants median concentrations were within the reference levels, peak values of $PM_{10}$ (1,730 μg/m$^3$) in summer, as well as, TVOC (973 μg/m$^3$; 931 μg/m$^3$), $CO_2$ (2,313 mg/m$^3$; 2,697 mg/m$^3$) and bacteria (2,282 CFU/m$^3$; 996 CFU/m$^3$) in both seasons, exceeded the reference levels, compromising indoor air comfort and possibly worsening the already existent respiratory chronic diseases. Fungi median concentrations are slightly above references in the winter season (185 CFU/m$^3$ indoor >166 CFU/m$^3$ outdoor) and the indoor peak values in both season also raise concern (2,224 CFU/m$^3$; 1,218 CFU/m$^3$). Moreover



**Table 1.** LTC air quality and contaminants descriptive statistics by season

| | *N* | Median [$P_{25}$–$P_{75}$] | Min-Max | *P* | References | |
|---|---|---|---|---|---|---|
| | | | | | International | National |
| $PM_{10}$ (μg/m$^3$) | | | | | | |
| Summer | 133 | 40 [20–70] | [20–1,730] | 0.01* | 150[a] | 50[h] |
| Winter | 132 | 50 [30–70] | [20–86] | | | |
| $PM_{2.5}$ (μg/m$^3$) | | | | | | |
| Summer | 120 | 30 [20–68] | [20–2,120] | – | 35[a] | 25[h] |
| Winter | 119 | 30 [20–60] | [20–43] | | | |
| TVOC (μg/m$^3$) | | | | | | |
| Summer | 123 | 48 [30–90] | [14–973] | 0.01* | 200[b] | 600[h] |
| Winter | 132 | 78 [47–134] | [14–931] | | | |
| Formaldehyde (μg/m$^3$) | | | | | | |
| Summer | 77 | <42 [<42–< 42] | [<42–63] | – | 100[c] | 100[h] |
| Winter | 84 | <42 [<42–< 42] | [<42–320] | | | |
| CO (mg/m$^3$) | | | | | | |
| Summer | 131 | 0.1 [0.1–0.6] | [0.1–7.1] | – | 10[c] | 10[h] |
| Winter | 131 | 0.3 [0.1–0.9] | [0.1–3.0] | | | |
| $CO_2$ (mg/m$^3$) | | | | | | |
| Summer | 131 | 721 [628–820] | [538–2,313] | 0.001* | 1,300[d] | 2,250[h] |
| Winter | 131 | 975 [762–1,321] | [541–2,697] | | | |
| Bacteria (CFU/m$^3$) | | | | | | <outdoor (until 350 CFU/m$^3$ more)[h] |
| Summer | 131 | 254 [142–392] | [6–2,282] | 0.01* | – | 143 |
| Winter | 127 | 182 [102–398] | [14–996] | | | 48 |
| Fungi (CFU/m$^3$) | | | | | | <Outdoor[h] |
| Summer | 126 | 211 [119–386] | [6–2,224] | – | 500[e] | 230 |
| Winter | 124 | 185 [101–302] | [18–1,218] | | | 166 |
| Air temperature (°C) | | | | | | |
| Summer | 131 | 24 [22–26] | [14–32] | 0.001* | Summer [22.8–26.1] | [18–22] up to 25[i] |
| Winter | 131 | 20 [18–22] | [13–27] | | Winter [20.0–23.6][f] | |
| Relative humidity (%) | | | | | | |
| Summer | 131 | 56 [41–63] | [21–75] | – | [30–65][g] | [50–70][i] |
| Winter | 131 | 53 [39–61] | [5–75] | | | |

[a]Environmental Protection Agency (2012).
[b]European Collaborative Action (1997).
[c]World Health Organization (2010).
[d]Finnish Society of Indoor Air Quality in 'The Thade Report' (2004).
[e]World Health Organization (2009).
[f]ASHRAE 55.
[g]IAQA 01–2003.
[h]Ordinance No. 353-A/2013 of December 4th.
[i]Decree-Law No 243/86 of 20th August 1986.
*Significant differences in indoor measurements by Season (summer/winter).

4% of fungi samples were positive for *Aspergillus* species known potential pathogenic/toxigenic species which constitute a threat predominantly to subjects with immunity disorders [14] such as older persons. TVOC, bacteria, CO and $CO_2$ showed significantly higher indoor levels compared to outdoor, in both seasons showing predominance of indoor sources. Indoor TVOC and $CO_2$ presented significant differences between seasons ($P < 0.001$). There were also significant differences between LTC evaluated spaces for TVOC ($P < 0.001$), $CO_2$ ($P < 0.001$) and bacteria ($P < 0.01$).

### Respiratory health outcomes

From the 668 older people living in the studied LTC, 21% ($n = 143$) were within the inclusion criteria and agreed to answer the health questionnaire. Table 2 presents the general characteristics of the subjects. The sample is characterised mainly by women (85%) with most people in the age group above 85 years old (47%). Most of them are widowers (60%) living in the LTC for about 2–10 years (58%). Regarding occupation, the majority of residents were working class person who performed manual labour (57%) with elementary and middle school education (65%). Forty per cent of the residents considered themselves sick and most of them (61%) had an observed degree of physical impairment and mobility (use of mobility aids such as crutches, canes and wheelchairs) or were bedridden. Concerning the non-respondents (79%) they were also mostly women (62%), 53% lived in the LTC in between 2 and 10 years and 46% had more than 85 years old. The known causes of this high rate of non-response were disability and disease compromising the cognitive and interpretative skills to answer the questionnaire (60%), older people refusal (32%) and to be younger than 65 years (8%). In older people respondents (Supplementary data, Table S1, available in *Age and Ageing* online), cough (23%) and sputum (12%) were the major respiratory symptoms, and allergic rhinitis (22%) the main self-reported illness. Heart troubles were reported by 37% of the residents.

**Table 2.** Characteristics of the subjects ($n = 143$)

| | *n* (%) |
|---|---|
| Gender | |
| Female | 121 (84.6) |
| Male | 22 (15.4) |
| Age group | |
| [65–75] | 19 (13.2) |
| [76–85] | 57 (39.9) |
| >85 | 67 (46.9) |
| Marital status | |
| Single | 36 (25.5) |
| Married | 11 (7.8) |
| Divorced | 9 (6.4) |
| Widower | 85 (60.3) |
| Education | |
| Illiterate + read and write | 22 (15.6) |
| Elementary & middle school | 91 (64.5) |
| High school & university | 28 (19.9) |
| Occupation | |
| Administrative and scientific | 33 (23.1) |
| Services and seller | 29 (20.3) |
| Blue-collar workers | 81 (56.6) |
| Region of birth | |
| North of Portugal | 114 (79.7) |
| Other regions | 29 (20.3) |
| Years living in the ECC | |
| ≤1 year | 37 (25.9) |
| [2–10] | 83 (58.0) |
| >11 | 23 (16.1) |
| Impaired physical mobility and bedridden | 85 (61.2) |
| Self-perceived health status (consider themselves sick) | 52 (40.3) |

### Impact of indoor air contaminants on older people respiratory health

Table 3 represents the analysis of the mixed effects logistic regression models between the main health outcomes (wheezing, cough, sputum, asthma and allergic rhinitis) and the monitored IAC, adjusted for age, smoking habits, gender and the number of years living in the LTC. Older people exposed to $PM_{10}$ above the reference levels demonstrated higher odds of allergic rhinitis (OR = 2.9, 95% CI: 1.1–7.2). For each degree increase in temperature a 20% decrease in the odds of having allergic rhinitis (OR = 0.8, 95% CI: 0.6–1.0) was found. No significant associations between wheezing, cough, sputum from the chest and asthma, and environment were found.

## Discussion

Our main goal in this study was to associate the influence of IAQ and contaminants on LTC residents' respiratory health. Our sample was very aged, with a large proportion of women. These data are consistent with a recent European study performed in several LTC [5]. The high rates of self-perceived sickness and degree of physical impairment indicate a very dependent population, living in the LTC for 2–10 years. Older people are more susceptible to the effects of indoor air pollution since they spend the large majority of their time indoors [15, 16] associated with a decline in immune defences and respiratory function [17].

In terms of IAQ scenario, the main concern issue is the overall high $PM_{2.5}$ concentrations both in winter and summer seasons. The comparison between national and international reference values was explored in a previous IAQ study [18]. Other studies [15, 19] have found high levels of $PM_{2.5}$ in similar indoor environments, and a link with lung function [20] and respiratory diseases such as COPD [21, 22] was demonstrated. $PM_{2.5}$ also influences blood pressure and autonomic function [23]. Although people (particularly the older people of our study) spend most of their time indoors, a major portion of indoor $PM_{2.5}$ came from outdoor mobile sources. In fact, the Cardiovascular Health and Air Pollution Study (CHAPS) showed that indoor-infiltrated particles from mobile sources are more strongly correlated with adverse health effects observed in the older subjects living in the studied retirement communities compared with other particles found indoors

Table 3. Associations between health outcomes and IAC adjusted odds ratio (95% CI)

| | Crude odds ratio (95% CI) | Adjusted odds ratio (95% CI) |
|---|---|---|
| Wheezing in the past 12 months | | |
| Fungi | 3.21 (0.69–14.90), $P = 0.136$ | 3.74 (0.78–17.78), $P = 0.097$ |
| Age | | 1.04 (0.96–1.13), $P = 0.315$ |
| Relative humidity | 3.75 (0.88–16.04), $P = 0.075$ | 4.09 (0.93–18.02), $P = 0.062$ |
| Age | | 1.03 (0.95–1.12), $P = 0.402$ |
| Cough | | |
| Fungi | 2.29 (0.87–2.06), $P = 0.095$ | 2.38 (0.88–6.44), $P = 0.088$ |
| Age | | 1.00 (0.95–1.07), $P = 0.820$ |
| Allergic rhinitis | | |
| $PM_{10}$ | 2.44 (1.03–5.78), $P = 0.044$ | 2.87 (1.14–7.24), $P = 0.025$ |
| Age | | 1.02 (0.94–1.09), $P = 0.567$ |
| Gender | | 0.07 (0.009–0.54), $P = 0.010$ |
| Smoked cigarettes | | 8.74 (1.97–38.72), $P = 0.004$ |
| CO | 1.74 (1.11–2.74), $P = 0.017$ | 1.62 (0.95–2.77), $P = 0.078$ |
| Age | | 1.02 (0.95–1.10), $P = 0.514$ |
| Gender | | 0.09 (0.01–0.72), $P = 0.023$ |
| Smoked cigarettes | | 6.66 (1.47–30.15), $P = 0.014$ |
| $CO_2$ | 1.00 (0.99–1.00), $P = 0.052$ | 1.00 (0.99–1.00), $P = 0.091$ |
| Age | | 1.02 (0.95–1.09), $P = 0.641$ |
| Gender | | 0.08 (0.01–0.65), $P = 0.018$ |
| Smoked cigarettes | | 7.43 (1.65–33.49), $P = 0.009$ |
| Temperature | 0.79 (0.64–0.97), $P = 0.024$ | 0.79 (0.64–0.98), $P = 0.031$ |
| Age | | 1.01 (0.94–1.09), $P = 0.775$ |
| Gender | | 0.09 (0.01–0.69), $P = 0.020$ |
| Smoked cigarettes | | 7.27 (1.69–31.10), $P = 0.007$ |

[24]. Additionally, a recent study conducted in Belgium [25] presented high correlations between outdoor and indoor $PM_{2.5}$ in LTC, confirming mainly the outdoor origin of IAC. $PM_{2.5}$ also correlates with atherosclerosis and cardiovascular disease in a specific study [2]. Furthermore, our study indicates peak values of $PM_{10}$, TVOC, $CO_2$, bacteria and fungi exceeding the reference levels, compromising indoor air comfort and deteriorating the already existent respiratory chronic diseases.

Concerning the respiratory assessment, cough and sputum were the major respiratory symptoms and allergic rhinitis the main self-reported illness in older people living in LTC. A 2013 Australian study showed results similar to ours in older population [26] and found that people reported asthma more commonly than the diagnosis of COPD. Another Portuguese study also detected a large proportion of underdiagnosed COPD disease [8]. Underreport and underdiagnosis could justify the small rates of self-reported diseases in our study people.

We obtained a higher risk of allergic rhinitis among older people who had smoked cigarettes and were exposed to high concentrations of $PM_{10}$, and temperature below the reference levels. The first result could be explained by the deposition of larger particles such as $PM_{10}$ in the upper respiratory system causing susceptibility to allergic reactions. Concerning indoor air temperature, the literature indicates that low temperatures may potentiate respiratory tract infections to older people [27, 28] and increase hospital admissions. The other IAC were not associated with self-reported symptoms, despite the high median values of some pollutants, such as $PM_{2.5}$. Nonetheless, it is important to remind that institutionalised older people are a very susceptible population due to their compromised health.

Our study has some limitations, particularly regarding the sample size. This limitation mainly occurred due to the characteristics of the population living in the studied LTC. In this sense several older LTC residents with cognitive impairments could not participate in the sample. Regarding the LTC participation rate, there was a high number of institutions that did not accept to participate in the study. Despite this, six of the seven parishes in the city had at least one participating LTC. Also, this is a city study and may not generalise to other towns, villages or rural areas. Although the reliability of *P*-values associated to hypothesis testing is limited—as in this case—by the presence of multiple comparison, these data provide an exploratory analysis on the quality of LTC indoor conditions and its possible impact on resident's health. More studies relating indoor environment conditions in susceptible populations such as older people are welcome.

## Conclusions

Indoor environment has a potential influence in chronic respiratory symptoms on older people living in LTC due to their health susceptibility. In the LTC that participated in this study, allergic rhinitis was the main self-reported illness. High levels of $PM_{10}$ were associated with a 3-fold odds of allergic rhinitis. No associations were found between IAC and respiratory symptoms.

With a view to improve the LTC indoor environments, adequate measures such as local exhaust ventilation systems near cooking and gas burning devices, as well as daily slightly moist cleaning of the rooms surfaces would reduce particle accumulation and re-suspension. Low indoor temperatures and discomfort, especially on winter season, could be prevented by simple measures such as insulating ceilings, walls and windows, maintaining natural and passive ventilation.

## Key points

- Cough and sputum were the major respiratory symptoms, and allergic rhinitis the main self-reported illness.
- Overall $PM_{2.5}$ median concentration was above reference levels both in winter and summer season.
- Peak values of $PM_{10}$, TVOC, $CO_2$, bacteria and fungi exceeded the reference levels, compromising indoor air comfort.
- Older people exposed to $PM_{10}$ above the reference levels have a higher risk of self-reported allergic rhinitis.

## Conflicts of interest

None declared.

## Funding

This work was supported by GERIA Project PTDC/SAU-SAP/116563/2010, a PhD Grant (SFRH/BD/72399/2010) from Foundation for Science and Technology (Fundação para a Ciência e Tecnologia - FCT) through Operational Competitiveness Programme (COMPETE) as part of the National Strategic Reference Framework and a grant funded by AIRC (Associazione Italiana per la Ricerca sul Cancro).

## Supplementary data

Supplementary data mentioned in the text is available to subscribers in *Age and Ageing* online.

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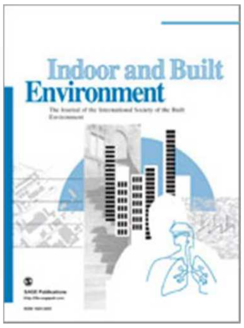
**Received 13 November 2014; accepted in revised form 30 September 2015**

## V. The Influence of Thermal Comfort on the Quality of Life of Nursing Home Residents

Submitted to Indoor Built and Environment in 2016




# THE INFLUENCE OF THERMAL COMFORT ON THE QUALITY OF LIFE OF NURSING HOME RESIDENTS

| | |
|---|---|
| Journal: | *Indoor and Built Environment* |
| Manuscript ID | Draft |
| Manuscript Type: | Original Manuscript |
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| Keywords: | Thermal comfort, predicted mean vote, predicted percent of dissatisfied people, nursing homes, older people, quality of life |

| | |
|---|---|
| Abstract: | Thermal comfort (TC) parameters were measured in 130 rooms from nursing homes (NH), following ISO 7730:2005, to evaluate the influence of winter season TC indices on older people's quality of life (QoL). Mean radiant temperature (mrT), predicted mean vote (PMV) and predicted percent of dissatisfied people (PPD) indices and the respective measurement uncertainties were calculated by Monte Carlo Method. The WHOQOL-BREF questionnaire was conducted from September 2012 to April 2013, along the winter season TC sampling campaign.<br>Winter PMV and PPD indices showed median values out of the standardized range for comfort and significant differences between season ($p < 0.001$). There were also significant differences between season for air temperature $p < 0.001$; air velocity $p < 0.011$; mrT $p < 0.001$ and relative humidity $p < 0.020$. The winter PMV index showed a 'slightly cool' [≤ -1] to 'cool' [≤ -2] in thermal sensation scale [-3 to 3]. PPD index reflects this discomfort with a high rate of predicted dissatisfied occupants (64 %). The influence of winter season TC in older people QoL results showed that values of PMV above -0.7 had higher mean score of QoL (coefficient estimate: 11.13 units) when compared with values of PMV below -0.7. |
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# THE INFLUENCE OF THERMAL COMFORT ON THE QUALITY OF LIFE OF NURSING HOME RESIDENTS

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## Abstract

Thermal comfort (TC) parameters were measured in 130 rooms from nursing homes (NH), following ISO 7730:2005, to evaluate the influence of winter season TC indices on older people's quality of life (QoL). Mean radiant temperature (mrT), predicted mean vote (PMV) and predicted percent of dissatisfied people (PPD) indices and the respective measurement uncertainties were calculated by Monte Carlo Method. The WHOQOL-BREF questionnaire was conducted from September 2012 to April 2013, along the winter season TC sampling campaign.

Winter PMV and PPD indices showed median values out of the standardized range for comfort and significant differences between season ($p < 0.001$). There were also significant differences between season for air temperature $p < 0.001$; air velocity $p < 0.011$; mrT $p < 0.001$ and relative humidity $p < 0.020$. The winter PMV index showed a 'slightly cool' [≤ -1] to 'cool' [≤ -2] in thermal sensation scale [-3 to 3]. PPD index reflects this discomfort with a high rate of predicted dissatisfied occupants (64 %). The influence of winter season TC in older people QoL results showed that values of PMV above -0.7 had higher mean score of QoL (coefficient estimate: 11.13 units) when compared with values of PMV below -0.7.

## Keywords

Thermal comfort; predicted mean vote; predicted percent of dissatisfied people; nursing homes; older people; quality of life.

## Introduction

The World Health Organization (WHO) guidance on thermal comfort (TC) is driven by protecting health from both high and low indoor temperatures. The guidance for the home environment aim to protect the health of those most susceptible and fragile to temperatures outside the comfort range, such as children and older people [1]. The European PHEWE Project [2] reported a statistically significant short-term increase in cardiovascular mortality of 1.72% in association with a 1◦C decrease in a 15-day average temperature [3]. Additionally, was also found a short-term increased risk of myocardial infarctions at higher and lower temperatures. The TC is considered by WHO to provide health gains for individuals, and economic benefits for society [1] by protecting health from high and low indoor temperatures. Furthermore, associations showing an increased risk of cardiovascular events at higher as well as lower temperatures have been reported [3]. In this regard, thermal environment in homes does not usually cause serious illness, however it has a very significant impact on the general well-being and daily performance of its residents. Poor thermal environment can also aggravate the impact of air pollutants on occupant's health [4]. Over the last few decades, concern about the quality of life (QoL) in older population has increased. More specifically, health related QoL which involves perceptions of well-being and functioning in physical, mental, social and environment in daily life activities comprising a summary quantification of perceived health [5]. The QoL group of the WHO [6] has defined QoL broadly as "An individual's perception of his or her position in life in the context of the culture and value system where they live, and in relation to their goals, expectations, standards and concerns". When studying older people living in nursing homes (NH) facilities, there has been a practice to include QoL as an outcome parameter [7].

The present study explores season variations of TC parameters in 21 NH located in Porto, Portugal, including the predicted mean vote (PMV) - predicted percent of dissatisfied people (PPD) model integrated with the QoL assessment. The main aim of this study was to evaluate the influence of winter season TC indices on older people's QoL.

## Materials and methods

*Building characterization*

All NH located within the Porto urban area and included in the *'Portuguese Social Charter'* were invited to participate in our study. Out of a total of 58 NH, 36% (n = 21) accepted to participate. It was performed a building characterization by a walk-through survey including the following information: type of building construction (concrete, masonry, etc.); thermal isolation of the building envelope (type of windows and doors, presence of weather stripping, etc.); ventilation system (natural, mechanical, hybrid, etc.); types of indoor materials; use of gas burning appliances; evidence of dampness or mold; ventilation practices (opened windows). Smoking was not legally allowed in any indoor location of any NH [8]. Outdoor relative air humidity (RH), and air temperature (airT) were monitored using a portable monitor (GasData, model PAQ). After equipment stabilization, measurements were recorded continuously and transferred to an informatics system using PCLogger 32 V3.0 software.

*Thermal comfort assessment*

The study was completed during winter and summer seasons, starting from November 2011 till August 2013, in 130 NH indoor areas within common areas such as dining rooms, drawing rooms and medical offices, and private areas (bedrooms), including the bedridden subgroup. TC parameters were measured following ISO 7730:2005 [9], including variables measured in the environment, such as, airT, RH and mean radiant temperature (mrT) to estimate the heat exchange between human body and environment, as well as, relative air speed. In order to determine PMV and PPD indices, metabolic rate and clothing insulation personal variables were taken into consideration. According to ISO 7730:2005 and confirmed by observation, elderly occupants' daily activity is characterized by a metabolic rate of 1.0 met (seated, relaxed) and to a clothing thermal insulation of 1 clo (underwear with short sleeves and legs, shirt, trousers, jacket, socks and shoes) in summer, and of 1.3 clo (underwear with long sleeves, long trousers, long shirt, jersey, thermo-jacket, socks and shoes) in winter. Fanger [10, 11] showed that man and women seem to prefer similar thermal environments. Women's skin temperature and evaporative loss are slightly lower than those of man, and this balances the slightly lower metabolism of women [12].

The TC assessment was conducted in a discreet fashion in order not to disturb occupants' normal life. The monitoring phase included daytime sampling (starting at 10 a.m. and continuing for at least 4 h during normal activities). NH rooms homogeneous distribution of temperatures and air flows, and steady-state environment were tested according to ISO 7726 [13] specifications with TSI 8386A-M-GB thermo-anemometer. Moderate environments (class C – comfort standard) were considered. Objective physical data, including airT, mrT measured using a black-globe thermometer, RH and air velocity were collected by Delta Ohm HD 32.1 - Data logger, placed at a height of 0.60 meters above the floor (sitting - abdomen level). All monitoring data were collected as close as possible to the center of the room, with the sampling points no closer than 1 meter to a wall, a window, a door or an active heating system. After 25 minutes equipment stabilization in each room, the measurements were recorded during 10 minutes, sampling data each 15 seconds [9]. The data for each room was obtained using the software DeltaLog10 version 1.30. The PMV and PPD indices were computed using the data acquired from the experimental measurements performed in the building, including the metabolic rate and clothing insulation occupant's factors. Results were compared to Table A.1 (Categories of thermal environment) from Annex A of ISO 7730 [9].

*Environmental data quality assurance and quality control*

PMV and PPD indices, mrT and their measurement uncertainties were calculated by Monte Carlo Method using MatLab R2013b software (MathWorks Inc., Natick, MA, United States). Expanded uncertainty was evaluated for 95% confidence interval based on probability distributions propagation of measurands obtained by multiple samples and considering instrumental uncertainty obtained from traceable calibrations.

*Questionnaires*

In each NH the Portuguese version of the WHOQOL-BREF questionnaire [14-16] was conducted from September 2012 to April 2013, along the winter season TC sampling campaign. It was administered by a trained interviewer to the older people who gave their informed consent and were able to participate.

The WHOQOL-BREF questionnaire instrument is a 26-item version of the WHOQOL-100 assessment. The Portuguese version [17] of the WHO QoL WHOQOL-BREF questionnaire was used for this purpose [18]. It is focused on the QoL definition advocated by the WHO, which includes the culture and context that influence individual's health perception. It comprises 24 core items organized into four domains: physical health (7 items), psychological health (6 items), social relationships (3 items) and environmental health (8 items). These four domain scores denote an individual's perception of QoL in each particular domain. There are two additional items, intended as indicators of overall QoL and health perception. Domain scores are scaled in a positive direction (higher scores denote higher QoL). The mean score of items within each domain is used to calculate the raw domain score. Then, two transformations methods are used: the first one converts domain raw scores to range between 4 to 20 and the second converts domain scores to a 0-100 scale. Considering the 4-20 scale, the midpoint where QoL is judged to be neither good nor poor is 12.0 [19] (which correspond to 50 in the 0-100 scale). In the present study we considered the 0-100 scale. In the analysis were considered only the WHOQOL-BREF questionnaires with less than 20% of missing answers.

Along with the WHOQOL-BREF questionnaire a general socio-demographic questionnaire and two well-known cognitive and depression validated questionnaires were applied to perform a thorough characterization of the elderly population:

(i) the Mini Mental State Examination (MMSE), used to evaluate cognitive status [20]. It is an easy to administer questionnaire, which allows cognitive function assessment in temporal and spatial orientation, calculation, memory, verbal and written skills. The maximum score is 30. Considering the education level [18], the cut-off values for the Portuguese population indicative of cognitive impairment are: ≤ 15 (for illiterates), ≤ 22 (for those with one to 11 years of schooling) and ≤ 27 (for people with more than 11 years of schooling).

(ii) the Geriatric Depression Scale (GDS-15), used to evaluate the depression status) [21, 22]. In GDS-15, for each positive answer on items 2 to 4, 6, 8 to 10, 12, 14 and 15 is allocated one point. In turn, for each negative answer on items 1, 5, 7, 11 and 13 is also given one point. Considering the Portuguese population, interpretation is the following: more than five points and less than 10 is considered suggestive of depression and more than 10 points is considered indicative of depression.

This study was approved by the Ethics Committee and the Portuguese Data Protection Authority. In order to participate in the study, the elderly should be at least 65 years old, had been living in the NH for more than two weeks, have cognitive and interpretative skills to receive the QoL questionnaire, and sign the informed consent.

*Statistical analysis*

An exploratory analysis was carried out for all variables. Categorical data were presented as frequencies and percentages, and continuous variables as median and inter-quartile range (25th percentile-75th percentile) or range (min-max). Due to the fact that most of the rooms were not the same in both seasons, the two samples were considered to be independent. Mann–Whitney and Kruskal–Wallis tests were used to compare seasonal effects assessment because of the existence of outliers, high variability and skewed distributions. The outcome QoL variables were the physical health, psychological health, social relationships and environment WHOQOL-BREF domains in a 0-100 scale. Mixed effects linear regression models were used to study the association between the QoL domains and winter season PMV index (categorized within [-0.7; 0.7] and outside the comfort categories). The 95% confidence intervals (CI) were also calculated. A 0.05 level of significance was used for all analyses. Data were analyzed using IBM SPSS 21.0 (SPSS, Inc., Chicago, IL, USA) and STATA 12.0. (StataCorp LP, Stata Statistical Software; TX, USA).

## Results

*Nursing homes*

The 21 NH were located in the city center of Porto with 78% of them in areas of heavy traffic. A total of 668 older people lived in these facilities with a range of 7 to 136 occupants per building. As regards construction characteristic, 64% were an adaptation to NH of an existing residential building, and 42% also had a day center activities for non-residents older people. Most of them were built in stone masonry construction (46%) with single pane windows (87%). Only 31% had roof and walls insulation and half of the sampled buildings presented condensations and infiltrations along walls and roofs inside the buildings. Most of NH (91%) presented mixed ventilation (natural ventilation in the rooms along with exhaustion systems in the kitchen and bathrooms) while 9% had only natural ventilation in all the indoor areas. There were no cooling systems apart from some passive measures, such as blinds and curtains on the windows. During monitoring, the mean daily ambient airT in Porto was 17 ºC [11–23 ºC], with 49% [18–80%] RH in the winter, and 24 ºC [17–34 ºC] with 47% [18–76%] RH in the summer.

*Thermal comfort assessment scenario*

Table 1 presents the overall results of TC in the NH by season. These results showed median levels of airT, RH and air velocity within the reference limits. Still minimum and maximum levels of airT and RH were out of the recommended range. Regarding the TC indices median summer PMV presented values within the ISO 7730 category A [-0.2; 0.2], while summer PPD presented median results in category C (< 15%). The winter results for PMV and PPD indices showed median values out of the standardized range for comfort. This event may be due to the lack of insulation (31%) in the NH buildings failing to protect the residents from the outdoor temperature variations during winter season. Also, there were significant differences for all the TC parameters between seasons (Table 1). The winter PMV index showed a ‘slightly cool’ [≤ -1] to ‘cool’ [≤ -2] thermal sensation scale [-3 to 3]. The winter PPD index reflects this discomfort with a high rate of predicted dissatisfied occupants (64 %).

< Table 1 about here >

When analyzing the median results by room and season (Table 2) the dining room was the area with lowest airT in winter season, opposite to the bedridden which was warmest. In terms of RH and air velocity both in summer and winter season, the median results in all areas were within the references. Concerning the PMV and PPD indices, summer results were within the comfort categories. However, winter results showed all values out of the references for PPD index and PMV indices between ‘slightly cool’ [≤ -1] to ‘cool’ [≤ -2] in the seven-point thermal sensation scale [9]. The rooms with lower median of PMV were the dining rooms (-2.1) followed by the bedrooms (-1.8). There were also significant differences for airT ($p < 0.001$), air velocity ($p < 0.011$), mrT ($p < 0.001$), PMV and PPD indices ($p < 0.001$) between seasons in each type of room. Figure 1 presents graphically the season differences found in the PMV index. The summer season PMV median values in the different studied rooms ranged between + 1 (slightly warm) to -1 (slightly cool) in the thermal sensation scale, including the ‘0’ (neutral) where thermal balance is obtained and the internal heat production in the body is equal to the loss of heat to the environment. Contrarily, in the winter season results showed median values of PMV between -1 (slightly cool) to -2 (cool) and and the interquartile range ($P_{75}$- $P_{25}$) between -1 and -3 (cold) (Figure 1). These values were out of the categories for comfort and its range excluded the thermal balance (neutral).

Figure 1 also presents summer season PPD indices within the references with category B in bedridden rooms and medical offices, and category C for dining rooms, drawing rooms and general bedrooms. The PPD winter indices showed higher rates of predicted dissatisfied occupants between 2 times above the category C referential (< 15%) in the medical offices until 5 times overhead this same referential in the dining rooms.

< Table 2 about here >

< Figure 1 about here >

*Quality of life outcomes*

From the 668 older people living in the studied NH, 21% (n=143) were within the inclusion criteria and agreed to answer the QoL questionnaire. Concerning the non-eligible (79%), they were mostly women (62%), 53% lived in the NH in between 2 and 10 years and 46% had more than 85 years old. The main reasons to not participate in the study were disability, disease compromising the cognitive and interpretative skills to answer the questionnaire (60%), refusal (32%) and to be younger than 65 years (8%). The sample is characterized mainly by women (85%) with most people in the age group above 85 years old (47%). Most of the residents (61%) had an observed degree of physical impairment and mobility (use of mobility aids such as crutches, canes and wheelchairs) or were bedridden. In the surveyed sample, 40% presented MMSE cognitive impairment and 35% a GDS-15 score indicative or suggestive of depression. The description of the sample is presented in Table 3.

< Table 3 about here >

Table 4 present the QoL status of the studied sample population according to the WHOQOL-BREF. The median scores of all domains were above the 50 cut-off point. The percentage of scores below the cut-off point was higher in the domain 1 - physical health (29%) followed by the domain 2 – psychological health (24%). The domain 4 environment had the lowest percentage of scores below the cut-off point (7%).

< Table 4 about here >

*Influence of thermal comfort in older people quality of life*

Previously Table 1 and 2 showed only negative PMV values in the thermal sensation scale for the winter season TC assessment. In this sense the winter season was considered the worst case scenario by the research team. When applying the mixed effects models for testing the influence of winter season TC in older people QoL, the results showed a weak evidence ($p$ = 0.055) that values of PMV above -0.7 (towards zero and within the comfort categories) had higher mean score of QoL (domain 2) (coefficient estimate: 11.13 units) when compared with values of PMV below -0.7 (towards -3 and outside the comfort categories).

**Discussion**

Our study presented results for seasonal variation of TC assessment in NH and the winter season TC parameters influence in the self-perceived QoL of older people. Our sample of buildings was mostly an adaptation to NH of an existing residential building. According to Idchabani et al. (2014) [23] a well design building will be more efficient and less expensive than a building renovated afterwards. In addition, most of the studied NH presented single pane windows and absence of roof and walls insulation. These factors along with natural ventilated environments presenting condensations and infiltrations on walls and roofs inside the buildings can be a substantial challenge to maintain a comfortable indoor environment for elderly populations, especially in winter season [24, 25]. TC is a major issue for the elderly and can be associated with cardio-mortality due to low temperatures in poor insulated houses [26, 27].

In our study, the winter TC results showed concern with median PMV and PPD indices out of the standardized range for comfort [9, 28] and significant differences for all the TC parameters between seasons as well as rooms were found. In general, elderly seem to perceive TC differently from the young due to a combination of physical ageing and behavioral differences [29, 30]. These results along with the decrease to regulate body temperature with age and a reduction in the sweating activity of aged men [29] and women [31] compared to younger age groups may increase the risk of respiratory tract infections in this susceptible population [32]. Mourtzoukou and Falagas [32] report that cold air inhalation, cold stress, lower core body temperature and body surface cause pathophysiological responses such as vasoconstriction in the respiratory tract mucosa and suppression of immune responses, which are responsible for increased susceptibility to infections. In addition, the longer the duration of exposure the higher risk of infection. On average, older adults have a lower activity level, and thus metabolic rate, than younger which is the main reason why they require higher ambient temperatures [33]. On the contrary, it is inferred that older people may suffer from more susceptible upper airways at low RH [34]. An RH about 40% is healthier for the eyes and upper airways than levels of RH below 30%. Nevertheless, depending on the mucous membranes dryness the optimal RH may differ for the eyes and the airways [34].

Our study showed only negative PMV values in the thermal sensation scale for the winter season TC assessment. Several studies [26, 29, 33, 35] on older people suggested that, physiologically and psychologically older adults preferred a warmer environment (+ 2ºC) than younger people. The 20 - 24ºC comfort zone is not warm enough for older adults that found an optimum temperature around 25.3ºC for sedentary elderly. Moreover, measures of indoor operative temperatures (what humans experience thermally in a space) in Portuguese NH [35] ranged between 16ºC and 25ºC in winter and 22ºC and 31ºC in summer. Also, these evidences are supported for more recent studies [36, 37] presenting clearly that elderly preferred a higher temperature in comparison with the young adults.

Furthermore, self-reported poor health was significantly associated with poor thermal comfort in a recent review article by Ormandy and Ezratty [1] as well as, in a previous study in the same studied NH [38]. In our study when applying the mixed effects models for testing the influence of winter season TC parameters in older people QoL, the results also showed an evidence (although weak) that values of PMV within the comfort categories had higher values of QoL (domain 2 - psychological health) when compared with values of PMV out of the categories of thermal environment. Moreover, the European WHO LARES project [39, 40] also found that TC related problems such as cold indoor temperature, problems with the heating system or inadequate insulation were mostly associated with respiratory problems in elderly over 65 years and older. Additionally, there was also a significantly higher reporting of arthritis in homes that were perceived as cold in winter.

*Limitations of the study*

The main limitation of this study occurred due to the characteristics of the individuals living in the studied NH which compromised the older people sample size. In this sense several older NH residents with cognitive impairments could not participate in the study. Regarding the NH participation rate, there was a high number of institutions that did not accept to participate in the study. Despite this, six of the seven parishes in the city had at least one participating NH. This is also a city study and may not generalize to other towns, villages or rural areas.

To overcome it, TC measurements were systematically obtained during periods of typical activities in the NH, in a period of steady occupancy. For future sampling we would recommend a larger sample size of NH and older people participating in the questionnaires. More studies relating indoor TC conditions in susceptible populations such as older people are welcome.

*Recommendations to nursing homes regarding thermal comfort*

In order to contribute to improve the health of residents living in NH related to TC, it is very important to change inadequate ventilation, control thermal parameters and adjust clothing to environmental characteristics. The aeration should be done when there are no occupants in these divisions, preferring the lunchtime period, when residents are in the dining room. The renewed air can reach temperature equilibrium while minimizing the impact on the TC, by closing the windows some time before the return of the occupants. It is also very important to keep an airT of comfort, which should take into account the activity performed by residents: (i) in the absence of physical activity, closer to 25°C; (ii) in the presence of physical activity, lower temperature, however higher than 20°C; (iii) keep the relative humidity between 25% and 55% [41]. In the rehabilitation of old buildings and construction of new ones the bedrooms and drawing rooms should be equipped with ventilation system. Chose preferably bottom hung or tilt and turn windows, because the impact of outside air flow in the occupied zone is smaller [42, 43].

## Conclusions

Winter indoor environment and TC have a potential influence in QoL of older people living in NH due to their susceptibility to this season temperature. Our study showed PMV and PPD indices median values out of the standardized range for comfort in the winter season. We found 'slightly cool' to 'cool' PMV index in thermal sensation scale which may increase the risk of respiratory tract infections in this susceptible population. The PPD index reflects this discomfort with a high rate of predicted dissatisfied occupants. The influence of winter season TC parameters in older people QoL results showed that values of PMV within the comfort categories had higher mean score of QoL when compared with values of PMV out of the categories of thermal environment. Further studies are needed in order to analyze TC variables in these environments thus improving the wellbeing of our elderly population. The improvement measures should be tested for their consistency in the future if the NH owners agree to implement them.



## Funding

This work was supported by GERIA Project (www.geria.webnode.com): PTDC/SAU-SAP/116563/2010 and a PhD Grant (SFRH/BD/72399/2010) from Foundation for Science and Technology (Fundação para a Ciência e Tecnologia - FCT) through Operational Competitiveness Programme (COMPETE) as part of the National Strategic Reference Framework. SB work was supported by a grant funded by AIRC (Associazione Italiana per la Ricerca sul Cancro).

**Acknowledgements**

We gratefully thank Cristiana Pereira and Paula Neves, who contributed to the planning, field work and laboratory analysis. Also to Álvaro Silva Ribeiro by the support with the Matlab software.

**Conflict of Interest**

The authors declare that they have no conflict of interest.

**Author's contribution**

All authors contributed equally in the preparation of this manuscript.

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Table 1. Nursing homes thermal comfort parameters: descriptive statistics by season

| | N | Median [$P_{25}$-$P_{75}$] | Min-Max | *p* | References |
|---|---|---|---|---|---|
| **Air Temperature** (ºC) | | | | | |
| Summer | 68 | 23.8 [21.2-25.7] | [15.9-32.8] | 0.001 | Summer [22,8 - 26,1] |
| Winter | 62 | 20.3 [17.9-21.7] | [15.8-23.8] | | Winter [20,0 - 23,6] [g)] |
| **Relative Humidity** (%) | | | | | |
| Summer | 68 | 53.9 [38.9-62.0] | [24.0-75.2] | 0.020 | [30-65] [h)] |
| Winter | 62 | 46.8 [34.8-59.2] | [19.7-77.7] | | |
| **Air Velocity** (m/s) | | | | | |
| Summer | 68 | 0.02 [0.01-0.07] | [0.01-0.75] | 0.011 | < 0.25 [h)] |
| Winter | 62 | 0.01 [0.01-0.02] | [0.01-0.27] | | |
| **Mean Radiant Temperature** (ºC) | | | | | |
| Summer | 68 | 24.2 [a)] [21.5-28.9] | [15.5-33.1] | 0.001 | - |
| Winter | 62 | 20.5 [b)] [18.1-22.1] | [15.6-27.8] | | |
| **PMV** | | | | | |
| Summer | 68 | -0.2 [c)] [(-0.7)-0.5] | [(-3.0)-2.3] | 0.001 | Category A [-0.2; 0.2] [i)] |
| Winter | 62 | -1.8 [d)] [-2.4-(-1.1)] | [(-3.0)-(-0.3)] | | B [-0.5; 0.5] |
| | | | | | C [-0.7; 0.7] |
| **PPD** (%) | | | | | |
| Summer | 68 | 11.3 [e)] [6.5-35.1] | [5.0-99.1] | 0.001 | Category A < 6 [i)] |
| Winter | 62 | 64.4 [f)] [31.8-90.2] | [6.8-99.2] | | B < 10 |
| | | | | | C < 15 |

a) $U_{95\%}$ = 0.16; b) $U_{95\%}$ = 0.16; c) $U_{95\%}$ = 0.06; d) $U_{95\%}$ = 0.09; e) $U_{95\%}$ = 0.9; f) $U_{95\%}$ = 3.3; g) ASHRAE 55; h) IAQA 01-2003; i) ISO 7730:2005

Table 2. Thermal comfort descriptive statistics by room & season

| | Median [$P_{25}$-$P_{75}$] Min-Max | | | | |
|---|---|---|---|---|---|
| | **Dining Room** n = 13 | **Drawing Room** n = 42 | **Bedroom** n = 54 | **Bedridden** n = 15 | **Medical Office** n = 6 |
| **Air Temperature** (ºC) * | | | | | |
| SUMMER | 24.7 [22.3 – 25.4]<br>17.4 - 26.6 | 24.1 [22.1 – 25.9]<br>17.7 – 32.8 | 22.3 [20.1 – 25.3]<br>15.9 – 31.5 | 23.8 [21.7 – 25.9]<br>20.5 – 27.6 | 25.0 [24.0 - ]<br>24.0 – 26.0 |
| WINTER | 19.1 [17.3 – 20.4]<br>16.4 – 21.1 | 20.3 [17.7 – 21.7]<br>16.1 – 23.8 | 20.3 [17.7 – 22.0]<br>15.8 – 23.4 | 20.6 [19.3 – 22.3]<br>17.7 – 22.5 | 21.7 [20.7 – 22.1]<br>20.4 – 22.2 |
| **Relative Humidity** (%) | | | | | |
| SUMMER | 49.4 [38.5 – 55.4]<br>36.7 – 70.9 | 53.4 [44.1 – 61.6]<br>26.2 – 71.0 | 55.1 [38.5 – 67.8]<br>29.0 – 75.2 | 57.5 [48.2 – 62.5]<br>24.0 – 63.4 | 37.8 [36.4 - ]<br>36.4 – 39.1 |
| WINTER | 47.1 [42.9 – 53.2]<br>33.1 – 59.1 | 43.9 [31.9 – 59.7]<br>19.7 – 77.7 | 44.3 [32.0 – 60.1]<br>25.9 – 73.8 | 52.9 [43.1 – 60.9]<br>42.6 – 70.4 | 42.6 [28.8 – 54.7]<br>26.4 – 56.6 |
| **Air Velocity** (m/s) ** | | | | | |
| SUMMER | 0.01 [0.01 – 0.10]<br>0.01 – 0.11 | 0.04 [0.01 – 0.11]<br>0.01- 0.75 | 0.01 [0.01 – 0.04]<br>0.01 – 0.48 | 0.04 [0.01 – 0.06]<br>0.01 – 0.18 | 0.1 [0.1 – 0.1]<br>0.1 – 0.1 |
| WINTER | 0.02 [0.01 – 0.05]<br>0.01 – 0.07 | 0.02 [0.01 – 0.03]<br>0.01 – 0.27 | 0.01 [0.01 – 0.01]<br>0.01 – 0.18 | 0.01 [0.01 – 0.01]<br>0.01 – 0.01 | 0.01 [0.01 – 0.1]<br>0.01 – 0.13 |
| **Mean Radiant Temperature** (ºC) * | | | | | |
| SUMMER | 25.6 [a)] [22.4 – 27.1]<br>17.6 – 28.1 | 24.4 [g)] [22.2 – 26.2]<br>17.4 – 33.1 | 22.5 [m)] [20.1 – 25.5]<br>15.5 – 31.6 | 23.7 [s)] [22.5 – 26.3]<br>20.9 – 27.7 | 25.1 [24.5 - ]<br>24.5 – 25.6 |
| WINTER | 19.5 [b)] [17.6 – 20.8]<br>15.5 – 21.4 | 20.6 [h)] [18.0 – 22.0]<br>15.8 – 25.0 | 20.3 [n)] [18.0 – 22.6]<br>15.6 – 27.4 | 20.9 [t)] [19.2 – 22.4]<br>18.0 – 22.5 | 22.0 [20.9 – 22.4]<br>20.6 – 22.3 |
| **PMV** * | | | | | |
| SUMMER | 0.5 [c)] [-0.3 – 0.6]<br>-2.5 – 0.9 | -0.2 [i)] [-0.8 – 0.5]<br>-2.5 – 2.3 | -0.3 [o)] [-1.6 – 0.2]<br>-3.0 – 2.0 | -0.1 [u)] [-0.9 – 0.5]<br>-1.3 – 0.8 | 0.4 [0.2 - ]<br>0.2 – 0.6 |
| WINTER | -2.1 [d)] [-2.6 – (-1.7)]<br>-2.8 – (-1.4) | -1.7 [j)] [-2.5 – (-1.1)]<br>-2.9 – (-0.3) | -1.8 [p)] [-2.4 – (-1.0)]<br>-3.0 – (-0.3) | -1.6 [v)] [-2.2 – (-0.8)]<br>-2.5 - (-0.8) | -1.2 [-1.6 – (-1.0)]<br>-1.7 – (-1.0) |
| **PPD** (%) * | | | | | |
| SUMMER | 10.4 [e)] [6.8 – 22.8]<br>5.1 – 93.8 | 11.9 [k)] [7.1 – 29.6]<br>5.2 – 93.2 | 11.5 [q)] [6.5 – 71.6]<br>5.0 – 99.1 | 9.8 [x)] [5.3 – 28.9]<br>5.2 – 41.4 | 8.8 [5.6 - ]<br>5.6 – 11.9 |
| WINTER | 78.2 [f)] [62.5 – 94.6]<br>42.9 - 98 | 61.1 [l)] [32.5 – 93.2]<br>7.4 – 98.6 | 63.7 [r)] [23.6 – 91.1]<br>6.8 – 99.2 | 57.2 [z)] [19.5 – 82.89]<br>17.8 – 92.9 | 32.4 [27.4 – 54.1]<br>26.4 – 60.6 |

* Significant differences by room and season (summer/winter) $p < 0.001$

** Significant differences by room and season (summer/winter) $p < 0.01$

a) $U_{95\%} = 0.17$; b) $U_{95\%} = 0.16$; c) $U_{95\%} = 0.07$; d) $U_{95\%} = 0.17$; e) $U_{95\%} = 1.20$; f) $U_{95\%} = 7.20$; g) $U_{95\%} = 0.16$; h) $U_{95\%} = 0.16$; i) $U_{95\%} = 0.07$; j) $U_{95\%} = 0.10$; k) $U_{95\%} = 1.40$; l) $U_{95\%} = 3.70$; m) $U_{95\%} = 0.16$; n) $U_{95\%}$ = 0,16; o) $U_{95\%} = 0.04$; p) $U_{95\%} = 0.06$; q) $U_{95\%} = 0.40$; r) $U_{95\%} = 2.10$; s) $U_{95\%} = 0.16$; t) $U_{95\%} = 0.17$; u) $U_{95\%} = 0.07$; v) $U_{95\%} = 0.08$; x) $U_{95\%} = 2.10$; z) $U_{95\%} = 3.95$.

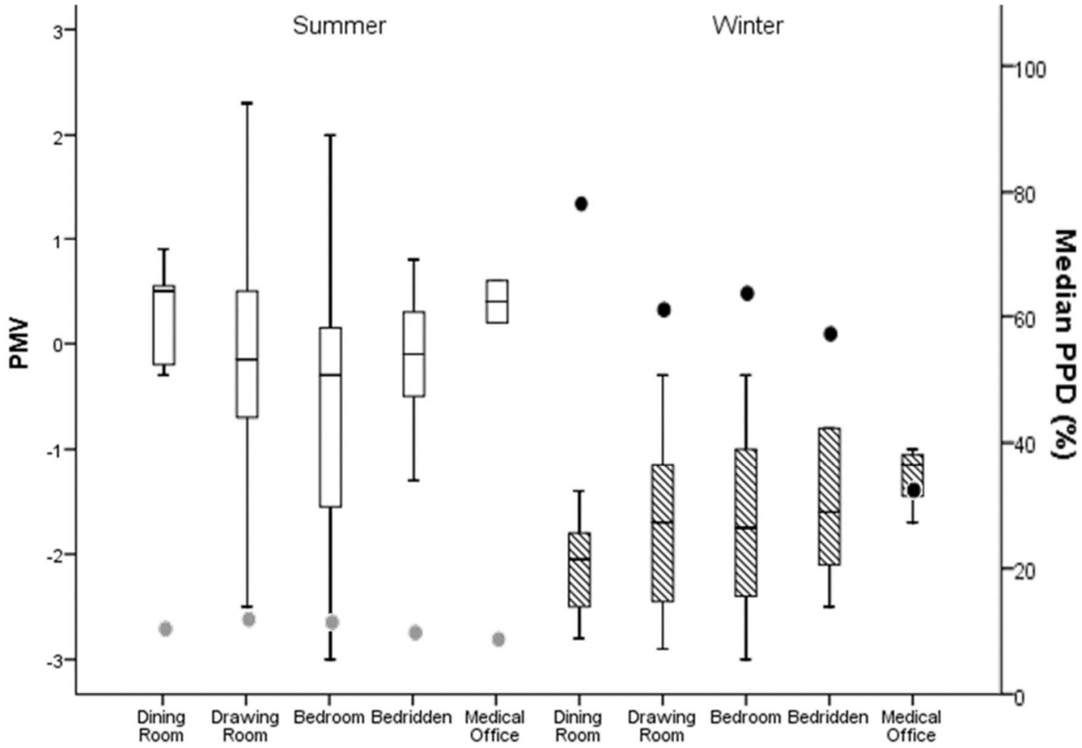


Figure 1. PMV indices (boxplots) and median PPD (dots) by room and season

Table 3. General descriptive of the elderly subjects (n = 143)

| | n (%) |
|---|---|
| **Gender** | |
| Female | 121 (84.6) |
| Male | 22 (15.4) |
| **Age group** | |
| [65-75] | 19 (13.2) |
| [76-85] | 57 (39.9) |
| > 85 | 67 (46.9) |
| **Years living in the NH** | |
| ≤ 1 year | 37 (25.9) |
| [2-10] | 83 (58.0) |
| > 11 | 23 (16.1) |
| Dementia (**MMSE questionnaire**) * | 57 (40.4) |
| Depression (**GDS15 questionnaire**) ** | 49 (35.3) |
| Impaired physical mobility and bedridden | 85 (61.2) |

* Scores greater than or equal to 27 points (out of 30) indicates a normal cognition but need to be corrected for educational attainment and age. Cut-off points for a maximum of 30 points: Illiterate ≤ 15 points; one to eleven years of education: ]15, 22] points; above 11 years education: ]22, 27] points;

** Scores of 0-4 are considered normal, depending on age, education, and complaints. Values higher than 5 indicate depression (the considered cut-off point for a maximum of 15 points: > 5).

Table 4. Descriptive of self-perceived QoL status

| | n | Median [$P_{25}$-$P_{75}$] | *% below 50 score cut point* |
|---|---|---|---|
| Overall QoL | 140 | 63 [38-75] | 29 |
| Domain 1 Physical health | 132 | 61 [46-75] | 29 |
| Domain 2 Psychological health | 139 | 66 [50-75] | 24 |
| Domain 3 Social relationships | 101 | 75 [58-75] | 12 |
| Domain 4 Environment | 108 | 69 [59-75] | 7 |

Scale ranging from 0 to 100: a higher score indicates a higher QoL. Cut-off point: 50 score [44]

# 5. GLOBAL DISCUSSION

Aging is associated with a decline in immune defense and respiratory function, and predisposition to respiratory infections [99]. Due to these conditions, older people are more susceptible to the effects of air pollution, and since they spend the large majority of their time indoors, monitoring IAQ and TC in ECC is a public health priority [70]. With this purpose this study aimed: (i) to characterize the ECC indoor environment and explore the influence of building characteristics on IAQ parameters; (ii) associate the influence of indoor environment parameters on ECC residents' respiratory health; (iii) evaluate the influence of winter season TC indices on older people's QoL; and (iv) produce guidelines on remedial measures and recommendations to ECC. The following sections sum up the discussion of the previous aims.

## 5.1 Indoor Air Quality and Thermal Comfort Results

Our study showed higher levels of $PM_{2.5}$ in all ECC spaces in both seasons, revealing as particle matter concentrations is a critical parameter of air quality, both for its sensitivity and for its possible influence on human health. Findings [100] showed as this parameters is strongly depending to season, filter usage, relative humidity, air exchange ratios, number of occupants, outdoor PM levels, sweeping/dusting, and presence of a central air conditioner, reported a number of critical issue for any programs aimed at preventing exposure to inhalable toxic agents of the elderly population. Our mean and median overall indoor $PM_{2.5}$ evaluations were about 3 times above the US EPA [91] reference levels, with the highest values in the bedridden subset and medical office. This might be due to combination of outdoor contamination, occupation rate and the accelerated particle resuspension in spaces dedicated to indoor activities [101]. Other studies [72, 102] showed, high levels of $PM_{2.5}$ in similar indoor environments, and the link with lung function [103] and respiratory diseases such as chronic obstructive pulmonary disease (COPD) [104, 105] has been quite demonstrated. Whether generated by indoor or outdoor pollution the $PM_{2.5}$ is acknowledged by WHO and by EPA as a known cause health risk for lung and heart diseases (including asthma) [106].

Although people (particularly the older people of our study) spend most of their time indoors, a major portion of indoor $PM_{2.5}$ came from outdoor mobile sources. In fact, the Cardiovascular Health and Air Pollution Study (CHAPS) showed that indoor-infiltrated particles from mobile sources are more strongly correlated with adverse health effects observed in the older subjects living in the studied retirement communities compared with other particles found indoors [107]. Additionally, a recent study conducted in

Belgium [108] presented high correlations between outdoor and indoor $PM_{2.5}$ in ECC, confirming mainly the outdoor origin of indoor air contaminants. $PM_{2.5}$ was also correlated with atherosclerosis and cardiovascular disease in a specific study by Wilker *et al.* (2011) [109].

Although all the other indoor air pollutants were within the reference levels peak values of $PM_{10}$, TVOC, $CO_2$, bacteria and fungi exceeded the reference levels, compromising indoor air comfort and worsening the already existent respiratory chronic diseases. A VOC study in the elderly French dwellings show statistically significant associations between breathlessness and living in dwellings with elevated concentrations of toluene and o-xylene in elderly population [70]. When TVOC, bacteria, CO and $CO_2$ indoor levels are compared with ambient air they were higher in both seasons, suggesting as indoor pollution is the most important source of exposure, at least in this population. Indoor ECC activities influence pollution levels, especially in the winter season. Seasonality is a critical parameter affecting the level of exposure to $PM_{10}$, TVOC, bacteria and $CO_{2,}$ and simple behaviors such as opening and closing windows may dramatically change these values. Dining rooms and drawing rooms are expected to have the highest mean and maximum levels of $PM_{10}$, $CO_2$ and bacteria concentration due to higher occupation rate in these rooms when compared to bedrooms and medical offices. An inadequate ventilation can increase exposure not bringing in enough outdoor air to dilute emissions from indoor sources and allowing indoor air pollutants out of the rooms [69]. Similar conditions may explain significant differences between rooms and season for TVOC, bacteria and $CO_2$.

In our study significant differences between bacteria concentrations in both seasons were found. In agreement with our study Rintala *et al.* (2008) [110] also found higher bacterial concentrations (total concentrations of cultivable bacteria) in summer than winter in a study of indoor air of 20 homes in Chicago. In another study cited by this author [110], airborne bacteria did not exhibit an equally clear seasonal pattern. In this study, the increase of outdoor concentrations resulted in a corresponding rise of indoor concentrations in most houses. Biological sources are often located outdoors. Therefore, the influence of these sources on human exposure largely depends on the fraction of outdoor bioaerosols, which is subjected to indoor penetration [111]. Bacterial concentrations and occupancy showed an association in our study. During occupancy, resuspension and direct shedding of microorganisms from humans are potential sources of bacterial aerosol particles. The origin of many of the airborne bacteria is from human skin, hair, nostrils, and the oral cavity. Desquamated human skin cells are an important contributor to particles in indoor air, and there is evidence that bacteria are associated with these skin cells. Overall, these data suggest that relative contribution of human associated bacteria is variable and environment dependent [101].

Although the most predominant airborne fungi species found in the ECC were *Cladosporium* and *Penicillium species*, which are common in indoor and outdoor environments, we also found samples positive for the genotoxic and pathogenic species of *Aspergillus*. These species may infect patients with reduce or compromised immune systems and may cause invasive lung infections in susceptible individuals such as elderly. The lack of building insulation causes ECC rooms to have similar temperature and humidity of outdoors, while the high rate of building pathology, e.g., condensations and infiltrations, may influence positive results, since the environmental parameter ‘Fungi’ was strictly associated to the building characteristics ‘Insulation’ and ‘Building pathologies’ [112, 113]. Temperature and humidity levels can also increase the concentration of some pollutants [65].

In an overall perspective this study shows reassuring results about IAQ in the ECC evaluated such as showed in a recent review by [114]. More than 1/3 of the studied ECC reported excellent results, regarding the control of chemical and biological pollutants. However, although no ECC requires immediate intervention according to international and national reference levels, these thresholds may not be appropriate for susceptible populations, and specifically for elderly, which besides the increased biological sensitivity to the effect of air pollution spend nearly the 100% of their time in indoor spaces. Dedicated exposure/effect models should be developed for this population [115].

Thermal environmental comfort is another major issue for the elderly population [55]. Several studies demonstrated the effect of ambient temperature on cardio-respiratory mortality [116] and these findings were replicated with indoor climate [117]. Several studies [50, 52, 55, 56] on older people suggested that, physiologically and psychologically older adults preferred a warmer environment (+ 2ºC) than younger people. The 20 - 24ºC comfort zone is not warm enough for older adults that found an optimum temperature around 25.3ºC for sedentary older adults [50].

The TC results of our study showed significant differences between room and season for air temperature, especially for PMV and PPD indices, suggesting that the building and heating characteristics may affect indoor variance in the winter/summer temperature and RH. Moreover, thermal comfort depends also by individual parameters such as the degree of activity, the clothing worn by the individual, the age, health status, gender, and the adaptation to the local environment and household. Other factors like rooms crowding or under-occupation may have an influence, and so is for the variability during the day and over time [58]. However, the results of the winter season PMV index in our study show that thermal sensation scale in all analyzed rooms ranged between the 'slightly cool' (-1) and 'cool' (-2), while minimum winter and summer indoor air temperatures were constantly out of the comfort levels. Colder environments may potentiate elderly respiratory tract infections and also increase hospital consultations [118]. Among the other results also the inflammation caused by respiratory syncytial virus may be modified by the biologically active contaminants of indoor air [119]. The prevalence in our study group of buildings built in stone masonry with poor insulation and a limited availability of double-pane glass may explain this low thermal sensation scale index (PMV) and the high percentage of PPD index in the winter season, and pave the way for the most urgent structural interventions. To be noted that the presence of diverse heating systems in the ECC evaluated did not significantly affect average indoor temperature in the winter season (≈ 19ºC), which constantly stay below reference values for neutral/comfort temperature.

### 5.2 The Impact of Indoor Environment on Respiratory Health of Older People

Our sample was very old (47% of the individuals in the age group above 85 years old) and characterized mainly by women (85%). This data is consistent with a recent European study performed in several ECC [69]. The high rates of self-perceived sickness and degree of physical impairment indicates a very dependent population, living in the ECC for 2 to 10 years. Older people are more susceptible to the effects of indoor air pollution since they spend the large majority of their time indoors [70, 72] associated with a decline in immune defenses and respiratory function [99].

Concerning the respiratory assessment, cough and sputum were the major respiratory symptoms and allergic rhinitis the main self-reported illness in older people living in ECC. A 2013 Australian study presented results similar to ours in population aged 75 years and older [120] and found that people reported asthma more commonly than the diagnosis of COPD. Another Portuguese study also detected a large proportion of underdiagnosed COPD disease [121]. Underreport and underdiagnosis could justify the small rates of self-reported diseases in our study people.

We obtained a higher risk of allergic rhinitis among older people who had smoked cigarettes and was exposed to high concentrations of $PM_{10}$, and temperature below the reference levels. The first result could be explained by the deposition of larger particles such as $PM_{10}$ in the upper respiratory system causing susceptibility to allergic reactions. Concerning indoor air temperature, the literature indicate that low temperatures may potentiate respiratory tract infections to older people [118, 119] and increase hospital admissions. The other environmental parameters were not associated with self-reported symptoms, despite the high median values of some pollutants, such as $PM_{2.5}$. Nonetheless, it is important to remind that institutionalized older people are a very susceptible population due to their compromised health.

### 5.3 THE INFLUENCE OF PHYSICAL PARAMETERS IN OLDER PEOPLE QUALITY OF LIFE

In this study the winter TC results showed concern with median PMV and PPD indices out of the standardized range for comfort [47, 122] and significant differences for all the TC parameters between seasons as well as rooms. In general, elderly seem to perceive TC differently from the young due to a combination of physical ageing and behavioral differences [46, 50]. These results along with the decrease to regulate body temperature with age and a reduction in the sweating activity of aged men [50] and women [51] compared to younger age groups may increase the risk of respiratory tract infections in this susceptible population [59]. Most of the available evidence from laboratory and clinical studies suggests that inhaled cold air, cooling of the body surface and cold stress induced by lowering the core body temperature cause pathophysiological responses such as vasoconstriction in the respiratory tract mucosa and suppression of immune responses, which are responsible for increased susceptibility to infections [43, 59]. In addition, the longer the duration of exposure the higher the risk of infection. On average, older adults have a lower activity level, and as consequence, lower metabolic rate than younger which is the main reason why they require higher ambient temperatures [52]. On the contrary, it is inferred that older people may suffer from more susceptible upper airways at low RH. Studies indicate that RH about 40% is better for the eyes and upper airways than levels below 30% [123]. The optimal RH may differ for the eyes and the airways regarding desiccation of the mucous membranes [123, 124].

The TC assessment results of this study presented only negative PMV values in the thermal sensation scale for the winter season. Measures of indoor operative temperatures (what humans experience thermally in a space) in Portuguese ECC [56] ranged between 16ºC and 25ºC in winter and 22ºC and 31ºC in summer. These studies showed clearly that elderly preferred a higher temperature in comparison with the young adults [57]. Individual differences are too large to draw an unequivocal conclusion on the requirements of older adults regarding their preferred thermal environment. However, TC related problems such as cold indoor temperatures, problems with the heating system or inadequate insulation were mostly associated with respiratory problems in elderly over 65 years and older, in the European WHO LARES project. Additionally, there was also a significantly higher reporting of arthritis in homes that were perceived as cold in winter [125, 126].

The QoL status of the studied population according the WHOQOL-BREF presented median scores of all domains above the 50 cut-off point. The percentage of scores below the cut-off point were higher in the domain 1 - physical health (29%) followed by the domain 2 – psychological health (24%). The domain 4 environment had the lowest percentage of scores below the cut-off point (7%). When applying the mixed models for testing the influence of winter season TC in older people QoL the results showed that values of PMV above -0.7 (towards zero and within the comfort categories) had higher mean score of QoL (domain 2) (coefficient estimate: 11.13 units) when compared with values of PMV below -0.7 (towards -3 and outside the comfort categories). Moreover, self-reported poor health was significantly associated with poor thermal comfort in a recent study by [58].

## 5.4 RECOMMENDATIONS FOR IMPROVEMENT OF INDOOR ENVIRONMENT QUALITY IN ELDERLY CARE CENTERS

Increased emphasis is placed on the residential environment for older people as the number of ECC increases [127] as well as on identifying the relationship between health and the residential environment for older people. Taking into account the relationship between IAQ and respiratory vulnerability found in this study, the proposed recommendations and guidelines (Table 7 and Table 8) expect to lead to health and QoL improvement of elderly residents in ECC. It is very important to revise overcrowding, change inadequate ventilation, identify sources of contamination, control thermal parameters and adjust clothing to environmental characteristics [128]. The following information is based on the published literature review performed by [128-130].

Table 7. Recommendations for improvement of indoor environment quality in elderly care centers: Ventilation, thermal comfort and rehabilitation & construction.

| | |
|---|---|
| ***Ventilation*** | • Open external windows daily in all rooms, for about one hour, and close the internal doors to prevent air drafts;<br>• In days of bad weather, open the windows never less than 15 minutes;<br>• During Spring, open the windows in the early afternoon, when pollens are dispersed in the higher layers of the atmosphere and close them around 6 p.m., when pollens go back to the ground;<br>• The aeration should be done when there are no occupants in these divisions, preferring the lunchtime period, when residents are in the dining room;<br>• So that the renewed air can reach temperature equilibrium while minimizing the impact on the thermal comfort, close the windows some time before the return of the occupants;<br>• Keep internal doors open, whenever compatible with the privacy of residents. |
| ***Thermal comfort*** | • Keep an air temperature of comfort, which should take into account the activity performed by residents: (i) in the absence of physical activity, closer to 25°C; (ii) in the presence of physical activity, lower temperature, however higher than 20°C;<br>• Keep the relative humidity between 25% and 55%. |
| ***Rehabilitation & construction*** | • In case of works in the building, keep the divisions not intervened closed;<br>• Bedrooms and sitting rooms should be equipped with ventilation system;<br>• Prefer bottom hung or tilt and turn windows, because the impact of outside air flow in the occupied zone is smaller;<br>• Promote building practices such as insulating ceilings, walls, and windows. |

Table 8. Recommendations for improvement of indoor environment quality in elderly care centers: Moisture on the walls & ceilings, cleaning and daily life activities

| | |
|---|---|
| ***Moisture on the walls & ceilings*** | • Wash walls and ceilings with dilute bleach in water, at a ratio of 1 of bleach to 10 of water, and then aerate well the division;<br>• Paint walls and ceilings with antifungal paint and aerate well the division;<br>• It is not advisable to have plants and aquariums in the interior, particularly near bedrooms, as they are a focus of moisture. |
| ***Cleaning*** | • The cleaning should be done when there are no occupants in the divisions, being in other divisions.<br>• Wash weekly bed clothes at 60°C;<br>• Wash pillows, duvets and blankets every three months, if possible at 60°C;<br>• Avoid flannel bed linen, wool blankets and feather duvets, opting for cotton linen and synthetic duvets that can be washed at 60°C;<br>• Avoid storage underneath beds that make it difficult cleaning;<br>• Avoid excessive decorative items that make it difficult cleaning;<br>• Clean the dust with a slightly damp cloth;<br>• Avoiding the use of "sprays", air fresheners and detergents with intense smell, since these products may be irritating to the respiratory tract, and promote aeration after cleaning;<br>• Clean well the dust on the bookshelves, removing the books regularly. It is preferable to keep the books in closed bookshelves to avoid dust accumulation;<br>• Avoid excessive carpets, fitted carpeting, plaids on the sofas and draperies;<br>• Vacuuming often carpets, fitted carpeting and sofas;<br>• Wash carpets and curtains every three months, if possible at 60°C;<br>• Wash often carpets, fitted carpeting and sofas, at least 2 times per year, if possible at 60°C;<br>• Prefer vacuuming instead of sweeping;<br>• Change vacuum filter regularly and if possible, use a cleaner with high efficiency filter (HEPA - high efficiency particulate air);<br>• Avoid wallpaper, that is a focus of development of mites and fungus. If there is wallpaper, it should be replaced when becomes damaged;<br>• Avoid using heating vent because it promotes the suspension of dust in the air preferring to use convector heaters;<br>• If there is air conditioning, do filter maintenance often. |
| ***Daily life activities*** | • After baths, always close the door of the bathroom and open the window or turn on the extractor, preventing water vapor from spreading through the building;<br>• During food preparation, always close the kitchen door and open the windows, preventing fumes and odors from spreading through the building. If there is an exhauster, always turn it on and clean the filters regularly;<br>• It is recommended placing forced extractors in internal bathrooms, kitchen and in rooms with high pollution sources (e.g. where smoking is allowed, atelier, …), avoiding contamination to other divisions;<br>• Ironing clothes in a location that has forced extraction or window, always closing the door, preventing water vapor and particulate matter from spreading through the building. Do not iron clothes in the rooms nor sitting rooms;<br>• In elderly with respiratory vulnerability avoid contact of animals with fur or feathers. |

# 6. 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 host factors like age, gender, genetic heritage, and underlying state of health. Nevertheless, indoor environment has a potential influence in chronic respiratory symptoms on older people living in ECC due to their health susceptibility.

Our study focused on the assessment of indoor environment variables in the ECC that might influence elderly comfort and wellbeing and interact with their already existent chronic diseases. The IAQ and TC on these sites have been rarely evaluated and our study revealed several concerns. Attention is needed to indoor parameters concentrations, in particular, particle matter and fungi species that might compromise IAQ comfort. The overall $PM_{2.5}$ median concentrations was above national references in both seasons and even though fungi main species found were *Cladosporium* and *Penicillium*, considered to be common in indoor air, *Aspergillus flavus*, *Aspergillus fumigatus* and *Aspergillus niger* were also identified These species produce mycotoxins and therefore may produce several adverse health effects. It is important to notice that, although biological concentrations were considerable acceptable, in light of Portuguese references, it doesn't assure that there is no risk for people who spend most of the day, or even consecutive days, inside these rooms. Especially the older people: a group that is known for their impaired immune system and therefore ability to develop diseases, such as respiratory illnesses or airborne infections. Also, were found peak values of $PM_{10}$, as well as, TVOC, $CO_2$ and bacteria in both seasons that could raise concern. High levels of $PM_{10}$ were associated with a 3-fold odds of allergic rhinitis and PMV and PPD indices median values were out of the standardized range for comfort in the winter season. We found 'slightly cool' to 'cool' PMV index in thermal sensation scale which may increase the risk of respiratory tract infections in this susceptible population. The PPD index reflects this discomfort with a high rate of predicted dissatisfied occupants. The influence of winter season TC in older people QoL results showed that values of PMV within the comfort categories had higher values of QoL when compared with values of PMV out of the categories of thermal environment.

The concentration reduction of indoor air pollutants, in particular, particle matter and its health effects range from regulatory measures (stricter air quality standards, limits for emissions from various sources), structural changes (such as reducing energy consumption, especially that based on combustion sources, changing modes of transport, land use planning) as well as behavioral changes by individuals, for example, using cleaner modes of transport or household energy sources. Still, adequate measures, such as, local exhaust ventilation systems near cooking and gas burning devices, as well as daily slightly moist cleaning of the rooms surfaces would reduce particle accumulation and re-suspension. Most of the evaluated ECC presented condensations and infiltrations along walls and roofs inside the buildings. For an improvement of IAQ regarding biological agents, control of indoor RH is essential, eliminating all dampness and mold present in walls, roofs, and surfaces. Number of occupants and their habits are also contributors to the proliferation of microorganisms. Ventilation is a crucial factor that provides healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it through supply of outdoor air into a building or a room, and distribution within it. Ventilation systems require good maintenance in order for the required air change rate to be achieved and sustained, and otherwise it serves as a source of several microorganisms with harm to health. Opening windows or other sources of fresh and clean air, when the room is empty, is another effective and cheap measure that improves IAQ by removing biological agents from its composition. The results suggest the need to improve the balance between IAQ and TC parameters. Indoor environment and TC has a potential influence on QoL in older people living in ECC due to their susceptibility to winter season temperatures. Low indoor temperatures and discomfort, especially on winter season, could be prevented by simple measures such as insulating ceilings, walls and windows, maintaining natural and passive ventilation, solutions that are common in Portugal due to the advantage of the country's generally mild weather.

More studies on indoor pollutants and health in the elderly are needed, with focus on exposure assessment, providing a better understanding of the adverse health effects induced by indoor air pollution in elderly. Further studies analyzing TC variables in ECC are welcome in order to improving the wellbeing of our elderly population. The improvement measures should be tested for their consistency in the future if the ECC owners agree to implement them.

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# APPENDICES

# A

## RESPIRATORY HEALTH AND QUALITY OF LIFE QUESTIONNAIRE

Codificação indivíduo

Data: - -

Hora de início: :

ID do Inquiridor:

**SÓCIO-DEMOGRÁFICO:**

1. Sexo: O Feminino O Masculino

2. Em que **ano nasceu**?

3. Qual é o seu **estado civil**? O Solteiro O Casado / União de facto O Separado / Divorciado O Viúvo

4. Que **estudos completou**? **anos completos**

O Analfabeto O 1º a 4º anos O 7º a 9º anos O Estudos univers./ form. pós-grad.
O Sabe ler e/ou escrever O 5º a 6º anos O 10º a 12º anos

5. Qual a sua **profissão**?
*(principal)*

6. **Onde nasceu**?
*(Distrito)*

7. **Migrou**? O Não O Sim

**Se migrou**, especifique
*(Distrito, País)*

8. **Duração da residência atual**: **anos**



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**SAÚDE:**

9. **CONTENÇÃO FÍSICA OBSERVÁVEL** ○ Não ○ Sim

**Vamos falar agora da sua saúde.**

10a. Como **avalia** a sua **saúde**?

| Muito Má | Má | Nem má nem boa | Boa | Muito boa |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

10b. Até que ponto está **satisfeito(a)** com a sua **saúde**?

| Muito insatisfeito | Insatisfeito | Nem satisfeito nem insatisfeito | Satisfeito | Muito satisfeito |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

10c. Se **saúde** "Nem boa nem má", "Nem satisfeito nem insatisfeito", **considera isso negativo ou positivo**?

○ Negativo ○ Positivo

10d. Diga-me, agora, qual das seguintes opções **contribui mais para a sua saúde**?

○ Não ter/ter poucas Dores
○ Ter Autonomia/não depender de outros
○ Dormir bem
○ Estar bem
○ Ter Energia/força
○ Outro (especifique): 

11a. **Está atualmente doente**? ○ Não ○ Sim

***Se respondeu Não, passe para a Questão 12***

11b. **Que doença(s) é que tem**?

| **Doença** | **Há quanto tempo tem essa doença?** |
|---|---|
| | anos |
| | anos |
| | anos |
| | anos |

<u>**MEDICAMENTOS**</u> (*legível, maiúsculas*):

**QUEIXAS RESPIRATÓRIAS (BOLD)**

**Vamos agora falar de questões que são essencialmente sobre o seu peito.**

**Por favor responda Sim ou Não,** se possível**. Em caso de dúvida,** por favor**, responda Não.**

12. Costuma ter **TOSSE**, habitualmente? O Não O Sim

*Se respondeu Não, passe para a Questão 16*

13. Costuma **tossir 4 a 6 vezes ao dia, em 4 ou mais dias da semana**? O Não O Sim

14. Costuma **tossir dessa forma na maioria dos dias**, durante **3 ou mais meses do ano**? O Não O Sim

15. Desde **há quantos anos tem** esta tosse? ☐☐ **anos** O <2 O 2 a 5 O >5

16. Costuma **deitar fora EXPECTORAÇÃO** (CATARRO) do seu peito? O Não O Sim

*Considere a expectoração associada ao 1º cigarro ou quando sai para a rua. Exclua as secreções provenientes do nariz. Valorize a que é engolida.*

*Se respondeu Não, passe para a Questão 20*

17. Costuma **expectorar** dessa maneira pelo menos **2 vezes ao dia, em 4 ou mais dias da semana**? O Não O Sim

18. Costuma **expectorar** dessa forma, na maioria dos dias, durante **3 ou mais meses consecutivos do ano**? O Não O Sim

19. Desde **há quantos anos tem** essa expectoração? ☐☐ **anos** O <2 O 2 a 5 O >5

20. Já alguma vez teve um ataque de **PIEIRA** no peito (SILVOS NO PEITO) que o tenha feito **sentir dificuldade em respirar**? O Não O Sim

*Se respondeu Não, passe para a Questão 25*

21. **Que idade tinha** quando teve o **primeiro ataque de pieira** no peito? ☐☐ **anos**

22. Já **teve 2 ou mais episódios** de pieira? O Não O Sim

23. Já **alguma vez necessitou de medicamentos ou tratamento** para esse(s) ataque(s) de pieira? O Não O Sim

24. **Teve** alguma vez **pieira nos últimos 12 meses**? O Não O Sim

25. Tem LIMITAÇÕES DO ANDAR por **DIFICULDADE EM RESPIRAR** (FALTA DE AR), por outra **situação não relacionada com o coração e os pulmões**? O Não O Sim

*Se respondeu Não, passe para a Questão 32*

26. Se Sim, especifique: ☐

27. Costuma sentir-se **atrapalhado pela falta de ar** quando anda mais depressa ou **quando sobe uma pequena inclinação**? O Não O Sim

*Se respondeu Não, passe para a Questão 32*

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28. Tem que **andar mais devagar** do que as pessoas da sua idade **em terreno plano**, devido à falta de ar?

O Não O Sim

29. Já alguma vez **teve que parar para respirar quando caminha no seu próprio passo, em terreno plano**?

O Não O Sim

30. Já alguma vez teve que **parar para respirar após andar cerca de 100 metros (ou após andar alguns minutos) em terreno plano**? O Não O Sim

31. Sente-se **impedido de sair à rua** (sair do Lar) **pela falta de ar**, ou **sente falta de ar enquanto se veste ou despe**?

O Não O Sim

**DOENÇAS RESPIRATÓRIAS (BOLD)**

32. Já algum médico lhe disse que tinha **ENFISEMA**? O Não O Sim

33. Já algum médico lhe disse que tinha **ASMA**? O Não O Sim

***Se respondeu Não, passe para a Questão 37***

34. Ainda tem **asma**? O Não O Sim

35. **Com que idade começou** a asma? ☐☐ **anos**

36. **Se já não tem** asma, **com que idade deixou de ter queixas**? ☐☐ **anos**

37. Já algum médico lhe disse que tinha **TUBERCULOSE**? O Não O Sim

***Se respondeu Não, passe para a Questão 41***

38. Ainda tem tuberculose? O Não O Sim

39. **Com que idade começou** a tuberculose? ☐☐ **anos**

40. **Se já não tem** tuberculose, **com que idade deixou de ter queixas**? ☐☐ **anos**

41. Já algum médico lhe disse que tinha **PNEUMONIA**? O Não O Sim

***Se respondeu Não, passe para a Questão 45***

42. Ainda tem **pneumonia**? O Não O Sim

43. **Com que idade começou** a pneumonia? ☐☐ **anos**

44. **Se já não tem** pneumonia, **com que idade deixou de ter queixas**? ☐☐ **anos**

45. Já algum médico lhe disse que tinha **RINITE ALÉRGICA**? O Não O Sim

***Se respondeu Não, passe para a Questão 49***

46. Ainda tem **rinite alérgica**? O Não O Sim

47. **Com que idade começou** a rinite alérgica? ☐☐ **anos**

48. **Se já não tem** rinite alérgica, **com que idade deixou de ter queixas**? ☐☐ **anos**

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49. Já algum médico lhe disse que tinha **OUTRA DOENÇA RESPIRATÓRIA**? O Não O Sim

***Se respondeu Não, passe para a Questão <u>54</u>***

50. Se Sim, especifique: [ ]

51. Ainda tem **essa doença respiratória**? O Não O Sim

52. **Com que idade começou** essa doença respiratória? [ ][ ] **anos**

53. **Se já não tem** essa doença respiratória, **com que idade deixou de ter queixas**? [ ][ ] **anos**

54. Já algum médico lhe disse que tinha **PROBLEMAS DO CORAÇÃO**? O Não O Sim

55. Fez algum t**ratamento para problemas cardíacos** nos últimos 10 anos? O Não O Sim

56. Já algum médico lhe disse que teve um **ATAQUE CARDÍACO** (enfarte do miocárdio, obstrução coronária, trombose coronária)? O Não O Sim

**<u>AMBIENTE E TABAGISMO</u> (BOLD)**

57. Alguma vez **TRABALHOU** durante um ano ou mais num **LUGAR POIEIRENTO**? O Não O Sim

***Se respondeu Não, passe para a Questão <u>59</u>***

58. **Quantos anos** trabalhou nesse emprego? [ ][ ] **anos**

59. Já alguma vez **FUMOU CIGARROS?** O Não O Sim

***Não** significa: menos de 20 maços de cigarro ou 340g de tabaco durante a sua vida ou menos de 1 cigarro por dia durante um ano.*

***Se respondeu Não, passe para a Questão <u>65</u>***

60. **Fuma cigarros?** (*atualmente / no último mês*) O Não O Sim

61. **Com que idade começou** a fumar habitualmente? [ ][ ] **anos**

62. **Se parou** de fumar cigarros por completo, **que idade tinha quando parou**? [ ][ ] **anos**

63. Quantos **cigarros fuma por dia** atualmente? [ ][ ] **cigarros/dia**

64. Em média, durante todo o tempo em que fumou, **quantos cigarros fumou por dia**? [ ][ ] **cigarros/dia**

**COGNIÇÃO (MMS)**

**Vou fazer-lhe agora outras perguntas.**

**Orientação temporal**

65. Em que ano estamos? O certo O errado [ ] O N/S O N/R

66. Em que mês estamos? O certo O errado [ ] O N/S O N/R

67. Quantos são hoje (dia do mês)? O certo O errado [ ] O N/S O N/R

68. Em que estação do ano estamos? O certo O errado [ ] O N/S O N/R

69. Que dia da semana é hoje? O certo O errado [ ] O N/S O N/R

**Orientação espacial**

70. Como se chama o nosso país? O certo O errado [ ] O N/S O N/R

71. Em que distrito vive? O certo O errado [ ] O N/S O N/R

72. Em que terra vive? O certo O errado [ ] O N/S O N/R

73. Como se chama esta casa? O certo O errado [ ] O N/S O N/R

74. Em que andar estamos? O certo O errado [ ] O N/S O N/R

**Retenção**

**Agora vou dizer-lhe 3 palavras. Queria que as repetisse e que procurasse decorá-las, porque dentro de alguns minutos vou pedir-lhe que me diga essas 3 palavras. As palavras são: Pêra, Gato, Bola. Repita as 3 palavras.**
*Repetir todas as palavras até serem totalmente aprendidas, num máximo de 6 tentativas. Se as palavras não forem aprendidas não se pode fazer a Evocação.*

75. Pêra O certo O errado [ ] O N/S O N/R

76. Gato O certo O errado [ ] O N/S O N/R

77. Bola O certo O errado [ ] O N/S O N/R

**Atenção e cálculo**

**Agora peço-lhe que me diga quantos são 30 menos 3 e que ao número encontrado volte a subtrair 3, até eu lhe dizer para parar.**
*Parar ao fim de 5 respostas. Se fizer um erro na subtracção, mas continuar a subtrair correctamente a partir do erro, conta-se como um único erro.*

78. 1º cálculo O certo O errado [ ] O N/S O N/R

79. 2º cálculo O certo O errado [ ] O N/S O N/R

80. 3º cálculo O certo O errado [ ] O N/S O N/R

81. 4º cálculo O certo O errado [ ] O N/S O N/R

82. 5º cálculo O certo O errado [ ] O N/S O N/R

*Se o sujeito for analfabeto e errar em mais do que 3 questões do cálculo anterior, realizar este teste.*

**Vou dizer-lhe 3 números e queria que me dissesse esses 3 números, mas ao contrário, isto é do último para o primeiro. Os números são: 5 9 2**

83. 1ª resposta ○ certo ○ errado ○ N/S ○ N/R

84. 2ª resposta ○ certo ○ errado ○ N/S ○ N/R

85. 3ª resposta ○ certo ○ errado ○ N/S ○ N/R

**Evocação**

**Agora veja se me consegue dizer quais foram as 3 palavras que lhe pedi há pouco para decorar.**
*Só se efectua se o sujeito tiver aprendido as 3 palavras da prova de retenção.*

86. Pêra ○ certo ○ errado ○ N/S ○ N/R

87. Gato ○ certo ○ errado ○ N/S ○ N/R

88. Bola ○ certo ○ errado ○ N/S ○ N/R

**Nomeação**

**Como se chama isto?**

89. Relógio ○ certo ○ errado ○ N/S ○ N/R

90. Lápis ○ certo ○ errado ○ N/S ○ N/R

**Repetição frase**

91. Repita a frase: **"O rato rói a rolha"** ○ certo ○ errado ○ N/S ○ N/R

**Compreensão verbal**

**Vou dar-lhe uma folha de papel. Quando eu lhe entregar o papel** (entregar o papel com ambas as mãos)**: pegue nele com a sua mão direita, dobre-o ao meio e coloque-o sobre a mesa.**

92. Mão direita ○ certo ○ errado ○ N/S ○ N/A

93. Dobrar ao meio ○ certo ○ errado ○ N/S ○ N/A

94. Colocar sobre a mesa ○ certo ○ errado ○ N/S ○ N/A

**Compreensão leitura**

95. Leia e cumpra o que diz neste cartão* *(mostrar a frase num cartão).* Se o sujeito for analfabeto o examinador deverá ler-lhe a frase.

○ certo ○ errado ○ N/S ○ N/A

**Escrever frase**

96. Escreva uma frase. *Deverá ter sujeito, verbo e ter sentido. Erros gramaticais e troca de letras não contam.*

○ certo ○ errado ○ N/S ○ N/A

**Fazer desenho**

97. Copie o desenho que lhe vou mostrar* *(mostrar o desenho num cartão). Devem estar presentes os 10 ângulos e 2 deles devem estar intersectados. Tremor e erros de rotação não contam.*

○ certo ○ errado ○ N/S ○ N/A

**<u>QUALIDADE DE VIDA</u> (WHOQoL-BREF)**

<u>Este questionário</u> procura **conhecer a sua qualidade de vida, saúde, e outras áreas da sua vida.**
Peço-lhe para **responder a todas as perguntas**. Se não tiver a certeza da resposta a dar a uma pergunta, **escolha a que lhe parecer mais apropriada**. Esta pode muitas vezes ser a resposta que lhe vier primeiro à cabeça.
Pedimos-lhe que tenha em conta a sua vida **nas 2 últimas semanas.**

98. Como **avalia** a sua **qualidade de vida** (QV)?

| Muito Má | Má | Nem má nem boa | Boa | Muito boa |
|---|---|---|---|---|
| O | O | O | O | O |

99. Se **QV** "Nem boa nem má", "Nem satisfeito nem insatisfeito", **considera isso negativo ou positivo**?

O Negativo O Positivo

<u>As perguntas que se seguem</u> são para ver até que ponto **sentiu certas coisas** nas 2 últimas semanas

| | Nada | Pouco | Nem muito nem pouco | Muito | Muitíssimo |
|---|---|---|---|---|---|
| 100. Em que medida **as suas dores (físicas) o(a) impedem de fazer o que precisa de fazer**? | O | O | O | O | O |
| 101. Em que medida **precisa de cuidados médicos para fazer a sua vida diária**? | O | O | O | O | O |
| 102. Até que ponto **gosta da vida**? | O | O | O | O | O |
| 103. Em que medida s**ente que a sua vida tem sentido**? | O | O | O | O | O |
| 104. Até que ponto **se consegue concentrar**? | O | O | O | O | O |
| 105. Em que medida **se sente em segurança no seu dia a dia**? | O | O | O | O | O |
| 106. Em que medida **é saudável o seu ambiente físico**? | O | O | O | O | O |

<u>As seguintes perguntas</u> são para ver até que ponto **experimentou ou foi capaz de fazer certas coisas nas 2 últimas semanas**

| | Nada | Pouco | Moderadamente | Bastante | Completamente |
|---|---|---|---|---|---|
| 107. Tem **energia** suficiente **para a sua vida diária**? | O | O | O | O | O |
| 108. É capaz de **aceitar** a sua **aparência física**? | O | O | O | O | O |
| 109. Tem **dinheiro suficiente para** satisfazer as suas **necessidades**? | O | O | O | O | O |
| 110. Até que ponto tem fácil **acesso às informações necessárias para** organizar **a sua vida diária**? | O | O | O | O | O |
| 111. Em que medida **tem oportunidade para** realizar **atividades de lazer** *(se entreter)*? | O | O | O | O | O |

112. **Como avaliaria a sua mobilidade** *(capacidade para se movimentar e deslocar por si próprio)*?

| | Muito Má | Má | Nem má nem boa | Boa | Muito boa |
|---|---|---|---|---|---|
| | ○ | ○ | ○ | ○ | ○ |

<u>As perguntas que se seguem</u> destinam-se a avaliar **se sentiu bem ou satisfeito(a) em relação a vários aspectos da sua vida** nas 2 últimas semanas

| | Muito insatisfeito | Insatisfeito | Nem satisfeito nem insatisfeito | Satisfeito | Muito satisfeito |
|---|---|---|---|---|---|
| 113. Até que ponto está satisteito(a) com **o seu sono**? | ○ | ○ | ○ | ○ | ○ |
| 114. Até que ponto está satisteito(a) com **a sua capacidade para desempenhar as actividades do seu dia a dia**? | ○ | ○ | ○ | ○ | ○ |
| 115. Até que ponto está satisteito(a) com **a sua capacidade de trabalho**? | ○ | ○ | ○ | ○ | ○ |
| 116. Até que ponto está satisteito(a) **consigo próprio**? | ○ | ○ | ○ | ○ | ○ |
| 117. Até que ponto está satisteito(a) com **as suas relações pessoais**? | ○ | ○ | ○ | ○ | ○ |
| 118. Até que ponto está satisteito(a) com **a sua vida sexual**? | ○ | ○ | ○ | ○ | ○ |
| 119. Até que ponto está satisteito(a) com **o apoio que recebe dos seus amigos**? | ○ | ○ | ○ | ○ | ○ |
| 120. Até que ponto está satisteito(a) com a**s condições do lugar em que vive**? | ○ | ○ | ○ | ○ | ○ |
| 121. Até que ponto está satisteito(a) com **o acesso que tem aos serviços de saúde**? | ○ | ○ | ○ | ○ | ○ |
| 122. Até que ponto está satisteito(a) com **os transportes que utiliza**? | ○ | ○ | ○ | ○ | ○ |

Estamos quase a finalizar este questionário, mas antes de terminar gostaríamos de saber como se sente (ao nível das suas emoções) no seu dia-a-dia.

123. Com que frequência tem **sentimentos negativos**, tais como **tristeza, desespero, ansiedade ou depressão**?

| | Nunca | Poucas vezes | Algumas vezes | Frequentemente | Sempre |
|---|---|---|---|---|---|
| | ○ | ○ | ○ | ○ | ○ |

**<u>DEPRESSÃO</u> (GDS15)**

| | | |
|---|---|---|
| 124. Está **satisfeito(a) com a sua vida?** | O Não | O Sim |
| 125. Pôs de lado muitas das suas **actividades e interesses**? | O Não | O Sim |
| 126. Sente a sua **vida vazia**? | O Não | O Sim |
| 127. Fica muitas vezes **aborrecido(a)**? | O Não | O Sim |
| 128. **Está bem disposto(a)** a maior parte do tempo? | O Não | O Sim |
| 129. **Tem medo** que lhe vá acontecer alguma coisa de mal? | O Não | O Sim |
| 130. **Sente-se feliz** a maior parte do tempo? | O Não | O Sim |
| 131. **Sente-se** muitas vezes **desamparado(a)**? | O Não | O Sim |
| 132. **Prefere ficar** no Lar, **em vez de sair e fazer coisas novas**? | O Não | O Sim |
| 133. Acha que tem mais **problemas de memória** do que as outras pessoas? | O Não | O Sim |
| 134. Pensa que **é bom estar vivo(a)**? | O Não | O Sim |
| 135. Sente-se **inútil**? | O Não | O Sim |
| 136. Sente-se **cheio(a)de energia**? | O Não | O Sim |
| 137. Sente que para si **não há esperança**? | O Não | O Sim |
| 138. Pensa que a situação da maioria **das pessoas é melhor do que a sua**? | O Não | O Sim |

139. Este questionário foi preenchido,

- O Respondeu autonomamente
- O Com ajuda de cuidador
- O Com ajuda de familiar
- O Com ajuda de cuidador e familiar

Hora de fim: ☐☐:☐☐



45078

# B

# BUILDINGS AND ROOMS CHARACTERIZATION QUESTIONNAIRE

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

GERIA – Geriatric Study in Portugal on Health Effects of Air Quality in Elderly Care Centers

**Levantamento das Características Construtivas do Edificado e Monitorização do Ambiente Interior**

## INFORMAÇÃO GERAL

ID / Nome da instituição: -

Diretor: -

Data:

Endereço: -

Contactos: -

## 1. CARACTERIZAÇÃO DO EDIFICADO

**Tipo de Edifício**
- ☐ Edifício Unifamiliar
- ☐ Edifício Multifamiliar

**Implantação**
- ☐ Isolado
- ☐ Geminado
- ☐ Em banda

**Ocupação do edifício**
- ☐ Lar
- ☐ Lar + outras utilizações

Quais:

**N.º de pisos do edificado:**

**Ano de construção:**

## 1.1 INSERÇÃO URBANA

**Caracterização da zona envolvente**
- ☐ Campo (construção isolada em zona não urbanizada)
- ☐ Zona Urbanizada
  - ☐ no campos
  - ☐ nos arredores da cidade / subúrbios ou zona de pequena densidade de construçãonos arredores da cidade
  - ☐ no interior da cidade

**Fontes de Poluição**
- ☐ Zona sem fontes de
- ☐ Proximidade de indústrias
- ☐ Proximidade de vias com tráfego intenso

## 1.2 CARACTERIZAÇÃO DO AMBIENTE EXTERIOR

Equipamento: -

| | | | |
|---|---|---|---|
| Hora entrada: | **CO2 [ppm]** | **Humidade %** | **Temperatura °C** |
| | | - | |
| Hora saída: | **CO2 [ppm]** | **Humidade %** | **Temperatura °C** |

## OBSERVAÇÕES

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

GERIA – Geriatric Study in Portugal on Health Effects of Air Quality in Elderly Care Centers

**Levantamento das Características Construtivas do Edificado e Monitorização do Ambiente Interior**

**INFORMAÇÃO GERAL**

| | | |
|---|---|---|
| ID / Nome da instituição: - | | Diretor: - |
| Data: | Endereço: - | Contactos: - |

**2. CARACTERIZAÇÃO DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL - ORGANIZAÇÃO FUNCIONAL DO LAR**

☐ Estrutura residencial ☐ Unidade Funcional Capacidade (n.º de idosos a residir no lar) n.º

Nome da Unidade:

N.º total de Idoso:

**2.1 CARACTERIZAÇÃO CONSTRUTIVA**

| | | | |
|---|---|---|---|
| **Paredes** (registar a espessura da parede) | ☐ Alvenaria de Tijolo | ☐ C/ isolamento térmico<br>☐ S/ isolamento térmico | ☐ Madeira ou derivados de madeira<br>☐ Betão |
| | ☐ Alvenaria de Pedra | ☐ C/ isolamento térmico<br>☐ S/ isolamento térmico | |
| **Cobertura** | ☐ Inclinada | ☐ C/ isolamento térmico<br>☐ S/ isolamento térmico | **Revestimento da cobertura**<br>☐ Telha Cerâmica |
| | ☐ Plana | ☐ C/ isolamento térmico<br>☐ S/ isolamento térmico | ☐ Zinco<br>☐ Outro tipo: |

**Caixilharia**

| | | | | | |
|---|---|---|---|---|---|
| **Material** | ☐ Alumínio | ☐ C/ corte térmico<br>☐ S/ corte térmico | Vidro | ☐ Simples<br>☐ Duplo | |
| | ☐ Aço | ☐ C/ corte térmico<br>☐ S/ corte térmico | Tipo de folha móvel (abertura das folhas) | ☐ Batente<br>☐ Correr<br>☐ Oscilobatente | ☐ Basculante (folha de ventilação) |
| | ☐ PVC | ☐ C/ corte térmico<br>☐ S/ corte térmico | Junta móvel | ☐ S/ vedantes<br>☐ C/ Borracha<br>☐ C/ Pelúcia | |
| | ☐ Madeira | ☐ C/ corte térmico<br>☐ S/ corte térmico | | | |
| **Proteção Solar** | ☐ Interior | ☐ Madeira<br>☐ PVC | ☐ Metálico | ☐ Outros | |
| | ☐ Exterior | ☐ Madeira<br>☐ PVC | ☐ Metálico | ☐ Outros | |

**2.2 VENTILAÇÃO DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

Admissão de ar
- ☐ Mecânica
- ☐ Natural
  - ☐ Aberturas Dedicadas
  - ☐ Abertura de Janelas

Exaustão ar
- ☐ Mecânica
- ☐ Natural
  - ☐ Aberturas Dedicadas
  - ☐ Abertura de Janelas

**2.3 CLIMATIZAÇÃO DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

Arrefecimento
- ☐ Ligado
- ☐ Desligado

Aquecimento
- ☐ Ligado
- ☐ Desligado

Estratégia
- ☐ Centralizado
- ☐ Aparelhos
- ☐ Ar
- ☐ Água

Quais:

Fonte de energia
- ☐ Eletricidade
- ☐ Gás
- ☐ Gasóleo

**2.4 AQUECIMENTO DE ÁGUAS SANITÁRIAS DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

**Tipo de aparelho**
- ☐ Caldeira
  - ☐ Gás
  - ☐ Gasóleo
- ☐ Esquentador
- ☐ Equipamento Elétrico

**Localização do aparelho**
- ☐ Exterior ao edifício
- ☐ Interior do edifício
- ☐ Em compartimento próprio
- ☐ Na Cozinha
- ☐ Nas instalações sanitárias
- ☐ Outro:

NOTAS:

**2.5 COCÇÃO DE ALIMENTOS DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

Local
- ☐ Cozinha
- ☐ Outro:

Fonte de energia
- ☐ Gás
- ☐ Eletricidade

NOTAS:

**2.6 PATOLOGIAS RELACIONADAS COM O APARECIMENTO DE FUNGOS E/OU BOLORES DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

- ☐ S/ Patologia
- ☐ C/ Patologia
  - ☐ Condensações
    - ☐ Caixilharia
    - ☐ Pavimento
    - ☐ Paredes
  - ☐ Infiltrações
    - ☐ Caixilharia
    - ☐ Paredes
    - ☐ Cobertura
    - ☐ Instações de água e esgotos

Data da realização de obra de melhoramento das instalações:

**2.7 PRÁTICAS DOS UTILIZADORES DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

**Ventilação**

| | | | |
|---|---|---|---|
| **Primavera** | Acesso principal | ☐ Abertas<br>☐ Fechadas | |
| | Vãos de janela e portas exteriores | ☐ Abertas<br>☐ Fechadas<br>☐ Sempre Fechadas | Nota: |
| **Verão** | Acesso principal | ☐ Abertas<br>☐ Fechadas | |
| | Vãos de janela e portas exteriores | ☐ Abertas<br>☐ Fechadas<br>☐ Sempre Fechadas | Nota: |
| **Outono** | Acesso principal | ☐ Abertas<br>☐ Fechadas | |
| | Vãos de janela e portas exteriores | ☐ Abertas<br>☐ Fechadas<br>☐ Sempre Fechadas | Nota: |
| **Inverno** | Acesso principal | ☐ Abertas<br>☐ Fechadas | |
| | Vãos de janela e portas exteriores | ☐ Abertas<br>☐ Fechadas<br>☐ Sempre Fechadas | Nota: |

**2.9 OPINIÃO DOS UTILIZADORES DA ESTRUTURA RESIDENCIAL / UNIDADE FUNCIONAL**

| | | | | |
|---|---|---|---|---|
| **Conforto** | Conforto no Verão | ☐ Sim<br>☐ Não<br>☐ Não sabe / não responde | Conforto no Inverno | ☐ Sim<br>☐ Não<br>☐ Não sabe / não responde |
| **Qualidade do ar** | Primavera | ☐ Boa<br>☐ Má<br>☐ Não sabe / não responde | Verão | ☐ Boa<br>☐ Má<br>☐ Não sabe / não responde |
| | Outono | ☐ Boa<br>☐ Má<br>☐ Não sabe / não responde | Inverno | ☐ Boa<br>☐ Má<br>☐ Não sabe / não responde |

# C

## RESPIRATORY HEALTH AND QUALITY OF LIFE QUESTIONNAIRE

## DECLARATION CONSENT

ID

**CONSENTIMENTO INFORMADO E INFORMAÇÃO COMPLEMENTAR**

**Vimos convidá-lo(a) a participar no estudo GERIA.**
**É um Estudo Geriátrico dos Efeitos na Saúde da Qualidade do Ar Interior em Lares da 3ª Idade de Portugal, que decorrerá em Lisboa e no Porto.**
Esperamos que os resultados deste estudo venham ajudar a compreender melhor o ambiente que o rodeia e a influência deste na sua saúde e qualidade de vida.
**Para participar basta que:**

- **Preencha o consentimento em participar no estudo;**
- **Responda às questões do estudo sobre saúde e bem-estar.**

A sua colaboração, que muito agradecemos, é muito importante e poderá contribuir para melhorar o acompanhamento das pessoas idosas.
Cabe a si decidir participar. **A participação é gratuita.** Não fica prejudicado(a) se decidir não participar.
**Toda a informação recolhida será confidencial.** Se tiver alguma dúvida, não hesite em pedir mais informações.
Muito obrigado pela sua colaboração.

Professor Doutor João Paulo Teixeira
Investigador Principal do Projeto GERIA

Professora Doutora Maria Amália Botelho
Investigador Responsável pela Equipa da Saúde

-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-

Eu, abaixo assinado (nome completo) ............................................................................................, nascido a ....../....../.............., declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências.
Desta forma, aceito participar no estudo "GERIA – Estudo Geriátrico dos Efeitos na Saúde da Qualidade do Ar Interior em Lares da 3ª Idade de Portugal" e permito a utilização dos dados que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação e nas garantias de confidencialidade e anonimato que me são dadas pelos investigadores.

Assinatura: ..........................................................................................................................................

Data: ....../....../..............

SE NÃO FOR O PRÓPRIO A ASSINAR POR IDADE OU INCAPACIDADE

NOME: ......................................................................................................................
BI/CD Nº: .......................................... DATA OU VALIDADE ..... /..... /........
GRAU DE PARENTESCO OU TIPO DE REPRESENTAÇÃO: ....................................................
ASSINATURA .......................................................................................................................

**ESTE DOCUMENTO É COMPOSTO DE UMA PÁGINA E FEITO EM DUPLICADO:**
**UMA VIA PARA O/A INVESTIGADOR/A, OUTRA PARA A PESSOA QUE CONSENTE**

geriastudy@gmail.com

# D

## INDOOR ENVIRONMENT REPORT TO THE PARTICIPANT

## ELDERLY CARE CENTERS

Departamento de Saúde Ambiental
Unidade de Ar e Saúde Ocupacional

**RELATÓRIO DE ENSAIO**

GERIA 17/2014 (FINAL)

***Análise das Condições Ambientais***

Departamento de Saúde Ambiental – Unidade de Ar e Saúde Ocupacional
Laboratório de Qualidade do Ar
Centro de Saúde Pública Doutor Gonçalves Ferreira
Rua Alexandre Herculano, n.º 321, 4000-055 - Porto – Portugal
Tel: (351) 22 340 11 40 / Fax: (351) 22 340 11 49
e.mail: csao.porto@insa.min-saude.pt // www.insarj.pt

## 1 - IDENTIFICAÇÃO DO LOCAL E DATA DA AVALIAÇÃO

| LAR | XXXXX | |
|---|---|---|
| | **Data Monitorização** | **Condições meteorológicas externas** |
| **Inverno:** | 09-11-2012 | Céu limpo ($T_{ext}$: 17ºC; $HR_{ext}$: 61 %) |
| **Verão:** | 27-07-2012 | Céu limpo ($T_{ext}$: 26 ºC; $HR_{ext}$: 54 %) |

## 2 - OBJECTIVO

No âmbito da participação do ***Projeto GERIA – Estudo Geriátrico dos Efeitos na Saúde da Qualidade do Ar Interior em Lares da 3ª Idade em Portugal***, procedeu-se ao estudo ***'Análise das Condições Ambientais'*** no Lar da terceira idade acima mencionado. Para cumprir o objetivo do estudo foram estudados os seguintes parâmetros no ar ambiente interior:

| | |
|---|---|
| ***Agentes Químicos*** | **Poeiras Suspensas no ar** (fracção $PM_{10}$ e $PM_{2.5}$)<br>**Compostos Orgânicos Voláteis Totais ($COV_{totais}$)**<br>**Formaldeído (HCHO)**<br>**Dióxido de Carbono ($CO_2$)**<br>**Monóxido de Carbono (CO)** |
| ***Agentes Microbiológicos*** | **Contagem de Bactérias**<br>**Contagem e Identificação de Fungos** |
| ***Agentes Físicos*** | **Conforto térmico:**<br>**Índices do Voto Médio Previsto (PMV – Predicted Mean Vote)**<br>**Percentagem de Insatisfeitos Previstos (PPD – Predicted Percentage Dissatisfied** |

Departamento de Saúde Ambiental
Unidade de Ar e Saúde Ocupacional

**3 – REFERÊNCIAS**

| | |
|---|---|
| ***Legislação Nacional*** | **Decreto-Lei n.º 118/2013 de 20 de Agosto**: Sistema Certificação Energética dos Edifícios (SCE) [Regulamento de Desempenho Energético dos Edifícios de Habitação (REH), e o Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços (RECS)].<br>**Portaria n.º 353-A/2013 de 4 de Dezembro**: Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços (RECS) - Requisitos de Ventilação e Qualidade do Ar Interior. |
| ***Normas*** | **ISO 16000-6:2011 Indoor air - Part 6**: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID, first edition.<br>**ISO 7730:2005 – Ergonomics of the thermal environment**: Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. International Organisation for Standardisation, 2005.<br>**ISO 7726:1998 – Ergonomics of the thermal environments**: Instruments for measuring physical quantities. International Organisation for Standardisation, 1998.<br>**CSN EN 13098 -** Workplace atmosphere - Guidelines for measurement of airborne micro-organisms and endotoxin<br>**ISO 4833:2013 - Microbiology of food and animal feeding stuffs**: Horizontal method for the enumeration of microorganisms - Colony-count technique at 30ºC. |
| ***Métodos analíticos e Estudos Científicos*** | **Manual of Analytical Methods**. National Institute of Occupational Safety and Health (EUA). NMAM. NIOSH, 4th edition.<br>**Method IP-10A**: Determination of Respirable Particulate Matter in Indoor Air Using Size Specific Impaction, EPA Methods, William T. Winberry Jr. et al., 1992, ndc.<br>**Levin J.**, Lindahl R. and Andersson K. 1986. A passive sampler for formaldehyde in air using 2,4 dinitrophenylhydrazine-coated glass fiber filters. Environmental Science & Technology, Vol. 20, 12:1273-1276. |

Departamento de Saúde Ambiental
Unidade de Ar e Saúde Ocupacional

## 4. DEFINIÇÕES

| | |
|---|---|
| **Qualidade do Ar Interior (QAI)** | Parâmetros e classificações de aceitabilidade de uma atmosfera interior. Um indicador de tipos e concentrações de poluentes no ar passíveis de causar desconforto ou risco adverso para a saúde do ser humano. |
| **Compostos Orgânicos Voláteis Totais ($COV_{Totais}$)** | São compostos com pontos de ebulição (à pressão atmosférica normal de 101,3 kPa) entre o limite mínimo de 50ºC a 100ºC e um limite máximo de 240ºC a 260ºC e coexistem no ambiente interior como gases incolores. Podem derivar do exterior para o interior ou serem emitidos no interior por uma grande variedade de materiais tais como materiais de construção, mobiliário, produtos de limpeza, cosméticos, vernizes, carpetes, material adesivo, tintas e processos de combustão (tabaco, gás, fuel óleo, carvão, madeira e parafina). Podem causar danos para a saúde ao nível das mucosas, sistema neurológico e respiratório. |
| **Conforto Térmico** | É a condição de espírito que exprime a satisfação dos trabalhadores com o ambiente térmico. O conforto térmico é função de seis variáveis, quatro ambientais (temperatura do ar, temperatura radiante média, humidade relativa do ar e velocidade do ar) e duas pessoais (taxa metabólica e isolamento térmico do vestuário). A conjugação de todas estas variáveis dá origem aos índices PMV (Predicted Mean Vote ou Voto Médio Previsível) e PPD (Predicted Percentage Dissatisfied ou Percentagem de Insatisfeitos Previstos). |
| **Dióxido de Carbono ($CO_2$)** | É um gás incolor, inodoro e não inflamável resultado de processos de combustão em fontes de aquecimento, de produção de energia e de reações de metabolização dos seres vivos. Concentrações elevadas deste gás estão normalmente associadas a baixas taxas de ventilação dos espaços (reduzida introdução de ar novo), o que provoca sintomas adversos nos ocupantes tais como: dores de cabeça, náuseas, fadiga. |
| **Formaldeído (HCHO)** | É o mais simples dos aldeídos. À temperatura ambiente é um gás inflamável, incolor e com um odor intenso. É carcinogéneo nos animais e potenciador de cancro nos humanos. Produz irritação nos olhos, nariz, garganta e vias respiratórias, dores de cabeça, enjoos e fadiga. Em ambientes interiores as fontes de formaldeído são diversas: carpetes, cortinas, tapeçarias, mobiliário, contraplacados, fumo de tabaco, produtos de limpeza, tintas e vernizes. |
| **Índice PMV** | Este índice prevê o valor médio de votos de um largo grupo de pessoas numa escala de sensações térmicas de 7 pontos (Tabela 1), baseada no balanço térmico do corpo humano. |

| | |
|---|---|
| **Índice PPD** | Este índice estabelece a quantidade estimada de pessoas insatisfeitas termicamente com o ambiente. Baseia-se na percentagem de um grande grupo de pessoas que gostariam que o ambiente estivesse mais quente ou mais frio, votando +3, +2, -2 ou -3, na escala de sensação térmica, conforme consta da tabela seguinte.<br>Tabela 1. Escala de Sensação Térmica<br>PMV / Sensação Térmica:<br>+ 3 – Muito Quente<br>+ 2 – Quente<br>+ 1 – Ligeiramente Quente<br>0 – Neutro<br>- 1 – Ligeiramente Fresco<br>- 2 – Fresco<br>- 3 – Frio |
| **Microrganismos (bactérias)** | Microrganismo com uma organização de tipo celular (citoplasma delimitado por uma parede e uma membrana) mas, ao contrário das células dos organismos mais complexos, o seu material genético não está organizado dentro de um núcleo. Podem ter formas variadas (esféricas, cilíndricas, filamentosas, etc.) ocorrer isoladamente ou agregarem-se em colónias com formas características que permitem a sua identificação. Fontes internas de bactérias – sobrelotação dos espaços, torres de refrigeração, condensadores, chuveiros, aquecedores de água, pele e feridas. Alguns efeitos adversos na saúde provocados por estes microrganismos são: infecções, irritações de mucosas, pneumonia de hipersensibilidade. |
| **Microrganismos (fungos)** | Um grupo de organismos onde estão incluídos os cogumelos, leveduras e os bolores. Os fungos estão presentes no solo, ar, água, mas só algumas espécies causam doenças. Os principais efeitos nocivos na saúde causados por fungos podem ser do foro respiratório e dérmico. |
| **Monóxido de Carbono (CO)** | Gás inodoro, incolor, e sem sabor que se forma pela queima do carbono ou combustíveis orgânicos na presença de pouco Oxigénio. A inalação deste gás pode causar danos no sistema nervoso central e asfixia, dependendo da concentração e da duração da exposição. A toxicidade desde poluente é baseada na reação CO-hemoglobina no sangue. |
| **Partículas Suspensas no Ar ($PM_{10}$)** | Partículas de fração torácica com diâmetro ≤ 10 µm com consequências para a saúde humana ao nível da irritação da pele, mucosas e aparelho respiratório. |
| **Partículas Suspensas no Ar ($PM_{2.5}$)** | Partículas de fração com diâmetro ≤ 2.5 µm com capacidade de penetração nas vias respiratórias inferiores (pulmões e brônquios). Risco de doença respiratória e cardiovascular. |

## 5 - METODOLOGIA

A análise teve por base informações recolhidas através da aplicação do questionário 'Levantamento das Características Físicas dos Edifícios', observação dos locais, e medição dos parâmetros atrás referidos. As recolhas de amostras de ar foram realizadas entre 0,75 a 1,20 m do pavimento.

Os critérios de avaliação seguem os valores de limiar de proteção apresentados na **Portaria n.º 353-A/2013 de 4 de Dezembro**: Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços (RECS) - Requisitos de Ventilação e Qualidade do Ar Interior e as orientações fixadas pela ***Norma Internacional ISO 7730:2005*** – *"Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria",* relativamente aos índices de conforto térmico.

Tabela 2 – Requisitos de Amostragem e técnicas analítica correspondentes aos parâmetros avaliados

| PARÂMETRO | AMOSTRAGEM | TÉCNICA ANÁLISE | MÉTODO |
|---|---|---|---|
| **Partículas Suspensas no ar** (fracção $PM_{10}$ e $PM_{2.5}$) | Bombas de alto fluxo para recolha de ar + filtros PTFE, 37mm, 2 micron c/ PMP ring | Análise Gravimetria | Procedimentos Internos baseados nas Normas designadas no Capítulo 3. |
| **$COV_{totais}$** | Bombas de baixo fluxo para recolha de ar + Tubos Tenax GR | Cromatografia em fase gasosa de detetor de ionização de chama (CG-FID) com desadsorção térmica. | |
| **Formaldeído** | Bombas de alto fluxo para recolha de ar + filtros fibra de vidro 13mm | Cromatografia líquida de alta pressão (HPLC) | |
| **Bactérias Totais** (contagem) | Amostrador Microbiológico de recolha de amostras de ar por impacto + meios de cultura selectivos *Tryptic Soy Agar* e *Malt Extract Agar* | Contagem de bactérias e fungos e identificação de fungos por Procedimento Interno | |
| **Fungos Totais** (contagem e identificação) | | | |
| **CO e $CO_2$** | Equipamento de leitura directa | | |
| **Índices PMV e PPD** | | | |

## 6 - RESULTADOS

Os valores médios encontrados para os parâmetros analisados nas épocas de Inverno e Verão, constam nas Tabelas 3, 4 e 5 onde são também referidos os respetivos valores de limiar de proteção e de referência recomendados.

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Tabela 3 – Resultados da monitorização ambiental (concentrações médias) e valores de limiar de proteção: **Parâmetros químicos**

| Parâmetro/Local | Sala convívio | | Sala Refeições | | Quarto 111 | | Quarto 112 | | Quarto 109 | | Gabinete Médico | | Limiar de Proteção | Exterior | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | V | I | V | I | V | I | V | I | V | I | V | | I | V |
| **CO** (mg/m³) | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | - | **10** | 0,6 | 0,1 |
| **$CO_2$** (mg/m³) | 845 | 927 | 1573 | 878 | 750 | 619 | 761 | 662 | 759 | 543 | 581 | - | **2250 *** | 540 | 549 |
| **$COV_{totais}$** (mg/m³) | 0,3 | 0,03 | 0,1 | 0,1 | 0,1 | 0,02 | 0,1 | 0,03 | 0,1 | 0,02 | 0,04 | - | **0,6 *** | 0,3 | - |
| **Formaldeído** (mg/m³) | < 0,0002 | | < 0,0002 | | < 0,0002 | | < 0,0002 | | < 0,0002 | | < 0,0002 | | **0,1** | - | |
| **Partículas Suspensas no Ar** (fracção $PM_{10}$) (mg/m³) | 0,04 | 0,03 | 0,04 | 0,05 | 0,07 | 0,05 | 0,03 | 0,03 | 0,02 | 0,03 | 0,03 | - | **0,05 *** | 0,03 | - |
| **Partículas Suspensas no Ar** (fracção $PM_{2.5}$) (mg/m³) | 0,03 | 0,03 | 0,04 | 0,02 | 0,02 | 0,08 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | 0,02 | **0,025 *** | 0,03 | 0,02 |

(***Legenda:*** I – Inverno; V – Verão)

* A Portaria n.º 353-A/2013 de 4 de Dezembro, prevê margens de tolerância para os valores de limiar de proteção, aplicáveis a edifícios existentes e edifícios novos sem sistemas mecânicos de ventilação.



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Tabela 4 – Resultados da monitorização ambiental (concentrações médias) e valores de referência: **Parâmetros biológicos**

| Parâmetro/Local | Sala convívio | | Sala Refeições | | Quarto 111 | | Quarto 112 | | Quarto 109 | | Gabinete Médico | | Limiar de Proteção | Exterior | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | V | I | V | I | V | I | V | I | V | I | V | | I | V |
| **Bactérias Totais** (UFC/m³) | 284 | 438 | 150 | 212 | 304 | 172 | 456 | 308 | 228 | 272 | 38 | - | **< exterior** (até 350 UFC/m³ mais) | 8 | 154 |
| **Fungos Totais** (UFC/m³) | 176 | 92 | 186 | - | 116 | 92 | 180 | 150 | 148 | 126 | 242 | - | **< exterior** | 304 | 108 |

Tabela 5 – Resultados da monitorização ambiental e valores de referência: **Índices de Conforto Térmico**

| Parâmetro/Local | Sala convívio | | Quarto 111 | | Quarto 109 | | Valor de Referência |
|---|---|---|---|---|---|---|---|
| | I | V | I | V | I | V | |
| **PMV** | -0,1 | 0,3 | 0,4 | 0,4 | 0,1 | 0,4 | **Class A [-0.2; 0.2]**<br>**Class B [-0.5; 0.5]**<br>**Class C [-0.7; 0.7]** |
| **PPD** (%) | 5 | 6 | 8 | 8 | 5 | 9 | **Class A < 6**<br>**Class B < 10**<br>**Class C < 15** |

## 7. ANÁLISE DOS RESULTADOS E RECOMENDAÇÕES

A análise global dos resultados obtidos para os parâmetros avaliados mostra que, de um modo geral, (nas condições em que o estudo foi realizado) os valores encontrados enquadram situações de conforto.
Os parâmetros avaliados cumprem os valores de limite de referência, com exceção para os parâmetros $PM_{10}$, $PM_{2.5}$, Bactérias, Fungos nos locais assinalados a **vermelho** que ultrapassam os limiares de proteção recomendados.

Nesse sentido devem ser tomadas medidas para controlo destes parâmetros, nomeadamente:

| | |
|---|---|
| **Medidas técnicas de engenharia** | - Adoção de um sistema de ventilação que permita a regulação da temperatura;<br><br>- Isolamento da cobertura pode permitir a melhoria das condições térmicas interiores. |
| **Medidas de Manutenção e Limpeza** | - Promoção de uma desinfeção eficiente de todos os utensílios, equipamentos, materiais e instalações, com uma frequência suficiente para evitar o crescimento de microrganismos. |
| **Medidas de boas práticas de trabalho** | - Cumprimento das regras e procedimentos do Sistema HACCP (*Hazard Analysis and Critical Control Points*), nomeadamente quanto a evitar a contaminação cruzada e formação de aerossóis. |
| **Medidas de promoção de ventilação** | A Tabela I.04 da Portaria n.º 353-A/2013 de 4 de Dezembro estabelece como caudal mínimo de ar novo, **16 $m^3$/(hora.$m^2$)** nos quartos e **24 $m^3$/(hora.$m^2$)** para as salas de convívio e de refeições. Os funcionários do lar devem ser sensibilizados para a abertura de portas e janelas nas horas de não ocupação dos espaços, de forma a permitirem o arejamento dos locais. |

Porto, 10 de Janeiro de 2014

| | |
|---|---|
| A Responsável do Laboratório da Qualidade do Ar | O Investigador Principal do Projeto GERIA |
| _______________________________ | _______________________________ |
| (Maria Paula Neves, Dr.ª) | (João Paulo Teixeira, Doutor) |

E

CHAPTER QUALITY OF LIFE in PROJECT GERIA E-BOOK

# GERIA

**Geriatric Study in Portugal on Health Effects of Air Quality in Elderly Care Centers**

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ISPUP
INSTITUTO DE SAÚDE PÚBLICA DA UNIVERSIDADE DO PORTO

**Title:** Geriatric Study in Portugal on Health Effects of Air Quality in Elderly Care Centers

**Editors:** João Paulo Teixeira, Amália Botelho, Nuno Neuparth, Iolanda Caires, Ana Papoila, Pedro Martins, Paulo Paixão, Daniel Aelenei, João Viegas, Manuela Cano, Ana Mendes

Logo design by Carla Ribeiro azul
Cover design and content organization by Iolanda Caires

Published by Instituto de Saúde Pública
Universidade do Porto
4050-600 Porto

ISBN: 978-989-98867-7-3 (ebk)

## Acknowledgements

We have to thank the following support without which this work would not be possible:

**All elderly participants**
**Elderly care centers staff**
**Authorities involved**

**Scientific Consultant**

Stefano Bonassi | Head, Clinical and Molecular Epidemiology
Area of Systems Approaches and Non Communicable Diseases IRCCS
San Raffaele Pisana, Rome, Italy

IRCCS San Raffaele Pisana

**Partner**

Fundação Porto Social

Porto.

**Funding**

PTDC/SAU-SAP/116563/2010

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

COMPETE

QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL

UNIÃO EUROPEIA

## Contents

## Quality of Life

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### 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 [1]. Increased spontaneous demand, by older adults, for health care prevention and maintenance programs requires greater investment into aging accommodations. Institutions such as elderly care centers (ECC) have the potential to influence people's lives socially, physically, and psychologically [2]. ECC is considered a facility where users of 65 years or older reside permanently in a substitute environment and are offered shelter and elderly care.

Over the last few decades, concern about the quality of life (QoL) in this population has increased. More specifically, health-related quality-of-life involves perceptions of wellbeing and functioning in physical, mental, social, and daily life activities that comprise a summary quantification of perceived health. The QoL group of the World Health Organization (WHO) has defined QoL broadly as “an individual’s perception of his or her position in life in the context of the culture and value system where they live, and in relation to their goals, expectations, standards and concerns”. When studying older people living in ECC facilities, there has been a tradition to include QoL as an outcome parameter. Active aging implies growing old in good health and as a participative member of society, feeling fulfilled, autonomous in daily life, and more involved as citizens. No matter how old, the elderly plays an active part in society and enjoy a good QoL. The challenge is to make the most of the potential that older citizens harbor no matter their age [3]. Aging is associated with a decline in immune defense and respiratory function, and predisposition to respiratory infections [4]. In this population, the majority of situations of dependence are associated with chronic conditions that can be exacerbated by indoor environmental settings. Much can be done to cope with this decline. Rather small changes in the environment may make a great difference to individuals suffering from health impairments and disabilities.

Older individuals spend approximately 19-20 h/d indoors [5] and may be particularly at risk of detrimental effects from air pollutants, even at low concentrations, due to their reduced immunological defenses and multiple underlying chronic diseases. Due to these conditions, elderly are more susceptible to the effects of air pollution, and since they spend the large majority of their time indoors, monitoring IAQ in ECC is a public health priority [6]. In addition to IAQ, thermal comfort (TC) is a key indoor factor that might affect comfort, health and performance. Exposure to poor IAQ may produce or exacerbate eye irritation, nausea, upper respiratory complications, cognitive impairment, asthma, respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease and cancer [7]. Thus, IAQ is a special concern for ECC residents, important for both health and QoL.

Research to understanding such effects, especially taking into account that older individuals often have multiple diseases and live in restricted indoor environments that place them at increased risk of exposure to indoor pollutants, is an important endeavor and a natural shift in the focus of IAQ and TC studies. With this purpose the GERIA project aimed to characterize the ECC indoor environment and explore the influence of the indoor settings in the residents' QoL. Our study focused on the assessment of indoor environmental variables that might influence elderly comfort and wellbeing and interact with their already existent chronic diseases.

**Methods**

Within the scope of this study, 53 ECC (33 in Lisbon and 20 in Oporto) were selected through proportional stratified random sampling (by parish) from the 151 included in the Portuguese Social Charter (95 in Lisbon and 56 in Oporto). These 53 ECC were attended by 2,110 residents (1,442 in Lisbon and 668 in Oporto).

The Portuguese version of the WHO Quality of Life WHOQOL-BREF questionnaire [8] was administered by a trained interviewer to the older people who gave their informed consent and were able to participate. The questionnaire was conducted along the winter season environmental sampling campaign. All the participants were ≥65 years old, lived in the ECC for more than 2 weeks and possessed cognitive and interpretative skills in order to complete the questionnaires. This study was approved by the Ethics Committee and the Portuguese Data Protection Authority.

The WHOQOL-BREF questionnaire instrument is a 26-item version of the WHOQOL-100 assessment. Its psychometric properties were analyzed using cross-sectional data obtained from a survey of adults carried out in 23 countries. It applies the definition of QoL advocated by the WHO, which includes the culture and context which influence an individual's perception of health. The first two questions evaluate self-perceived QoL and satisfaction with health. The remaining 24 questions represent each of the twenty-four facets of which the original instrument is composed (WHOQOL-100), divided into four domains: physical health (7 items), psychological health (6 items), social relationships (3 items) and environment health (8 items). These four domain scores denote an individual's perception of quality of life in each particular domain. Domain scores are scaled in a positive direction (higher scores denote higher quality of life). The mean score in each domain indicates the individuals' perception of their satisfaction with each aspect of their life, relating it with QoL. The mean score of items within each domain is used to calculate the raw domain score. Considering the 4-20 scale, the midpoint where QoL is judged to be neither good nor poor is 12.0 [9] (which correspond to 50 in the 0-100 scale). In the present study we considered the 0-100 scale.

QoL has to be seen from a holistic perspective and interventions may not be limited to one aspect, as Kelley-Gillespie [10] concludes when developing an integrated conceptual model of QoL for older adults [11].

Median, 25$^{th}$ and 75$^{th}$ percentiles were estimated for every WHOQOL-BREF domain. Spearman correlations coefficients were computed to evaluate the linear relationship between scales. The internal consistency reliability of the WHOQOL-BREF was assessed by Cronbach's coefficient alpha. The floor and ceiling effects were measured for the scales domains with floor effect being the percentage of subjects with the lowest possible domain scores and the ceiling effect being the percentage of subjects with the highest possible domain scores. A low quality of life domain score was considered if the WHOQOL-BREF transformed score was <50 in the 0-100 scale.

**Results and Conclusions**

The overall questionnaire´s answer rate was 44% (931/2,110). The main reasons to not participate in the study were lack of collaboration due to incapacity (75%), elderly refusal (9.5%), to be younger than 65 years (9.5%) and institution refusal (6%). Even though, in the analysis were considered only the WHOQOL-BREF questionnaires with less than 20% of missing answers (n=887).

The surveyed sample included 79% females and 21% males, with a mean age of 84 years (SD 7 years). There was no statistical difference between respondents and non-respondents (p=0.534) in what concerns gender. The mean age of non-respondents was 83 years (SD 11 years) and despite being similar to the respondents, it was statistically different (p=0.004).

The internal consistency of the WHOQOL-BREF for the whole questionnaire was 0.86. The Cronbach's coefficient alphas for the different domains were: 0.78 for the physical health, 0.80 for the 0.59 for the social relationships psychological health, and 0.73 for the environmental. The Spearman correlations estimates between the four WHOQOL-BREF domains were: physical health/psychological health rs=0.65 (p<0.001), physical health/social relationships rs=0.35 (p<0.001), physical health/environmental health rs=0.52 (p<0.001), psychological/social rs=0.42 (p<0.001), psychological health/environmental health rs=0.56 (p<0.001) and social relationships/environmental health rs=0.41 (p<0.001).

Most domains had no marked floor or ceiling effects, exception to WHOQOL-BREF social relationships (ceiling effect of 2.9%). The floor effects were 0.2%, 0.1%, 0.2% and 0.1% for the physical health, psychological health, social relationships and environmental health domains, respectively. Ceiling effects were 0.4%, 0.8%, 2.9% and 1.3% for the physical health, psychological health, social relationships and environmental health domains, respectively.

Overall median scores for the different domains were modest (Table 1), with the exception of social relationships domain where a median of 75 ($P_{25}$-$P_{75}$: 58.3-75.0) was found. Overall QoL and health perception was low, particularly for respiratory diseases.

**Table 1.** Quality of Life (WHOQOL-BREF) assessment

| | **Total of participants (%)** | **Median ($P_{25}$ - $P_{75}$)** |
|---|---|---|
| **WHOQOL-BREF score** | | |
| **Overall perception of QoL and health** | | 50.0 (37.5 – 75.0) |
| < 50 | 560 (63.1) | |
| ≥ 50 | 313 (35.3) | |
| NA | 14 (1.6) | |
| **Physical health** | | 64.3 (47.3 – 75.0) |
| < 50 | 248 (28.0) | |
| ≥ 50 | 603(68.0) | |
| NA | 36 (4.0) | |
| **Psychological health** | | 62.5 (50.0 – 75.0) |
| < 50 | 242 (27.3) | |
| ≥ 50 | 619 (69.8) | |
| NA | 26 (2.9) | |
| **Social relationships** | | 75.0 (58.3 – 75.0) |
| < 50 | 60 (6.8) | |
| ≥ 50 | 525 (59.2) | |
| NA | 302 (34.0) | |
| **Environmental health** | | 62.5 (56.3 – 71.9) |
| < 50 | 111 (12.6) | |
| ≥ 50 | 647 (72.9) | |
| NA | 129 (14.5) | |

NA: not available; QoL: Quality of life; $P_{25}$: 25$^{th}$ percentile; $P_{75}$: 75$^{th}$ percentile

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Funding

September 2015