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IMPACT OF INDOOR AIR POLLUTION ON CHILDHOOD ASTHMA

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IMPACT OF INDOOR AIR POLLUTION ON CHILDHOOD ASTHMA

Dissertation presented by

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ABSTRACT

Air pollution has been associated with several adverse health effects on human health, mainly impairing respiratory system, especially among frail populations like children. Those impacts were extensively documented for outdoor air, although children spend most of their time indoors, particularly in nursery and primary schools, their primary place of social activity.

Thus, this thesis intended to contribute for the understanding of the impact of indoor air pollution on childhood asthma, in order to contribute to a better supported development of preventive and mitigation measures. This was accomplished by: i) characterising indoor air quality in nursery and primary schools from both urban and rural sites in northern Portugal, considering major relevant indoor air pollutants and quantifying their determinants; ii) modelling children's exposure to indoor air pollutants in those environments; and iii) evaluating the impact of indoor air pollution on childhood asthma at different age groups.

Major indoor air pollutants, namely carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), formaldehyde, total volatile organic compounds (TVOC), particulate matter ($PM_{2.5}$ and PM_{10}), radon and temperature and relative humidity as thermal comfort indicators, were continuously sampled for periods of at least 24 hours indoors the major scholar indoor microenvironments (classroom, bedroom and canteen). Poor indoor air quality was commonly found, with CO_2, $PM_{2.5}$ and PM_{10} often above reference values (international guidelines and national legislation) and mainly influenced by indoor sources. CO_2 exceeded the reference value in 41.3% of the classrooms, while $PM_{2.5}$ exceeded in 54.9% and 69.0% of the classrooms (respectively for 8h and 24h mean). Formaldehyde and TVOC, influenced by the presence of specific indoor sources, also exceeded reference values, although less frequently (respectively in 27.8% and 6.3% of the studied classrooms). CO, NO_2 and O_3, influenced by outdoor air, never exceeded reference values. Significant determinants of indoor air pollution included heating, flooring material, indoor thermal comfort indicators, type of school management, and background concentrations (non-occupancy periods). Radon measurements (short-term sampling) also highlighted some high concentrations, which enhances the importance of radon evaluation in nursery and primary schools through a national survey.

Childhood asthma prevalence and risk factors in Portuguese pre- and primary school children was evaluated. Firstly, asthma prevalence was estimated from parent-reported information in a validated questionnaire, being achieved a prevalence of 10.7 % in children attending nursery schools at urban sites. As asthma estimated merely based on reported data may introduce important bias, asthma was then diagnosed in pre- and primary school population according to the 2018 international guidelines from Global Asthma Initiative (GINA): based on reported history of characteristic respiratory symptoms and demonstration of variable expiratory airflow limitation by spirometry with reversibility test. Asthma prevalence was 5.5%, non-significantly higher in primary school children and in urban areas, and was under-diagnosed in both age groups from urban and rural settings. Separate bivariate and multivariate logistic regression models were used to analyse respectively individual and combined risk effects of potential risk factor for childhood asthma. Host factors that mainly predispose a child to develop asthma included being male, older age and having at least one asthmatic parent; environmental factors included paracetamol administration in the previous year (currently), and antibiotics administration in child's first year of life.

Based on time-activity-location information gathered from parent- and teacher-reported daily diaries, indoor air pollutant's exposure and inhaled dose were modelled for the entire study population (1530 pre- and primary school attending the studied nursery and primary schools). Pre-schoolers were subjected to higher exposure and inhaled dose, as their classrooms were usually more crowded and less ventilated. Multipollutant logistic regression models were used to evaluate the impact of exposure and inhaled dose to indoor air pollutants on childhood asthma outcomes (active wheezing, reported and diagnosed asthma, obstructive disorder (airflow limitation associated with reduced FEV_1/FVC) and reduced FEV_1). Overall, no evidence of a significant association with childhood asthma prevalence was found. However, significant associations were found with other asthma-related health outcomes, namely with an increase in the odds of having active wheezing due to NO_2, and abnormal lung function (reduced FEV_1) due to O_3 and $PM_{2.5}$, although NO_2 and O_3 were always below the thresholds. Multinomial logistic regression models were also used to estimate the effect of indoor air pollutants' exposure and inhaled dose on the probability that asthma diagnosed is: asthma with aeroallergen sensitisation, asthma without aeroallergen sensitisation or no asthma. Results suggested that children sensitised to common aeroallergens are more likely to develop asthma during childhood due to inhaled PM in nursery and primary schools' indoor air.

These findings supported the need for developing and implementing mitigation measures to reduce indoor air pollutants' levels in nursery and primary schools and prevention actions to reduce children's exposure, thus avoiding health impacts.

Keywords: indoor air pollution, exposure, inhaled dose, school, childhood asthma

RESUMO

A poluição do ar tem sido associada a diversos efeitos adversos na saúde, principalmente no sistema respiratório, afetando em particular grupos mais vulneráveis da população como as crianças. Esses impactos estão extensivamente documentados para o ar exterior. Contudo, as crianças passam a maior parte do tempo em espaços interiores, particularmente em infantários e escolas primárias, que constituem os seus primeiros locais de atividade social.

Desta forma, esta tese tem como principal objetivo contribuir para a compreensão do impacto da poluição do ar interior na asma infantil, suportando o desenvolvimento de medidas preventivas e de mitigação. Isto foi conseguido através de: i) caracterização da qualidade do ar interior em infantários e escolas primárias em áreas urbanas e rurais no norte de Portugal, considerando os principais poluentes do ar interior e quantificando os seus determinantes; ii) modelização da exposição das crianças aos poluentes do ar interior nesses locais; e iii) avaliação do impacto da poluição do ar interior na asma infantil em diferentes faixas etárias.

Os principais poluentes do ar interior, nomeadamente dióxido de carbono (CO_2), monóxido de carbono, dióxido de azoto (NO_2), ozono (O_3), formaldeído, compostos orgânicos voláteis totais (TVOC), partículas em suspensão ($PM_{2.5}$ e PM_{10}), radão, temperatura e humidade relativa como indicadores de conforto térmico, foram monitorizados em contínuo por períodos superiores a 24 horas no interior dos principais microambientes escolares (sala de aula, dormitório e refeitório). Má qualidade do ar foi encontrada frequentemente, com concentrações de CO_2, $PM_{2.5}$ e PM_{10} acima dos limiares de referência (diretrizes internacionais e legislação nacional) e influenciadas predominantemente por fontes interiores. As concentrações de CO_2 excederam o limiar de referência em 41.3% das salas de aulas, enquanto as de $PM_{2.5}$ excederam em 54.9% e 69.0% das salas de aula (respetivamente para médias de 8h e de 24h). Nos casos do formaldeído e dos TVOC, maioritariamente influenciados pela presença de fontes interiores, também ocorreram excedências aos valores de referência, embora com menor frequência (respetivamente em 27.8% e 6.3% das salas de aulas estudadas). Nos casos do CO, do NO_2 e do O_3, predominantemente influenciados pelo ar exterior, nunca excederam os limites de referência. Os principais determinantes da poluição do ar interior incluíram sistemas de aquecimento, revestimento do chão, condições meteorológicas dos espaços interiores (temperatura e humidade relativa), tipo de gestão da escola, e concentrações de fundo (durante períodos de não ocupação). A avaliação preliminar de radão (curta duração) encontrou algumas concentrações elevadas, o que releva a importância de avaliar radão nos infantários e escolas primárias, nomeadamente através de um estudo nacional.

Foi avaliada a prevalência e fatores de risco de asma infantil em crianças portuguesas com idade pré-escolar e escolar primária. Inicialmente, com base apenas na informação reportada pelos pais num questionário validado, a asma foi avaliada em 10.7% das crianças que frequentavam infantários e escolas primárias em áreas urbanas. Uma vez que estimar asma apenas com base em informação reportada pode introduzir viés importantes, esta doença foi posteriormente diagnosticada em crianças em idade pré-escolar e escolar primária de acordo com as recomendações de 2018 da *Global Asthma Initiative* (GINA): baseada no histórico reportado de sintomas respiratórios característicos e na demonstração de limitação variável do fluxo expiratório através de teste espirométrico com reversibilidade. A prevalência de asma foi 5.5%, mais elevada (embora não significativamente) nas crianças de escolas primárias e de áreas urbanas. Ambas as faixas etárias de ambos os contextos (urbano e rural) apresentavam asma sub-diagnosticada. Foram usados, separadamente, modelos de regressão logística bivariada e multivariada para analisar respetivamente o risco de potenciais fatores de risco para a asma infantil. Os principais fatores de risco individuais incluíram: sexo masculino, idade/faixa etária (escola primária) e ter pelo menos um dos pais asmático. Os principais fatores de risco ambientais incluíram a administração de paracetamol no ano anterior (atualmente), e a administração de antibióticos no primeiro ano de vida da criança.

Baseado em informação sobre tempo-atividade-localização recolhida através de diários preenchidos pelos pais e professores, foi possível modelizar a exposição e dose inalada dos poluentes do ar interior em toda a população de estudo (1530 crianças em idade pré-escolar e escolar a frequentar os infantários e as escolas primárias). As crianças em idade pré-escolar foram sujeitas a maior exposição e dose inalada, uma vez que as suas salas eram geralmente mais lotadas e menos ventiladas. Foram utilizados modelos de regressão logística multi-poluente para avaliar o impacto da exposição e dose inalada aos poluentes do ar interior na asma infantil (pieira ativa, asma reportada e diagnosticada, distúrbio obstrutivo (limitação do fluxo de ar associada a um reduzido VEF_1/VFC) e VEF_1 reduzido). Globalmente, não se encontrou evidência significativa com a prevalência de asma infantil. Contudo, foram encontradas associações significativas com outros efeitos na saúde respiratória, nomeadamente com um aumento na probabilidade de ter pieira ativa devido ao NO_2, e função pulmonar anormal (VEF_1 reduzido) devido ao O_3 e $PM_{2.5}$, apesar de se terem registado concentrações de NO_2 e O_3 sempre abaixo dos limiares. Foram ainda utilizados modelos de regressão logística multinomial para estimar o efeito da exposição (e dose inalada) aos poluentes do ar interior na probabilidade da asma diagnosticada ser: asma com sensibilização a aeroalergénios, asma sem sensibilização a aeroalergénios, ou não ter asma. Os resultados sugerem que as crianças sensibilizadas a aeroalergénios comuns são mais propensas a desenvolver asma durante a infância devido à exposição a matéria particulada em suspensão no ar interior de infantários e escolas primárias.

Estes resultados evidenciaram a necessidade do desenvolvimento e implementação de medidas de mitigação para redução dos níveis dos poluentes do ar interior em infantários e escolas primárias, e de ações preventivas para redução da exposição das crianças, evitando assim impactos na saúde.

Palavras-chave: poluição do ar interior, exposição, dose inalada, escola, asma infantil

RÉSUMÉ

La pollution atmosphérique est associée à plusieurs effets sur la santé, surtout sur le système respiratoire des populations dites fragiles, comme les enfants. L'impact sur la santé respiratoire est largement documenté en regard de la pollution atmosphérique, mais la plupart du jour des enfants est passé à l'intérieur, à l'école ou à la crèche, leur primordial lieu d'activité sociale.

Le but de cette thèse est de mieux comprendre l'impact de la qualité de l'air à l'intérieur sur le développement de l'asthme infantile, afin de supporter une amélioration des mesures visant la prévention et l'atténuation de ce problème. Les démarches pour le réussir ont inclus: i) la caractérisation de la qualité de l'air à l'intérieur aux chèches et écoles primaires, situés dans des endroits urbains et ruraux, considérant les principaux polluants et quantifiant leurs déterminants; ii) la modélisation de l'exposition des enfants aux polluants chez les endroits étudiés; iii) l'évaluation de l'impact de la qualité de l'air à l'intérieur sur le développement de l'asthme infantile, dans les différents groupes de l'âge.

Les principaux polluants ont été mesurés continuellement, en périodes d'au moins 24-heures, aux salles de cours et cantines, dans chaque école participante. Des polluants gazeux, chimiques et particulaires ont été inclus dans cette analyse, à savoir le dioxyde de carbone (CO_2), le monoxyde de carbone (CO), le dioxyde d'azote (NO_2), l'ozone (O_3), le formaldéhyde, les composés volatiles organiques (TVOC) et les particules en suspension ($PM_{2.5}$ and PM_{10}), le gaz radon, bien que la température et l'humidité relative, les paramètres de confort. De manière générale, les concentrations mesurés de CO_2, $PM_{2.5}$ and $PM_{10,}$ influencées par des sources à l'intérieur, ont fréquemment dépassé leurs valeurs de référence, par rapport aux recommandations internationales et la loi portugaise. Les valeurs de référence pour le CO_2 ont été dépassés en 41.3% des salles de classe, et les valeurs de référence pour les $PM_{2.5}$ ont été dépassé en 54.9% et 69.0% des salles (respectivement pour 8h et 24h moyennes). En plus, les concentrations de formaldéhyde et TVOC ont souvent été élevées (dépassés en 27.8% et 6.3% des salles, respectivement), suggéraient la présence de sources à l'intérieur. En revanche, les concentrations de CO, NO_2 and O_3, sur l'influence de la pollution à l'extérieur, n'ont jamais dépassé les limites établis. Les déterminants trouvés significatifs de la qualité de l'air à l'intérieur comprirent l' échauffement, le matériel composant le sol, les paramètres de confort (température et humidité relative), le type de gestion scolaire et les concentrations de fond des polluants, mesurées aux périodes de non-occupation des pièces. L' évaluation préliminaire de radon effectuée a aussi trouvée des concentrations élevées, reconnaissant l'importance d'une évaluation des niveaux du gaz radon aux écoles par un étude national.

La prévalence et les facteurs de risque pour le développement de l'asthme chez les enfants à l'âge préscolaire et scolaire ont été étudiés. D'abord, l'utilisation des questionnaires validés, reportant les symptômes typiques de la maladie ont été remplis par les parents, établissant le diagnostique dans 10,7% des enfants appartenant aux crèches en milieu urbain. Cependant, le diagnostique basé exclusivement en symptômes reportés introduit un biais important, raison pour laquelle le diagnostique de l'asthme a suivi les dernières recommandations de Global Asthme Initiative (GINA), publiées en 2018, considérant l'ensemble des symptômes respiratoires typiques liés à la réalisation d'une spirométrie montrant une limitation au flux d'air expiré et un test de réversibilité positif. Ceci a établi la prévalence de l'asthme dans cette population en 5,5%, non-supérieur dans le groupe des enfants en âge scolaire ni dans le milieu urbain. Dans tous les sous-groupes de population, l'asthme ait trouvé sous-diagnostiqué. L'analyse statistique, utilisant des modèles logistiques bivariés et multivariés, a été conduite pour évaluer l'effet individuel et combiné des facteurs de risque potentiels dans le développement de l'asthme. Parmi les variables analysées, les suivantes prédisposent les enfants à la maladie: le sexe masculin, l'âge et avoir un parent avec le diagnostique d'asthme, l'administration de paracétamol dans l'an dernier et des antibiotiques dans le premier année de vie.

Une modélisation de l'exposition et de la dose inhalée des polluants trouvés dans l'air à l'intérieur a été conduite, incluant la globalité de la population de l'étude (1530 enfants en âge préscolaire et scolaire). Pour supporter la modélisation, un horaire quotidien a été construit avec les informations recueillis auprès de parents et des professeurs, concernant le type d'activité, sa localisation et sa durée. Les enfants en âge préscolaire ont subi une exposition et une dose inhalée plus élevée, en raison des salles de cours surpeuplées et faiblement ventilées. L'impact de l'exposition sur l'asthme infantile et ses équivalents (respiration sifflante active, asthme rapporté dans les questionnaires, asthme diagnostiqué, maladie pulmonaire obstructive associé à une réduction du FEV_1/FVC et une réduction du FEV_1) a été évalué utilisant des modèles de régression logistique multinomiales avec la combinaison des polluants. Globalement, une association importante entre l'exposition et la prévalence de l'asthme n'a pas été trouvée. Cependant, autres associations entre l'exposition aux polluants et des altérations respiratoires chez les enfants sont à considérer, notamment: l'exposition au NO_2 et la respiration sifflante récurrente; l'exposition au O_3 et aux $PM_{2.5}$ et la diminution du FEV_1, bien que les concentrations de NO_2 and O_3 n'ont jamais surpassé les limites légales. Des modèles de régression logistique multinomiales ont été utilisés pour estimer l'effet de l'exposition et de la dose inhalée sur la probabilité du développement de l'asthme, divisée en trois catégories: asthme avec sensibilisation allergique, asthme sans sensibilisation allergique et pas de diagnostique. Les résultats suggèrent que les enfants déjà sensibilisés aux aéroallergènes sont plus à risque de développer de l'asthme en raison de l'exposition aux PM présents dans l'air intérieur des crèches et écoles primaires.

Les résultats présents supportent le besoin de développer et implémenter des mesures d'atténuation des polluants de l'air à l'intérieur chez les chèches et écoles primaires. Ces actions de prévention permettent la réduction de l'exposition des enfants, décroissant les effets sur la santé respiratoire.

Mots-clés: pollution de l'air à l'intérieur, exposition, dose inhalée, écoles, asthme infantile

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AIC	Akaike's Information Criteria
ANOVA	Analysis of Variance
aOR	Adjusted Odds Ratio
AS	Aeroallergen Sensitisation
ASHRAE	American Society of Heating Refrigerating and Air-conditioning Engineers
ATS	American Thoracic Society
BC	Before Christ
BMI	Body Mass Index
CFD	Computational Fluid Dynamics
CI	Confidence Interval
CRM	Continuous Radon Monitors
DAC	Dominated Air Conditioning
DNV	Dominated Natural Ventilation
EID	Electronic Integrating Devices
ERS	European Respiratory Society
ETS	Environmental Tobacco Smoke
EU	European Union
FEV_1	Forced Expiratory Volume in 1 second
FVC	Forced Vital Capacity
GINA	Global Initiative for Asthma
GLI	Global Lung Initiative
IAP	Indor Air Pollution
IAQ	Indor Air Quality
ICRP	International Committee for Radiological Protection
INAIRCHILD	Project - Indoor Air Pollution on Nurseries and Primary Schools: Impact on Childhood Asthma
IQR	Interquartile Range
IR	Inhalation rate
ISAAC	International Study of Asthma and Allergies in Childhood
MT	Margin of tolerance
NA	Not applicable
NDIR	Non-Dispersive Infrared Detection
NMVOC	Non-Methane Volatile Organic Coumpounds
OR	Odds Ratio
PAH	Polycyclic Aromatic Hydrocarbons
PFT	Pulmonary Function Test
PM	Particulate Matter
PM_1	Particulate Matter with aerodynamic diameters smaller than or equal to 1 μm
PM_{10}	Particulate Matter with aerodynamic diameters smaller than or equal to 10 μm
$PM_{2.5}$	Particulate Matter with aerodynamic diameters smaller than or equal to 2.5 μm
RH	Relative Humidity
SBS	Sick Building Syndrome

SD	Standard Deviation
SES	Socioeconomic Status
SPT	Skin Prick Test
T	Temperature
TSP	Total Suspended Particles
TVOC	Total Volatile Organic Compounds
USA	United States of America
USEPA	United States Environmental Protection Agency
VIF	Variance Inflation Factor
VOC	Volatile Organic Compounds
WHO	World Health Organization

PART I

INTRODUCTION

Chapter 1

Framework

This thesis was carried out between 2014 and 2019 at the Laboratory for Process Engineering, Environment, Biotechnology and Energy (LEPABE) in the Chemical Engineering Department of the Faculty of Engineering, University of Porto (FEUP). The project "*INAIRCHILD – Indoor air pollution on nurseries and primary schools – Impact on childhood asthma*" (PTDC/SAL-SAP/121827/2010) backed-up this thesis. This study was approved by both the Ethics Commission for Health of *Centro Hospitalar de São João, Porto* (now called *Centro Hospitalar Universitário de São João, Porto*) and the Ethics Commission of University of Porto. This work allowed to the publication of seven papers in international scientific peer-reviewed journals included in the scientific citation index, having two more been submitted.

1.1 Relevance

Nothing is more natural than breathing. However, breathing is as natural as it is necessary to human life, but unfortunately, not all the air we breathe is healthy. Recently (2016), the World Health Organization (WHO) estimated that around 7 million people died prematurely harmed from air pollution, both ambient (outdoor) and household (indoor), of which 543 000 were children under 5 years old and 52 000 were children aged 5-15 years old (WHO, 2018a; WHO, 2018b). Although those deaths mainly occurred in low- and middle-income countries, air pollution is a global challenge that must be tackled by all.

Indoor air quality (IAQ) in public and private buildings where people spend a large part of their lives is an essential determinant of healthy life and people's welfare. Still, in contrast to outdoor environments, people may have a greater ability to modify indoor environmental exposures, and that ability makes addressing indoor air pollution (IAP) an attractive target for disease prevention (Breysse et al., 2010). Unlike homes, non-residential buildings tend to serve diverse populations. As such, IAP exposure concerns differ in many cases from those that occur in residential buildings (Godish, 2001). In this particular field, nursery and primary schools are a very interesting case study for two main reasons, although less studied in comparison with other environments (Sousa et al., 2012a): i) firstly, children are more vulnerable to the health effects of air pollution than adults, being considered a frail population (Annesi-Maesano et al., 2003; Schwartz, 2004), because of their not fully developed immune system and lungs, their relative higher amount of air inhalation (the air intake per weight unit of a resting infant is twice that of an adult) and their growing tissue and organs (Mendell and Heath, 2005); and ii) secondly, because children spend more time in schools (or nursery schools/ pre-schools in the case of younger children) than in any other indoor environments besides home, and it is their primary place of social activity. Unlike other buildings, managing IAQ in schools involves not only maintenance related concerns, but also child safety issues (Alves et al., 2013; USEPA, 2005).

There are evidences that pollutants in indoor air may cause acute effects such as irritation in the skin, eyes, nose, throat and upper airways, as well as may contribute to changes in lung function and to the prevalence of chronic respiratory diseases, especially asthma (Sousa et al., 2012a). In fact, asthma is the most common chronic disease among children, whose morbidity contributes to a high socio-economic burden to children, their family, caretakers, society and healthcare providers (Mirabelli et al., 2016), reflected by school days' lost (absenteeism), increased hospital admissions and medicines' administration, and negative impacts on parents' and caregivers' lives (Van Den Akker-van Marle et al., 2005). Childhood asthma prevalence has been associated with the adoption of a modern urban lifestyle, thus attracting scientific community's interest (Asher and Pearce, 2014; Croisant, 2014). Still, population studies usually consider the diagnosis of asthma based on reported history of characteristic respiratory symptoms, although the most recent guidelines from the Global Initiative for Asthma (GINA) recommends diagnosing asthma based on the presence of both respiratory symptoms and physical confirmation of variable expiratory airflow by medical exams (GINA, 2018). Although challenging, exposure studies can be used to establish where air pollutants' exposure occurs, the sources of those air pollutants, and their associated impacts on health (Weisel, 2002). This allows us to understand the most influential factors, which is essential for eliminating or reducing contacts with toxicants or for altering children's activities/habits before a problem arises (Lioy, 2010).

1.2 Objectives

This thesis mainly intended to contribute for the understanding of the impact of indoor air pollution on childhood asthma, in order to contribute to a better supported development of preventive and mitigation measures. This was accomplished by:

i. Characterising indoor air quality in nursery and primary schools from both urban and rural sites in northern Portugal, by considering major relevant indoor air pollutants and quantifying their determinants;
ii. Modelling children's exposure to indoor air pollutants in those environments;
iii. Evaluating the impact of indoor air pollution on childhood asthma at different age groups.

1.3 Outline

The thesis is divided into four parts, covering two complementary areas of research: environment (IAQ in nursery and primary schools) and health (childhood asthma), evaluating impacts of the former on the second.

Part I (present Part) is the introduction describing the relevance, work objectives and thesis structure (Chapter 1). This part also provides an overview of IAQ, including some historical background, general description and sources of indoor air pollutants, methods to assess children's exposure, and effects of IAP on children's health (Chapter 2).

Part II presents the detailed characterization of IAQ in nursery and primary schools, including the evaluation of IAQ in nursery schools from urban areas (carbon dioxide and comfort, gaseous pollutants, and particulate matter, respectively in Chapters 3 to 5), the quantification of IAQ determinants in nursery and primary schools from both urban and rural sites (Chapter 6) and the radon evaluation in nursery and primary schools from both sites (Chapter 7).

Part III addresses childhood asthma impacts from IAP in nursery and primary schools, estimating asthma prevalence and risk factors in early childhood (nursery schools) based on reported information on validated questionnaires (Chapter 8), assessing asthma prevalence in pre- and primary schoolchildren from both urban and rural sites, and evaluating whether host and environmental reported factors have an independent or combined risk effect on childhood asthma, by diagnosing asthma based on physical diagnosis according to the latest guidelines (Chapter 9), and quantifying children's exposure and inhaled dose to IAP in nursery and primary schools, evaluating their associations with childhood asthma (Chapter 10).

Part IV appraises the main conclusions pointing out the main findings and the future directions of research to continue the present study (Chapter 11).

Chapter 2

Indoor air quality and children's health

2.1 Indoor air quality

2.1.1 Historical perspective

IAQ is an important determinant of people's health and welfare. Although it is usually seen as a concern of the modern times, it has been noticed in many ways throughout human history. One of the basic human needs is shelter, and IAQ has been an issue ever since man first lit fires in caves and shelters. The primitive arrangement was a central fire and a central roof opening for smoke exhaust. Later, the fire was moved to different parts of the dwelling and various layouts were tried to improve the efficiency to provide warmth and enable cooking. Driven by thermal comfort concerns, Romans built underfloor heating to make indoor climate in their palaces and spas more comfortable – the so called "hypocaustum" (Hensen Centnerová, 2018).

Throughout history, humans have understood that polluted air may be damaging for health (Sundell, 2004). Greeks and Romans were aware of the adverse effects of polluted air in crowded cities and mines (Hippocrates, 460-377 BC). In the Bible, the book of Leviticus from the Old Testament (Leviticus 14, 34-57) describes a "leprous" house, indicating that people were aware that residing in damp buildings was dangerous to their health, and drastic remedies were proposed (i.e., get rid of all affected parts of the building):

"If the priest, on examining it, finds that the infection on the walls of the house consists of greenish or reddish depressions which seem to go deeper than the surface of the wall, he shall close the door of the house for seven days. On the seventh day, the priest shall return to examine the house again. If he finds that the infection has spread on the walls, he shall order the infected stones to be pulled out and cast in an unclean place outside the city. The whole inside of the house shall be scraped, and the mortar that has been scraped off shall be dumped in an unclean place outside the city. Then, new stones shall be brought and put in the place of old stones, and the new mortar shall be made and plastered on the house."

Along the medieval era, small steps forward have been accomplished in this field. Important steps towards the improvement of indoor air conditions and comfort were given only centuries after. In the 15th Century, the invention of the chimney was a major advance in heating which had influence in thermal comfort and IAQ, although it took 200 years to be widely adopted (Hensen Centnerová, 2018). In 1600, with the goal to improve smoke removal, King Charles I of England passed a law which required all new homes to have a ceiling of at least 10 feet (3 meters), and that windows had to be higher than they were wide. Around 1700, the general idea was that breathing was primarily a way of cooling the heart – the substance of air was not required, only its coolness – but it was also common sense that expired air was unfit for breathing until refreshed (Sundell, 2004). The role of oxygen in breathing was pointed out years later, in 1781, by Antoine Lavoisier considered the father of the gaseous chemistry. About 100 years earlier, in 1667, Boyle (1627-1691) and Hooke (1635-1703) found that the supply of air to the lungs was essential for life, and Mayow (1643-1678) discovered that there was an exchange within the lungs between the inhaled air and the body. In his primitive studies of oxygen and CO_2 in the air of crowded rooms he concluded that excess CO_2 – rather than a reduction of oxygen – caused sensations of stuffiness and bad air (Janssen, 1999).

During the following half century it was accepted that CO_2 concentration was a measure of whether the air was fresh or stale (Sundell, 2004). Later, Pettenkofer (1818-1901), the first professor in hygiene in Munich, noted that unpleasant sensations of stale air were not due merely to warmth or humidity, nor CO_2 or oxygen deficiency, but rather to the presence of trace quantities of organic material exhaled from the skin and the lungs (Sundell, 2004). In his view, CO_2 was not important on itself, but was an indicator of the amount of other noxious substances present, produced by humans. He believed, as did other contemporary colleagues, that CO_2 was a useful surrogate for vitiated air (Tredgold, 1836). Thomas Tredgold, a Cornish mining engineer, published the first estimate of the fresh airflow needed (2 l/s) for breathing and candle burning (Tredgold, 1836).

In the following years, some studies of ventilation in schools, theatres, homes and other indoor environments were conducted with CO_2 concentration as the measure of ventilation rate per person. An extensive study was conducted in Stockholm schools with different ventilation systems by the first Swedish professor in hygiene, Elias Heyman (1829-1889). That study included CO_2 measurements of schools with and without measures for ventilation and concluded that not even one schoolroom was adequately ventilated. Thus, ventilation was primarily a question of comfort and not of health.

Possibly the first complete overview of the relationship between indoor environment and health was brought about by Florence Nightingale (1820-1910), commonly considered as the ‘founder of modern nursing’ and a ‘nurse and structural engineer’ (Iddon, 2015). The first chapter of her book entitled “Notes for Nursing, What it is, and What it is not” focused not on patient care, but on ventilation (Nightingale, 1859), and she wrote: ‘The first task of nursing: to keep the air that breathes the patient as pure as the outside air, without cooling them’. She also made other recommendations, including: i) to bring air from outside, open windows and close doors; ii) natural air temperature fluctuations are necessary to stay healthy; iii) light is essential for both health and recovery; and iv) the body and mind degenerate without sunlight.

In the late 19th Century, doctors began recommending parents in urban apartments to regularly expose their children to fresh air, as it was believed this would strengthen the child's immune system and increase general health and vigour. Patented in 1922 by Emma Read of Spokane, in Washington, United States of America (USA), the so called "baby cages" were touted as the 'it' parenting product in London in the 1930s, as the cities became more dense and apartments increasingly smaller. Parents in those early cities did not have the same access to backyards and parks as countryside dwellers. That was a large – apparently secure – wide crate that could be attached to the outside of apartment windows, providing city-dwelling infants the opportunity to get "fresh air" from outdoors (Figure 2.1). Possibly due to safety concerns, baby cages lost popularity in the 1940s.

Figure 2.1 – Babies placed in cages out of windows so that they could get 'fresh air'. Credit: Getty images.

Environmental issues were mainly focused on IAQ until 1960s. After Rachel L. Carson wrote her book 'Silent Spring', in 1962, environment was suddenly synonymous with outside air and industrial environment, and environmental protection received worldwide attention but IAQ in non-industrial environments was not on the list of environmental problems (Hensen Centnerová, 2018). Not until the problems that arose regarding radon and environmental tobacco smoke (ETS) with lung cancer in the late 1960s, volatile organic compounds (VOC), formaldehyde, and 'sick building syndrome' in the 1970s, and house dust mites, and allergies and asthma in the following decades, did health issues related to indoor air again enter the scientific agenda (Sundell, 2017). The term Sick Building Syndrome (SBS) refers to non-specific complaints, including upper-respiratory irritative symptoms, headaches, fatigue, and rash, which are usually associated with a particular building by their temporal patterns of occurrence and clustering among inhabitants or colleagues (Redlich et al., 1997). With the advent of new more energy-efficient, "airtight" buildings, SBS has been reported with increasing frequency since the 1970s (Redlich et al., 1997). In nearly 1970s, and resulting from the early studies on IAQ and thermal comfort, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) introduced two new standards: ASHRAE Standard 55-1966 for thermal comfort, and ASHRAE Standard 62-1973 for ventilation (Janssen, 1999).

In fact, the modern scientific history started in the 1970s with a question: "does indoor air pose a threat to health as outdoor air?", and soon it was recognized that indoor air is more important than outdoor air, from a health point of view (Sundell, 2017). Since then, the number of publications related to indoor air rapidly increased, as showed in the Figure 2.2, confirming that the topics related to IAQ have been attracting the attention of the scientific community.

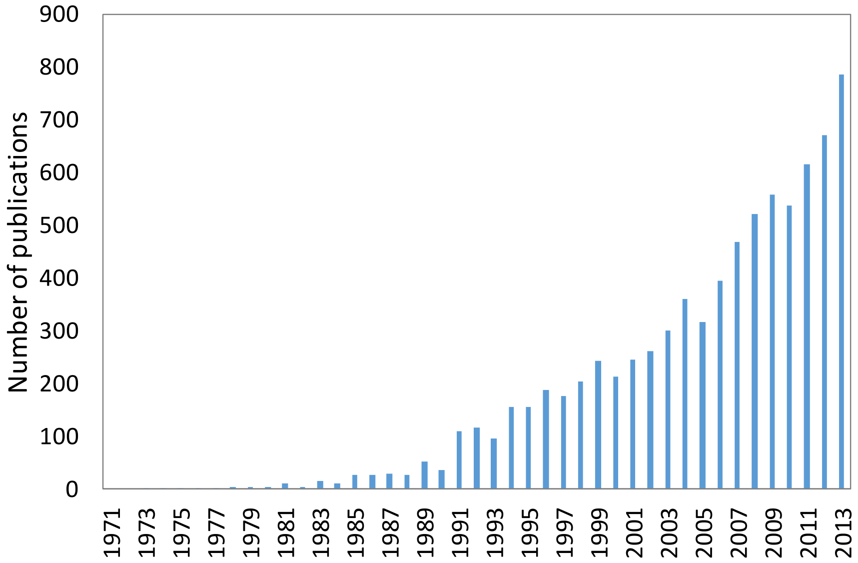

Figure 2.2 - Number of articles published per year from 1970 to 2013 with "indoor air" as the topic, based on a bibliographic search on Web of Science (Web of Science, 2018).

More recently, in the beginning of the 21st Century, WHO Regional Office for Europe agreed on a set of statements on "The right to healthy indoor air", derived from fundamental principles in the fields of human rights, biomedical ethics and ecological sustainability, and focus on interactions among them (WHO, 2000). Everyone has a right to healthy indoor air, so these statements inform the individuals and groups responsible for healthy indoor air about their rights and obligations, and empower the general public by making people familiar with those rights (Table 2.1).

Table 2.1 –"The Right to Healthy Indoor Air" proposed by WHO Regional Office for Europe (WHO, 2000).

Principle 1	**Under the principle of the human right to health**, everyone has the right to breathe healthy indoor air.
Principle 2	**Under the principle of respect for autonomy ("self-determination"),** everyone has the right to adequate information about potentially harmful exposures, and to be provided with effective means for controlling at least part of their indoor exposures.
Principle 3	**Under the principle of non-maleficence ("doing no harm"),** no agent at a concentration that exposes any occupant to an unnecessary health risk should be introduced into indoor air.
Principle 4	**Under the principle of beneficence ("doing good"),** all individuals, groups and organizations associated with a building, whether private, public, or governmental, bear responsibility to advocate or work for acceptable air quality for the occupants.
Principle 5	**Under the principle of social justice**, the socioeconomic status of occupants should have no bearing on their access to healthy indoor air, but health status may determine special needs for some groups.
Principle 6	**Under the principle of accountability**, all relevant organizations should establish explicit criteria for evaluating and assessing building air quality and its impact on the health of the population and on the environment.
Principle 7	**Under the precautionary principle**, where there is a risk of harmful indoor air exposure, the presence of uncertainty shall not be used as a reason for postponing cost-effective measures to prevent such exposure.
Principle 8	**Under the "polluter pays" principle**, the polluter is accountable for any harm to health and/or welfare resulting from unhealthy indoor air exposure(s). In addition, the polluter is responsible for mitigation and remediation
Principle 9	**Under the principle of sustainability**, health and environmental concerns cannot be separated, and the provision of healthy indoor air should not compromise global or local ecological integrity, or the rights of future generations.

2.1.2 Thermal comfort parameters and indoor air pollutants

Thermal comfort and IAQ are two of the major factors that define indoor environmental quality (Sarbu and Sebarchievici, 2013).

Thermal comfort

As stated in the previous section, along history, thermal comfort played an important role in IAQ perception. Feeling comfortable in an interior space (home, office, school) has a direct impact on people's mood, affecting also productivity. According to the international standard EN ISO 7730, thermal comfort is "that condition of mind which expresses satisfaction with the thermal environment" (EN ISO 7730:2005). In simple terms, it is the comfortable condition where a person is not feeling too hot or too cold. According to ASHRAE standard 55 (ASHRAE, 2010), thermal comfort is assessed by subjective evaluation as a cumulative effect resulting from environmental factors (temperature, thermal radiation, humidity and air speed), and from personal factors (activity and clothing).

Although thermal comfort evaluation relies on subjective factors, it is the effect of temperature and humidity combined in the enthalpy of air that is essential for the perceived air quality (Fanger, 2000). Thermal conditions are important for IAQ because temperature and humidity can affect pollutant emission rates, the growth of microorganisms on building surfaces, the survival of airborne infectious pathogens, the survival of house dust mites which are a source of allergens, people's perception of the quality of indoor air, prevalence rates of building related health symptoms, and work performance (ASHRAE, 2017). Besides affecting thermal comfort, indoor temperature (T) and relative humidity (RH) affect global IAQ by influencing concentrations of indoor air pollutants in buildings, essentially because ventilation is usually performed to control those parameters (Fang et al., 1998; Fang et al., 2004). Changes in indoor temperature are easily perceived by humans. Besides outdoor temperature, sources of heat inside buildings include the individuals (human metabolism activity, which varies from person to person), heating systems and equipment, and artificial lightning systems (Fang et al., 1998; Humphreys, 1978).

Although changes in RH are more difficult to be perceived by humans than changes in T (Wolkoff and Kjaergaard, 2007), air humidity contributes to the body's ability to cool itself by evaporation of perspiration, thus a high humidity influences a person's well-being by the inhibition of perspiration at skin level (Teodosiu et al., 2003). It also interferes with the skin temperature and the body heat balance. Humidity in indoor air results from the balance between the ventilation and the production of water vapour. Major humidity sources of buildings' indoor air include human metabolism of occupants and their activities (like washing, cooking, among others), water leaks, outdoor humidity infiltrations, deficit thermal building isolation, and insufficient or non-homogenous ventilation.

Indoor air pollutants

IAQ represents the indoor air concentrations of pollutants that are known or suspected to affect people's comfort, environmental satisfaction, health, work or school performance (ASHRAE, 2017). Besides physical agents like thermal parameters, IAQ can also be affected by various chemicals (including particles and fumes, VOC and other gases), and biological agents (like bacteria, fungi and pollen). IAP is ubiquitous, and takes many forms, ranging from smoke emitted from solid fuel combustion, especially in buildings in developing countries, to complex mixtures of volatile and semi-volatile organic compounds present in modern buildings (Zhang and Smith, 2003). In fact, indoor environments represent a mix of outdoor pollutants and indoor contaminants. The first are associated with vehicular traffic and industrial activities, which can enter by infiltrations and/or through natural and mechanical ventilation systems. The latter originate inside the building, from combustion sources (such as burning fuels, coal, and wood; tobacco smoke; and candles), emissions from building materials and furnishings, central heating and cooling systems, humidification devices, moisture processes, electronic equipment, products for cleaning, pets, and the behaviour of building occupants (Cincinelli and Martellini, 2017). Some of the most relevant pollutants for indoor air are described in more detail in this section. Although often considered indoor air pollutants, other compounds like biological agents (bacteria, fungi, *legionella*, pollens) were beyond the scope of this thesis, and they were not described.

Carbon dioxide (CO_2)

Historically, as one of the first gases measured in indoor environments, CO_2 is a colourless, odourless, and non-flammable gas. Although present in outdoor air at low concentrations, acting as a greenhouse gas, according to Jones (1999) indoor/outdoor ratio is 3/1 for the majority of indoor environments.

CO_2 has been often used as a surrogate of air change rate/ ventilation, mainly because high concentrations indicate a poor air renovation rate which in turn might indicate an accumulation of other pollutants in indoor air (Griffiths and Eftekhari, 2008). Major indoor sources include combustion processes and exhalation through breathing of living beings.

Carbon monoxide (CO)

Carbon monoxide (CO) is a colourless, non-irritant, odourless and tasteless toxic gas, emitted from all combustion sources. It is produced by the incomplete combustion of carbonaceous compounds, like wood, petrol, coal, natural gas and kerosene. Small amounts of CO are also produced endogenously (Alm et al., 1999). It is not detectable by humans either by sight, taste or smell, but in the human body it reacts with haemoglobin to form carboxyhaemoglobin, interfering with the oxygen carrying capacity of blood (WHO, 2010). Evidence has been made of two major concerns: short-term exposure to relatively high concentrations, that have the potential to cause death or acute illness, and chronic exposures to relatively low concentrations, which may be associated with unvented combustion appliances and other circumstances (Godish, 2001).

It is one of the most common outdoor air pollutants. Anthropogenic emissions are responsible for about two thirds of the CO in the atmosphere and natural emissions account for the remaining one third. Indoors, CO is produced by combustion sources (cooking and heating) and is also introduced through the infiltration from outdoor air into the indoor environment (WHO, 2010). In developed countries, the most important indoor source of CO is emissions from faulty, incorrectly, poorly maintained or poorly ventilated cooking or heating appliances that burn fossil fuels, while in developing countries the burning of biomass fuels and tobacco smoke are the most important sources (WHO, 2010). Other indoor sources include clogged chimneys, wood-burning fireplaces, decorative fireplaces, gas burners, supplementary heater without properly working safety features. However, in the absence of indoor sources, current concentrations of CO in indoor air in European and North American cities are well below the levels of existing air quality guidelines and standards (Chaloulakou and Mavroidis, 2002; WHO, 2010).

Nitrogen dioxide (NO_2)

There are seven oxides of nitrogen (NO_x) that may be found in outdoor air, but the air pollutant species of most interest from the air quality and health point of view are NO and NO_2. The former is a relatively non-toxic gas, produced in the high-temperature reaction of nitrogen (N_2) and oxygen (O_2) in combustion, and rapidly oxidized to nitrogen dioxide (NO_2), a substance with greater toxicity. NO_2 is a water-soluble red to brown gas with a pungent acrid odour. It is considerably non-soluble in tissue fluids, thus it enters the lungs reaching the lower smaller airways and alveolar tissue (Godish, 2001).

Indoor levels of NO_2 are a function of both indoor and outdoor sources, meaning that high outdoor levels originating from local traffic or other combustion sources influence indoor levels (Kousa et al., 2001; Wichmann et al., 2010). Thus, distance from major roadways and traffic density appears to be correlated with its indoor levels in buildings, including schools (Kodama et al., 2002). Besides air exchange rate between indoors and outdoors, NO_2 indoor levels also vary widely depending on the presence of indoor sources, air mixing within and between rooms, the characteristics and furnishing of buildings, and reactive decay on interior surfaces (WHO, 2010). Indoor sources include fuel-burning stoves (wood, kerosene, natural gas, propane, etc.) and fuel-burning heating systems (wood, oil, natural gas, etc.). In the absence of indoor sources, indoor levels are lower than outdoors, although indoor levels may exceed those found outdoors in the presence of indoor sources, especially unvented combustion appliances (WHO, 2006).

Ozone (O_3)

Ozone (O_3) is a colourless gas and a strong oxidizing agent, being a normal constituent of the atmosphere, with peak concentrations in the middle stratosphere. At ground-level atmosphere (troposphere), it is considered a pollutant. However, O_3 is not directly emitted by primary sources, but of secondary origin (it is formed in the atmosphere rather than being emitted) (Sousa et al., 2006). The precursors that contribute most to the formation of oxidant species in polluted atmospheres are NO_2 and non-methane volatile organic compounds (NMVOC), especially unsaturated VOC. O_3 exhibits a considerable special variation in the atmosphere, with highest concentrations usually occurring on the vicinity of large urban conglomerates (WHO, 2006).

Indoors, O_3 can be produced by equipment that uses ultraviolet light or causes air ionization, including photocopiers, laser printers and ionizers. As it is highly reactive, it is usually only found in substantial concentrations near the source, and generally does not tend to accumulate in the indoor environment. It also reacts quickly with surfaces when penetrating indoors, which is why O_3 levels indoors are generally much lower than those measured outdoors. O_3 concentrations, however, are generally high during hot and sunny weather, precisely the conditions under which people open their windows and doors and spend more time outdoors (WHO, 2006). In the absence of other indoor sources, outdoor air is expected to be the major source of O_3 indoors (Lee et al., 2004)

Formaldehyde

Formaldehyde is a colourless, gaseous substance with a strong, pungent odour. It is molecularly the smallest and the simplest aldehyde. Due to its unique molecular structure (the carbonyl is attached directly to two hydrogen atoms), it is highly reactive chemically and photochemically. It has a good thermal stability relative to other carbonyls and has the ability to undergo a variety of chemical reactions, which makes it useful in industrial and commercial processes. As a chemical feedstock, formaldehyde is used in many different chemical processes, namely urea and phenol-formaldehyde resins (those of particular significance for indoor environments, accounting for 50% of formaldehyde consumed annually) (Godish, 2001). Formaldehyde is produced in the thermal oxidation of a variety of organic materials, thus it is found in the emissions of motor vehicles, combustion appliances, wood fires, and tobacco smoke. It is also produced in the atmosphere as a consequence of photochemical reactions and hydrocarbon scavenging processes, and in indoor air as a result of chemical reactions.

Formaldehyde is omnipresent in both outdoor and indoor environments. Indoor concentrations vary from structure to structure, depending on the nature of sources present and environmental factors which may affect emissions and indoor concentrations. Those factors include the strength of formaldehyde-emitting products present, the loading factor (m^2/m^3), which is described by the surface area (m^2) of formaldehyde-emitting materials relative to the volume (m^3) of interior spaces, environmental factors, materials/products age, interaction effects, and ventilation conditions. Pressed wood products have been the major source of formaldehyde contamination in indoor environments, while other have also been relevant, namely particle board as underlayment, floor decking, components of cabinetry, furniture, and a variety of consumer products, as well as a decorative wall panelling (Godish, 2001). Formaldehyde-emitting products have historically differed in their emission potential – essentially decreasing with product improvements along the time.

Volatile organic compounds (VOC)

VOC comprise a very wide range of hydrocarbons, oxygenates, halogenates and other carbon compounds existing in the atmosphere in the vapour phase. Leakage from pressurized systems, evaporation of a liquid fuel, combustion of fossil fuels and incineration processes, exhaust pipe of vehicles, as well as organic solvent used for example in paints and adhesives, are among the predominant sources of VOC (WHO, 2006). VOC vary widely from building to building, depending on sources present as well as human activities. Due to these factors, some authors assume levels of total volatile organic compounds (TVOC), avoiding its individual quantification (Jones, 1999; Yoon et al., 2011). Despite inherent difficulties in sampling and identifying VOC present in mixtures at low concentrations, available evidence indicates that a large and variable number of those compounds are present in indoor air (Godish, 2001).

Many microenvironmental and behavioural factors can affect indoor concentrations of VOC (Jia et al., 2008). Outdoor air, emissions from building materials and occupants' activities are the main indoor VOC sources. Outdoor air entering the building can bring VOC from outdoor sources, especially in traffic and industrial sites. Attached garages or parking lots are relevant cases (Jones, 1999). Still, major indoor sources are endogenous, namely construction and finishing VOC-emitting products (paints, varnishes, glues), coatings (carpets, thermal and noise isolation), furniture (plywood, foams, polymers), cleaning and disinfection products, personal care products (cream, lotions, perfumes), fresheners and combustion processes (heating systems, tobacco smoke) (WHO, 2010).

Particulate Matter (PM)

Particulate air pollutants (particulate matter, PM) comprise material in solid or liquid phase suspended in the atmosphere. They can have different shapes and sizes, may consist of many chemical and biological compounds (droplets, fumes, dust, pollens, bacteria and fungi spores) and, consequently, coming from various sources (WHO, 2006). Such particles can be either primary or secondary, depending on their origin and formation processes, and cover a wide range of sizes. Primary particles are emitted directly from natural and anthropogenic sources, while secondary particles are produced from both naturally emitted gaseous substances and anthropogenic sources as a result of chemical processes involving gases, aerosol particles and water vapour. The size of suspended particles varies, from a few nm to tens of µm. In practical terms, measurements of total suspended particulates (TSP) have been replaced by: i) PM_{10} – particles with an aerodynamic diameter smaller than or equal to 10 µm, also called "thoracic particles" as they can penetrate into the lower respiratory system; and ii) $PM_{2.5}$ – particles with an aerodynamic diameter smaller than or equal to 2.5 μm, also called "respirable particles" as they can penetrate into the gas exchange region of the lungs (Brunekreef and Holgate, 2002; Monn, 2001). In fact, $PM_{2.5}$ are an important indicator of risk to health from particulate pollution, as they can penetrate deeper into the lungs, become trapped inside the alveoli and worse effects on human health might be expected (Brunekreef and Holgate, 2002; Schwartz and Neas, 2000).

Indoors, PM major sources include: i) burning processes, like tobacco smoke, fireplaces, burning candles, oil lamps, or incense sticks; ii) cooking activities, varying with the activity itself, e.g. baking, roasting, frying, toasting, as well as varying with the respective cooking goods, the ventilation conditions and the room geometry, with high pollution expected when cooking on open fireplaces; iii) cleaning activities, while removing dust from surfaces, in particular sweeping, and the use of some cleaning agents which lead to the formation of new particles and/ or particle growth through oxidative processes in the indoor environment; iv) outdoor air, depending on the particle fraction, ventilation behaviour of the room user, tightness of the building envelope, dust deposition rates indoors, resuspension effects in the room and coagulation behaviour of particles (Fromme, 2012). Other important influencing factors for indoor PM include season, and age and location of the building (Heroux et al., 2010; Martuzevicius et al., 2008). Although PM may enter the building through windows and doors or even through leakages in the building envelope, indoor sources seem to be the main influence to indoor PM concentrations, sometimes being reported higher than outdoors (Wichmann et al., 2010).

Radon

Radon is by far the most important source of ionizing radiation among those of natural origin, and a major contributor to ionizing radiation dose received by the general population. It is a colourless, odourless and tasteless natural radioactive gas with origin in the decay of uranium that is found on soil and rocks. Although all rocks contain some uranium, outdoor radon concentrations are usually small in comparison with those typically found indoors, as radon travels through the soil and enters buildings through cracks in the foundations.

In fact, the main source indoors is the radon produced by the decay of radium in the soil. Although usually not so significant, other sources include radon exhaling from building materials. Radon levels in dwellings are usually subject to a typical diurnal variation with higher concentrations during the night and dawn, and are also subject to a typical seasonal variation with the highest concentrations during the heating season (October to April) (WHO, 2009). Annual random variations are also usual, and they can be related to several factors, such as weather patterns and occupants' behaviour (Dumitru et al., 2015). The radioactive particles (decay products) from radon decay during breathing can be retained in the lungs, continuously releasing ionizing radiation that can harm human health (WHO, 2009). It is considered by the

United States Environmental Protection Agency (USEPA) and the WHO as the main cause of lung cancer among non-smokers and the second cause of lung cancer in the general population (smoking being the first) and there is no known threshold below which exposure to radon does not present risk (Dumitru et al., 2015; Schmid et al., 2010; USEPA, 2003; WHO, 2009). Therefore, the International Committee for Radiological Protection (ICRP) emphasized the importance of monitoring and controlling radon concentrations in dwellings and work places (ICRP, 2007).

There are numerous indoor sources of air pollutants, some related to combustion processes and others related to other human activities. Less obvious are those related to building materials and products used indoors. Table 2.2 summarizes the reviewed indoor air parameters and pollutants and their major sources inside buildings.

Table 2.2 - Summary of the main indoor sources of the indoor air parameters and pollutants reviewed.

Parameter/pollutant	**Main indoor sources**
Temperature	Outdoor temperature, occupants (human metabolism), heating systems and equipment, artificial lighting systems
Relative humidity	Occupants (human metabolism) and their activities (washing, cooking, and others), water leaks, outdoor humidity infiltrations
Carbon dioxide (CO_2)	Exhaled through breathing of living beings, combustion processes
Carbon monoxide (CO)	Outdoor air, combustion sources, cooking, burning biomass fuels, gas burners, tobacco smoke
Nitrogen dioxide (NO_2)	Outdoor air, fuel-burning stoves (wood, kerosene, natural gas, propane, etc.), fuel-burning heating systems (wood, oil, natural gas, etc.)
Ozone (O_3)	Outdoor air, ultraviolet light or ionization equipment (photocopiers, laser printers, ionizers)
Formaldehyde	Formaldehyde-emitting products (pressed wood, particle board, floor decking, components of cabinetry, furniture, consumer products, decorative wall panelling)
Volatile organic compounds (VOC)	Construction and finishing VOC-emitting products (paints, varnishes, glues), coatings (carpets, thermal and noise isolation), furniture (plywood, foams, polymers), cleaning and disinfection products, personal care products (cream, lotions, perfumes), fresheners, combustion processes (heating systems, tobacco smoke)
Particulate Matter (PM)	Burning processes (tobacco smoke, fireplaces, burning candles, oil lamps, incense sticks), cooking activities (baking, roasting, frying, toasting), cleaning activities (vacuum cleaning, sweeping), outdoor air
Radon	Radon produced by the decay of radium in the soil, entering building through cracks in the foundations

2.1.3 International guidelines and national legislation

In 2010, the WHO Regional Office in Europe published a document entitled "WHO guidelines for indoor air quality: selected pollutants" (WHO, 2010) containing guidelines for the protection of public health from health risks due to a number of chemicals commonly present in indoor air. Although it included radon, a specific document for this indoor air pollutant was published one year before entitled "WHO Handbook on Indoor Radon - a public health perspective" (WHO, 2009). These guidelines were based on a comprehensive review and evaluation of the accumulated scientific evidence by a multidisciplinary group of experts studying the toxic properties and health effects of these pollutants. The primary aim of these guidelines was to provide a uniform basis for the protection of the population from adverse effects of indoor exposure to air pollution, and to eliminate or reduce to a minimum the exposure to those pollutants that are known or are likely to be hazardous. Although they have the character of recommendations, these guidelines provide a scientific basis for legally enforceable standards.

Some national governments and organizations adopted other reference values. In this particular case and although not regulating indoor air, USEPA published a few guidelines to assist in protecting IAQ, namely the "EPA Assessment of Risks from Radon in Homes" (USEPA, 2003), establishing guidelines for radon concentrations indoors. In the case of radon, also the European Union (EU) recommended annual average radon concentrations below 300 Bq m^{-3} in dwellings and mixed-use buildings, like primary and nursery schools (EU, 2013). Although more focused on ventilation, ASHRAE published the most used worldwide ASHRAE standard 62 for "Ventilation for Acceptable Indoor Air Quality", and they also published ASHRAE standard 55 for "Thermal Environmental Conditions for Human Occupancy", in which they established reference values for indoor temperature and relative humidity among other parameters (ASHRAE, 2007).

In Portugal, the government published in 2006 the new Regulation of Energy and Air Conditioning Systems in Buildings (Decreto-Lei nº 79/2006), transposing the Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on energy performance of buildings. Besides regulating air conditioning and energy efficiency in buildings, that Portuguese legislation went further and included mandatory requirements for ventilation and good IAQ by setting maximum reference concentrations for relevant indoor air pollutants, including PM_{10}, CO_2, CO, O_3, formaldehyde, TVOC and radon. A few years later, in 2013, the Portuguese government transposed the new European Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings for a new national law (Decreto-Lei nº 118/2013) revoking the previous. In its article 36 b), this new legal document pointed to a new Portuguese ordinance for IAQ (Portaria nº 353-A/2013). This is the current Portuguese legislation, and it established the reference concentrations (8-hour mean values) for indoor air pollutants in buildings, as well as the sampling methods and compliance criteria that must be taken into account. Table 2.3 summarizes the main reference values for indoor air pollutants considered along this thesis.

Table 2.3 - Summary of reference values from the World Health Organization (WHO, 2010), Portuguese 2006 legislation (Decreto-Lei nº 79/2006) and Portuguese 2013 legislation (Portaria nº 353-A/2013).

Pollutant	**WHO**	**Portuguese 2006 legislation**	**Portuguese 2013 legislation** [a]
CO_2	NA	1800 mg m^{-3}	2250 µg m^{-3} (+ 30% MT)
CO	100000 µg m^{-3} (15 min) 35000 µg m^{-3} (1 h) 10000 µg m^{-3} (8 h) 7000 µg m^{-3} (24 h)	12500 µg m^{-3}	10000 µg m^{-3}
Formaldehyde	100 µg m^{-3} (30 min)	100 µg m^{-3}	100 µg m^{-3}
NO_2	200 µg m^{-3} (1 h) 40 µg m^{-3} (annual)	ND	ND
O_3	ND	200 µg m^{-3}	ND
TVOC	ND	600 µg m^{-3}	600 µg m^{-3} (+ 100% MT)
$PM_{2.5}$	25 µg m^{-3} (24 h) 10 µg m^{-3} (annual)	ND	25 µg m^{-3} (+ 100% MT)
PM_{10}	50 µg m^{-3} (24 h) 20 µg m^{-3} (annual)	150 µg m^{-3}	50 µg m^{-3} (+ 100% MT)
Radon	100 Bq m^{-3} [b]	400 Bq m^{-3} [c]	400 Bq m^{-3} [c]

[a] reference values for Portuguese 2013 legislation are for 8-hour means; [b] proposed reference level (WHO, 2009), although if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq m^{-3}; [c] mandatory only in buildings located in granitic zones, namely in the districts of Braga, Vila Real, Porto, Guarda, Viseu and Castelo Branco; MT – margin of tolerance; min – minutes; h – hour; ND – not defined.

2.2 Children's exposure to air pollution[*]

Duan (1982) and Ott (1982) introduced in the early 80's the concept of *human exposure* (or simply *exposure*), which was defined as "an event that occurs when a person comes in contact with the pollutant" (Ott, 1982). Thus, exposure to air pollution occurs whenever a human being breathes air in a location where there are at least trace amounts of airborne pollutants (Klepeis, 2006). Conceptually, this occurs along the "environmental pathway" between concentration and dose as represented in Figure 2.3.

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[*] adapted from: Branco PTBS, Alvim-Ferraz MCM, Martins FG, Sousa SIV, 2014. The microenvironmental modelling approach to assess children's exposure to air pollution – A review. *Environmental Research* 135, 317-332.

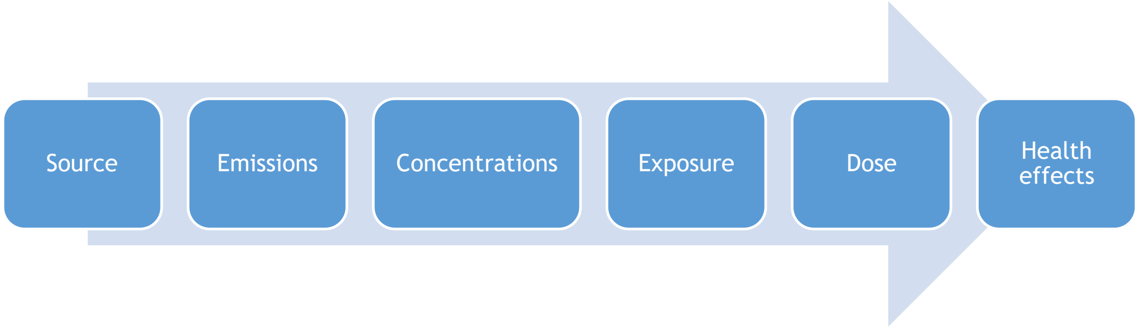


Figure 2.3 - The "environmental pathway" proposed by World Health Organization (WHO, 2006).

Exposure studies on children are usually a great ethics challenge especially for young children, because they cannot intentionally be exposed to contaminants and, according to the Helsinki declaration, they are not old enough to make a decision on their participation. Using adult surrogates for these studies introduces bias, because adults do not behave like young children, therefore they cannot mimic their contact activities (Cohen Hubal et al., 2000). This is why it is challenging to develop a realistic estimation of children's exposures to air pollution.

In their daily routine, children move from one location to another and are exposed to a large number of air contaminants for different time durations, raising serious questions about whether such exposures are likely to cause adverse health effects, and which are pollutants' sources. Thus, a complex multifactorial approach for exposure assessment seems appropriate aiming to: i) associate exposure with health effects; ii) link health effects with pollution sources; and iii) determine the exposure value of an individual or group of individuals relative to the population exposure distribution (Moschandreas and Saksena, 2002). In this field, epidemiological studies provide the opportunity to assess the effects of exposure to air pollution on children's health, i.e., the exposure-response relationship. Multiple outcomes from this type of studies are of interest (Gilliland et al., 2005), including the prevalence of asthma and respiratory diseases, as well as the associated morbidity and mortality. In several countries, as the example of China (Ye et al., 2007), despite the increasing concern about environmental health, most risk-assessment activities are conducted focusing on adults, making environmental health policies inefficient in protecting children's health. Children exposure should be developed to characterize real-life situations, whereby i) potentially exposed populations are identified; ii) potential pathways of exposure are recognized; and iii) the magnitude, frequency, duration and time-pattern of contact with a pollutant are quantified (Cohen Hubal et al., 2000). Assessing children's exposure to air pollution cannot be merely reduced to the measurements of air pollutants concentrations in one or more environments. In fact, exposure studies can be used to establish where air pollutants exposures occur and the source of those air pollutants (Weisel, 2002).

Cohen Hubal et al. (2000) reviewed the factors that strongly influence children's exposure, and concluded that: i) the physiologic characteristics and behavioural patterns of children result not only in exposure differences between children and adults, but also in differences among children of different developmental stages; ii) significant challenges are associated with developing and verifying exposure factors for young children, so it is necessary to develop and improve the methods for monitoring children's exposures and activities; iii) the data usually available for conducting children's exposure assessments are highly variable, depending on the route of exposure considered, so it requires the collection of their physical activity data (especially young children) to assess exposure by all routes. Socioeconomic status also greatly influences children's exposure to air pollution (Chaix et al., 2006).

2.2.1 Methods to assess children's exposure to air pollution

The study of exposure assessment has evolved significantly over the past 30 years (Lioy, 2010), through the appearance of a myriad of methods for assessing personal exposure levels to air pollution. Two different approaches, direct and indirect, described below, have been used to assess personal exposure to air pollution (Ott, 1982).

There are two available direct methods: i) personal monitoring, which monitors pollution concentrations using portable equipment worn by the subjects, and can work actively (pumped) or passively (diffusive); and ii) biomonitoring, which is the use of biomarkers to assess exposure to air pollution, although its usability on exposure studies to air pollution is very specific. Simplicity of design and freedom from modelling assumptions are the advantages of the direct approach (Duan et al., 1991; Wallace and Ott, 1982). Despite the fact that direct measurements clearly reflect individual personal exposure levels, measurements of personal exposures are expensive, time consuming and difficult to apply (Monn, 2001), especially to young children (Jones et al., 2007). It is important to note that a personal measurement does not *a priori* provide more valid data than a stationary measurement, i.e. a personal sample in a study investigating effects from a specific place or source is often influenced by other sources than those on focus of the investigation, and may thus confound the exposure-effect outcome. Nevertheless, in 1984 USEPA performed two large studies of carbon monoxide (CO) exposure in Washington, DC and Denver, Colorado, where 1987 persons were followed for 24 hours in Washington and 1139 persons were followed for two days in Denver. The specific personal monitor used provided exact times in each microenvironment without having to write them down in a questionnaire. This was the first and the most complete study to ever include actual ME measurements, and included many more MEs than in subsequent studies, although being a personal monitoring study (Akland, 1985). While biomarkers offer clear advantages, some important criteria must be met when using them for this purpose (Cohen Hubal et al., 2000): i) biomarkers that can accurately quantify the concentration of an environmental contaminant and/or its metabolite(s) in easily accessible biological media (blood, urine, and breath) must be available; ii) biomarkers must be specific to the contaminant of interest; iii) the pharmacokinetics of absorption, metabolism, and excretion must be known; and iv) the time between exposure and biomarkers sample collection must be known. Although there are a number of biomarkers that meet these criteria, few studies using biomarkers have collected all of the information required to accurately estimating exposure. In studies with large sample sizes, long duration and diverse outcomes and exposures, efforts for exposure assessment should rely on modelling to provide estimates for the entire cohort. This should be supported by subject-derived questionnaire data, although assessment of some exposures of interest requires individual measurements using snapshots of personal and microenvironmental exposures over short periods and/or in selected microenvironments (Gilliland et al., 2005). In addition, significant challenges are associated with collecting biomarkers' data from children (Weaver et al., 1998). Although findings from Sexton et al. (2000) indicated that, with proper care, it could be practicable to obtain personal VOC measurements from elementary school children wearing personal VOC samplers, direct methods are unusual on children studies due to their difficult applicability on their time-space-activity specifications. For example, personal monitors for suspended PM may be particularly impractical for infants or young children due to the requirement of attached pumps (Jones et al., 2007).

Exposure modelling is the indirect method that assesses (estimates or predicts) personal exposures derived from ambient measurements (i.e., measurements made in locations frequented by the study participants) combined with time-activity data, which results in exposure models (MacIntosh and Spengler, 2000; Monn, 2001; Ott, 1982). Some authors reviewed the existing exposure models and tried to classify them, considering different categories, like Klepeis (2006) and Zou et al. (2009). The most common classification is the division into three major groups, as reviewed by Milner et al. (2011): i) Statistical regression models (not unanimously considered as models), in which linear and nonlinear regression techniques are used to relate personal exposure to its determinants based on measurement data (Kollander, 1991); ii) Computational Fluid Dynamics (CFD), used to model the spatial and temporal variations in pollutants' concentrations at an extremely fine scale, working on the basic fluid dynamics principles; and iii) Microenvironmental modelling, an approach in which weighted average exposure is calculated using time spent and time-averaged concentrations at various places where the population under observation is likely to circulate (Duan, 1981; 1975). There are also examples where different models can be complementary (Mölter et al., 2010a; Mölter et al., 2010b), increasing the amount of available data for assessing personal exposure to air pollution, or using both indirect and direct approach to compare the exposure values estimated by the indirect approach with the real personal sampling measured values, which can also be done to validate the model. It is feasible to believe that the indirect methods of exposure assessment can yield estimates closely matching those of the direct method (Malhotra et al., 2000). However, CFD is not considered appropriate for generic population exposure modelling, because it is primarily a research tool used for ventilation, airflow and contaminants' modelling, rather than individual or population exposure modelling. In the same way, and despite being frequently used in epidemiological studies, regression models have major issues that could be constraints to their applicability, like their transferability to other locations and to other periods of time, when compared to a mechanistic approach like microenvironmental modelling (Ashmore and Dimitroulopoulou, 2009). In this field, microenvironmental modelling can be used to determine exposures to both individuals and large populations, because it is not often financially practical to make a sufficient number of exposure measurements to completely characterise the spatial and temporal range of exposures in large populations, and to predict what changes in emissions or activities are most effective to reduce exposure (Weisel, 2002). Furthermore, it has several advantages, such as the possibility to be rapidly and inexpensively used to calculate estimates of exposure over a wide range of exposure scenarios (Klepeis, 1999), and also the most appropriate way to examine the potential outcomes of future environmental and/or building interventions and policies, safeguarding the importance to consider indoor exposure modelling (Milner et al., 2011). However, and according to Klepeis (1999), a main disadvantage of this approach, compared to the direct approach, is the currently research needed for its systematic validation, i.e., the results of a fully developed indirect exposure assessment must be compared to an independent set of directly measured exposure levels. The main advantages and limitations of the methods and approaches available to assess children's exposure to air pollution, as well as several examples of studies using them, are summarized in Table 2.4.

2.2.2 The microenvironmental modelling approach

Despite the several available methods within different approaches to assess human exposure to air pollution, the microenvironmental modelling approach, an indirect approach, seemed to be the best to assess children's exposure to air pollution. This is because it is a faster and less expensive method when compared to others, and it is relatively straightforward to apply, taking into consideration several levels of pollution to which a child is exposed during the course of the day (Malhotra et al., 2000). The earlier researchers Fugas (1975), Duan (1981), and Ott (1982) introduced the concept of calculating exposure as the sum of the product of time spent by a person in different microenvironments and the time-averaged air pollution concentrations occurring in those microenvironments. Equation 2.1 represents the standard mathematical formula for integrated exposure.

$$E_i = \sum_{j=1}^{m} C_{ij} t_{ij} \tag{2.1}$$

E_i is the exposure of the i^{th} individual, C_{ij} is the concentration of the pollutant measured in the j^{th} microenvironment of the i^{th} individual, t_{ij} is the time spent by the i^{th} individual in the j^{th} microenvironment, and m is the number of different microenvironments.

Table 2.4 – Methods and approaches to assess children's exposure to air pollution: main advantages and limitations, and examples of children's studies.

Approach and method		Main advantages	Main limitations	Examples
Direct	Personal monitoring	- Simplicity of design - Freedom from modelling assumptions	- Expensive and time-consuming - Limited for large population studies (e.g. cohort/panel studies) and for young children	Gonzalez-Flesca et al. (2007); Thiriat et al. (2009); Buonanno et al. (2013); Both et al. (2013)
	Biomonitoring	- Useful measure of direct exposure - Aggregate over all sources and pathways	- Expensive and time-consuming - Complex methodologies - Hard to collect all of the info required to accurately estimate exposure	Delfino et al. (2006); Neri et al. (2006a); Neri et al. (2006b); Ruchirawat et al. (2007)
Indirect	Statistical regression models	- Frequently used in epidemiologic studies	- Limited extrapolation to other locations and to other periods of time	Gauvin et al. (2002); Chaloulakou and Mavroidis (2002); Delfino et al. (2004); Zhou and Zhao (2012)
	CFD[a]	- Enables modelling at an extremely fine scale - Good as a research tool for ventilation, air flow and contaminants modelling	- Not considered appropriate for generic population exposure modelling - High technical and very specific knowledge and software required	Huang et al. (2004); Valente et al. (2012)
	ME[b] modelling	- Conceptually easy to apply - Can be used to determine exposure to both individuals and large populations - Rapidly and inexpensively calculates exposures over various scenarios - The best way to predict the potential outcomes of future interventions and policies to reduce exposure	- There is a research need for its systematic validation	Mölter et al. (2012); Wang et al. (2008); Ballesta et al. (2006); Briggs et al. (2003)

[a]CFD – Computer Fluid Dynamics; [b]ME - Microenvironmental

By considering the pollutants' concentrations in different locations frequented by the study participants (microenvironments), and the time they spend in those locations (time-activity patterns information), it is possible to determine the children's exposure to air pollution, both in individuals and/or extend it to populations' groups. By using a ME exposure model, the researcher can quantify, in each case, the exposure distribution of study subjects and examine the likely influence of each location and other exposure factors (Klepeis, 2006). When the required input data are available or can be reliably estimated, the target population exposure distributions can be predicted accurately enough for the most practical purposes using a microenvironmental modelling approach (Hanninen et al., 2003).

In a review, Milner et al. (2011) distinguished the following types of ME models: i) measurement-based ME models, based on observational (measured) data, usually long-term averages, whether from air quality monitoring stations or local outdoor or indoor measurements; ii) mass-balance ME models, which model the movement of air pollution throughout a system of one or two ME compartments and from outdoors based on principles of mass conservation; iii) multizone ME models, based on the same principles as mass-balance ME models, although in this case a larger number of microenvironments are modelled, with exceptionally detailed input data requirements; and iv) sub-zonal ME models, similar to multizone but additional sub-zones are considered to capture within-room gradients, being useful for buildings/rooms which may have high gradients of concentration. Measurement-based was the ME model type mostly found in the literature.

Time-activity patterns are an important determinant of personal exposure to air pollution and crucial in microenvironmental modelling exposure. This is not only because of the time spent on those microenvironments but also because: i) personal exposure to environmental toxics is largely dependent on people’s movement across locations or microenvironments; and ii) of the different contributions of microenvironments on specific population groups (Dons et al., 2011). Therefore, time spent in different microenvironments makes a significant contribution to the total exposure. Regarding children, differences in their behaviour, particularly the way children interact with their environment, may have a profound effect on the magnitude of exposures to contaminants. In fact, the manner in which children, in particular infants and toddlers, move is significantly different from the manner in which adults move, and this can significantly impact their exposure to the contaminants in the air (Cohen Hubal et al., 2000). Plus, socio-demographic and environmental factors define time-activity patterns and also define quantifiable differences in personal exposures to different sources and individual compounds (Edwards et al., 2006).

As far as known, there are a limited number of children’s exposure assessment studies using microenvironmental modelling approach. Between 2002 and 2012, there were published twenty-six research papers studying the assessment of children’s exposure to air pollution using a microenvironmental modelling approach. Almost half of them were performed in the United States of America, but there were studies also performed in Europe, Australia, Latin America, India and Asia, which confirms the possibility of a worldwide application of the microenvironmental modelling approach to assess children’s exposure to air pollution. Those papers were reviewed, focusing on the methodology, challenges and limitations, to provide a summary of the available scientific findings concerning study design and data collection (time-activity patterns information, microenvironments’ selection and pollution measurements), and to some extent look at the outcomes and ME model type. Although the majority of the reviewed studies were cross-sectional, thus involving measurements at one specific point in time, microenvironmental modelling approach to assess children’s exposure to air pollution was also found in longitudinal (panel and cohort) studies, which enhances the applicability of this approach to that kind of studies. In the majority of the studies found in the literature, children were selected through a probability sample, and in some cases a stratified sampling was also used. A school-based strategy (Sexton et al., 2000) is relevant to select the study population to assess air exposures of schoolchildren and related health effects, but it is also important to improve the understanding of other factors (e.g. cultural, economic, psychological, social) affecting the willingness of families/children to participate in such studies.

The methodology looks similar when using this approach on children or on adults' studies, however children's singularities lead to considerable differences in the application of this approach. These differences are essentially related to the data collection: i) the methods for collecting time-activities patterns must be different; and ii) the time-activity patterns are itself different, which leads to choose different microenvironments to pollutants' concentrations data collection. In fact, to gather information on time-activity patterns, the most used methods were questionnaires and diaries, although different methods were also found to be feasible for children studies (Chau et al., 2002; Freeman and Saenz de Tejada, 2002; Klepeis et al., 2001; Lee et al., 2004; Wu et al., 2005). The standard research tool is still the structured, self-reported and longitudinal diary (Decastro et al., 2007). Obtaining these diary data usually represents a considerable effort in an exposure assessment study, due to the development of the diary structure, checks on subjects' reporting compliance and clarification of subjects' diary entries. Daily basis time-activity patterns recordings were usual, but longer and shorter periods were also found, although rare. The longer the periods considered, the more reliable the information is. Although several time-intervals were possible, 15-minutes intervals were the most common to record time-activity patterns information. However, to obtain children's time-activity patterns data longer periods (30-minutes) were also used, due to their lower mobility along the day when comparing to adults.

Time-activity information led to the choice of the study microenvironments. The main microenvironments used were home and school (indoors and outdoors) and in traffic. The most common microenvironments considered are merely reduced to outdoor and indoor (home and school). Children spend most of their time indoors and consequently, according to Ashmore and Dimitroulopoulou (2009), their personal exposure is dominated by air pollution in three microenvironments: home, school and transport. As stated by Mejía et al. (2011) in a review, inside school, sometimes it is important to consider distinct microenvironments (e.g., kitchen, playground, different classrooms, and teacher's lounge). In that review, the methodologies employed to assess the exposure of children to air pollutants at school were explored, namely how these methodologies influenced the assessment of the impact of this exposure on children's health, in particular related with traffic emissions. Data on pollutants' concentrations can be obtained by in-situ measurements (fixed or personal samplers) or by predictive models, respectively measurement-based and mass-balance models and both cases were found in the reviewed studies. Some studies also reported this type of data estimated from databases or in the literature. The duration and time resolution of pollutants' measurements can vary from short to long periods and from single to multiple measurements' periods or campaigns. Multiple periods or campaigns seem to be useful to study seasonal variability of exposure (mainly in longitudinal studies) (Lee et al., 2013).

Although the use of the microenvironmental modelling approach in studies to assess children's exposure to air pollution is highly encouraged, it should be taken into account that there are uncertainties associated. They are mostly due to the lack of detailed time-activity information (particularly difficult in children studies), or to the assumptions and simplifications that are usually necessary along the assessment process (existing in children's studies) (Milner et al., 2011).

2.3 Effects of indoor air pollution on children's respiratory health

Although we know much less about the health risks from IAP than we do about those attributable to the contamination of outdoor air, there has been increasing concern within the scientific community for the effects of IAQ on health (Jones, 1999). Initial interest in chemicals in indoor environments focused primarily on irritant and toxic properties of individual chemicals such as VOC and combustion products, but later concerns were also raised about the potential for chronic health effects (primarily cancer) related to exposures to organic compounds (Mitchell et al., 2007).

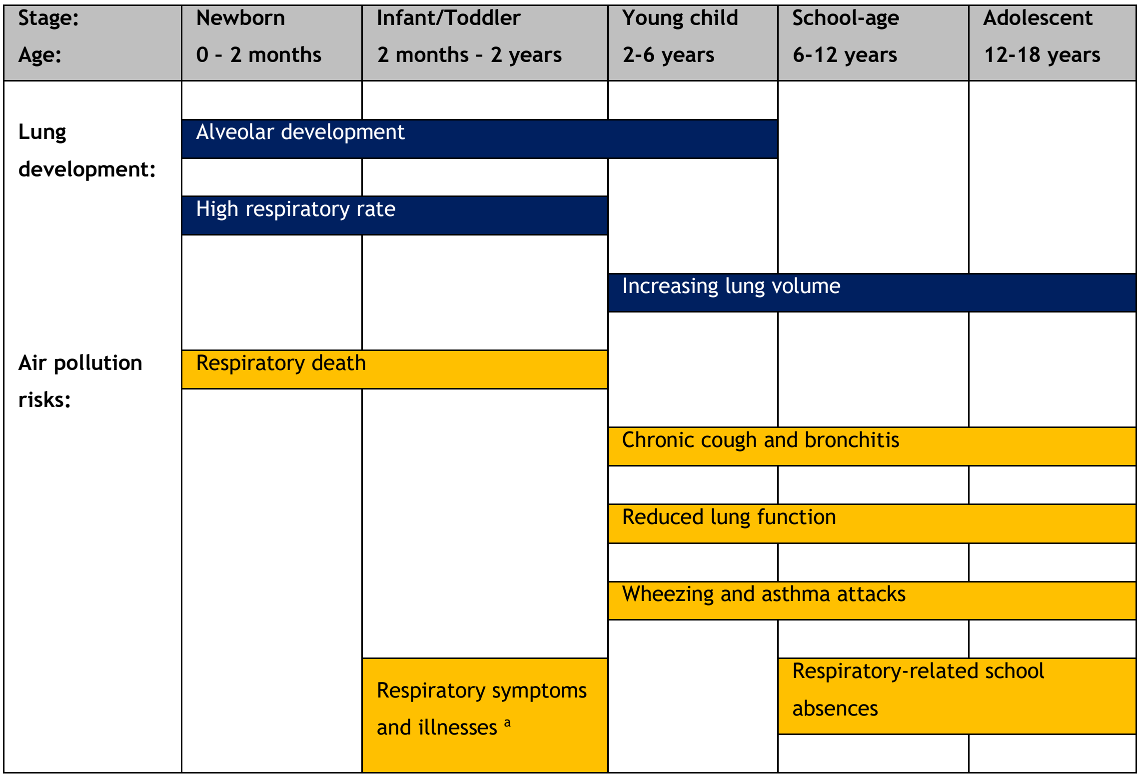
Despite the majority of the modern buildings exhibit no immediately apparent problems, IAQ plays a major role regarding public health (Sundell, 2004). The health risks from exposure to IAP may even be greater than those related to outdoor air pollution, and particularly harmful to vulnerable groups of the population such as children and those suffering chronic respiratory and/or cardiovascular diseases (Cincinelli and Martellini, 2017).It is important to consider differences in susceptibility to pollutants between equally exposed individuals. Some specific mechanisms or factors have been associated with large differences in that susceptibility, including genetic factors, age, gender, nutritional status, pre-existing disease, allergy and asthma, and tobacco smoke (Berglund et al., 1992).

The impact of IAP on children may consist of undesired health effects of different types, ranging from sensory annoyance or discomfort to severe health injuries. Those impacts may also consist of short-term or chronic effects, or ultimately death. Observational or experimental human studies can be used when studying human health effects of IAP, although epidemiological studies of pollutants are mostly observational, i.e., the investigator has no means of experimentally exposing humans to pollutants, or of allocating subjects to exposed and unexposed groups. The main advantage is that humans are studied under realistic conditions of exposure. However, critical issues include the validity and precision of exposure assessment and the control for confounding factors (Berglund et al., 1992).

Epidemiological studies strongly suggest that air pollution damages children's health, with toxic effects mainly occurring at the air-tissue interface of the lung, although effects on other organs may also be important (Kulkarni and Grigg, 2008).

IAP was reported to have short-term and chronic impacts on several organs and systems. In schools, headache was linked to high indoor formaldehyde levels (Annesi-Maesano et al., 2013). Air pollution in schools was also associated with lack of attention and greater absenteeism rate, namely due to indoor CO_2, NO_2, O_3, inadequate temperature and low ventilation (Annesi-Maesano et al., 2013). Exposure of the skin or mucous membranes to IAP may affect the sensory system and may result in tissue changes. In fact, symptoms of irritation including a dry and/or sore throat and tingling sensation of the nose have been linked with exposure to formaldehyde indoors (Berglund et al., 1992). Epidemiological, clinical, and human exposure studies indicate that low RH plays a role in the increase of reporting eye irritation symptoms and alteration of the precorneal tear film (Wolkoff and Kjaergaard, 2007). Irritation in the eyes and skin was linked to indoor high levels of VOC (Annesi-Maesano et al., 2013; Berglund et al., 1992). Eye problems were also associated with elevated concentrations of CO (Annesi-Maesano et al., 2013) and formaldehyde (Berglund et al., 1992). Although less studied, an association of liver and kidney damage with indoor VOC concentrations has been described (Annesi-Maesano et al., 2013).Vrijheid et al. (2012) suggested that a small compromise on the mental development of young children might be associated with exposure to indoor air from gas cookers.

Although impacts on other organs and systems were reported, impacts on children's respiratory system are the most relevant and the most studied. In fact, several effects on the respiratory system have been associated with the exposure to IAP during the first years (Fuentes-Leonarte et al., 2009). These include acute and chronic changes in pulmonary function, increased incidence and prevalence of respiratory symptoms, acute respiratory symptoms, and sensitisation of the airways to allergens present in the indoor environment (Berglund et al., 1992). Figure 2.4 represents the major air pollution effects on the developing respiratory system along all the stages of childhood.



[a] Air pollution exposure has also been more recently linked to respiratory symptoms and illnesses in early life including cough, bronchitis, wheeze and ear infection

Figure 2.4 – Air pollution effects on the developing respiratory system, adapted from (Ritz and Wilhelm, 2008).

Of the potential adverse effects of air pollution on children's respiratory health, the effect of air pollution on lung function is the most robust. Lung function is an important measure of respiratory health and a predictor of cardiorespiratory morbidity and mortality (Götschi et al., 2008). Children's lungs are still growing, thus early exposure to air pollutants can more easily affect lung development and lung function (Esposito et al., 2014). Moreover, early life respiratory effects from air pollution can persist into adulthood and may increase the risk of developing adult lung diseases (Goldizen et al., 2016). During growth and development of the respiratory system there are specific periods during which toxic exposures can interrupt the normal development, causing long-term damage (Goldizen et al., 2016).

However, the mechanism for pollutant-impairment of lung growth is unclear – it may be mediated by persistent short-term injury, and reduced lung growth associated with air pollution appears to be partly reversible (Kulkarni and Grigg, 2008). It remains also unclear whether subjects with slower development of lung function compensate by prolonging the growth phase, or whether they end their development at a lower plateau, thus entering the decline phase with a reduced lung function (Götschi et al., 2008). Small, albeit significant, decrements in lung function in normal children may have little clinical significance, but there is good evidence from cohort and panel studies that air pollution is associated with an increased prevalence of respiratory symptoms (Kulkarni and Grigg, 2008).

Indoor PM concentrations have been related to a decrease in lung function (mainly decrease in FEV_1, the forced expiratory volume in 1 second), in particular among children with asthma, and to an increased risk of asthmatic and bronchitis-like symptoms (Delfino et al., 2004; Hulin et al., 2012). High concentrations of PM_{10} indoor schools was also associated with regular day and night cough (Annesi-Maesano et al., 2013). In fact, as PM are a mix of particles with different particle sizes and chemical composition, they can have different adverse respiratory effects depending on its deposition in the respiratory tract and the ability of the respiratory tree to remove them. Particles < 10 µm are usually removed at the upper airways, PM_{10} tend to deposit in the nasal, pharyngeal and laryngeal regions of the respiratory system and $PM_{2.5}$ tend to deposit in the tracheobronchial region and alveoli (Hulin et al., 2012). Higher risk for dry cough at night, as well as persistent cough was also linked with high mould concentrations in indoor environments (Annesi-Maesano et al., 2013). Strong evidence is available for establishing a link between acute childhood lower respiratory tract illnesses and exposure to ETS indoors (Etzel, 1995; Jones, 1999). Increase in nocturnal attacks of breathlessness and decrease nasal patency were linked to formaldehyde in indoor environments (Annesi-Maesano et al., 2013).

Among the respiratory diseases in childhood, asthma is the most common. Asthma is a heterogeneous disease, characterized by chronic airway inflammation. It is defined by the history of respiratory symptoms such as wheeze, shortness of breath, chest tightness and cough that vary over time and in intensity, together with variable expiratory airflow limitation (GINA, 2018). Both symptoms and airflow limitation characteristically vary over time and in intensity, from mild to very severe. These variations are often triggered by factors such as exercise, allergen or irritant exposure, changes in weather, or viral respiratory infections.

Important IAP determinants of asthma morbidity in urban environments include PM (particularly the coarse fraction), NO_2 and airborne mouse allergen exposure (Breysse et al., 2010). There is recent good evidence suggesting that children with atopy or asthma and infants who are at risk of developing asthma, are more sensitive to respiratory effects of NO_2 exposure. Indoor NO_2 exposure may also enhance asthmatic reactions to inhaled allergens (Bernstein et al., 2008). NO_2 indoor school environments was also associated with current asthma, asthma attacks and medication (Annesi-Maesano et al., 2013). Although the relationship of VOC to asthma, particularly in children, remains controversial (Mitchell et al., 2007) a few studies found that its exposure indoors was linked to allergic and respiratory disease, namely increased current asthma risk, and chronic airway symptoms, as well as airway inflammation (Annesi-Maesano et al., 2013). Indoor schools, formaldehyde concentrations have been related to new asthma diagnosis among children without history of atopy. Composite wood materials that emit formaldehyde, flexible plastics that emit plasticizers, and new paint have all been associated with asthma and increased wheeze, rhinitis, eczema, respiratory symptoms (cough and phlegm), bronchial obstruction, and pulmonary infection (Mendell, 2007). These evidences highlights the potential negative effects on children's health of some common practices, for instance, using pressed wood furnishings in children's bedrooms, repainting infant nurseries, and encasing mattresses and pillows with vinyl for asthmatic children. Only a few studies investigated the associations between CO_2 and children's health, and indoor CO_2 levels were associated with childhood asthma (asthma attacks, asthma medication, and current asthma) (Annesi-Maesano et al., 2013). Relative humidity was also associated with current asthma.

The diagnosis of the allergic disease should be based on the clinical history and signs, evidence of exposure, the presence of specific antibodies, response to inhalation challenge, and improvement with cessation of exposure. Epidemiological studies have shown that exposure to dust mites in homes during childhood is a major risk factor for the development of allergic asthma. Moreover, animal allergens are found commonly indoors, even where animals are not present. As an example, cat and dog allergens have been detected in settled dust in mattress and floor dust in day care centres and in curtain and floor dust in schools (Annesi-Maesano et al., 2013). Chemical constituents of plastic have been found in household dust and studies suggest those plasticizers may be related to allergic diseases in children (Mitchell et al., 2007).

Usually found in indoor environments, formaldehyde, benzene and radon are well known for their carcinogenic effects. Lung cancer is the cancer with the strongest evidence of association with exposure to IAP, mainly radon or tobacco smoke, both in smokers and in non-smokers. However, contributions to childhood cancer remain unclear. Although epidemiological studies can be used to detect whether human exposure to a substance is actually associated with an increased cancer incidence, large numbers of people need to be followed for a long time to unequivocally document changes in cancer incidence associated with that exposure.

PART II

INDOOR AIR QUALITY IN NURSERY AND PRIMARY SCHOOLS

In the recent decades, many studies have been carried out in children’s dwellings to study IAQ, but children’s dwelling is not, however, their only indoor microenvironment. Nursery and primary schools are the first places for social activities and the most important indoor environments for children besides home, being major contributors for children’s exposure to air pollution (Jones, 1999), and up till now indoor environment quality in those places has been poorly documented (Roda et al., 2011). In fact, usually children spend more time in school environments than in any other indoor environments besides home. Poor IAQ in schools can adversely affect health, comfort and performance of schoolchildren (Mendell and Heath, 2005; WHO, 2015). In addition to higher health concerns, classroom air quality also affects the performance on school activities by children, so it is important to understand cost-effective good practices and measures to improve IAQ in schools (Wargocki and Wyon, 2013).

As indoor air is a complex mixture of pollutants from various sources and varying along time, it is not possible to assess them all simultaneously, thus some representative pollutants and parameters should be considered to characterize IAQ in scholar indoor environments. WHO selected particulate matter ($PM_{2.5}$ and PM_{10}) and some gaseous compounds as crucial to verify IAQ, namely radon, CO, NO_2, polycyclic aromatic hydrocarbons (PAH), formaldehyde and other VOC as benzene, naphthalene, trichloroethylene, and tetrachloroethylene (WHO, 2010). Although indoor O_3 concentrations are usually lower than outdoors and significantly lower than WHO guideline value, there were reported situations in school settings where WHO guideline was exceeded (Salonen et al., 2018). Thermal comfort in educational buildings is also relevant for children wellbeing facilitating learning (Zomorodian et al., 2016). Air humidity, usually measured as RH, is relevant on the IAQ study, because it affects perceived IAQ comfort, causing irritation symptoms in eyes and airways, changes in work performance and voice disruption; synergistic effects may occur with air pollutants as well (Wolkoff, 2018). CO_2 has been used as an indicator for adequate ventilation, and low concentrations in classrooms are important to provide a stimulating environment for learning processes (Salthammer et al., 2016). PM concentrations on school facilities can be influenced by several factors and can arise from both indoor and outdoor sources. Physical activities of the pupils lead to the re-suspension of mainly indoor coarse particles and greatly contribute for increasing PM_{10} in classrooms (Fromme et al., 2008). Cleaning activities and ventilation are also major factors that determine indoor air PM concentrations in classrooms (Heudorf et al., 2009). Sousa et al. (2012b) reviewed the available studies that have been done concerning PM_{10} and $PM_{2.5}$ concentrations in nursery and primary schools from 2008 to 2012, and found that: i) PM concentrations observed worldwide exceeded several times national legislations and WHO guidelines; ii) indoor/outdoor ratios were several times higher than 1; and iii) PM concentrations were reported as mainly due to constant re-suspension of particles. Added to it, there is spatial and temporal heterogeneity in the distribution of air quality within school environments, which is affected by the penetration of outdoor pollutants, wall absorption, emissions from furniture and other materials, level and length of occupancy, and quality of ventilation (Mejía et al., 2011).

Studies in school indoor environments have been mainly carried out in primary or high schools, neglecting nursery schools where infants (including infants and toddlers) and pre-schoolers often spend a significant part of their day. Due to different occupation patterns, activities and building characteristics, IAQ in nursery schools seems to be different from primary or high schools (Yoon et al., 2011). Although this has been largely ignored (Ashmore and Dimitroulopoulou, 2009), there are some studies on nursery schools. Some of them were mainly focused on ventilation, like Gładyszewska-Fiedoruk (2011), and/or on CO_2 concentrations using them as a global IAQ indicator, like Theodosiou and Ordoumpozanis (2008), or even focusing on the study of allergens (Arbes Jr et al., 2005; Salo et al., 2009). Fromme et al. (2005) analysed respirable PM and elemental carbon levels in the indoor air of apartments and nursery schools in the urban area of Berlin (Germany), and found that outdoor motorway traffic was correlated with indoor air in the studied nursery schools. However, only 1-day measurements were performed (sampling time from 7 to 8 hours) and samples occurred merely in one place per nursery school. Zuraimi and Tham (2008) studied comfort parameters as well as air velocity and air exchange rates indoor, while investigating also indoor concentrations of several air pollutants and evaluating their sources in child care centres in the tropical region of Singapore. Despite the large number of child care centres, samplings were only conducted in the middle of the week and from 8 a.m. to 5 p.m. (occupation periods), which did not allow understanding potential differences in IAQ between occupation and non-occupation periods (including nights and weekends). Yang et al. (2009) characterized the concentrations of different indoor air pollutants, including PM_{10}, within Korean schools and nursery schools and concluded that, in average, children were more exposed to PM inside nurseries than outdoors and suggested that increasing ventilation rate could play a key role to improve IAQ in nurseries. Although measurement campaigns were performed during summer, autumn and winter, and it took into account the building age, this study did not performed measurements in the lunch rooms neither in different floors inside each studied building, and only considered the PM_{10} fraction. Wichmann et al. (2010) studied the extent of infiltration of $PM_{2.5}$ (as well as soot and NO_2) from outdoor to indoor in the major indoor environments occupied by children (10 pre-schools, 6 schools and 18 homes) in different locations (city centre, suburban area and background), and found that, despite outdoor infiltrations, $PM_{2.5}$ concentrations in these indoor environments were mainly due to indoor sources. However, this study was limited to places occupied by children over 6 years old and measurements were only made for $PM_{2.5}$ fraction and in one classroom per pre-school. Yoon et al. (2011) measured indoor air concentrations of CO_2, PM and other chemical compounds (including TVOC and formaldehyde), as well as comfort parameters levels (T and RH) in 71 classrooms from 17 Korean nursery schools (pre-schools). They searched for IAQ differences between urban and rural areas, and confirmed that PM concentrations indoors were higher than those outdoor, and also that those in urban areas were higher than in rural areas. However, NO_2 (also considered crucial to IAQ by WHO) was not considered in that study; lack of comparative analysis between different classrooms and other environments inside the same nursery and a limited analysis to the coarser PM fractions were the major limitations of this study. Roda et al. (2011) investigated IAQ of Paris child care centres to compare it with dwellings by measuring CO_2, T and RH, besides biological and other chemical pollutants. However, measurements were made passively during an entire week (except the weekend), which did not allow to understand pollutants variations along the day. St-Jean et al. (2012) also studied IAQ in day care centres of Montréal, in Canada, to determine its associations with building characteristics. Despite considering comfort parameters and CO_2, along with a few different chemical compounds including a VOC selection, passive sampling was also used for formaldehyde and VOC sampling, which did not allow understanding pollutants variations along the day, and no outdoor measurements were used to understand the outdoor influence on nursery schools' indoor air. Also in the AIRMEX study (Geiss et al., 2011), in which 23 different VOC were measured in public buildings including schools and kindergartens in eleven European cities, passive sampling was used with the duration of a full 7-days week, not allowing to understand variations along the day and between occupation and non-occupation periods. More recently, SINPHONIE project (Csobod et al., 2014) intended to evaluate 16 chemical, physical and comfort parameters in the indoor air in schools and childcare settings from 23 European countries, although passive sampling and low-cost continuous devices were used to monitor IAQ.

A special interest has also been observed in indoor radon measurements in both nursery and primary schools with studies being performed in many parts of the world (Vaupotic, 2011). The majority of them were also only focused on primary schools, while others considered only nursery schools, and some others considered both. The extent of the studies varied considerably from study to study. There were found studies (surveys) that included a considerable number of nursery and primary schools of a particular country or region (Clouvas et al., 2011; Fojtikova and Navratilova Rovenska, 2014; Kim et al., 2011) and others studied only a limited number of buildings (Vaupotic et al., 2012; Vuchkov et al., 2013). In the latter cases, a representative number of buildings was selected taking into account selection criteria that varied from case to case, like a comparison between two different cities (Bem et al., 2013) or a comparison between urban and rural contexts (Rahman et al., 2009). In most of the above referred studies, indoor radon concentrations were measured over a fixed time period using passive solid-state nuclear track detectors (CR-39 track detectors) and electret ionization chambers (EIC), although some studies used electronic devices such as electronic integrating devices (EID) and continuous radon monitors (CRM). In fact, CRM allows understanding differences in radon concentrations between occupation and non-occupation periods as well as the baseline room scenario. In order to investigate the influence of different factors on indoor radon concentrations the majority of the studies considered measurements in different locations and different floor levels inside the buildings. Furthermore, some authors considered other factors such as type of use, building age, building materials, building improvements and different geographic contexts (rural *vs.* urban).

Despite the large number of children attending nursery and primary schools in Portugal, a limited number of studies were found. The earlier project "SaudAr – *A Saúde e o Ar que respiramos*" (Borrego et al., 2008) evaluated air quality (PM_{10}, NO_x, O_3, and formaldehyde) in four primary schools in Viseu, a mid-size city in Portugal, using passive sampling (24h and 1 week sampling periods) and numerical modelling. There were found two studies focusing on PM in primary schools (Almeida et al., 2011; Pegas et al., 2012), besides another study focusing only on the levels of ultrafine particles in Portuguese nursery schools (pre-schools) (Fonseca et al., 2014). There was also found another study which assessed indoor CO_2 concentrations (as a ventilation surrogate marker) and comfort parameters (Carreiro-Martins et al., 2014). Despite the considerable number of buildings and the three classrooms per building analysed, that study did not consider other indoor microenvironments besides classrooms, and measurements were only performed for a short period of time during occupation (point in time determinations of CO_2 instead of continuous measurements); thus, it was not possible to analyse if the results achieved were due to occupation, building materials, ventilation or even activities of the occupants. A limited number of studies regarding IAQ in primary schools were found in recent years in Portugal. Canha et al. (2013) evaluated winter ventilation rates at primary schools. Moreover, besides one study focusing on ultrafine particles (Rufo et al., 2015), there were two more focusing on $PM_{2.5}$ and PM_{10} in 3 primary schools from Lisbon (Almeida et al., 2011) and in urban and rural primary schools (Canha et al., 2014), but both using passive sampling. Another study was found regarding VOC, aldehydes, $PM_{2.5}$, PM_{10}, bacteria and fungi, CO_2, CO, T and RH in urban primary schools in Porto (Madureira et al., 2015a), although limited to urban areas and missing some other relevant indoor pollutants. Regarding radon, only one study was found (Madureira et al., 2015b), limited to primary schools of Porto urban area.

The degraded IAQ in schools often exceeded WHO guidelines has been found (Chatzidiakou et al., 2012), and studies in the literature have been suggesting evidence that certain conditions, commonly found in schools can have adverse effects on the air quality and therefore on occupant's health, such as location, age and air tightness of school building, room design, ventilation rate, building and furnishing materials, occupant's activities and outdoor pollution (de Gennaro et al., 2014; Zuraimi and Tham, 2008). However, studies on the literature had some limitations: i) younger children were usually neglected when compared with primary/elementary school children; ii) studies usually focused on schools in urban environments, thus little information was available regarding rural areas and even less considering urban and rural comparisons, despite the obvious environmental and social differences that might influence IAQ; iii) passive sampling was usually considered, favouring discrete sampling instead of active and continuous sampling, thus not allowing understanding the accurate influence of background levels and activities during occupancy; iv) sampling were usually limited to one season, thus not evaluating potential seasonal variations and their influence; v) studies were usually focused in one or only a few pollutants (T and RH being often neglected), tending to be focused on specific factors neglecting interactions between different factors. Bluyssen (2017) reviewed that there is a need for studies that would provide more insight in potential causal relationships at individual level, but also insight in the total picture and interrelationships between different environmental parameters and other aspects (e.g. confounders).

To fulfil the gaps referred, the work specifically developed for this thesis and reported in the following chapters goes further on this field by characterizing IAQ in nursery and primary schools, both in urban and rural sites. It starts with a detailed characterization in four nursery schools from urban areas (from INAIRCHILD project) of CO_2 and comfort parameters (Chapter 3), gaseous pollutants (Chapter 4) and PM (Chapter 5). Thereafter, it continues with the global characterization of the 25 nursery and primary schools from INAIRCHILD project, as well as the quantification of IAQ determinants comparing both urban and rural sites (Chapter 6). Also, this part reports radon evaluation in 15 of those nursery and primary schools (Chapter 7).

Chapter 3

Indoor air in urban nursery schools: CO_2 and comfort assessment[*]

The present chapter aimed to: i) evaluate indoor concentrations of CO_2 in different microenvironments of urban nursery schools in Porto city; ii) assess comfort parameters (T and RH) in those microenvironments; and iii) analyse those concentrations and comfort parameters according to guidelines and references for IAQ and comfort.

3.1 Methodology

3.1.1 Sites description

This study was carried out on four different nursery schools (N_URB1, N_URB2, N_URB3 and N_URB4), all located at urban sites influenced by traffic emissions in Porto (Portugal), inside the study area represented in Figure 3.1. N_URB1, N_URB2 and N_URB4 buildings were located in the same traffic busy street, and the front facade of the first two were directly facing that street. N_URB3 building was located in the same area although not in the same street.

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[*] adapted from: Branco PTBS, Alvim-Ferraz MCM, Martins FG, Sousa SIV, 2015. Children's exposure to indoor air in urban nurseries-part I: CO_2 and comfort assessment. *Environmental Research* 140: 1-9.

Figure 3.1 – Location of the study area in Porto city, Portugal

A prior inspection to the studied nursery schools and rooms (throughout observations and interviews with the staff) was developed to capture relevant information on activities, building characteristics and potential sources of pollution that could influence the results obtained in this study. Appendix A present the indoor characterization form used. These four nursery schools had different management models: i) N_URB1 was a full private for-profit nursery; ii) N_URB2 was managed by a private institution of social solidarity, non-profit and with a mix of public and private funds; and iii) N_URB3 and N_URB4 were public pre-schools, entirely managed with public funds by the municipality authorities and the Ministry of Education.

General description of N_URB1, N_URB2, N_URB3 and N_URB4 was summarized in Tables 3.1 and 3.2. Infants (here defined as children < 3 years old) used to spent all the period in the nursery school inside the same classroom, both in N_URB1 and N_URB2. In all the nurseries, pre-school children (3-5 years old) went to the lunch room to eat, so they used to have different daily patterns. Air conditioners and/or heaters were only used in N_URB1, where windows were usually closed to prevent heat loss to the outside, so natural ventilation merely occurred throughout the doors to the inner corridors. Natural ventilation in the classrooms of N_URB2 and N_URB3 and in the lunch room of N_URB2 was made through windows opening to the small outdoor playgrounds. N_URB4 also had pre-school children, mixed in 3 different classrooms in the ground floor (single floor building). The electric heaters were sometimes used during the sampling periods. All the classrooms had trickle vents in windows to outdoor as a natural ventilation system.

Table 3.1 - Summary of the main characteristics for indoor air quality analysis in each studied microenvironment: type of use, children's age, floor, area and occupation.

Nursery school	Room	Type of use	Children's age (years)	Floor	Area (m^2)	Occupation (child+staff)
N_URB1	A	Classroom	1	Ground floor (back)	38	17+2
	B	Classroom	3	1st floor (front)	21	6+1
	C	Classroom	5	2nd floor (front)	59	23+2
	Lunch Room	Lunch room	3-5	Ground floor (back)	38	21 to 74
N_URB2	A	Classroom	<1	Ground floor (front)	34	10+2
	B	Classroom	2	Ground floor	40	18+2
	C	Classroom	4	Ground floor (back)	50	25+2
	Lunch Room	Lunch room	1-5	Ground floor (back)	92	17 to 68
N_URB3	A	Classroom	3-5	Ground floor	45	23+2
	B	Classroom	3-5	1st floor	36	35+2
	Lunch Room	Lunch room	3-5	Ground floor	56	17 to 45
N_URB4	A	Classroom	3-5	Ground floor	51	21+2
	B	Classroom	3-5	Ground floor	51	26+2
	Lunch Room	Lunch room	3-5	Ground floor	104	~240

Table 3.2 - Summary of the main characteristics for indoor air quality analysis in each studied microenvironment: period of occupation, ventilation and sampling days

Nursery school	Room	Period of occupation	Ventilation	Sampling days (week+weekend)
N_URB1	A	07h30-19h30	Windows to outdoor closed. Door to inner corridor almost always closed. A/C on.	5 + 2
	B	09h00-11h30 15h00-15h30	Windows to outdoor closed. Door to inner corridor almost always closed. No A/C. Electric/oil heater on.	3 + 2
	C	08h00-11h30 15h30-17h30	Windows to outdoor closed. Door to inner corridor almost always closed. No A/C. Electric/oil heater on.	3 + 2
	Lunch room	11h30-13h30	Open to kitchen and to inner corridor. No direct connection to outdoor.	7 + 2
N_URB2	A	09h00-12h00 15h30-18h00	Windows directly to outdoor (traffic street) closed – opened only after occupancy. Door to inner corridor always open. Open passage to cribs room and a small lunch room.	2 + 2
	B	09h30-11h00 12h00-16h30	Door to inner corridor almost always closed. Direct access to outdoor playground often opened. No A/C and heating off.	3 + 0
	C	09h30-12h00 14h00-16h30	Door to inner corridor almost always opened. Direct access to outdoor playground often closed. No A/C and heating off.	3 + 2
	Lunch room	11h00-12h30	Open to kitchen, to inner corridor, and to outdoor (during occupation).	2 + 0

Table 3.2 (cont.)- Summary of the main characteristics for indoor air quality analysis in each studied microenvironment: period of occupation, ventilation and sampling days

Nursery school	Room	Period of occupation	Ventilation	Sampling days (week+weekend)
N_URB3	A	09h00-11h30 13h30-16h00	Door to inner corridor often closed. Passage to outdoor playground usually opened. No A/C and heater.	3 + 2
	B	16h00-19h00	Door to inner corridor often opened. Window to outdoor open during occupancy. No A/C and heater.	2 + 0
	Lunch room	11h30-13h30	Open to inner corridor and kitchen. Windows to outdoor closed.	2 + 0
N_URB4	A	09h00-12h00 14h00-17h30	Trickle vents in windows to outdoor. Heating system was off.	2 + 2
	B	09h00-12h00 14h00-17h30	Trickle vents in windows to outdoor. Heating system was off.	2 + 0
	Lunch room	12h00-14h00	Windows to outdoor closed and no trickle vents. Heating system was off.	3 + 0

N_URB1 and N_URB2 had a lunch room on the ground floor, equipped with a kitchen using gas stoves. In N_URB3 and N_URB4 there were no cooking activities as the food were brought already cooked into those nursery schools.

Cleaning activities' patterns were also different in all the studied nursery schools. In N_URB1, the daily cleaning activities in the younger children classrooms (<3 years old) were made during sleeping time (after lunch), with children sleeping in their cots inside the classroom. In the other classrooms, cleaning used to be made during lunch time (when children were not in the classroom) or at the end of the afternoon after the occupation period. On the opposite, daily cleaning activities in the other three nursery schools were made at the end of the afternoon (after the occupation period). Besides daily cleaning, in N_URB2 there was also deep cleaning, which was made on weekends; and in N_URB3 some daily cleaning in corridors and common spaces was made during the occupation period.

3.1.2 Sampling and analysis

IAQ measurements were performed in 3 classrooms (A, B and C) in nurseries N_URB1 and N_URB2, and 2 classrooms (A and B) in N_URB3 and N_URB4, as well as in the lunch rooms of all the studied nurseries. Sampling periods can be seen in Table 3.2.

Indoor comfort parameters, namely T and RH, as well as CO_2, were continuously measured using an Haz-Scanner IEMS Indoor Environmental Monitoring Station (SKC Inc., USA) equipped with high sensitive sensors (Figure 3.2). Sampling methods and main characteristics of each sensor are summarized in Table 3.3.

Figure 3.2 - Haz-Scanner IEMS Indoor Environmental Monitoring Station

Table 3.3 - Sampling methods and main characteristics of temperature (T), relative humidity (RH) and CO_2 sensors.

Sensor	Detection methods	Sensor minimum resolution	Sensor accuracy	Measurement range
T	Electrochemical sensor	1 °C	+/- 3% of °C	-20 to 60 °C
RH	Electrochemical sensor	1%	+/- 3%	5-100%
CO_2	Non-dispersive infrared (NDIR) detection	92 mg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-9150 mg m^{-3}

The equipment was submitted to a standard zero calibration (available in the equipment) and data were validated prior to each measurement in the different rooms. Inside the rooms, the equipment was placed as close to the middle as possible, far from windows, doors and room's corners, and approximately at the same height of the breathing zone of the children. Depending on the authorizations for sampling in each nursery school, indoor measurements were performed from 2 to 9 days not simultaneously in each studied room, and in some cases both in weekdays and weekends. Sampling occurred between February and November 2013 (with a break during the summer holidays, from June to September). Measurements were logged each minute and hourly means were calculated.

The mean values were compared with reference standards and guidelines for general indoor environments, aiming to evaluate exceedances and/or non-compliances. Comparisons were performed, both for comfort parameters and CO_2 concentrations, considering national and international reference values, namely: i) Portuguese 2006 legislation (hourly means) (Decreto-Lei nº 79/2006) for CO_2 (reference value of 1800 mg m^{-3}); ii) Portuguese 2013 legislation (8 hour means) (Portaria nº 353-A/2013) for CO_2 (reference value of 2250 mg m^{-3}, plus 30% of margin of tolerance (MT) if no mechanical ventilation system was working in the room); and iii) ASHRAE standard reference ranges (ASHRAE, 2007) for T (20-23.9 ºC in winter season, and 22.8-26.1 ºC in summer season) and RH (30-60%). For the Portuguese 2013 legislation, 8-hour running means were calculated and the daily maximum was compared with the reference value. Although Portuguese 2006 legislation was officially replaced by the new Portuguese 2013 legislation, comparisons were made with both due to the clear differences between them; the comparison of these two legislations allowed concluding on the expected impacts from the application of the new one.

Outdoor T was also sampled, simultaneously and using an electronic sensor (Global Water, WE700) located in a representative place (Mesquita, 2007).

The differences between hourly mean values in different sampling days for each microenvironment were analysed by the non-parametric Kruskal-Wallis test for the microenvironments where there were more than two complete sampling days, and by the Wilcoxon Rank Sum Test (also called Mann-Whitney *U* test) for those where there were only two complete sampling days. Also the non-parametric Wilcoxon Signed Rank Test was used to analyse if the differences along the day were significant, and the non-parametric Wilcoxon Rank Sum Test was used to analyse other differences, namely between weekdays and weekends, as well as between different microenvironments and nursery schools. In all cases, a significance level (α) of 0.05 was considered. Descriptive statistics for the parameters were calculated using MS Excel® (Microsoft Corporation, USA), and other statistical analysis were determined using R software, version 3.1.2 (R Foundation for Statistical Computing, 2014).

3.2 Results and discussion

Tables 3.4 and 3.5 summarize the main statistical parameters (minimum, maximum, mean, median and standard deviation) of the hourly mean values of indoor and outdoor T, RH and CO_2, for each room of the four nursery schools studied.

Table 3.4 - Statistical parameters of the hourly mean data for indoor and outdoor temperature (T) in each room studied in the four nurseries (N_URB1, N_URB2, N_URB3 and N_URB4).

Nursery school	Room	T (°C)					T outdoor (°C)				
		Min	Max	Mean	Median	SD	Min	Max	Mean	Median	SD
N_URB1	A	16	22	18.4	18	1.6	2.7	15.5	11.2	11.8	2.9
	B	15	19	16.9	17	1.4	6.6	17.6	11.6	10.9	4.0
	C	14	19	15.5	15	1.1	4.4	15.5	11.0	10.7	2.6
	LR	15	18	16.6	17	0.8	6.3	18.1	12.7	13.1	2.5
N_URB2	A	20	22	20.6	20	0.7	10.1	24.9	17.2	16.6	4.4
	B	20	23	21.1	21	0.8	10.0	28.2	16.2	15.2	4.8
	C	16	20	17.6	17	0.8	7.6	18.8	12.3	11.9	2.6
	LR	19	22	20.5	21	0.8	10.9	23.4	16.7	16.4	3.6
N_URB3	A	18	21	20.1	20	0.8	9.1	26.2	17.6	18.3	4.7
	B	22	25	24.1	24	0.6	13.3	29.3	21.4	21.1	4.6
	LR	18	21	19.5	19	1.0	10.5	17.4	14.0	13.7	2.0
N_URB4	A	19	21	19.3	19	0.5	13.1	18.5	16.1	16.3	1.2
	B	18	19	18.3	18	0.4	8.1	20.2	14.1	14.2	3.3
	LR	18	21	19.1	19	0.9	9.4	21.9	15.0	14.5	3.5

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; SD – standard deviation; Min – Minimum; Max - Maximum

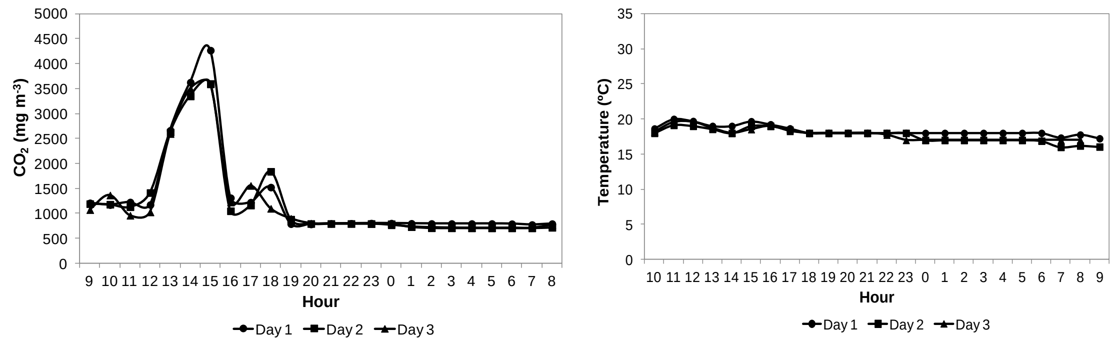
Table 3.5 - Statistical parameters of the hourly mean data for relative humidity (RH) and CO_2 in each room studied in the four nurseries (N_URB1, N_URB2, N_URB3 and N_URB4).

		RH (%)					CO_2 (mg m^{-3})				
Nursery	Room	Min	Max	Mean	Median	SD	Min	Max	Mean	Median	SD
N_URB1	A	37	80	66.7	69	9.7	792	3874	1489	956	909
	B	52	71	61.5	61	5.1	712	1730	954	936	246
	C	54	75	65.7	66	4.6	710	6096	1499	796	1308
	LR	54	75	65.4	66	4.8	706	2269	1230	1152	338
N_URB2	A	42	65	51.1	51	4.6	697	3472	978	704	601
	B	39	61	53.1	53	4.9	699	4198	1208	788	838
	C	56	68	60.4	60	2.6	704	4911	1072	709	776
	LR	41	61	55.3	57	5.1	699	1510	863	785	205
N_URB3	A	48	69	54.8	54	4.3	696	3150	852	701	415
	B	40	48	43.4	43	2.4	688	1102	760	744	85
	LR	41	62	51.5	51	5.3	700	1807	844	705	277
N_URB4	A	73	83	78.2	79	2.7	531	4806	1271	788	1049
	B	64	85	71.2	71	5.2	878	2961	1752	1639	647
	LR	46	71	59.1	59	5.9	703	2093	837	789	240

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; SD – standard deviation; Min – Minimum; Max - Maximum

When comparing two or more consecutive sampling days in each of the studied microenvironments, there were found statistical significant differences ($p < 0.05$) in only 25% of the cases regarding CO_2. This made possible to assume a daily mean scenario (daily mean profiles) for CO_2 further analysis. Although the differences in T and RH values between consecutive sampling days in each microenvironment seemed to be small, there were found statistical significant differences ($p < 0.05$) in 67% of the cases regarding both T and RH. Despite this, a daily mean scenario was also assumed for the following analysis.

Figure 3.3 shows, as an example, the daily profile for each day of measurement of (a) CO_2 in classroom B of N_URB2 on weekdays, and (b) T in classroom C of N_URB2 on weekdays.



(a) (b)

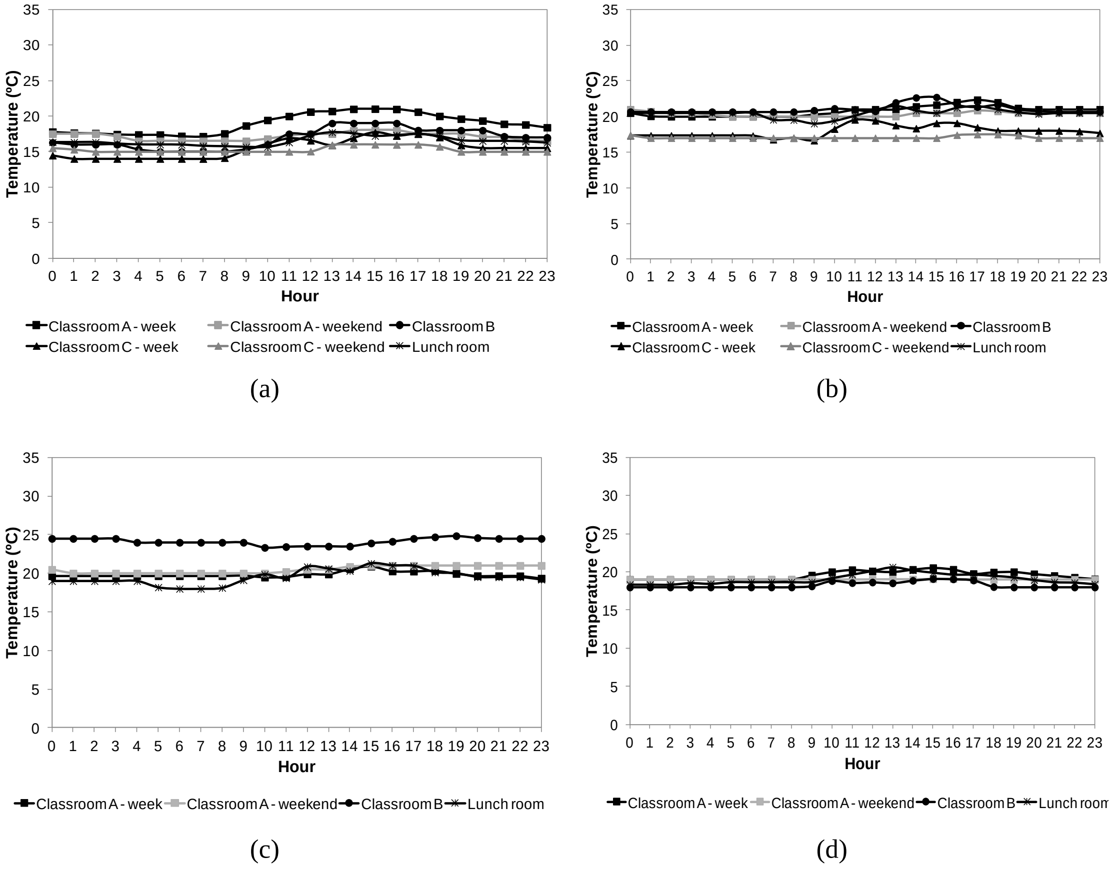
Figure 3.3 - Daily profile for each day of measurement of a) CO_2 in classroom B of N_URB2 on weekdays, and b) T in classroom C of N_URB2 on weekdays.

3.2.1 Comfort parameters

T and RH hourly means obtained in each studied room of the four nursery schools are represented respectively in: i) Figure 3.4 (a) N_URB1, (b) N_URB2, (c) N_URB3 and (d) N_URB4; and ii) Figure 3.5 (a) N_URB1, (b) N_URB2, (c) N_URB3 and (d) N_URB4. Both for T and RH, means were always very similar to the medians (Tables 3.4 and 3.5).

The highest T indoors was found in N_URB3 classroom B (25 ºC) and the lowest in N_URB1 classroom C (14 ºC). On weekend no significant variations ($p > 0.05$) were found along the day (Figure 3.4). On weekdays it was possible to find a slight increase during occupation periods, in all the studied nurseries. Outdoors, T hourly means were usually higher during sampling in N_URB2 and N_URB3 rather than during sampling in N_URB1 and N_URB4. Statistical significant differences ($p < 0.05$) in the range values of indoor T between the four nurseries seemed to be due to the differences observed in outdoor T (Figure 3.4 and Tables 3.4 and 3.5). Depending on the meteorological conditions outdoors, those indoor may also be altered, mainly due to the ventilation system used and the building thermal isolation. Thus, seasonal meteorological patterns may have an important influence in the indoor thermal conditions.

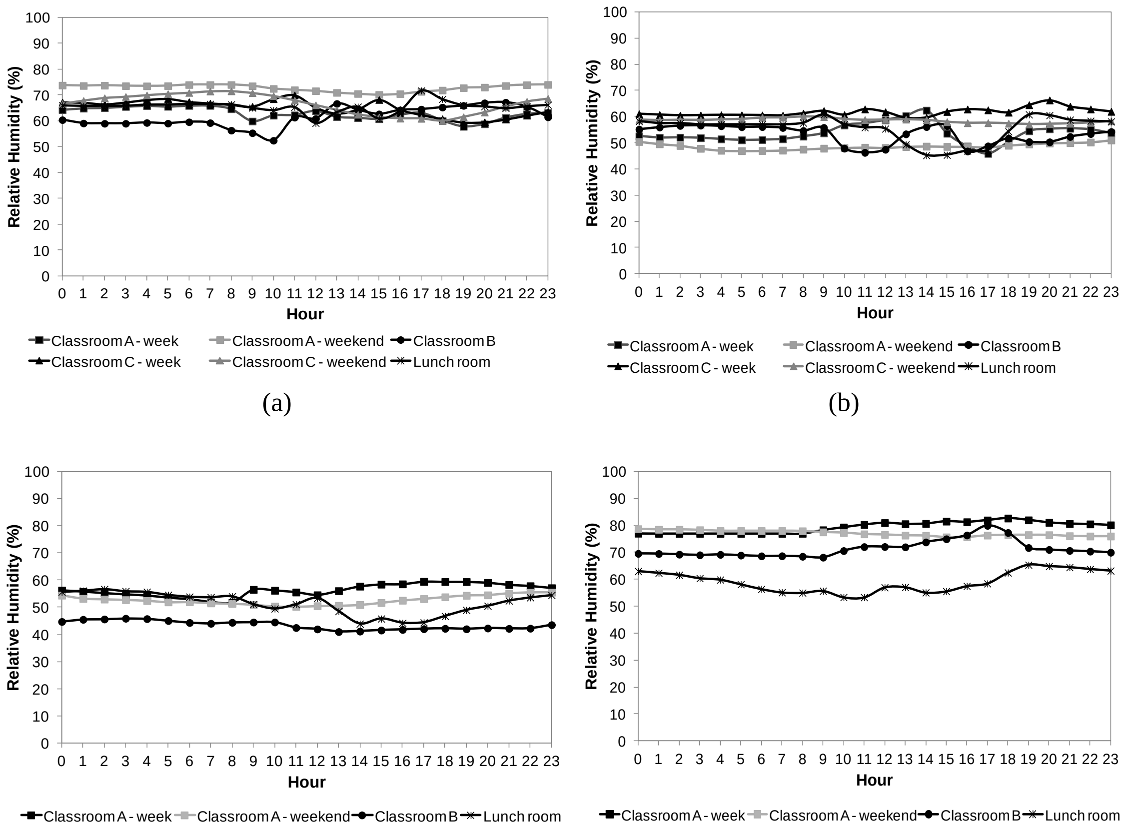
Regarding RH (Figure 3.5), the lowest RH was observed in N_URB1 (37%), and the highest in classroom B of N_URB4 (85%). RH was almost constant when there was no occupation in the rooms and fluctuations were verified during occupation periods. Those differences generally started as a decrease in RH in the first couple of hours, followed by an increase after that period of time. Although this was common in the studied rooms, in N_URB4 classrooms (A and B) RH slightly increased when occupation started. In N_URB3, classroom B had clearly the lowest RH with no statistically significant differences along the day ($p > 0.05$). In N_URB4, a major statistically significant difference ($p < 0.05$) was found between the lunch room and the classrooms, and RH on weekdays in classroom A were often found higher than 80%, especially during occupation periods.



(a) (b)

(c) (d)

Figure 3.4 - Daily profile of T means indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.



(a) (b)

(c) (d)

Figure 3.5 - Daily profile of RH means indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.

Table 3.6 shows the non-compliances (%) to the ASHRAE guidelines (referred in section 3.1.2) of T and RH mean values measured on weekends, weekdays and only during occupation periods. The values presented in the table are the percentage (%) of the total measured hourly means which were outside (below and/or above) the ASHRAE reference ranges.

Table 3.6 - Non-compliances (%) to ASHRAE guidelines for temperature (T) and relative humidity (RH) mean values measured on weekdays, only during occupation periods and on weekends.

Nursery school	Room	Weekdays		Only during occupation periods		Weekend	
		T[a]	RH[b]	T[a]	RH[b]	T[a]	RH[b]
N_URB1	A	68	67	38	62	100	100
	B	100	54	100	55	n.a.	n.a.
	C	100	85	100	96	100	85
	LR	100	87	100	63	n.a.	n.a.
N_URB2	A	100	9	100	24	100	0
	B	94	1	87	3	n.a.	n.a.
	C	100	72	100	71	100	19
	LR	100	9	100	0	n.a.	n.a.
N_URB3	A	100	33	100	22	100	0
	B	2	0	0	0	n.a.	n.a.
	LR	100	7	100	0	n.a.	n.a.
N_URB4	A	60	100	19	100	100	100
	B	100	100	100	100	n.a.	n.a.
	LR	73	44	0	67	n.a.	n.a.

a) % of hourly mean values above and/or below the reference range of 22.8-26.1°C; b) % of hourly mean values above and/or below the reference range of 30-60%; n.a. – data not available because there were no measurements on weekends in these rooms

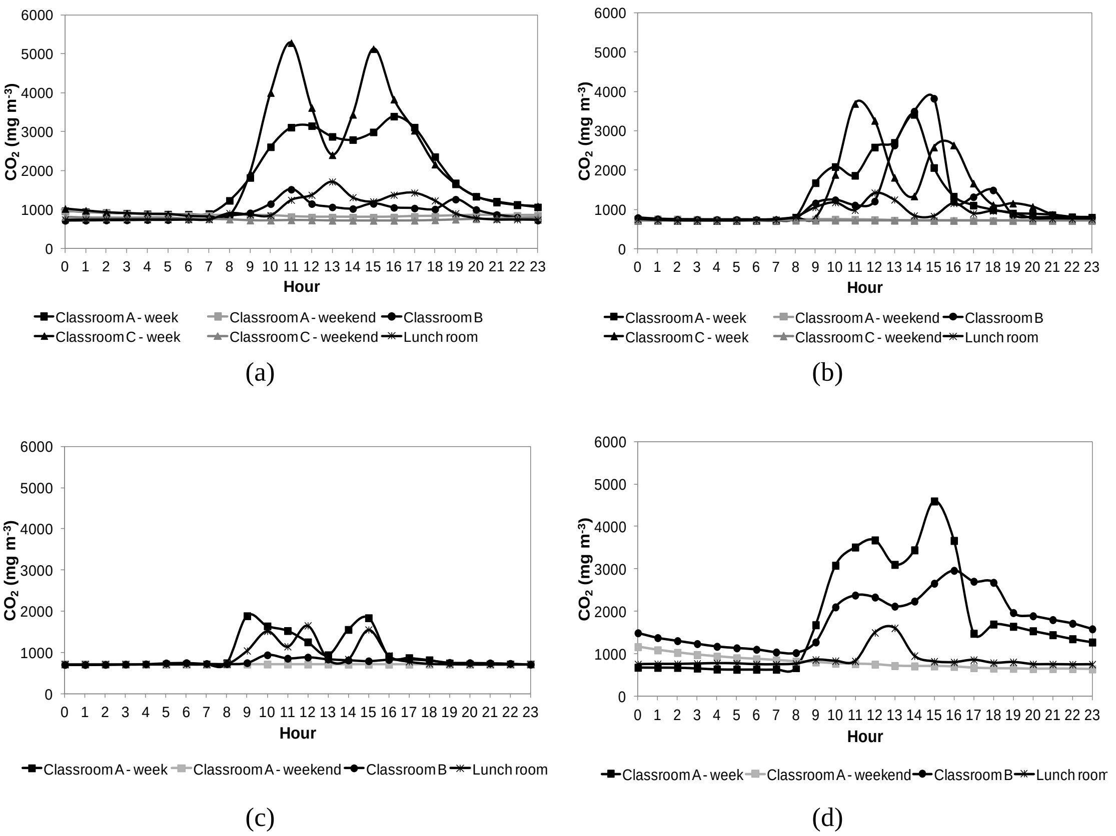
It was common to find lower T and higher RH values than those recommended by ASHRAE, mainly when rooms were unoccupied but also during occupation periods. Not only the building characteristics (such as the poor thermal isolation and the visible water infiltrations in classroom A in N_URB1), but also an inadequate use or misuse of heaters and air conditioning systems (in all the classrooms of N_URB1) were found to be the probable causes for these results.

Thermal discomfort is an expected symptom in children attending these nursery schools. In tropical child day care centres in Singapore, Zuraimi and Tham (2008) reported T and RH means of 29.4 °C and 74.3%, respectively, for natural ventilated classrooms, and 26.1 °C and 58.3%, respectively, for air-conditioned classrooms. Natural ventilated classrooms had higher values due to the higher outdoor temperatures (when compared with those indoors) in that tropical region, which were as expected higher than those found in this study. St-Jean et al. (2012) found higher T and much lower RH (mean T 22.3 °C, and mean RH 31.3%), in Montréal, Canadian child day care centres in a winter period when building ventilation was generally low. In Parisian child day care centres (75% of which using a mechanical ventilation system), Roda et al. (2011) registered mean T of 22.4 °C (cold season) and 23.4 °C (hot season) generally higher than those found in this study for both seasons, and RH of 35.4% (cold season) and 45.8% (hot season) lower than those found in the present study, and in both cases in the comfort range recommended by ASHRAE. Also Yoon et al. (2011) in Korean pre-schools in hot season (late spring and summer) found indoor T mean (25.7 ºC) higher than in N_URB2 and N_URB3, and RH mean (73.2% in the morning and 70.1% in the afternoon) higher than those found in N_URB1, N_URB2 and N_URB3 but similar to those of the two classrooms of N_URB4, and in all cases out of ASHRAE comfort range. In a Portuguese study of child day care centres in Porto and Lisbon urban areas (Carreiro-Martins et al., 2014) the T median (19.5 ºC) reported (for cold season) were higher than those of N_URB1 and N_URB4 classrooms. Additionally, lower RH median (54.6%) than in the majority of the classrooms studied except for classrooms A and B of N_URB2 and N_URB3 were also reported. However, comparing with those results could be difficult, not only because they were collected by point in time samplings and not continuously thus adding higher error margins, but also because of studies' seasonal differences.

3.2.2 CO_2 concentrations

CO_2 mean concentrations obtained for all the studied nursery schools are represented in Figure 3.6 (a) N_URB1, (b) N_URB2, (c) N_URB3, and (d) N_URB4).

A statistically significant difference ($p < 0.05$) was found between the daily profile in weekdays and in the weekend. For the latter, CO_2 concentrations were found to be almost constant ($p > 0.05$) along the day and were generally below 1000 mg m^{-3}. The same happened during weekdays on non-occupation periods. On the other hand, poor ventilation increased CO_2 concentrations during occupation periods. In fact, it was one of the main causes of the observed CO_2 concentrations and led to the accumulation of CO_2 in indoor air, mainly with two daily peaks of concentrations – one in the morning and another in the afternoon – corresponding to the periods of higher occupation and activities inside classrooms. It was a common phenomenon especially in those spaces without direct (natural or air-conditioned) ventilation to outdoors (like classrooms B and C of N_URB1). Nevertheless, in N_URB2 different behaviours were observed in classrooms A and B, because children slept there after lunch time. When children went to have lunch in the lunch rooms, lower concentrations were observed in classrooms, but usually not as low as those observed during the night and weekends. On the other hand and as expected, in the lunch rooms CO_2 concentrations increased during lunch time due to children's occupation. The highest concentrations were observed in classroom C of N_URB1 during the occupation period (Table 3.4 and 3.5). CO_2 concentrations in N_URB3 classrooms were in general lower than in the classrooms of the other nurseries during occupation periods, particularly in classroom B due to natural ventilation directly to outdoors.



(a) (b) (c) (d)

Figure 3.6 - Daily profile of CO_2 mean concentrations registered indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.

Besides poor ventilation, the high number of children in each classroom was concerning and a main determinant of the CO_2 concentrations found. Although always according to Portuguese legislation regarding the number of children per classroom, both for infants under 3 years old (Portaria nº 262/2011) and for pre-schoolers (Despacho nº 5048-B/2013), these nursery schools were exceeding ASHRAE recommended guidelines of 25 occupants per 100 m^2 (ASHRAE, 2007): the number of children per 100 m^2 varied between 29 (in classroom B of N_URB1 and in classroom A of N_URB2), and 51 (in classroom A of N_URB3 and in classroom B of N_URB4). Occupational densities were found higher in pre-schoolers' classrooms than in the ones for infants, and in public managed nurseries (N_URB3 and N_URB4) than in the private ones (N_URB1 and N_URB2). This circumstance led to the increase of CO_2 concentrations in classrooms to values above the Portuguese legislated standards. The Portuguese legislation regarding the number of children per classroom (Despacho nº 5048-B/2013; Portaria nº 262/2011), which was only made based on educational and economic criteria and less restrictive than ASHRAE recommended guidelines, showed to be insufficient to ensure good IAQ inside classrooms. Zuraimi and Tham (2008) and St-Jean et al. (2012) also described occupational density as a determinant factor for CO_2 concentrations and reported CO_2 concentrations higher than those found in the present study. Moreover St-Jean et al. (2012) also referred a high occupational density when comparing with ASHRAE recommendation.

Exceedances (%) to the Portuguese legislations (2006 and 2013) referred in the section 3.1.2 of the mean CO_2 concentrations measured on weekdays and only during occupation periods are represented in Table 3.7. The values presented on the table are the percentage (%) of the measured hourly or 8-hour running means which were above the Portuguese 2006 and 2013 reference values, respectively. Moreover, in the rooms where there were no mechanical ventilation, a 30% MT was applied to the Portuguese 2013 reference value (Portaria 353-A/2013). The CO_2 concentrations observed in this study were not only due to overcrowding, but also due to poor ventilation during occupation periods. Furthermore, although classrooms A and C of N_URB2, and lunch rooms of N_URB1, N_URB3 and N_URB4 had natural ventilation to inner corridors, contrarily to what happened in other classrooms in which doors/windows were always closed (Table 3.2), CO_2 concentrations were also high and above the reference values. Thus, natural ventilation to inner corridors was not enough to get CO_2 concentrations below the Portuguese standard during occupation periods. Indeed, other authors have reached similar conclusions. The overcrowding and closing of windows and doors during classrooms' occupation periods (to avoid noise and reducing indoor temperatures) caused the higher CO_2 concentrations found by Yang et al. (2009) (1817.81 µg m^{-3}) and by Yoon et al. (2011) (1546.56 µg m^{-3}). Gładyszewska-Fiedoruk (2011) reported similar CO_2 concentrations in a nursery on north-eastern Poland, and also highlighted the importance of good natural ventilation, which could be achieved by the correct use of a stack ventilation system. This type of system was used in the classrooms of N_URB4 (trickle vents in windows); nevertheless, it seemed to be insufficient to reduce CO_2 indoor concentrations during occupation periods, which led the authors to believe that it was not well dimensioned. Also Roda et al. (2011) reported the significance of ventilation for IAQ. In the referred study, similar and higher CO_2 mean concentrations were found in Parisian child day care centres (where a mechanical ventilation system was used in 75% of the cases studied, and higher CO_2 concentrations were found in cold season). Carreiro-Martins et al. (2014) reported a CO_2 median concentration of 1440 ppm (2685 µg m^{-3}) in indoor air of Portuguese child day care centres, which they reported to be a cause of occupation and poor ventilation. That value was higher than median values in the rooms studied in the present study; nevertheless that was collected by point in time samplings (short-term measurements) in the occupation period, thus being difficult to make these comparisons.

The high CO_2 concentrations found may indicate the accumulation of indoor air pollutants from indoor sources, like formaldehyde and other VOC, that are health concerning because they could lead to several symptoms and health effects on children, like headaches, fatigue, loss of concentration and absenteeism (Jones, 1999).

Table 3.7 - Exceedances (%) to the Portuguese legislation (2006 and 2013) of CO_2 mean concentrations measured on weekdays and only during occupation periods.

Nursery	Room	Weekdays			Only during occupation periods
		2006 legislation [a]	2013 legislation [b]	2013 legislation [c]	2006 legislation [a]
N_URB1	A	40	80	- [d]	78
	B	0	0	0	0
	C	43	100	100	76
	LR	5	0	0	38
N_URB2	A	21	50	0	59
	B	14	0	0	33
	C	23	33	33	65
	LR	0	0	0	0
N_URB3	A	17	0	0	33
	B	0	0	0	0
	LR	2	0	0	25
N_URB4	A	42	100	100	81
	B	47	100	100	88
	LR	1	0	0	33

a) % of hourly mean concentrations above the reference value of 1800 mg m^{-3}; b) % of 8-hour running mean concentrations above the reference value of 2250 mg m^{-3}; c) % of 8-hour running mean concentrations above the reference value of 2925 mg m^{-3} (2250 mg m^{-3}+ 30% of margin of tolerance); d) in this room the margin of tolerance was not applied because there was mechanical ventilation

It was possible to observe a considerable number of non-compliances for indoor comfort parameters, as well as for CO_2. Exceedances to Portuguese 2006 standards were always higher during occupation periods than on weekdays in general. Moreover, it is also important to refer that the results here presented were similar to those obtained in Portuguese child care centres by Carreiro-Martins et al. (2014) and in Portuguese primary schools by Almeida et al. (2011) (for CO_2), and Pegas et al. (2012) (for T, RH and CO_2). School activities and inadequate ventilation were also identified in those studies as some of the main determinants of IAQ in primary schools.

3.3 Conclusions

The presence of children (occupation) and their routines, building characteristics and ventilation habits seemed to be the main determinants of IAQ and comfort.

Building characteristics and an inadequate use of heaters and air conditioning systems seemed to determine low temperature and high relative humidity, being thermal discomfort an expected symptom in children attending these nursery schools.

CO_2 concentrations were also high, and exceeding several times the Portuguese standards, which was due to: i) high occupation rate (overcrowding) in the studied classrooms when compared to ASHRAE recommendation, although the number of children per classroom was always according to the Portuguese legislation for educational purposes; and ii) poor ventilation – closing windows and doors during classrooms' occupation periods (to avoid noise and heat loss). A worse scenario was found in the public managed nursery schools rather than in the private ones. Headache, fatigue, loss of concentration and absenteeism are possible health symptoms for children attending these nurseries.

Chapter 4

Indoor air in urban nursery schools: Gaseous pollutants' assessment*

The present chapter aimed to: i) evaluate indoor concentrations of several gaseous air pollutants in different microenvironments of urban nursery schools in Porto city; and ii) analyse those concentrations according to guidelines and references for IAQ and children's health.

4.1 Methodology

4.1.1 Sites description, sampling and analysis

This study was carried out in the city of Porto (Portugal) on four different nursery schools located at urban sites influenced by traffic emissions (N_URB1, N_URB2, N_URB3 and N_URB4), from March to June 2013 in N_URB1, N_URB2 and N_URB3, and in November 2013 in N_URB4. Their main characteristics (including occupation, ventilation and cleaning habits and other specific activities), indoor microenvironments considered, and sampling periods were fully described previously in section 3.1.1.

Indoor gaseous air compounds, namely CO, formaldehyde, NO_2, O_3, and TVOC, were continuously measured using the same Haz-Scanner IEMS Indoor Environmental Monitoring Station (SKC Inc., USA) as in the previous chapter 3, equipped with high sensitive sensors. Sampling methods and main characteristics of each sensor are summarized in Table 4.1. Sampling procedures, periods and duration were fully described previously in section 3.1.2.

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* adapted from: Branco PTBS, Nunes RAO, Alvim-Ferraz MCM, Martins FG, Sousa SIV, 2015. Children's exposure to indoor air in urban nurseries - Part II: Gaseous pollutants' assessment. *Environmental Research* 142: 662-670.

Table 4.1 - Sampling methods and main characteristics of carbon monoxide (CO), formaldehyde, nitrogen dioxide (NO_2), ozone (O_3), and total volatile organic compounds (TVOC) sensors.

Sensor	**Detection methods**	**Sensor minimum resolution**	**Sensor accuracy**	**Measurement range**
CO	Electrochemical detection	< 1746 µg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-58200 µg m^{-3}
Formaldehyde	Electrochemical detection	62.5 µg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-5000 µg m^{-3}
NO_2	Electrochemical detection	41 µg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-41000 µg m^{-3}
O_3	Electrochemical detection	2.14 µg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-1070 µg m^{-3}
TVOC	Photoionization detection (PID)	230 µg m^{-3}	< +/- 10% of reading or 2% of full scale – whichever is greater	0-115385 µg m^{-3}

The mean values were compared with reference standards and guidelines referred in section 2.1.3 aiming to evaluate exceedances and/or non-compliances. Comparisons were performed considering national and international reference values for general indoor environments referred in section 2.1.3, namely: i) Portuguese 2006 legislation (hourly means) (*Decreto-Lei nº 79/2006*) for CO (12 500 µg m^{-3}), O_3 (200 µg m^{-3}), formaldehyde (100 µg m^{-3}), and TVOC (600 µg m^{-3}); ii) Portuguese 2013 legislation (Portaria nº 353-A/2013) for CO (10 000 µg m^{-3}), formaldehyde (100 µg m^{-3}), and TVOC (600 µg m^{-3}, plus 100% of MT if no mechanical ventilation system was working in the room); iii) WHO guidelines (WHO, 2010) for CO (35000 µg m^{-3} for hourly mean), NO_2 (200 µg m^{-3} for hourly mean) and formaldehyde (100 µg m^{-3} for 30 minutes mean); and iv) Health Canada guidelines (HealthCanada, 2013) for NO_2 (480 µg m^{-3} for hourly mean) and formaldehyde (123 µg m^{-3} for hourly mean). For the Portuguese 2013 legislation, 8-hour running means were calculated and the daily maximum was compared with the reference value. Although Portuguese 2006 legislation was officially replaced by the new Portuguese 2013 legislation, comparisons were made with both due to the clear differences between them, which allowed concluding on the expected impacts from the application of the new one.

Simultaneously, hourly NO_2 and O_3 outdoor concentrations were obtained from the nearest air quality station, classified as urban traffic and representative of the area (CCDR-N, 2011), because only one equipment was available inhibiting simultaneous measurements outside the nursery schools. These measurements were conducted by the Air Quality Monitoring Network of Porto Metropolitan Area, managed by the Regional Commission of Coordination and

Development of Northern Portugal (*Comissão de Coordenação e Desenvolvimento Regional do Norte*) under the responsibility of the Ministry of Environment. These concentrations allowed calculating the correspondent indoor/outdoor (I/O) ratios.

4.1.2 Statistical analysis

Data were tested for normality with both Shapiro-Wilk and Anderson-Darling tests. If normal, differences between hourly mean concentrations in different sampling days for each microenvironment were analysed by a parametric unpaired *t*-test. In the other cases, the non-parametric Kruskal-Wallis test was used for the microenvironments where there were more than two complete sampling days, and the Wilcoxon Rank Sum Test (also called Mann-Whitney *U* test) was used for those where there were only two complete sampling days.

The one-sample parametric *t*-test was used to analyse if the differences along the day were significant for normal distributions; for other distributions, the non-parametric Wilcoxon Signed Rank Test was used.

To analyse other differences, namely between weekdays and weekends, as well as between different microenvironments and nursery schools, the parametric unpaired *t*-test or the non-parametric Wilcoxon Rank Sum Test was used, respectively when distributions were normal or not. In all cases, a significance level (α) of 0.05 was considered. Descriptive statistics was calculated using MS Excel® (Microsoft Corporation, USA), and other statistical analyses were determined using R software, version 3.1.2 (R Development Core Team, 2014).

4.2 Results and discussion

Tables 4.2, 4.3 and 4.4 summarize the main statistical parameters (minimum, maximum, mean, median and standard deviation) of the hourly mean for each room of the four nursery schools.

When comparing two or more consecutive sampling days of the studied microenvironments, statistically significant differences were found ($p < 0.05$) in 83.3%, 50% and 75% of the cases regarding CO, NO_2 and O_3, respectively. For formaldehyde and TVOC, it was not possible to make these statistical comparisons because concentrations were usually specific on time. Despite this, a daily mean scenario in each microenvironment was assumed for the following analyses of all the studied pollutants.

Table 4.2 - Statistical parameters of the hourly mean data for formaldehyde, and total volatile organic pollutants (TVOC) in each room studied.

Nursery school	Room	Formaldehyde (µg m^{-3})					TVOC (µg m^{-3})				
		Min	Max	Mean	Median	SD	Min	Max	Mean	Median	SD
N_URB1	A	0	146	2	0	12	0	354	17	0	59
	B	0	0	-	-	-	0	54	3	0	10
	C	0	0	-	-	-	0	373	8	0	42
	LR	0	9	0	0	1	0	132	8	0	27
N_URB2	A	0	0	-	-	-	0	202	92	90	54
	B	0	0	-	-	-	52	276	141	115	62
	C	0	204	8	0	33	0	2320	104	0	310
	LR	0	0	-	-	-	0	197	8	0	36
N_URB3	A	0	2	0	0	0	0	307	5	0	31
	B	0	0	-	-	-	0	20	2	0	6
	LR	0	6	0	0	1	0	388	12	0	58
N_URB4	A	0	50	35	38	9	0	0	-	-	-
	B	12	87	35	35	18	0	0	-	-	-
	LR	0	77	2	0	11	0	12	0	0	1

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; Min- Minimum; Max - Maximum; SD – standard deviation

Table 4.3 - Statistical parameters of the hourly mean data for carbon monoxide (CO) in each room studied.

Nursery school	Room	CO (µg m^{-3})				
		Min	Max	Mean	Median	SD
N_URB1	A	913	4956	2599	2476	940
	B	1577	4347	2765	2571	1043
	C	0	2578	463	158	608
	LR	0	2879	1230	1152	531
N_URB2	A	1498	3711	2359	2297	521
	B	1996	3902	2786	2723	520
	C	0	2689	971	893	577
	LR	1949	3211	2552	2511	333
N_URB3	A	1240	2618	1960	1984	329
	B	3077	3916	3477	3487	224
	LR	734	2544	1513	1438	541
N_URB4	A	0	1972	604	669	444
	B	0	89.9	4.2	0	15.7
	LR	0	1165	83	0	221

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; Min- Minimum; Max - Maximum SD – standard deviation;

Table 4.4 - Statistical parameters of the hourly mean data for nitrogen dioxide (NO_2) and ozone (O_3) in each room studied.

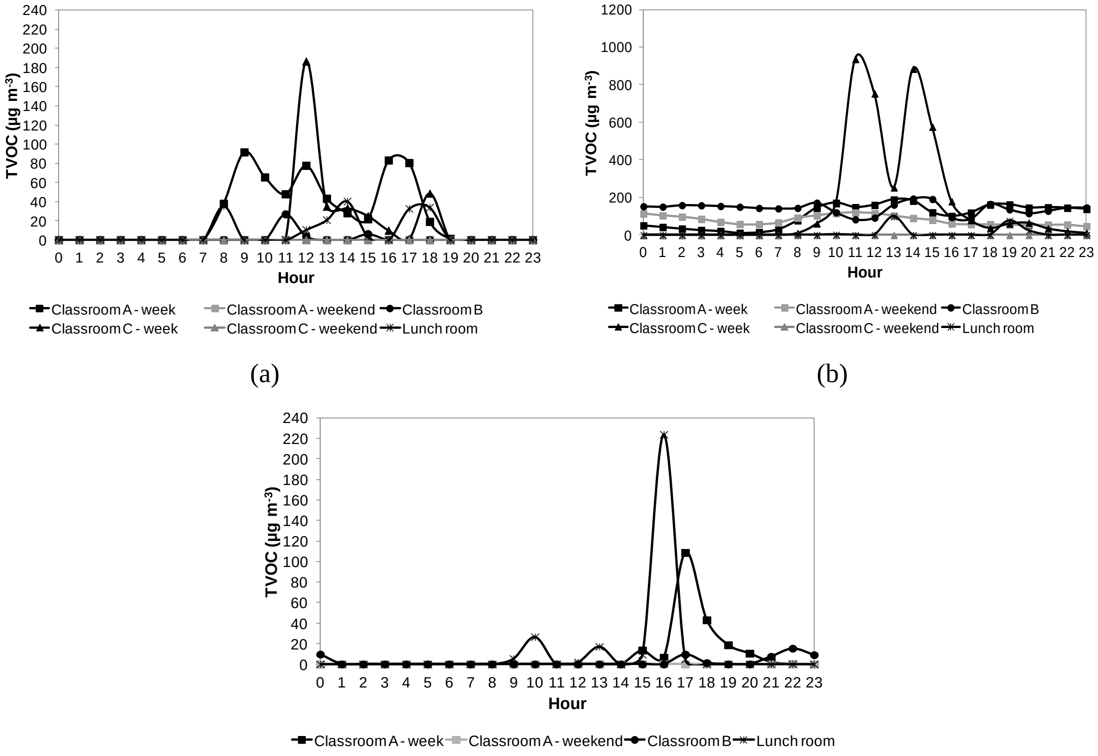
Nursery school	Room	NO_2 (µg m^{-3})					O_3 (µg m^{-3})				
		Min	Max	Mean	Median	SD	Min	Max	Mean	Median	SD
N_URB1	A	0	57	6	0	13	0	20	13	15	5
	B	-	-	-	-	-	15	32	24	23	5
	C	1	75	40	41	19	2	53	18	14	10
	LR	0	84	22	18	21	4	49	23	22	9
N_URB2	A	87	148	121	124	15	1	23	13	12	3
	B	49	131	73	72	15	8	39	17	15	7
	C	36	171	62	58	16	1	28	20	20	4
	LR	57	142	93	90	22	9	61	26	20	14
N_URB3	A	80	138	113	115	13	9	48	18	16	7
	B	109	189	136	133	20	10	25	16	15	4
	LR	114	155	138	140	9	17	57	38	40	7
N_URB4	A	-	-	-	-	-	7	27	9	8	3
	B	-	-	-	-	-	5	13	10	10	2
	LR	-	-	-	-	-	12	32	19	18	5

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; Min- Minimum; Max – Maximum; SD – standard deviation

4.2.1 TVOC and formaldehyde

TVOC mean concentrations from the studied class and lunch rooms in N_URB1, N_URB2 and N_URB3 are represented in Figure 4.1 a), b) and c), respectively. N_URB4 is not represented in Figure 4.1 because concentrations were zero or very close to zero (maximum concentration observed equal to 4 µg m^{-3}) (Table 4.2).

Although different concentrations and daily profiles were observed, it is clear that the presence of TVOC occurred mainly during occupation periods, which seemed to be the result of typical children activities associated with the use of paints and glues. The concentrations measured while the nursery schools were closed (night and weekend) were very close to zero. Exception of classrooms A (both on weekdays and weekend), B and C (on weekdays) of nursery school N_URB2 (Table 4.2) where it seemed to exist a continuous source of VOC. Additionally, peak concentrations were observed in the beginning of the morning, during or immediately after lunch time and in the afternoon. These TVOC concentrations in the indoor air immediately before and/or after the occupation periods in the classrooms were associated with the cleaning activities using products that emitted VOC.

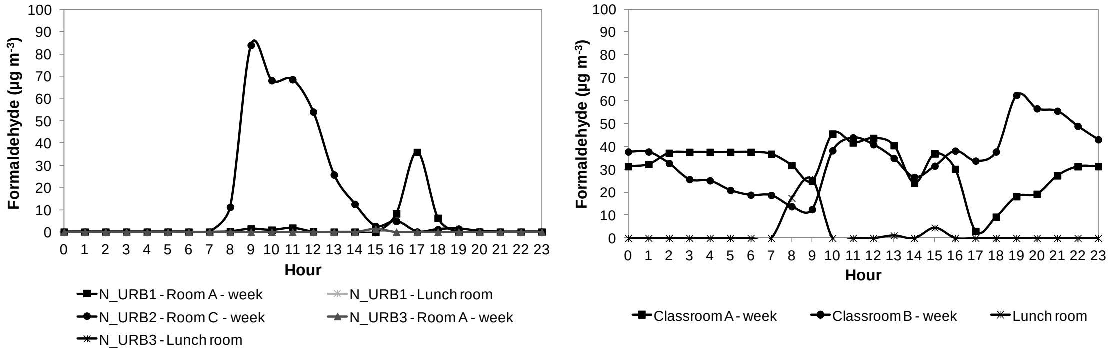


(a) (b)

(c)

Figure 4.1 - Daily profile of TVOC mean concentrations registered indoors of a) N_URB1, b) N_URB2, and c) N_URB3.

Figure 4.2 shows formaldehyde mean concentrations for a) classroom A (weekdays) and lunch room of N_URB1, classroom C (weekdays) of N_URB2 and classroom A (weekdays) and lunch room of N_URB3, and b) N_URB4. Formaldehyde concentrations for the remaining studied rooms are not represented because concentrations were close to zero (Table 4.2) in all those cases, except for weekend on classroom A of N_URB4 that was due to instrument error.



(a) (b)

Figure 4.2 - Daily profile of formaldehyde mean concentrations registered indoors in a) classroom A (weekdays) and lunch room of N_URB1, classroom C (weekdays) of N_URB2, classroom A (weekdays) and lunch room of N_URB3; and b) N_URB4.

No daily profile was found for formaldehyde concentrations on the different studied rooms. The highest concentrations were observed in classroom C of N_URB2 during weekdays, where there was a peak in the morning (after the opening hour), which decreased through the morning until the period after lunch and a second peak (lower) was found about 5 p.m.. These peaks matched the periods of entrance and exit from the classroom. In the other rooms represented in Figure 4.2 a) concentrations were close to zero. Regarding N_URB4, in the lunch room, concentrations were close to zero, except at the beginning of the morning, during and after lunch, also periods of entrance and exit. Indoor formaldehyde concentrations seemed to indicate the presence of specific indoor sources for this pollutant, namely the use of materials emitting formaldehyde (mainly furniture). The higher concentrations during occupation periods, characterized by some peaks, seemed to be mainly related to entrance and/or exit periods, associated with moving the furniture (tables and chairs).

Table 4.5 shows the number of non-compliances and exceedances (%) to the standards and guidelines referred in section 4.1.1. The values presented on the table are the percentage (%) of the measured hourly means which were above the Portuguese 2006 reference values, the percentage (%) of the 30-min means which were above WHO reference value (only for formaldehyde), and the percentage (%) of the daily maximum 8-hour running means which were above the Portuguese 2013 reference values.

In few situations the recommended standard and guideline values for formaldehyde and TVOC were exceeded. In the case of formaldehyde, exceedances were mainly found during occupation periods and mainly for WHO reference value (WHO, 2010). A health risk assessment approach could be important to assess the children's health risks of short-term exposure to those high concentrations, and to confirm if they are expected to cause mild or moderate eye irritation.

Formaldehyde concentrations in N_URB4 were similar to those registered by Yoon et al. (2011) in Korean urban pre-schools (45.27 μg m^{-3}), but far from those registered in Korean kindergartens (162.69 μg m^{-3}) (Yang et al., 2009). Both of those studies found much higher TVOC concentrations (591.2 μg m^{-3} and 642.11 μg m^{-3} respectively), and both also concluded that those problems in indoor air were caused by emissions from building materials and furnishing, worsened by insufficient ventilation as previously stated for the same nursery schools in chapter 3 of the present thesis. Formaldehyde concentrations found in classroom C of N_URB2 and in N_URB4 were often found higher than those reported by Roda et al. (2011), both in hot and cold season (10.7 and 14.8 μg m^{-3}, respectively), and higher than those reported by St-Jean et al. (2012) (22.9 μg m^{-3}). The selection of classroom materials to use in nursery schools' indoor environments should be performed with extreme caution by choosing formaldehyde-free materials to safeguard children's health. Moreover, better ventilation (amount of fresh air and its distribution) could help to reduce indoor formaldehyde and TVOC concentrations. It is important to notice that the analysis performed in the present study were made for TVOC, but further investigations in specific VOC are needed, as made in previous studies (Pegas et al., 2012; Roda et al., 2011; St-Jean et al., 2012) which reported considerable indoor concentrations in nursery and primary schools. That will allow comparing the results to better understand sources and pathways of children's exposure to specific VOC inside nursery schools.

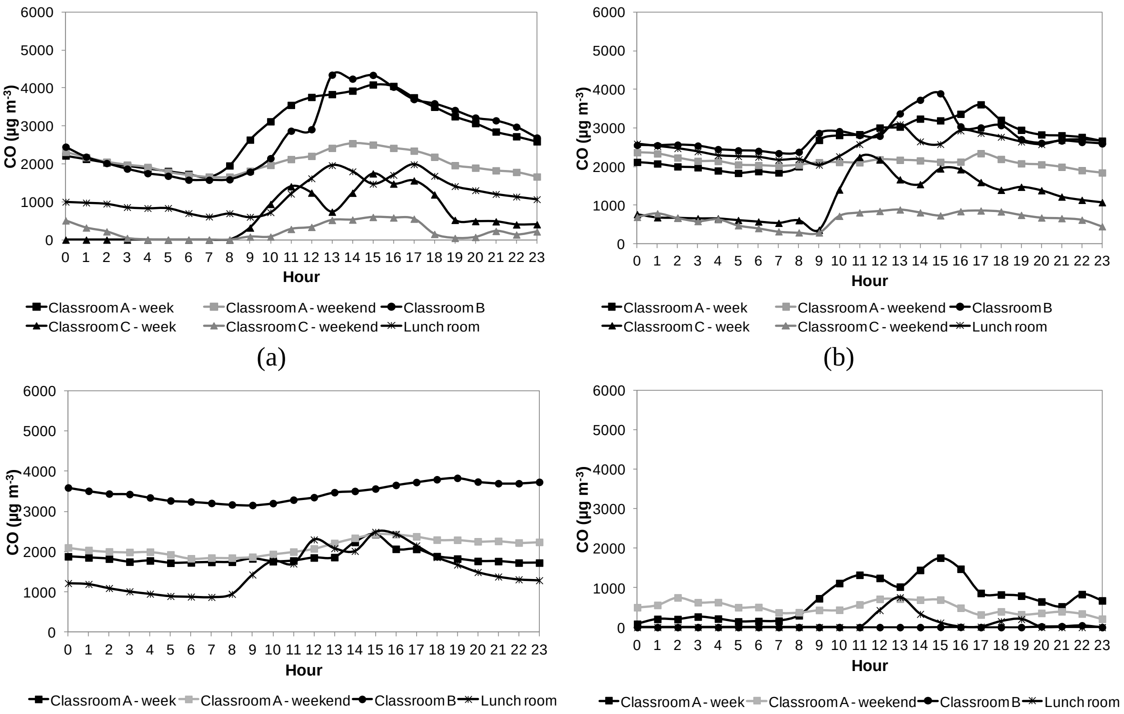
Table 4.5 - Exceedances (%) to WHO guidelines and Portuguese legislation (2006 and 2013) reference values of formaldehyde (CH_2O) and TVOC measured on weekdays and only during occupation periods.

Nursery school	Room	Weekdays					During occupation		
		Portuguese 2006 legislation		WHO	Portuguese 2013 legislation		Portuguese 2006 legislation		WHO
		CH_2O^a	$TVOC^b$	CH_2O^c	CH_2O^d	$TVOC^e$	CH_2O^a	$TVOC^b$	CH_2O^c
N_URB1	A	1	0	1	0	0	2	0	2
	B	0	0	15	0	0	0	0	22
	C	0	0	0	0	0	0	0	0
	LR	0	0	0	0	0	0	0	0
N_URB2	A	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	C	6	11	6	33	33	18	29	17
	LR	0	0	0	0	0	0	0	0
N_URB3	A	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	LR	0	0	0	0	0	0	0	0
N_URB4	A	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	LR	0	0	1	0	0	0	0	0

[a] % of the hourly mean concentrations above the reference value of 100 μg m^{-3}; [b] % of the hourly mean concentrations above the reference value of 600 μg m^{-3}; [c] % of the 30-min mean concentrations above the reference value of 100 μg m^{-3}; [d] % of 8-hour running mean concentrations above the reference value of 100 μg m^{-3} ; [e] % of 8-hour running mean concentrations above the reference value of 600 μg m^{-3}; A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room

4.2.2 CO, NO_2 and O_3

Figure 4.3 shows the CO mean concentrations in all the studied rooms of the four nursery schools ((a) N_URB1, (b) N_URB2, (c) N_URB3, and (d) N_URB4). It is possible to distinguish a similarity in the daily profile, especially during weekdays, in all the studied rooms – an increase in CO concentrations in the early morning and a decrease starting at the evening. During weekend, CO concentrations seemed to have an almost constant profile along the day. In general, CO concentrations were significantly lower ($p < 0.05$) in N_URB4 than in the other three nursery schools. The highest concentrations were found on weekdays in classrooms A and B of N_URB1 (respectively 4956 and 4347 μg m^{-3}) and the lowest were found in classroom B of N_URB4 (close to zero) (Table 4.3). In N_URB2, CO concentrations in classroom C were significantly lower ($p < 0.05$) than in the remaining rooms of that nursery school. In N_URB3, CO concentrations in classroom B were significantly higher ($p < 0.05$) than in the other rooms of that nursery school. As no indoor sources were found, outdoor CO concentrations were expected to be the main determinant of the indoor concentrations registered.

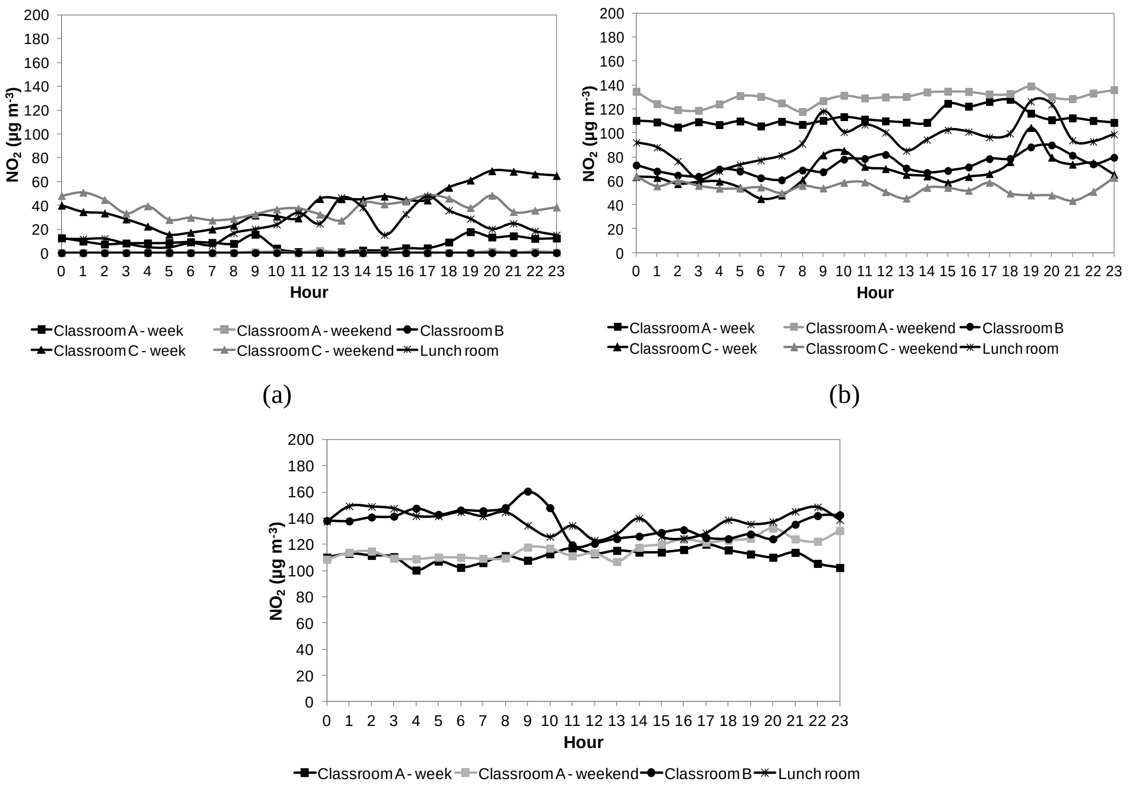


(a) (b)

(c) (d)

Figure 4.3 - Daily profile of CO mean concentrations registered indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.

NO_2 mean concentrations registered in N_URB1, N_URB2 and N_URB3 are represented in Figure 4.4 a), b) and c), respectively. NO_2 mean concentrations in N_URB4 and in classroom B of N_URB1 are not represented due to instrument error. The lowest concentrations were found in N_URB1 and the highest in N_URB3 (Table 4.4). In fact, in classrooms A (both weekend and weekdays) and B of N_URB1 concentrations were always very close to zero. Although without significant differences amongst them ($p = 0.06$), classrooms of N_URB2 (weekdays), as well as the studied rooms of N_URB3, showed higher values and significantly different profiles ($p < 0.05$) than those observed in N_URB1. All of these three buildings were located in a busy traffic street (N_URB1 and N_URB2 were located in the same street), but N_URB2 and N_URB3 had a road junction with traffic lights next to the front facade of the building, which could indicate higher NO_2 emissions from the vehicles exhaust and consequently higher concentrations of this compound entering into the building. In classroom A of N_URB2, both in weekdays and weekend, there were found significantly higher values ($p < 0.05$) than in the rest of that building, probably due to the location of this classroom (in the ground floor and with windows in the front facade of the building). In the weekend at some classrooms, indoor NO_2 concentrations were higher than in weekdays because there was no ventilation during the weekend. The high concentrations observed in Friday did not decrease maintaining a high and almost constant daily profile during the whole weekend.

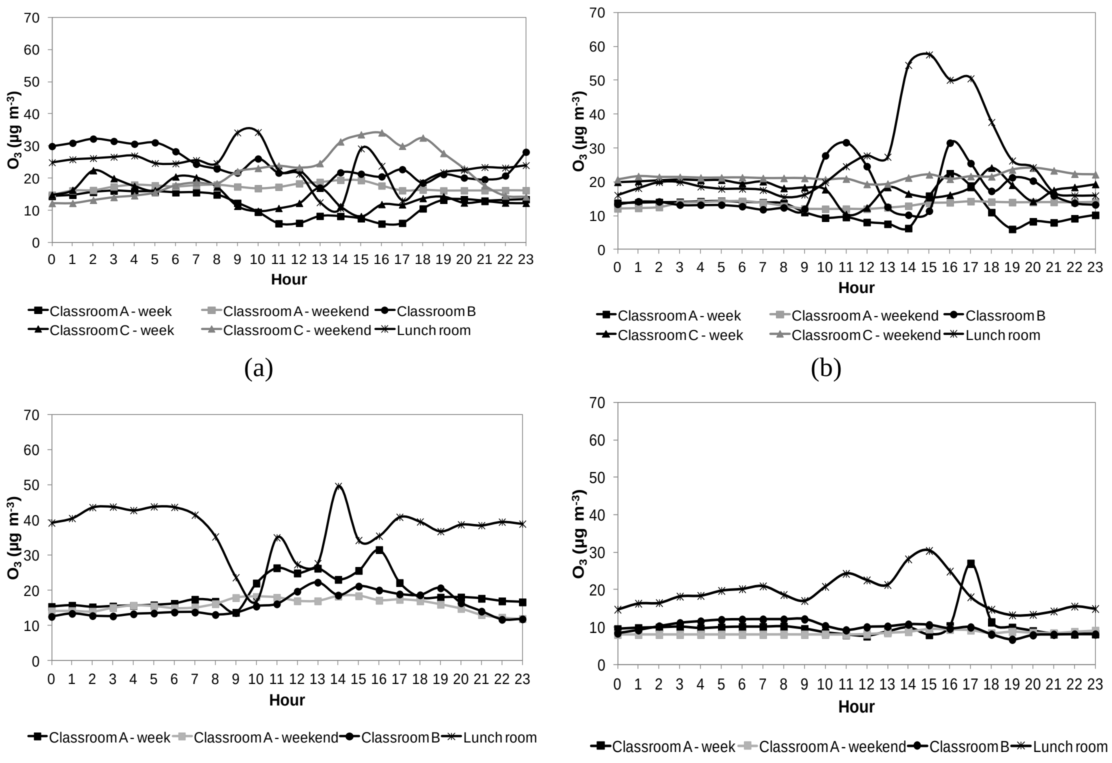


(a) (b)

(c)

Figure 4.4 - Daily profile of NO_2 mean concentrations registered indoors of a) N_URB1, b) N_URB2, and c) N_URB3.

Figure 4.5 a), b) c) and d) shows the O_3 mean concentrations determined in the studied rooms of N_URB1, N_URB2, N_URB3 and N_URB4, respectively. It was possible to observe O_3 concentrations with a similar order of magnitude among the different studied rooms in the four nursery schools, and without relevant variations along the day in all the studied classrooms. The highest values were often found in the lunch rooms (Table 4.4) during or immediately after lunch time, which in the absence of indoor sources might be associated with higher ventilation to outdoors during daytime. The accumulation in those indoor microenvironments led to the O_3 highest concentrations during the night and dawn found in the lunch rooms of N_URB3 and N_URB4. In N_URB4, no relevant variations in O_3 concentrations were found in the classrooms. As there were no indoor sources, O_3 concentrations indoors seemed to be associated with outdoor concentrations.

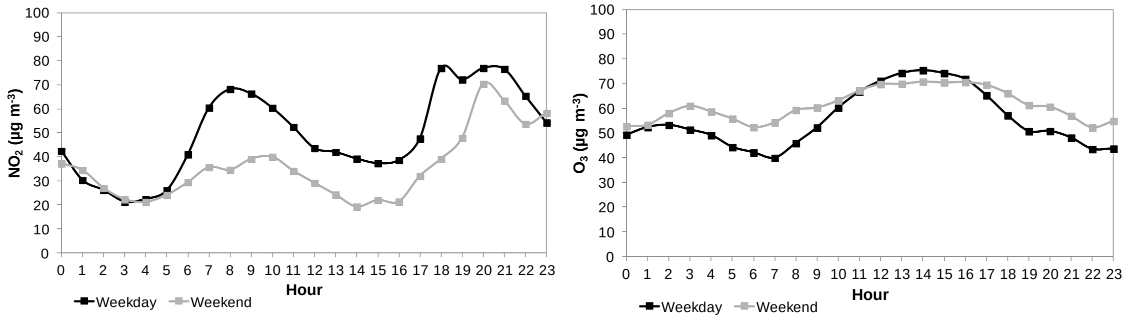


(a) (b)

(c) (d)

Figure 4.5 - Daily profile of O_3 mean concentrations registered indoors of a) N_URB1, b) N_URB2, c) N_URB3, and d) N_URB4.

Outdoor mean concentrations of NO_2 and O_3 allowed obtaining a mean daily profile, represented in Figure 4.6 a) and b) respectively. In both NO_2 and O_3 profiles a similar pattern was found between weekdays and weekend with NO_2 concentrations usually higher on weekdays and with O_3 concentrations usually higher on weekend. Daily variations in NO_2 concentrations boiled down to two significant peaks – one in the morning and another at the end of the afternoon, matching the two traffic rush periods, as expected for urban areas (Wichmann et al., 2010). From O_3 outdoor profiles, it was possible to observe the highest concentrations along the afternoon, as expected (Sousa et al., 2009). These profiles were generally similar to those typically found indoors, thus outdoor air seemed to be the main contributor to those concentrations found indoors.



(a) (b)

Figure 4.6 - Daily profile of outdoors mean concentrations for a) NO_2 and b) O_3.

Indoor concentrations were compared with those obtained outdoors using the I/O ratio. Outdoor concentrations were obtained from an air quality station instead of measured simultaneously outside each nursery school. Although the air quality station was representative of the study area (CCDR-N, 2011), this is a study limitation and results should be interpreted with care. Table 4.6 shows mean I/O ratios (and minima and maxima) for NO_2 and O_3 in each studied room. In N_URB1, NO_2 I/O ratios were usually below 1, showing indoor concentrations lower than outdoors, with the exception of classroom C, both in weekdays and weekend, although there were ratios below 1 in these cases. In the case of N_URB2 I/O median ratios were often above 1, and in N_URB3 all the I/O ratios were also above 1, which might be due to the steep decrease of outdoor concentrations which were not followed by the same decrease indoors. As indoor concentrations of NO_2 in N_URB4 were usually zero, I/O ratios were not represented. O_3 I/O ratios in N_URB1, N_URB2 and N_URB3 were usually below 1 both during weekdays and weekend. In N_URB4, the same was found in classroom A and B, but different results were found in the lunch room (2.53), which might be also due to the steep decrease of outdoor concentrations which were not followed by the same decrease indoors as referred for NO_2.

Table 4.6 - I/O ratios for NO_2 and O_3: median values observed in each studied site for weekdays and weekends, and respective minima and maxima values (min-max).

Nursery school	Room	NO_2		O_3	
		Weekday	Weekend	Weekday	Weekend
N_URB1	A	0.02 (0.00-2-26)	0.00 (0.00-0.23)	0.16 (0.00-1.15)	0.19 (0.16-0.22)
	B	0.00 (0.00-0.00)	-	0.33 (0.21-0.50)	-
	C	1.88 (0.50-4.41)	1.50 (0.42-4.88)	0.24 (0.03-6.11)	0.22 (0.14-0.62)
	LR	0.41 (0.00-3.43)	-	0.31 (0.05-1-78)	-
N_URB2	A	3.80 (1.18-7.88)	6.19 (1.63-13.73)	0.25 (0.06-0.99)	0.20 (0.16-0.50)
	B	2.94 (0.93-7.67)	-	0.30 (0.10-1.70)	-
	C	2.33 (0.36-5.11)	2.42 (0.71-4.68)	0.28 (0.01-1.07)	0.27 (0.18-0.65)
	LR	1.98 (0.79-4.20)	-	0.42 (0.11-2.49)	-
N_URB3	A	4.20 (1.46-15.93)	4.08 (1.25-9.77)	0.33 (0.17-1.08)	0.30 (0.17-3-97)
	B	2.70 (1.07-5.65)	-	0.22 (0.14-1-07)	-
	LR	6.79 (2.99-17.49)	-	0.57 (0.26-1.07)	-
N_URB4	A	-	-	0.15 (0.13-0.64)	0.19 (0.12-0.53)
	B	-	-	0.79 (0.12-8.03)	-
	LR	-	-	2.53 (0.30-19.88)	-

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room

Although influenced by outdoor concentrations, indoor O_3, CO and NO_2 concentrations did not exceed the standards and guidelines used for comparison referred in section 4.1.1. Zuraimi and Tham (2008) found much higher O_3 concentrations (62.65 µg m^{-3}), mainly determined by outdoor concentrations, shelf area and table cleaning, but CO concentrations observed in classrooms A and B of N_URB1, classrooms A, B and lunch room of N_URB2 and in N_URB3 were higher than those found in that study (1266.38 µg m^{-3} only determined by outdoor air). On the opposite, lower CO concentrations were found by Yang et al. (2009) (524.42 µg m^{-3}) and by Yoon et al. (2011) (812.89 µg m^{-3}). Roda et al. (2011) registered indoor NO_2 concentrations comparable to those found in N_URB1 but much lower than those detected in N_URB2 and N_URB3, ranging between 9.0 and 41.0 µg m^{-3}, which were determined by outdoor air influence in the absence of indoor sources, mainly due to the proximity to roadways with heavy traffic and by the fact that most of nursery schools' classrooms were located on the ground floor. There were not found exceedances to the Portuguese 2006 and 2013 standards for CO, O_3 or NO_2, which indicates that the registered concentrations of those pollutants are not expected to cause health effects on children attending these nursery schools. Exceedances to Portuguese 2006 standards were always higher during occupation periods than on weekdays in general. Moreover, it is also important to refer that the results here presented were similar to those obtained in Portuguese primary schools by Pegas et al. (2012) for NO_2 and VOC. School activity and indoor sources were also identified as increasing loadings of air pollutants in those primary schools, being inadequate ventilation, specific indoor sources (especially for VOC) and outdoor influence (NO_2) the main determinants of IAQ.

4.3 Conclusions

This study allowed a better understanding of the behaviour of several indoor air pollutants in the studied nursery schools, with and without occupation. The influence of outdoor air seemed to be determinant for O_3, CO and NO_2 indoor concentrations, and the observed formaldehyde and TVOC peak concentrations indicated the presence of specific indoor sources for these pollutants, namely materials emitting formaldehyde (mainly furnishing) and products emitting VOC associated to cleaning and children's specific activities (like paints and glues). For formaldehyde, baseline constant concentrations along the day were also found in some of the studied rooms, which enhances the importance of detailing the study of short and long-term children's exposure to this indoor air pollutant. While CO, NO_2 and O_3 never exceeded the national and international reference values for IAQ and health protection, exceedances were found for formaldehyde and TVOC.

Chapter 5

Indoor air in urban nursery schools: Particulate Matter assessment*

The main objectives of this study were: i) to evaluate indoor concentrations of particulate matter (PM_1, $PM_{2.5}$, PM_{10} and total suspended particles – TSP) on different indoor microenvironments in urban nurseries in Porto city; and ii) to analyse those concentrations according to guidelines and references for IAQ and children's health.

5.1 Methodology

This study was carried out on three different nursery schools (N_URB1, N_URB2 and N_URB3), all located at urban sites influenced by traffic emissions in Porto city, Portugal. Their main characteristics (including occupation, ventilation and cleaning habits and other specific activities), indoor microenvironments considered, and sampling periods were fully described previously in section 3.1.1. Measurements were performed in 4 classrooms in nursery N_URB1, 3 classrooms in nursery N_URB2, and 2 classrooms in nursery N_URB3, as well as in the lunch rooms/ canteens of all nursery schools.

Indoor concentrations of the different fractions of PM (PM_1, $PM_{2.5}$, PM_{10} and TSP) were continuously measured using a TSI DustTrak DRX 8534 particle monitor using light-scattering laser method (Figure 5.1). The minimum and maximum limit detections for this equipment are, respectively, 0.001 mg m^{-3} and 150 mg m^{-3}. The equipment was submitted to a standard zero calibration (available in the equipment) and data were validated prior to each new measurement (in each new room). Indoor measurements were performed from 2 to 9 days in each considered room, and, in some cases, both in weekdays and weekends, between February

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* adapted from: Branco PTBS, Alvim-Ferraz MCM, Martins FG, Sousa SIV, 2014. Indoor air quality in urban nurseries at Porto city: Particulate matter assessment. *Atmospheric Environment* 84: 133-143

and June 2013. Hourly averages were calculated from a set of four measurements per hour (each 15 minutes) per day of measurement.

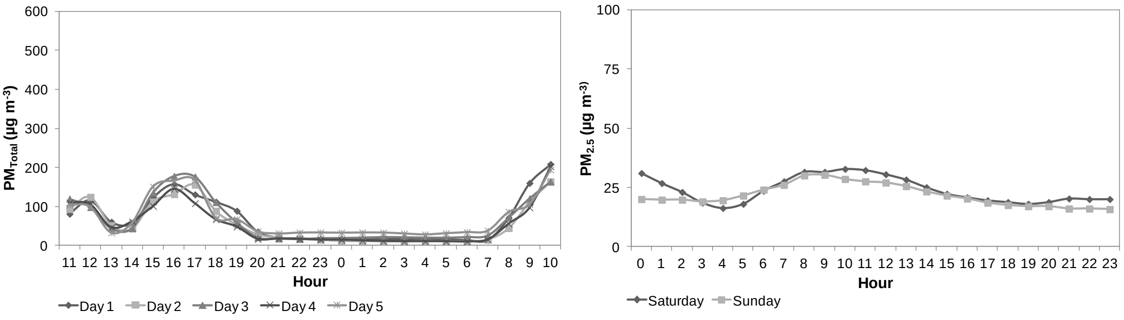
Figure 5.1 – TSI DustTrak DRX 8534 particle monitor

Simultaneously, hourly PM_{10} concentrations were obtained from the nearest air quality station classified as urban traffic. These measurements were conducted by the Air Quality Monitoring Network of Porto Metropolitan Area, managed by the Regional Commission of Coordination and Development of Northern Portugal (*Comissão de Coordenação e Desenvolvimento Regional do Norte*) under the responsibility of the Ministry of Environment.

5.2 Results

5.2.1 PM concentrations

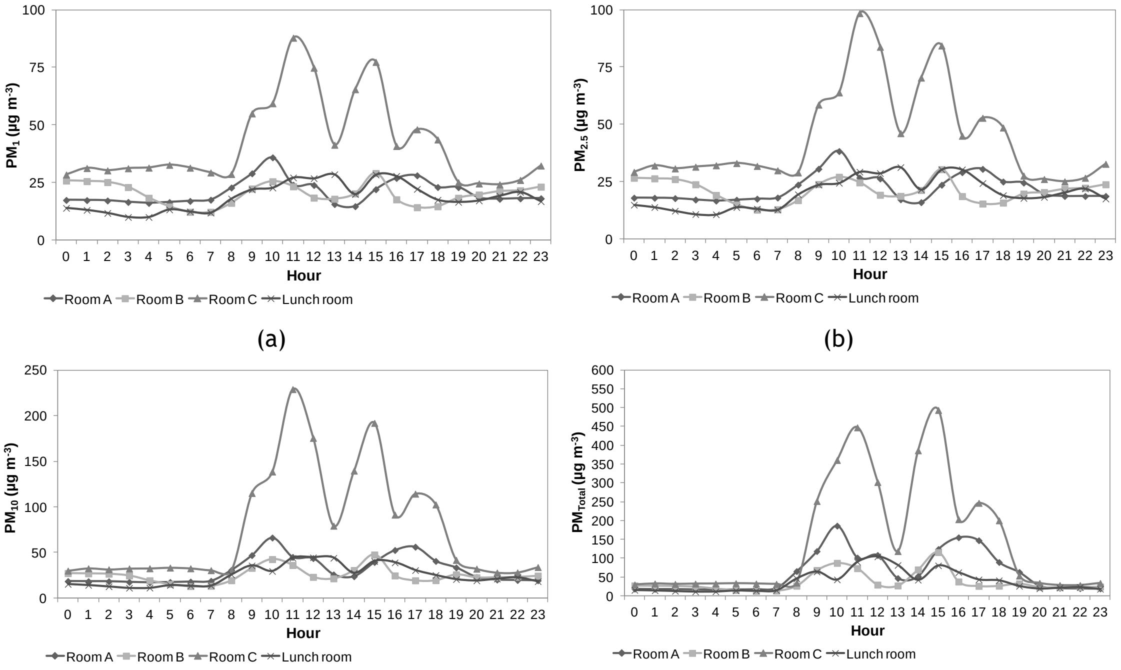
As previously stated and according to Tables 3.1 and 3.2 in section 3.1.1, samplings were performed for more than one day in each studied room of the three nursery schools and hourly averages were calculated. Figure 5.2 shows as an example (a) TSP measured during five days on weekdays at N_URB1 and (b) $PM_{2.5}$ measured on weekend at N_URB2. Assuming that there are no significant differences on IAP between different weekdays, and as the daily patterns during the different sampling weekdays in each room were very similar, average daily weekdays profiles were performed to represent an average IAQ scenario. The same was performed for weekends.



(a) (b)

Figure 5.2 - Distribution of PM hourly average concentrations of a) N_URB1 Room A weekdays, and b) N_URB2 Room A weekend.

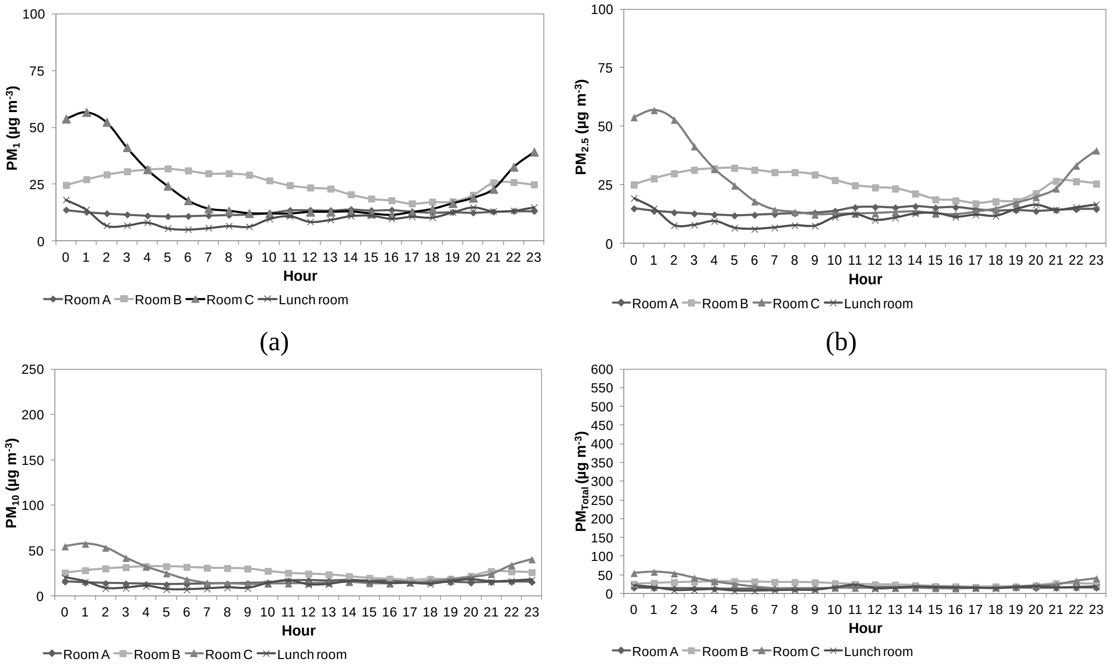
Figures 5.3 to 5.7 show the average daily profiles of PM$_1$, PM$_{2.5}$, PM$_{10}$ and TSP, respectively (a) to (d), for N_URB1 and N_URB2 during weekdays and weekends (respectively Figures 5.3 to 5.6) and N_URB3 during weekdays and weekends (Figure 5.7). Tables 5.1 and 5.2 summarize the statistical parameters (minimum, maximum, mean and median) of the hourly means for each room studied in the three nurseries.



(a) (b)

(c) (d)

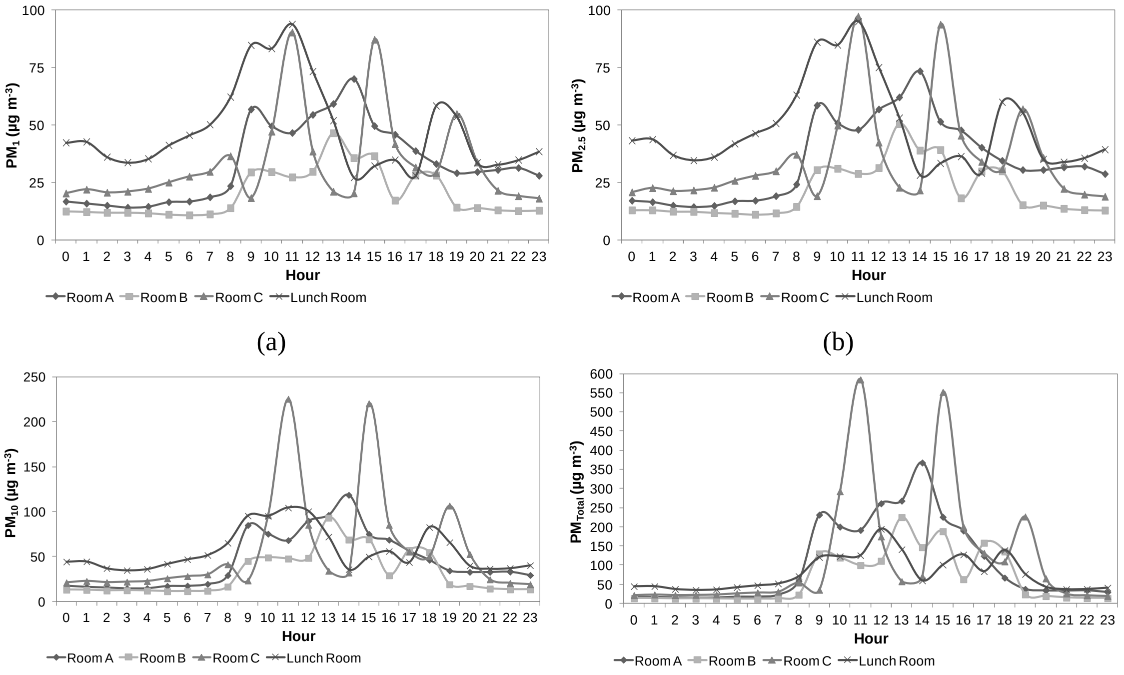
Figure 5.3 - PM average concentrations on weekdays in N_URB1: a) PM$_1$, b) PM$_{2.5}$, c) PM$_{10}$ and d) TSP (here represented as PM$_{Total}$).



(a) (b)

(c) (d)

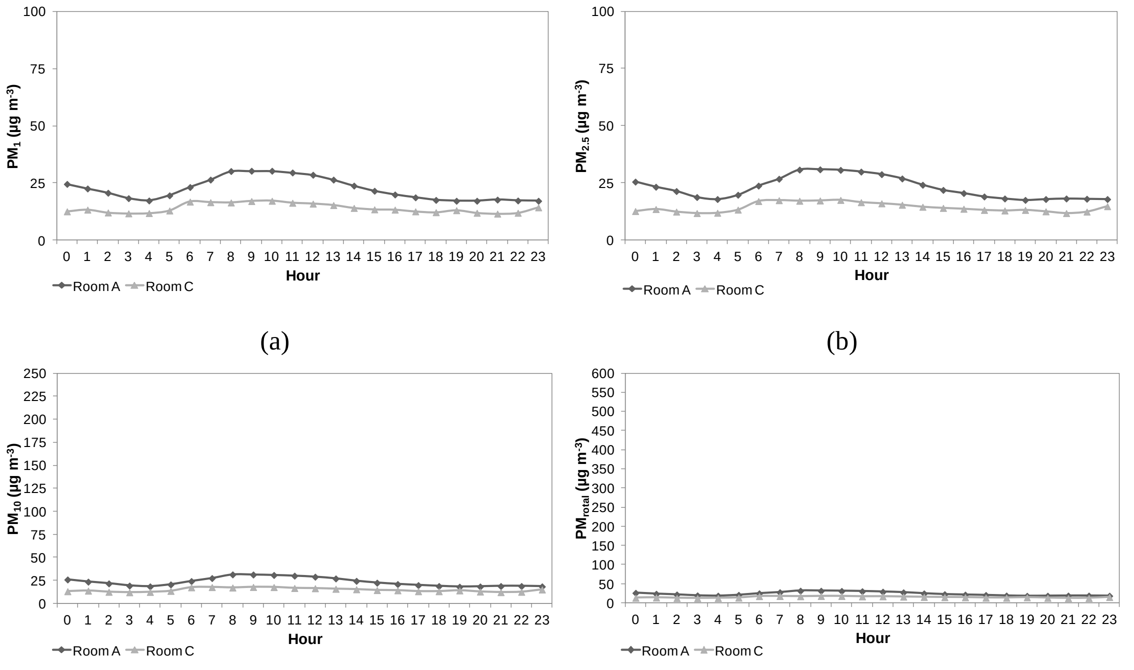
Figure 5.4 - PM average concentrations on weekends in N_URB1: a) PM$_1$, b) PM$_{2.5}$, c) PM$_{10}$ and d) TSP (here represented as PM$_{Total}$).



(a) (b)

(c) (d)

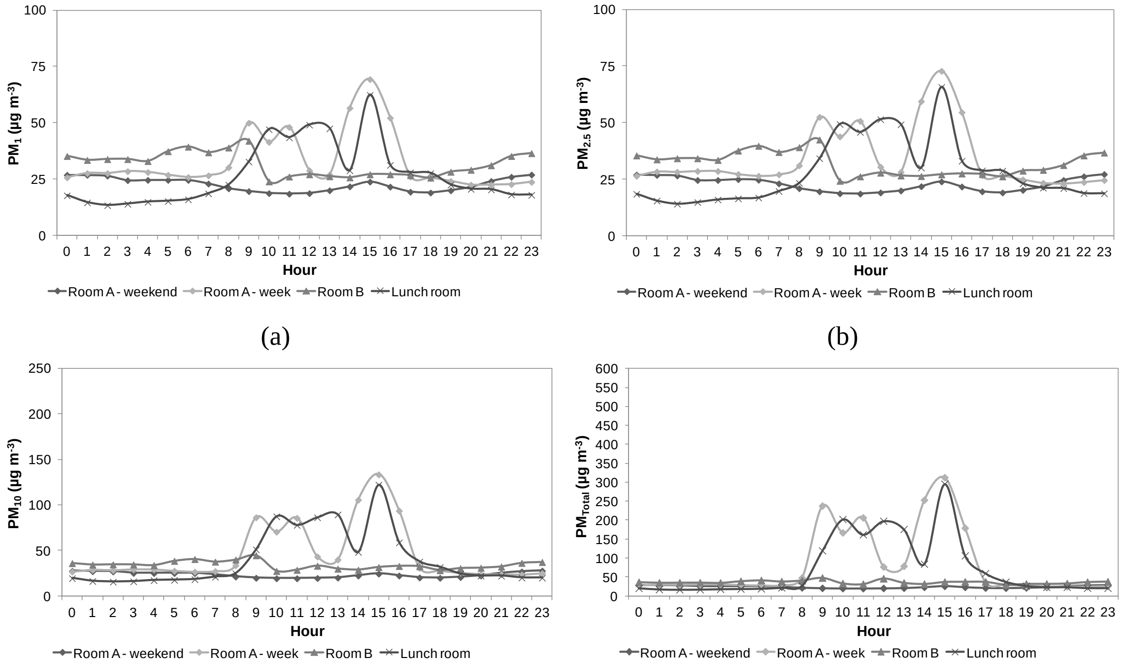
Figure 5.5 - PM average concentrations on weekdays in N_URB2: a) PM$_1$, b) PM$_{2.5}$, c) PM$_{10}$ and d) TSP (here represented as PM$_{Total}$).



(a) (b)

(c) (d)

Figure 5.6 - PM average concentrations on weekends in N_URB2: a) PM$_1$, b) PM$_{2.5}$, c) PM$_{10}$ and d) TSP (here represented as PM$_{Total}$).



(a) (b)

(c) (d)

Figure 5.7 - PM average concentrations in N_URB3: a) PM$_1$, b) PM$_{2.5}$, c) PM$_{10}$ and d) TSP (here represented as PM$_{Total}$).

Table 5.1 - Statistical parameters of the hourly mean data for PM_1 and $PM_{2.5}$ in each room studied in all the three nursery schools: N_URB1, N_URB2 and N_URB3 (values in µg m^{-3}).

Nursery school	Room	PM_1				$PM_{2.5}$			
		Min	Max	Mean	Median	Min	Max	Mean	Median
N_URB1	**A**	8.60	46.29	18.38	15.42	8.95	47.77	19.70	17.04
	B	7.25	45.25	21.97	19.38	8.00	46.00	22.75	20.00
	C	6.67	120.25	33.08	29.25	8.00	135.75	34.69	30.00
	LR	2.75	70.25	16.79	14.00	3.25	74.25	18.17	15.25
N_URB2	**A**	13.75	74.25	27.84	23.13	14.00	77.75	28.69	23.75
	B	4.00	54.75	19.95	21.00	4.25	58.75	21.09	21.50
	C	7.00	145.00	25.42	16.63	7.00	158.00	26.65	17.38
	LR	16.25	125.25	47.85	42.50	17.00	126.75	48.94	43.25
N_URB3	**A**	13.00	71.25	27.84	24.75	13.25	74.75	28.50	25.00
	B	11.75	62.00	32.29	33.25	12.00	62.75	32.63	33.25
	LR	7.00	82.00	26.74	19.25	7.25	86.50	28.01	20.75

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; Min – Minimum; Max - Maximum

Table 5.2 - Statistical parameters of the hourly mean data for PM_{10} and TSP in each room studied in all the three nursery schools: N_URB1, N_URB2 and N_URB3 (values in µg m^{-3}).

Nursery school	Room	PM_{10}				TSP			
		Min	Max	Mean	Median	Min	Max	Mean	Median
N_URB1	**A**	9.42	71.72	26.11	19.53	9.42	208.34	48.89	20.23
	B	8.00	71.00	25.56	21.75	8.00	190.50	32.61	23.00
	C	10.00	318.00	50.94	32.00	10.33	605.00	85.81	32.50
	LR	3.25	84.00	22.31	17.29	3.25	202.00	32.97	18.88
N_URB2	**A**	14.75	129.50	34.82	24.25	15.00	368.75	63.74	25.38
	B	5.00	104.50	31.62	23.63	5.00	248.25	66.09	23.63
	C	7.00	197.25	28.88	18.13	7.25	427.25	40.18	19.50
	LR	19.25	139.00	56.77	46.75	19.75	224.75	77.69	55.50
N_URB3	**A**	14.00	134.50	34.15	26.00	14.00	336.00	50.55	26.25
	B	13.25	73.50	34.86	35.00	14.25	86.00	37.04	36.25
	LR	7.75	166.00	40.15	23.00	8.00	401.25	70.55	23.25

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; Min – Minimum; Max - Maximum

Figures 5.3, 5.5 and 5.7 showed that PM concentrations in the classrooms started to rise up at the beginning of the occupancy period and started decreasing after the end of the occupancy period (time variable, depending on the room). Figures 5.4, 5.6 and 5.7 showed that the concentrations during weekends and non-occupancy periods did not seem to have high fluctuations neither peaks, thus being considered background concentrations for each respective room. The highest PM_1 and $PM_{2.5}$ concentrations were registered in N_URB2 (classroom C), while the highest PM_{10} and TSP concentrations were found in N_URB1 (classroom C). The minimum concentrations of all PM fractions were observed in LR of N_URB1. Likewise, the minima concentrations in N_URB3 were observed in LR; nevertheless, in N_URB2, LR had higher concentrations than the other measured rooms. Minima concentrations were always found during weekends or periods of non-occupancy and maxima concentrations were always registered during occupancy periods, as can be observed on Figures 5.3 to 5.7. Tables 5.1 and 5.2 showed that median values were very close to mean values, so there was not great scattering in the measurements in each room. The only exception was registered in TSP, in which mean concentrations were in general higher than median values.

5.2.2 PM size distribution

PM size ratios allowed to understand the size distribution on the PM measured concentrations. Three different ratios were used here: i) $PM_1/PM_{2.5}$; ii) $PM_{2.5}/PM_{10}$; and iii) PM_{10}/TSP. These ratios were calculated per microenvironment (room) and per nursery school, with the calculated hourly mean concentrations, in three different conditions: (i) occupancy; (ii) non-occupancy (according to data on Table 3.2 in section 3.1.1); and (iii) weekends (when applicable). These ratio results are represented in Tables 5.3 and 5.4.

Table 5.3 - PM size ratios in each studied microenvironment on weekdays: average values according to the occupancy patterns.

Nursery school	Room	Weekdays					
		During occupancy			**During non-occupancy**		
		$PM_1/PM_{2.5}$	**$PM_{2.5}/PM_{10}$**	**PM_{10}/TSP**	**$PM_1/PM_{2.5}$**	**$PM_{2.5}/PM_{10}$**	**PM_{10}/TSP**
N_URB1	A	0.93	0.63	0.42	0.96	0.95	0.97
	B	0.95	0.70	0.50	0.98	0.97	0.99
	C	0.91	0.50	0.51	0.98	0.95	0.98
	LR	0.92	0.75	0.59	0.94	0.95	0.98
N_URB2	A	0.96	0.69	0.41	0.97	0.95	0.98
	B	0.94	0.61	0.45	0.96	0.93	0.97
	C	0.94	0.60	0.49	0.97	0.94	0.98
	LR	0.97	0.76	0.61	0.98	0.95	0.97
N_URB3	A	0.95	0.64	0.50	0.97	0.97	0.97
	B	0.98	0.89	0.89	0.99	0.98	0.99
	LR	0.96	0.64	0.54	0.95	0.93	0.98

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; TSP – Total Suspended Particles

Table 5.4 - PM size ratios in each studied microenvironment on weekend: average values according to the occupancy patterns.

Nursery school	Room	Weekend		
		$PM_1/PM_{2.5}$	$PM_{2.5}/PM_{10}$	PM_{10}/TSP
N_URB1	A	0.90	0.94	0.99
	B	0.98	0.98	1.00
	C	0.98	0.96	0.98
	LR	0.87	0.88	0.95
N_URB2	A	0.97	0.97	0.99
	B	-	-	-
	C	0.97	0.97	0.99
	LR	-	-	-
N_URB3	A	0.99	0.97	0.99
	B	-	-	-
	LR	-	-	-

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; TSP – Total Suspended Particles

In N_URB1 during occupancy on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.91 to 0.95, $PM_{2.5}/PM_{10}$ ratio from 0.50 to 0.75, and PM_{10}/TSP ratio from 0.42 to 0.59. During non-occupancy periods on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.94 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.95 to 0.97, and PM_{10}/TSP ratio from 0.97 to 0.99. On weekends, $PM_1/PM_{2.5}$ ratio varied from 0.87 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.88 to 0.98, and PM_{10}/TSP ratio from 0.95 to 1.

On weekdays during occupancy in N_URB2, $PM_1/PM_{2.5}$ ratio varied from 0.94 to 0.97, $PM_{2.5}/PM_{10}$ ratio varied from 0.60 to 0.76, and PM_{10}/TSP ratio varied from 0.41 to 0.61. During non-occupancy periods on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.96 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.93 to 0.95, and PM_{10}/TSP ratio from 0.97 to 0.98. On weekends, ratios were very close to 1 ($PM_1/PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratios were 0.97, and PM_{10}/TSP ratio was 0.99).

In N_URB3 on weekdays during occupancy, $PM_1/PM_{2.5}$ ratio varied from 0.95 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.64 to 0.89, and PM_{10}/TSP ratio from 0.50 to 0.89. During non-occupancy periods on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.95 to 0.99, $PM_{2.5}/PM_{10}$ ratio from 0.93 to 0.98, and PM_{10}/TSP ratio from 0.97 to 0.99. On weekends, ratios were also very close to 1 ($PM_1/PM_{2.5}$ and PM_{10}/TSP ratios were 0.99, and $PM_{2.5}/PM_{10}$ ratio was 0.97).

5.2.3 Comparison with standard and guidelines

PM concentrations were compared with WHO guidelines and with the Portuguese 2006 legislation (Decreto-Lei nº 79/2006), referred in section 2.1.3. Table 5.5 summarizes the exceedances per room and per nursery school to WHO guidelines, as no exceedances were observed to the Portuguese standards.

Table 5.5 - Exceedances of 24-hour mean PM concentrations to WHO guidelines ($PM_{2.5}$ - 25 µg m^{-3} and PM_{10} - 25 µg m^{-3}).

Nursery school	**Room**	**24h exceedances (%)**	
		WHO ($PM_{2.5}$)	**WHO (PM_{10})**
N_URB1	A	0	0
	B	40	0
	C	80	40
	LR	11	0
N_URB2	A	50	0
	B	33	0
	C	40	20
	LR	100	50
N_URB3	A	60	0
	B	50	0
	LR	100	0

A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room; WHO – World Health Organization

In nursery school N_URB1, the worst scenario was found in classroom C, where WHO guidelines were exceeded 80% and 40% of the times, for $PM_{2.5}$ and PM_{10} respectively. On the opposite, in classroom A WHO guidelines were not exceeded. In N_URB2, it was possible to found the worst scenario in LR, where WHO guideline for $PM_{2.5}$ was always exceeded and for PM_{10} was exceeded half of the times. It is also important to point out that in classroom C WHO guidelines were exceeded 40% and 20% of times for $PM_{2.5}$ and PM_{10}, respectively. Lastly, in the case of N_URB3, WHO guideline for $PM_{2.5}$ was the most exceeded (60%, 50% and 100% of times, respectively in rooms A, B and LR). On the other hand, WHO guideline for PM_{10} was never exceeded in this nursery school.

5.2.4 Indoor/Outdoor ratios

Collected outdoor PM_{10} concentrations allowed obtaining an average daily profile of PM_{10}, represented in Figure 5.8. It was possible to observe an increase throughout the morning, a decrease in the early afternoon (12h-14h), and an increase throughout the rest of afternoon and evening, decreasing throughout dawn. According to the obtained results, PM_{10} concentration profiles were found similar on weekdays and weekends.

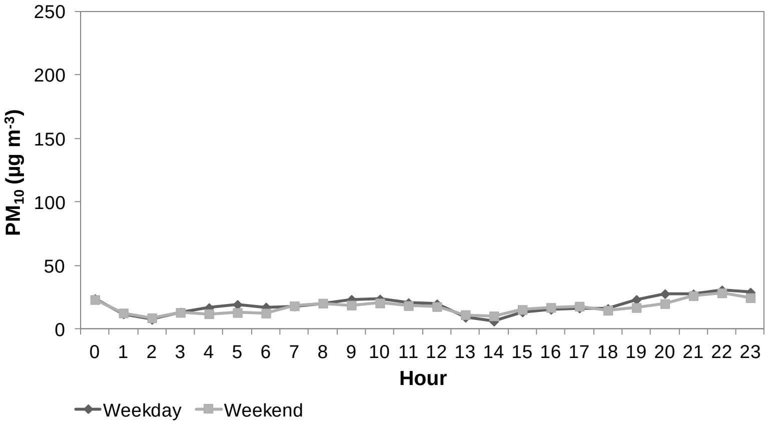


Figure 5.8 - Distribution of PM_{10} outdoor hourly average concentrations in weekdays and weekend.

Indoor measured concentrations were compared with outdoors using the I/O ratio. Mean I/O ratios were obtained for each studied room in the three nursery schools (Table 5.6). Generically, I/O mean ratios were always higher than 1. On a closer look, in N_URB1, the highest I/O mean ratio was found in LR and the lowest was found in classroom A, both for weekdays and weekends. Unfortunately, there was not enough outdoor data available to determine I/O ratio for classroom C (considering the period of measurement in this classroom). In N_URB2, it was possible to find the highest I/O ratio of all the studied nursery schools on weekdays (in classroom C). It is also important to point out the high I/O ratio observed in classroom A. In N_URB3, the worst scenario was found in LR. On weekends, I/O mean ratios were never higher 2.65 (N_URB3, classroom A).

Table 5.6 - PM_{10} I/O ratios: mean values observed in each studied site for weekdays and weekends, and respective minima (min) and maxima (max) values.

Nursery	Room	Weekday	Weekend
N_URB1	A	2.17 (min-max: 0.46-18.32)	1.06 (min-max: 0.34-9.42)
	B	2.23 (min-max: 0.42-12.75)	1.35 (min-max: 0.55-3.80)
	C	*	*
	LR	3.05 (min-max: 0.41-37.50)	1.54 (min-max: 0.35-11.50)
N_URB2	A	5.31 (min-max: 0.56-129.50)	2.02 (min-max: 0.40-20.00)
	B	1.96 (min-max:0.23-11.00)	-
	C	13.96 (min-max: 0.57-213.63)	2.02 (min-max: 0.39-7.00)
	LR	2.41 (min-max: 0.60-9.35)	-
N_URB3	A	2.67 (min-max: 0.48-10.44)	2.65 (min-max: 0.83-15.00)
	B	2.12 (min-max: 0.42-21.00)	-
	LR	4.57 (min-max:0.43-25.44)	-

* For room C in N_URB1 nursery, outdoor PM_{10} concentrations data available were only for less than 50% of the study period, which was not statistically relevant; A – Classroom A; B – Classroom B; C – Classroom C; LR – Lunch Room

5.3 Discussion

In nursery school N_URB1, classroom C had the highest PM concentrations which could have been the result of the cumulative effect of three major conditions: i) poor ventilation (there were no open direct access to the outdoor and the door to the inner corridor was almost always closed); ii) high occupancy, with a total of 25 persons, despites being the room with the higher volume; and iii) intense activity, characteristic of 5 years old children. Additionally, it was possible to notice three peaks in PM profiles for all the studied classrooms, which represented the three main occupancy periods (morning and afternoon before and after the break). In nursery school N_URB1, classroom B revealed the lower PM concentrations during occupancy, most probably due to the lower occupancy on this classroom (only 7 people) when comparing to the others. The lower concentrations observed in the LR on this nursery school were possibly due to its size and the existence of a small hall that creates a discontinuity between the kitchen and the LR, which possibly diminishes kitchen PM penetration into the lunch room. On weekends the concentrations were lower than on weekdays, and the behaviour for the different rooms was similar, with the exception of classroom C where they were higher on the first hours of the day. As this was clearly the room with the highest concentrations during weekdays, this was the result of the decrease of PM concentrations in the beginning of the weekend (Saturday dawn) – the settlement phenomenon.

In nursery school N_URB2, LR showed the highest PM concentrations for the finer fractions (PM_1 and $PM_{2.5}$) during the occupancy period and during the dawn and morning. Cooking activities are also one of the major indoor sources of PM (Monn, 2001) and might explain the higher concentrations observed as these activities started very early in the morning (8h) and ended late at the afternoon (19h). In this nursery school it was also possible to observe that classroom C had the maximum PM concentrations (peaks) in all fractions, but especially higher for TSP, which can be attributed to three major synergetic factors: i) a higher occupancy in this classroom when compared with others in this nursery school with similar areas (Table 3.1 in the section 3.1.1); ii) poor ventilation (doors to outdoor were always closed and to the inner corridor were almost always closed); and iii) normal activities characteristic of 4 years old children (occupants of this classroom). Also in classrooms C and B in this nursery, it was possible to observe the three peaks in the concentrations on weekdays, also in the three main occupancy periods (morning and afternoon before and after the break), and for the same reasons than in N_URB1. On the other hand, classroom A (baby nursery) showed a different pattern, with the highest concentrations being registered between 13-15h. This was the period of sleeping for the babies in the cribs room (next to and opened to classroom A) and for teachers/educators to do some tidying. On weekends, PM concentrations were lower and profiles were similar and almost constant for the two measured classrooms (A and C).

In nursery school N_URB3, PM concentrations in classroom A had a typical behaviour throughout the weekdays, with clear peaks matching the occupancy periods. On the opposite, classroom B had a peculiar PM profile, due to its occupancy (a wide space that was only used late at the afternoon, from 16 to 19h). In the lunch room of this nursery school, PM concentrations profile was slightly different from the other two lunch rooms (in N_URB1 and N_URB2). As there were no cooking activities in the kitchen attached to the lunch room and cleaning activities were made immediately after lunch time, PM concentrations were lower and the maximum was observed after lunch time (early afternoon). On weekends, concentrations were much lower, and there was an expected almost constant PM behaviour during this period.

There was occasionally an increase of PM concentrations at the end of the afternoon, which was kept even after the end of classroom occupancy, mainly due to cleaning activities. Fromme et al. (2005) also reported that cleaning activities could contribute to the increase of PM in the indoor air. To minimize this contribution, cleaning activities in nursery schools should be performed when children go home and with high ventilation rates to outdoor.

$PM_1/PM_{2.5}$ ratios were, in all situations, equal or higher than 0.90, i.e., very close to 1, meaning that the majority of the $PM_{2.5}$ was less than 1 µm diameter. On weekends and non-occupancy periods, PM concentrations were mainly due to the finer fraction, with $PM_{2.5}/PM_{10}$ ratios close to 1. The opposite was verified on periods of occupancy when $PM_{2.5}/PM_{10}$ (as well as PM_{10}/TSP) ratios were in average half of those in weekends and non-occupancy periods.

Overall, PM concentrations on nursery schools were much higher during occupancy periods than during non-occupancy periods and weekends and almost constant on the latter ones, which was consistent with the presence of children and their activities, even in LR. However, PM_{10} mean levels in all studied rooms were below mean level obtained by Yang et al. (2009) in Korean nursery schools (94.94 $\mu g\ m^{-3}$). This means that the presence of children and their activities in nursery schools' microenvironments potentiated, in general, the suspension and/or re-suspension phenomena of PM indoors, mainly coarser fractions, which was also found by Parker et al. (2008) for school buildings. In general, occupancy increases PM concentrations indoors (Sousa et al., 2012b).

PM concentrations were high in all the studied nursery schools, often above WHO guidelines, which is concerning, especially for the finer fractions. Those were often found in the classrooms of older children (4-5 years old). These have greater freedom and ability to move when compared with younger ones, which is reflected in their usual daily activities on nursery schools increasing PM concentrations in indoor air, as reported by Fromme et al. (2005). Lunch rooms also exceeded WHO guidelines, especially in N_URB2 and N_URB3, mainly due to cooking activities and children movements. Of concern were also the exceedances in 50% of the measurement days to WHO $PM_{2.5}$ guidelines in N_URB2 classroom 1, which is a baby nursery, and these younger children are the most vulnerable to adverse health effects of PM suspended in the air.

I/O ratios were always higher than 1, meaning that PM_{10} indoor concentrations were, in average, higher than outdoor levels, which is consistent with the findings from Yoon et al. (2011) in urban pre-schools in Korea and from Almeida et al. (2011) in Portuguese primary schools. On weekdays, indoor concentrations were always at least 2 times higher than those found outdoors. Even on weekends indoor concentrations were found to be until 2.65 times (in average) higher than those found outdoors. This suggested that outdoor influence on PM indoor concentrations was not significant when compared with indoor sources and re-suspension phenomena. In fact, the highest I/O ratios in N_URB1 and N_URB3 were found in lunch rooms, which is consistent with indoor sources already stated (cooking activities and children drives). The higher I/O ratio found in classroom C in N_URB2, as well as the high ratio found in classroom A in the same nursery, were also due to indoor sources and poor ventilation to outdoors. In fact, poor ventilation to outdoor turned indoor sources as the major increasing factor of indoor PM concentrations, which was also stated by Yang et al. (2009).

5.4 Conclusions

PM concentrations were often found high in the studied classrooms, mainly in the finer fractions (PM_1 and $PM_{2.5}$), and often above the limits recommended by WHO, which is concerning in terms of exposure effects on children's health. The classrooms occupied by older children were found to be those with the highest PM concentrations, due to their higher mobility when compared with younger ones, thus increasing PM re-suspension. Results allowed concluding that indoor sources were clearly the main contributors to indoor PM concentrations when compared with outdoor influence. Due to that, poor ventilation in these classrooms affected IAQ by increasing PM accumulation. Results also confirmed that cleaning activities increased PM concentrations in indoor air and suggested that cooking activities could increase PM concentrations in lunch rooms.

Chapter 6

Quantifying indoor air quality determinants in urban and rural nursery and primary schools*

The main aim of this study was to quantify the determinants of selected indoor air pollutants in nursery and primary schools from both urban and rural sites, and accounting for seasonal variations. To identify indoor air pollutants of major concern, their concentrations were compared with international and national reference values. To better characterize the influence of indoor air pollutants' determinants on children's exposure, this study assessed and quantified their concentrations considering both baseline (when spaces are unoccupied) and occupancy periods (when children are exposed), as well as scholar indoor microenvironments from early infancy to primary school age. Ultimately, this study intended to contribute with prevention and mitigation strategies concerning IAP in the nursery and primary schools evaluated.

6.1 Methodology

6.1.1 Sampling sites

This study was carried out in 25 nursery (5 for infants and 12 for pre-schoolers) and primary schools (8) from both urban (10) and rural (15) areas, in Northern Portugal (41ºN, 8ºW). One or more classrooms in each building were selected being representative of the classrooms per age group (infants, pre-schoolers and primary school children), considering the room characteristics, occupancy and activity patterns. A total of 63 rooms were studied: 50

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* adapted from: Branco PTBS, Alvim-Ferraz MCM, Martins FG, Sousa SIV, 2019. Quantifying indoor air quality determinants in urban and rural nursery and primary schools. *Environmental Research* 176:108534.

classrooms (11 for infants, 20 for pre-schoolers, and 19 for primary school children), 2 bedrooms (used only for infants' nap), and 11 canteens/ lunch rooms (from now on referred as canteens). Although measurements were performed twice in some rooms, namely cold season (October to March) and warm season (April to September), they cannot be considered repeated measurements as they occurred in distinct academic years (from 2013 to 2016), thus with distinct occupancy and activities' conditions. Thus, a total of 101 microenvironments (considering each room in each season) were considered independently, from which 82 corresponded to classrooms in each season. The governance bodies from all the nursery and schools involved in this study consented to perform this study.

Information on school and rooms' characteristics, as well as information on periods of occupation and number of occupants were collected via a combination of inspection and interviews with the staff. Occupancy periods varied between different studied rooms, depending not only if they were infants, pre-schoolers or primary school children, but also on each school organization, although they typically ranged between 11:30-14:00 in canteens, and between 7:30-20:00, 8:30-19:00, and 08:30-17:30, respectively in classrooms for infants, pre-schoolers and primary school children, which are typical timetables for Portuguese nursery and primary schools. Characteristics of the studied microenvironments are summarized in Table 6.1 and detailed in Appendix B (B1 and B2). The majority of the buildings were constructed after 2006, i.e., after the introduction of the first legislation in Portugal concerning IAQ, and located in background areas (with small traffic in the near road). The majority of the studied classrooms were located in the ground floor, with dominated natural ventilation (DNV), without heating, and with laminate flooring material. Chalkboard was not usual, and cleaning occurred usually daily after occupancy, being wash and sweep the most used methods for dust removal. In all the studied microenvironments with DNV, no device was used to control RH or T. Mean (and range) surface area of classrooms was 46.9 m^2 (17.0-89.0 m^2), and the mean (and range) number of children per classroom was 22 (1-37). Thus, mean occupant density was 49 occupants/100 m^2 (range 3-106 occupants/100 m^2), higher than recommended by ASHRAE for school facilities (25 occupants/100 m^2) (ASHRAE, 2007). Although all the rooms complied with the Portuguese legislation regarding the number of children per class (Despacho nº 5048-B/2013; Portaria nº 262/2011), only 4 classrooms had equal or less than the recommended occupant density, considering ASHRAE guidelines.

6.1.2 Indoor air pollutants sampling

Indoor concentrations of CO_2, CO, formaldehyde, NO_2, O_3, TVOC, and meteorological/ comfort parameters T and RH were continuously sampled using an Haz-Scanner IEMS Indoor Environmental Monitoring Station (Environmental Devices Corporation, USA) equipped with high sensitive sensors. Four different fractions of particulate matter (PM_1, $PM_{2.5}$, PM_{10} and TSP) were continuously sampled with a TSI DustTrak DRX 8534 particle monitor using light-scattering laser method. Gas sensors from Haz-Scanner IEMS were calibrated by Environmental Devices Corporation against NIST/EPA traceable Calibration Gas using NIST primary Flow Standard: LFE774300. TSI DustTrak DRX 8534 was calibrated by TSI under the standard ISO 12103-1, A1 test dust (Arizona Dust); flow and pressure were also verified. Both devices were yearly calibrated. Sampling methods and main characteristics of each sensor were previously described in detail in sections 3.1.2, 4.1.1 and 5.1.

Table 6.1 - Characteristics of the studied indoor microenvironments: all rooms (including classrooms, bedrooms and canteens), and only classrooms

Characteristics	**Categories**	**All rooms**		**Classrooms**	
		warm season, n (%)	**cold season, n (%)**	**warm season, n (%)**	**cold season, n (%)**
Type of management	private	29 (51.8)	25 (55.6)	22 (50.0)	20 (52.6)
	public	27 (48.2)	20 (44.4)	22 (50.0)	18 (47.4)
Date of construction	before 2006	22 (39.3)	19 (42.2)	16 (36.4)	15 (39.5)
	2006 or after	34 (60.7)	26 (57.8)	28 (63.6)	23 (60.5)
Traffic in the near road	medium/high	20 (35.7)	20 (44.4)	16 (36.4)	17 (44.7)
	small	36 (64.3)	25 (55.6)	28 (63.6)	21 (55.3)
Floor	ground floor	39 (69.6)	29 (64.4)	30 (68.2)	25 (65.8)
	1st	14 (25.0)	13 (28.9)	11 (25.0)	10 (26.3)
	2nd	3 (5.4)	3 (6.7)	3 (6.8)	3 (7.9)
Ventilation	DNV	52 (92.9)	41 (91.1)	40 (90.9)	34 (89.5)
	DAC	4 (7.1)	4 (8.9)	4 (9.1)	4 (10.5)
Heating	none	48 (85.7)	22 (48.9)	39 (88.6)	19 (50.0)
	electric	8 (14.3)	19 (42.2)	5 (11.4)	15 (39.5)
	gas or oil	0 (0.0)	4 (8.9)	0 (0.0)	4 (10.5)
Signs of dampness	yes	5 (8.9)	6 (13.3)	5 (11.4)	6 (15.8)
Flooring material	laminate	39 (69.6)	34 (75.6)	34 (77.3)	31 (81.6)
	ceramic tile	9 (16.1)	4 (8.9)	3 (6.8)	1 (2.6)
	hardwood	8 (14.3)	7 (15.6)	7 (15.9)	6 (15.8)
Chalkboard	yes	3 (5.4)	5 (11.1)	3 (6.8)	5 (13.2)
Cleaning frequency	daily	51 (91.1)	39 (86.7)	40 (90.9)	34 (89.5)
	twice a day	5 (8.9)	4 (8.9)	4 (9.1)	4 (10.5)
	less than daily	0 (0.0)	2 (4.4)	0 (0.0)	0 (0.0)
Cleaning schedule	after occupancy	53 (94.6)	41 (91.1)	41 (93.2)	34 (89.5)
	during occupancy	1 (1.8)	4 (8.9)	1 (2.3)	4 (10.5)
	before occupancy	2 (3.6)	0 (0.0)	2 (4.5)	0 (0.0)
Dust cleaning method	sweep	18 (32.2)	18 (40.0)	16 (36.3)	16 (42.1)
	vacuum	6 (10.7)	11 (24.4)	5 (11.4)	8 (21.1)
	wash	32 (57.1)	16 (35.6)	23 (52.3)	14 (36.8)

DNV – dominated natural ventilation; DAC – dominated air-conditioning

Samplers were submitted to standard zero calibrations (available in the equipment) and data were validated prior to each measurement in a new room. Inside the rooms, the apparatus was placed as close to the middle as possible, far from windows, doors and room's corners, and approximately at the same height of children's breathing zone. Indoor samplings were performed continuously from at least 24 hours to 9 consecutive days (not simultaneously) in each studied room; in some cases weekend was also considered. Previous results (in sections 3.2, 4.2 and 5.2) indicated that indoor air pollutants concentrations were mostly similar between two different weekdays, i.e. it seemed they were not dependent on the weekday, thus a daily mean scenario was considered.

6.1.3 Data analysis

Continuous measurements (logged each minute) allowed calculating hourly means and daily (24-hour) patterns for each studied compound sampled (gaseous, comfort parameters and particles), to visualize their daily behaviour and to quantify the difference between occupancy periods (when children are exposed) and baseline levels (non-occupancy periods). A descriptive statistical analysis of the concentrations of the various indoor air pollutants sampled were initially performed, indicating that the observed levels did not follow a normal distribution. Non-parametric Spearman's rank correlation (r_s) was calculated to evaluate the relationship between the various studied compounds, and between occupancy and non-occupancy periods. To understand the size distribution of the measured particulate matter concentrations along the day, three different hourly fraction ratios were also calculated ($PM_1/PM_{2.5}$, $PM_{2.5}/PM_{10}$ and PM_{10}/TSP).

Aiming to deepen IAQ analysis by understanding whether the levels are of concern or not, mean values were compared with national and international reference standard and guideline values for indoor environments referred in section 2.1.3 to calculate exceedances and/or non-compliances, specifically: (i) Portuguese legislation (Portaria nº 353-A/2013) for CO_2 (2250 mg m^{-3}, plus 30% of MT if no mechanical ventilation system was working in the room), CO (10000 µg m^{-3}), formaldehyde (100 µg m^{-3}), TVOC (600 µg m^{-3}, plus 100% of MT if no mechanical ventilation system was working in the room), and $PM_{2.5}$ and PM_{10} (25 µg m^{-3} and 50 µg m^{-3} respectively, plus 100% of MT if no mechanical ventilation system was working in the room); (ii) WHO guidelines (WHO, 2010) for CO (35000 µg m^{-3} for hourly mean), NO_2 (200 µg m^{-3} for hourly mean), $PM_{2.5}$ (25 µg m^{-3}, for daily mean) and PM_{10} (50 µg m^{-3} for daily mean); (iii) the ASHRAE standard reference ranges (ASHRAE, 2007) for T (20-23.9 ºC in cold season, and 22.8-26.1ºC in warm season) and RH (30-60%). For the Portuguese legislation, 8-hour running means were calculated and the daily maximum was compared with the reference value. As O_3 was not included in the most recent Portuguese legislation, levels were compared with the previous standard (200 µg m^{-3}) (Decreto-Lei nº 79/2006).

Aiming to study and quantify the determinants of selected indoor air pollutants, bivariate analysis were run by either Kruskall-Wallis or Wilcoxon rank sum tests for categorical predictors, and analysis of variance (ANOVA) tests for continuous predictors, as the outcome variables (daily mean values of indoor air pollutants' concentrations in occupancy or in non-occupancy periods) were not normally distributed. To ensure normality of the distributions of the outcome variables all linear regression models were built using log-transformed values of indoor air pollutants' concentrations. Variables that yielded a p-value lower than 0.20 in the bivariate analysis were selected to enter the multivariate linear regression models. Initially, a full multivariate linear regression model was built; then a stepwise model selection was run to get the "best" final model, based on Akaike's information criterion (AIC). Standard post-diagnostic tests were run on the final models distribution of the residuals, evaluation of influential observations (Cook's D) and variance inflation factor (VIF). Importance scores and relative importance of the predictors were also evaluated in the final models. A separate model was built for each indoor air pollutant, and for occupancy and non-occupancy periods, and all the models were adjusted for season of sampling to avoid bias. Statistical computations were performed with R software version 3.4.3. The level of statistical significance was set at 0.05.

6.2 Results

6.2.1 Characterization of IAQ

Figure 6.1 represents levels of comfort/meteorological parameters and indoor air pollutants concentrations by season of sampling in all the studied microenvironments. T was significantly ($p < 0.05$) higher and RH lower in warm season. CO_2, O_3 and $PM_{2.5}$ concentrations were significantly higher ($p < 0.05$) in cold season, while CO, NO_2, and TVOC concentrations were significantly higher ($p < 0.05$) in warm season. Formaldehyde concentrations were not significantly different between seasons ($p = 0.997$). IAQ levels by age group of children (infants, pre-schoolers and primary school children) and by site location were represented in Figures 6.2 and 6.3. Only CO_2 ($p = 0.38$) and TVOC ($p = 0.97$) concentrations did not significantly varied with the site location of the school building (urban or rural). Concentrations of CO_2, NO_2, TVOC and particulate matter, as well as levels of T and RH, varied significantly ($p < 0.05$) between classrooms for infants, pre-schoolers or primary school children. On the other hand, CO, formaldehyde and O_3 did not show statistically significant differences between classrooms for infants, pre-schoolers and primary school children.

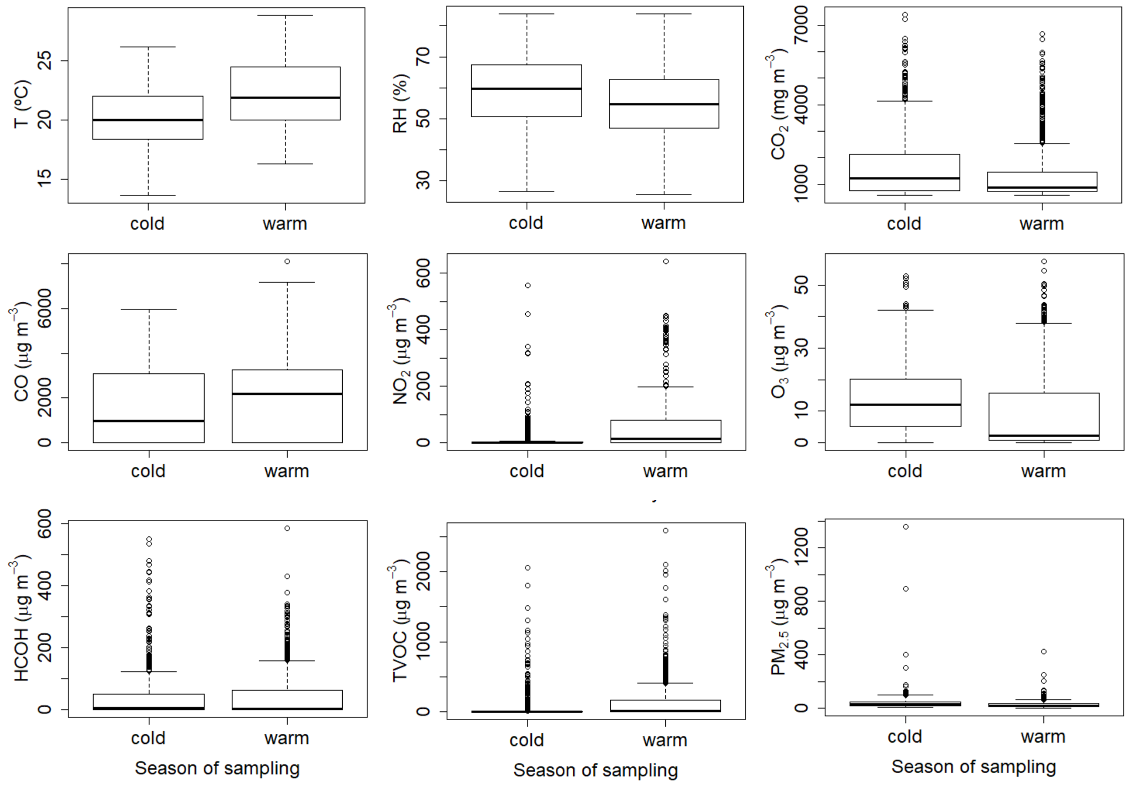


Figure 6.1 - Measured meteorological parameters and indoor air pollutants' concentrations (hourly mean values) by season of sampling in all the studied microenvironments (N =101).

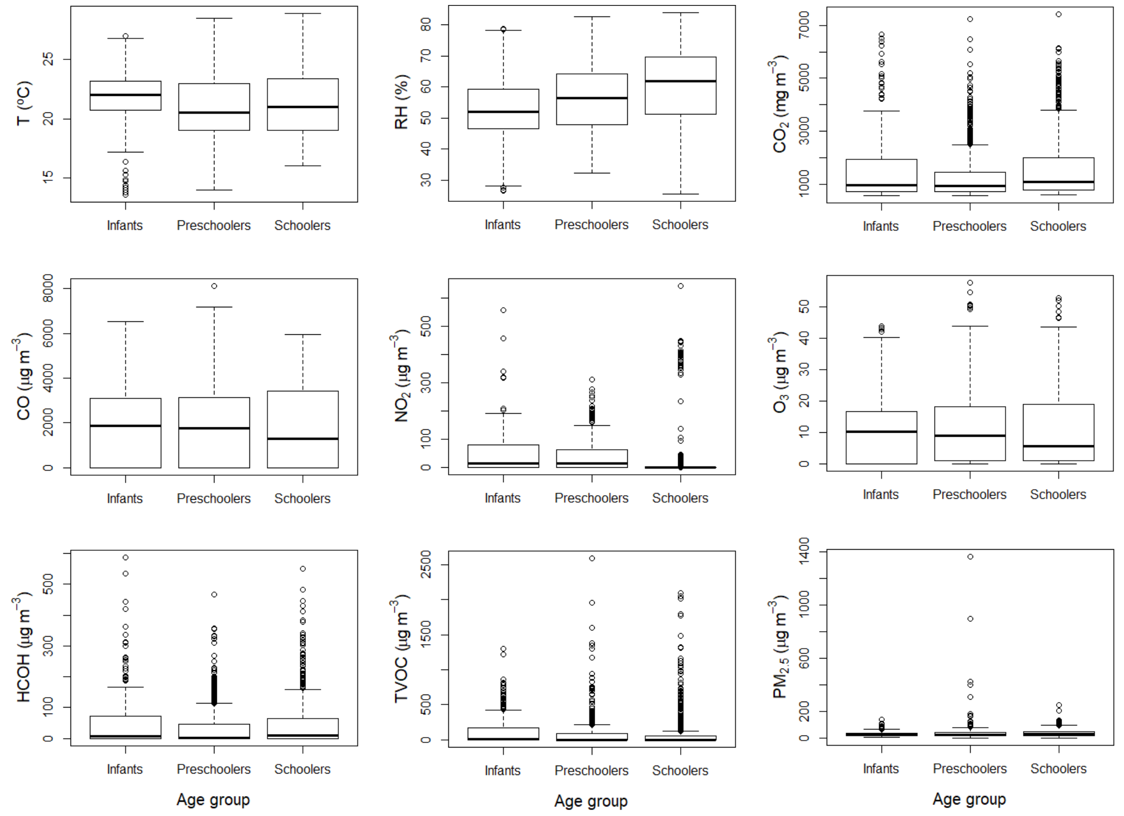
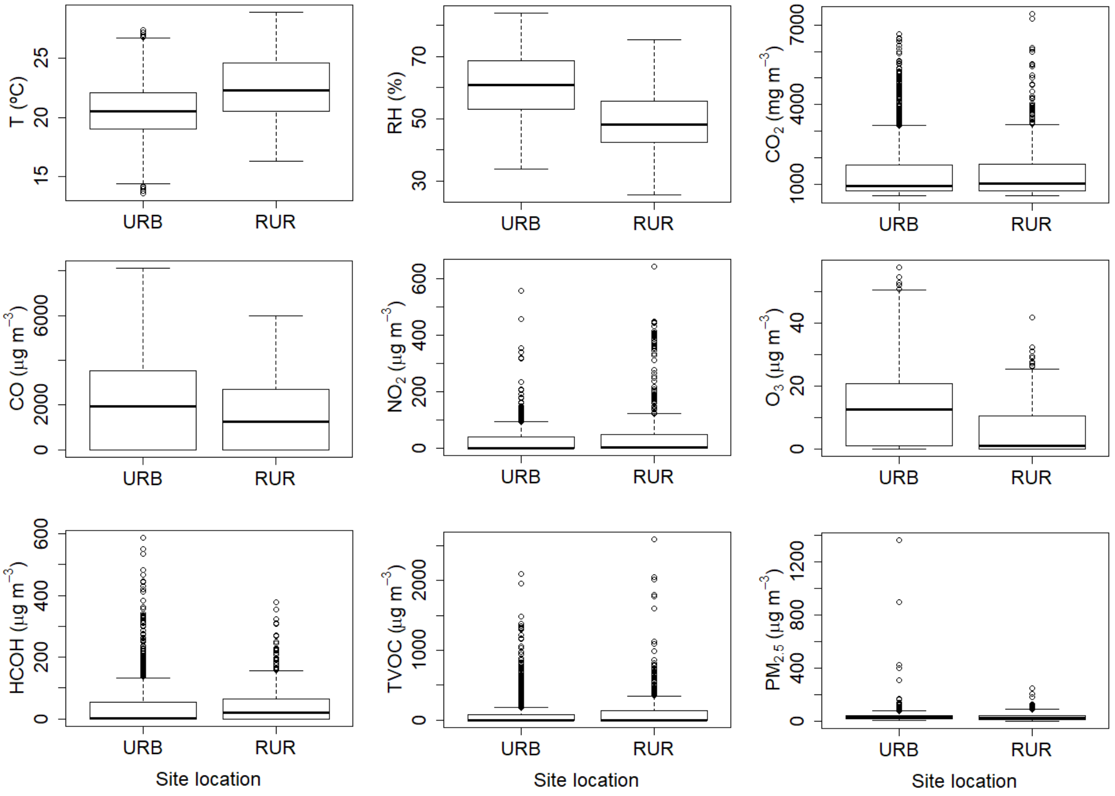


Figure 6.2 - Measured meteorological parameters and indoor air pollutants' concentrations (hourly mean values) by occupants' (children) age in all the studied microenvironments (N =101).

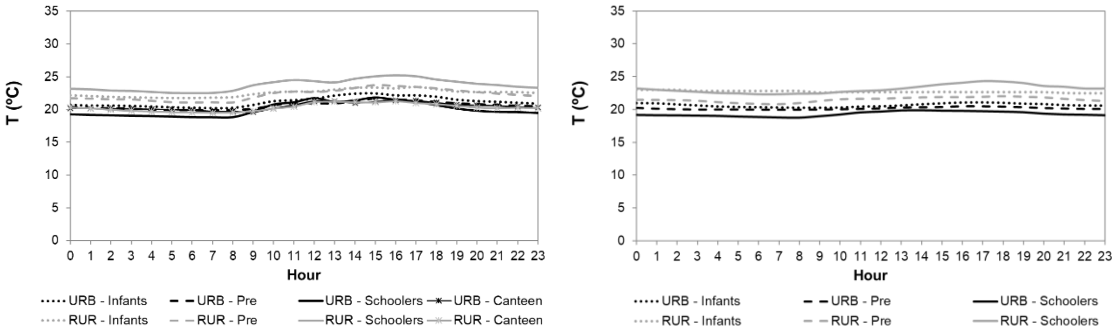


URB - urban; RUR - rural

Figure 6.3 - Measured meteorological parameters and indoor air pollutants' concentrations (hourly mean values) by site location in all the studied microenvironments (N =101).

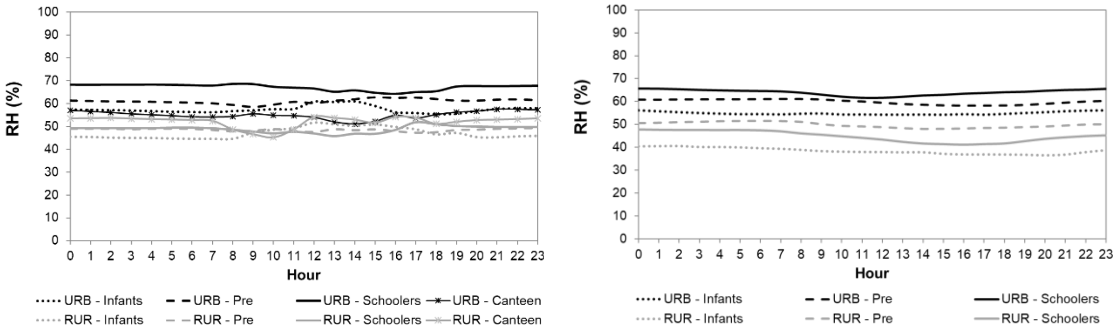
For a better IAQ characterization, analysis was divided for classrooms and canteens as well as for weekdays, weekend and occupancy periods. On weekdays, it was assumed that indoor air pollutants concentrations were independent on the day of the week (as stated in the previous sections 3.2, 4.2 and 5.2), thus an average daily profile was considered to represent an average IAQ scenario in each room. Median concentrations and interquartile range (IQR) for all the comfort parameters, gaseous and particle compounds evaluated were detailed in Appendix B (B3). Levels and concentrations were significantly different between weekdays and weekend ($p < 0.05$). Particulate matter concentrations were not significantly different between canteens and classrooms ($p = 0.31$, 0.36, 0.88 and 0.36, respectively for PM$_1$, PM$_{2.5}$, PM$_{10}$ and TSP). However, concentrations of CO$_2$, CO, formaldehyde, and TVOC were significantly higher in classrooms ($p < 0.05$), while NO$_2$ and O$_3$ were significantly higher in canteens ($p < 0.05$).

Continuous measurements allowed representing daily patterns of each studied compound and parameter, by site location (urban and rural) and by age group of the occupant's (infants, pre-schoolers, and primary school children) in Figures 6.4 to 6.13.



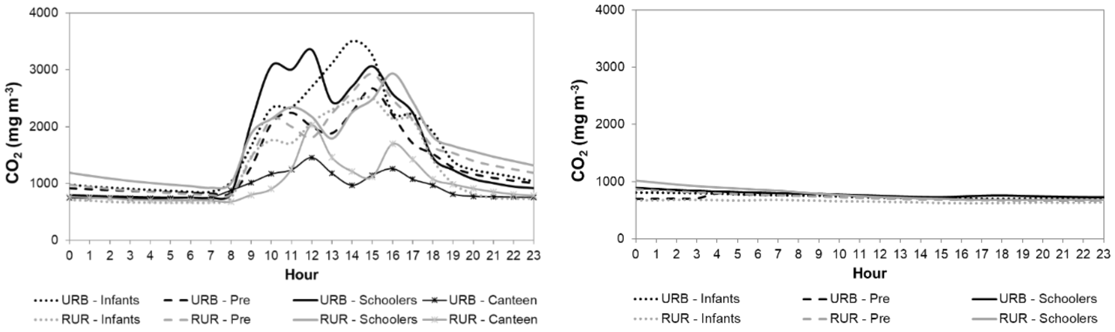
(a) (b)

Figure 6.4 - Daily patterns of levels of temperature (T) on weekdays (a) and on weekend (b).



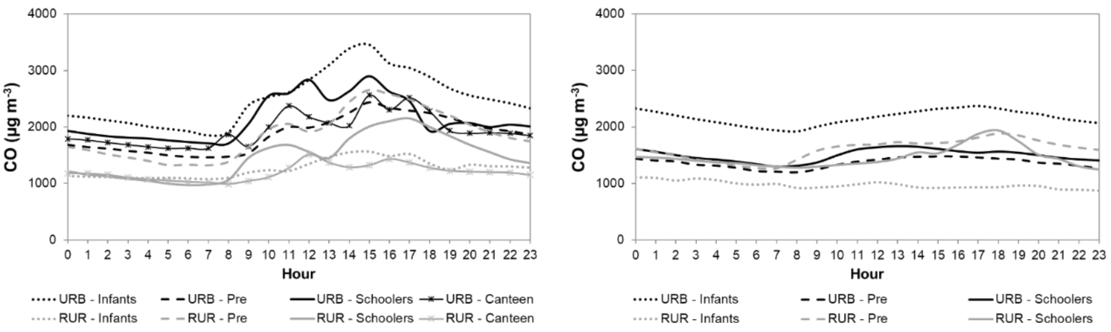
(a) (b)

Figure 6.5 - Daily patterns of levels of relative humidity (RH) on weekdays (a) and on weekend (b).



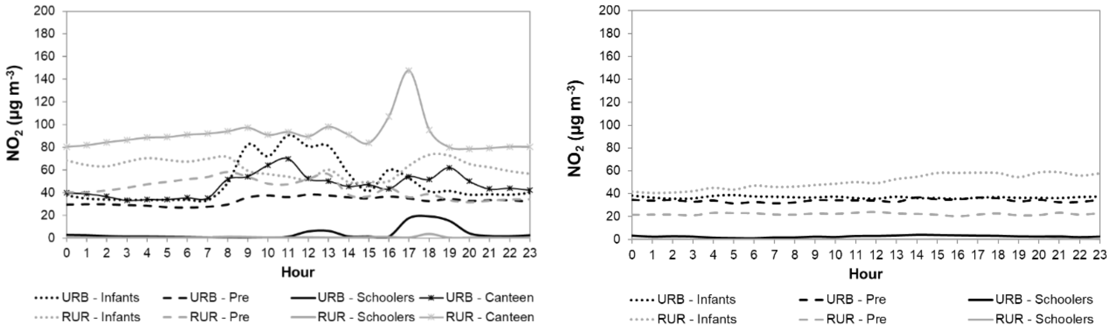
(a) (b)

Figure 6.6 - Daily patterns of levels of carbon dioxide (CO_2) on weekdays (a) and on weekend (b).



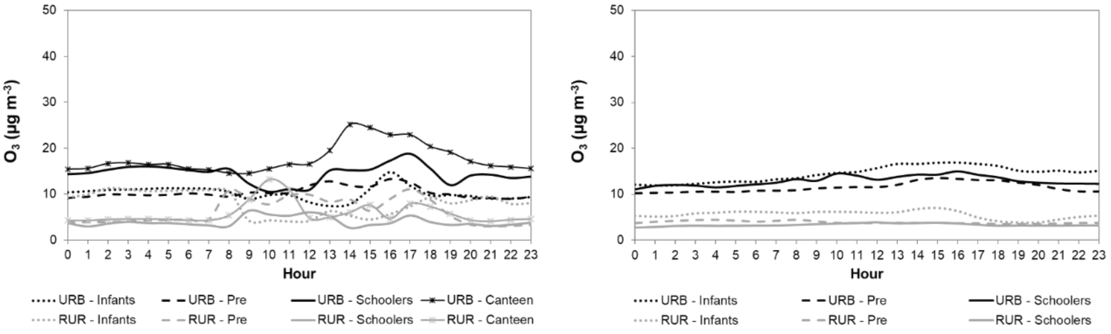
(a) (b)

Figure 6.7 - Daily patterns of levels of carbon monoxide (CO) on weekdays (a) and on weekend (b).



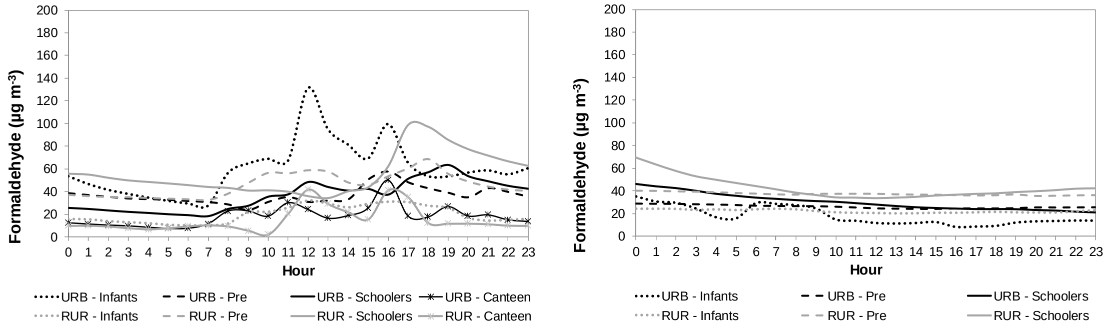
(a) (b)

Figure 6.8 - Daily patterns of levels of nitrogen dioxide (NO_2) on weekdays (a) and on weekend (b).



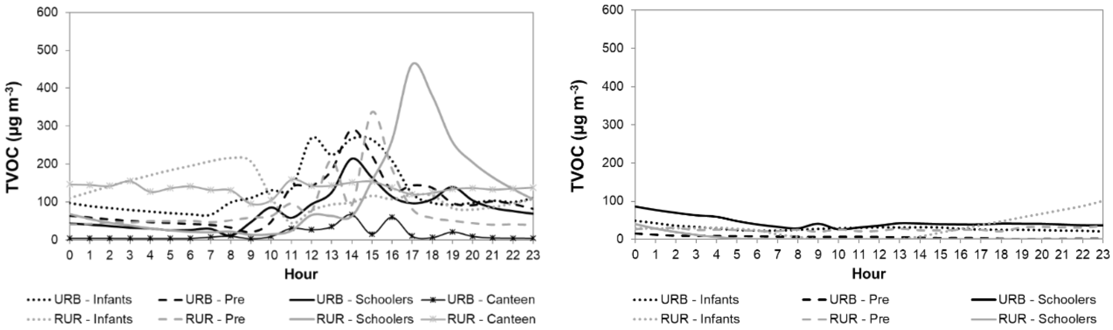
(a) (b)

Figure 6.9 - Daily patterns of levels of ozone (O_3) on weekdays (a) and on weekend (b).



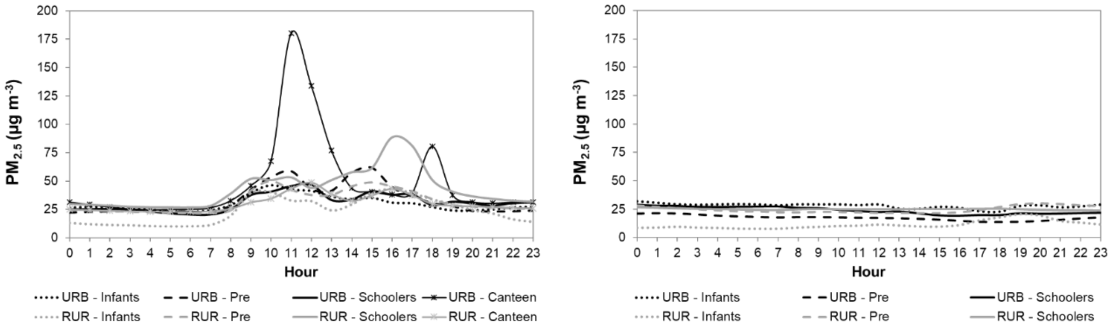
(a) (b)

Figure 6.10 - Daily patterns of levels of formaldehyde on weekdays (a) and on weekend (b).



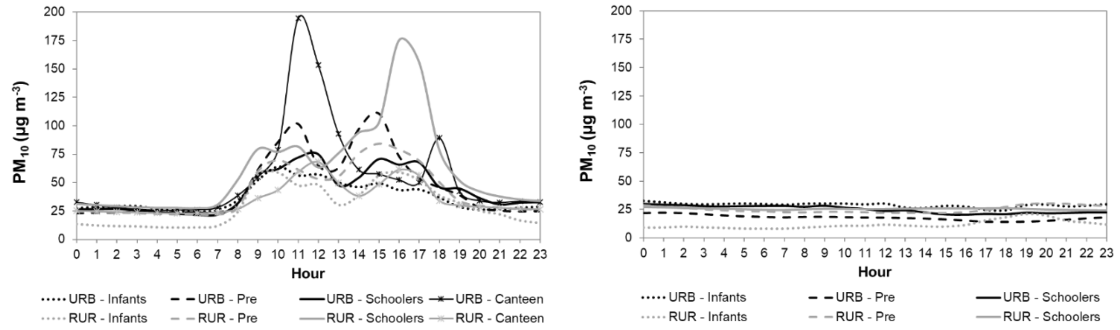
(a) (b)

Figure 6.11 - Daily patterns of levels of total volatile organic compounds (TVOC) on weekdays (a) and on weekend (b).



(a) (b)

Figure 6.12 - Daily patterns of levels of total $PM_{2.5}$ on weekdays (a) and on weekend (b).



(a) (b)

Figure 6.13 - Daily patterns of levels of total PM$_{10}$ on weekdays (a) and on weekend (b).

Levels of comfort parameters and indoor air pollutants concentrations were usually constant along the day on weekends (with exception of CO). On weekdays, they were usually higher during occupancy periods, i.e., depending on occupancy activities. However, this did not happened with RH (r_s = 0.93, p = 0.36), NO$_2$ (r_s = 0.77, p = 0.36) and O$_3$ (r_s = 0.87, p = 0.71), for which variations seemed not to be dependent on occupancy. In fact, for CO$_2$ (Figure 6.6), PM$_{2.5}$ and PM$_{10}$ (Figures 6.12 and 6.13), daily patterns clearly represented occupancy periods in classrooms, with an increase of concentrations at the beginning of occupancy and a decrease in the breaks (especially at lunch, when those concentrations increased in canteens) and at the end of the day (end of classes). CO concentrations also increased with occupancy, with NO$_2$ and O$_3$ showing less regular fluctuations during occupancy (Figures 6.7, 6.8 and 6.9). Concentrations of formaldehyde and TVOC (Figures 6.10 and 6.11) also varied during occupancy, both increasing and decreasing along the day, but it was more difficult to establish a regular pattern.

Correlogram with Spearman's rank correlation coefficients (r_s), represented in Appendix B (B2), showed that there were no strong correlations among the studied comfort parameters and indoor air pollutants, neither on weekdays, during occupancy periods, nor on weekends, except between particulate matter fractions. PM$_1$ and PM$_{2.5}$, as well as PM$_{2.5}$ and PM$_{10}$ were very well correlated in all the studied periods in classrooms (r_s = 1). Nevertheless, PM$_{2.5}$ and PM$_{10}$ correlation was lower during occupancy periods (r_s = 0.96). On weekend, all particle sizes were very well correlated (r_s > 0.98). Due to this, and to better understand the behaviour of PM fraction sizes along the day inside classrooms aiming to find the possible sources, PM$_1$/PM$_{2.5}$, PM$_{2.5}$/PM$_{10}$ and PM$_{10}$/TSP ratios were plotted in Figure 6.14. It was clear to observe that PM$_1$/PM$_{2.5}$ ratio was almost constant along the day and very close to 1, while PM$_{2.5}$/PM$_{10}$ and PM$_{10}$/TSP ratios decreased during occupancy periods.

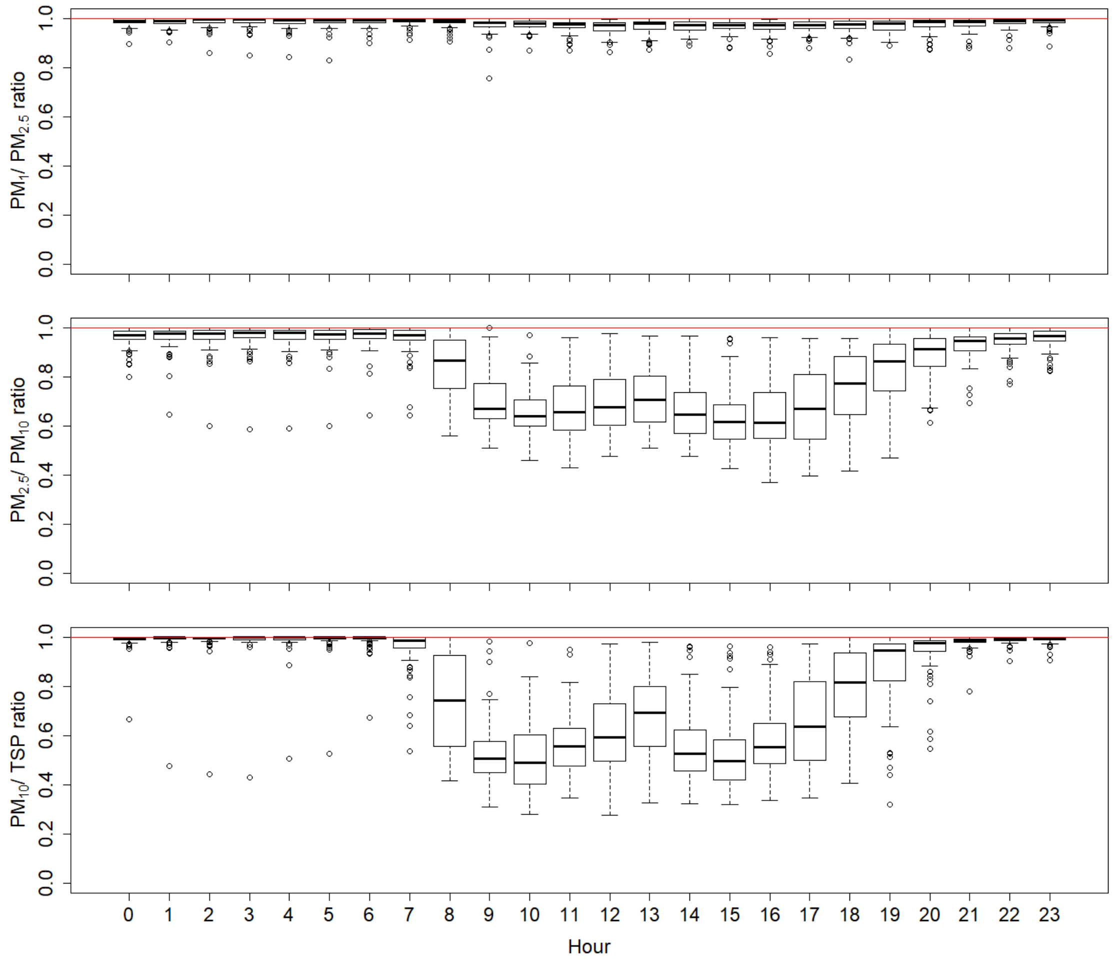
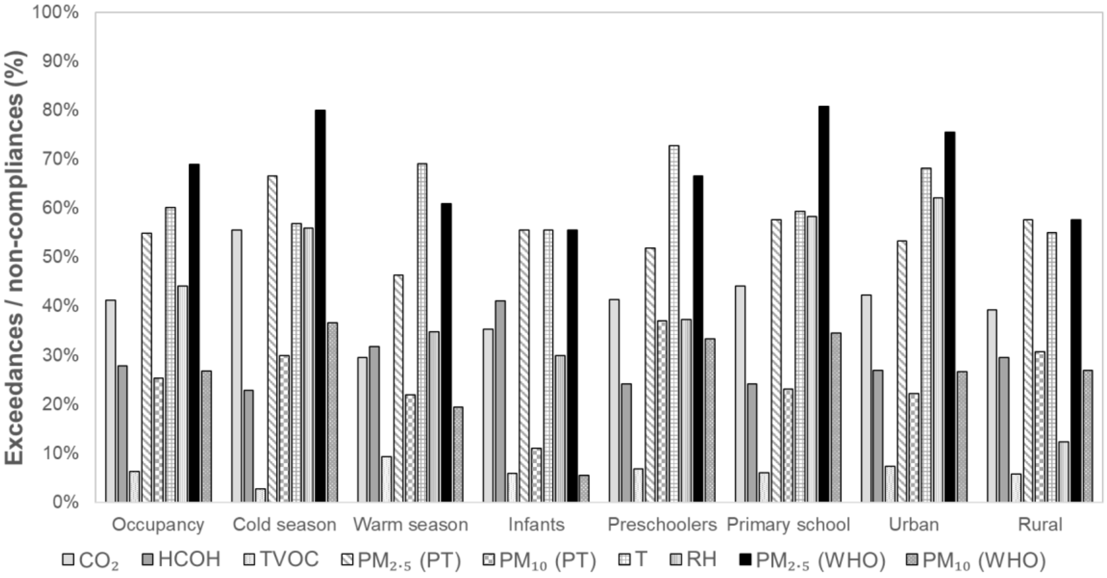


Figure 6.14 - Daily variations of particulate matter (PM) size fraction ratios on weekdays inside classrooms.

6.2.2 Comparison with standards and guidelines

CO, NO_2 and O_3 concentrations never exceeded the reference limits and guidelines considered. On the other hand, all of the other studied indoor air pollutants and parameters presented exceedances. Figure 6.15 summarizes the percentage of classrooms exceeding or not in compliance with the reference limits and guidelines considered in this study. TVOC reference values were exceeded in less than 6.3% of the classrooms during occupancy, and mainly in warm season, but similarly for school locations and amongst classrooms for infants, pre-schoolers and primary school children. Formaldehyde reference value was exceeded in 27.8% of the classrooms during occupancy, mainly in warm season and in classrooms for infants. Comfort parameters T and RH were in non-compliance in 60.1% and 44.1% of the classrooms during occupancy. T guideline was more frequently exceeded on warm season, in classrooms for pre-schoolers, and in urban areas, while RH presented more problematic situations on cold season, in primary school classrooms, and in urban areas. CO_2 concentrations exceeded the reference value in 41.3% of the classrooms during occupancy periods, mainly in cold season, in urban areas, and in classrooms for older children. $PM_{2.5}$ reference values were exceeded in 54.9% and in 69.0% of the classrooms (respectively for 8h and 24h mean), being more relevant in cold season. The same happened with PM_{10}, although exceeding in less classrooms (25.4% and 26.8%, respectively for 8h and 24h mean).



PT - Portuguese legislation; WHO - World Health Organization guidelines

Figure 6.15 - Percentage (%) of classrooms exceeding or not in compliance with the reference guidelines considered.

6.2.3 Modelling determinants of IAP

Considering the pollutants with higher exceedances, CO_2, $PM_{2.5}$ and PM_{10} as outcome variables, bivariate analysis for each of the main building and classroom characteristics of the nursery and primary schools studied were performed. This aimed to assess if those characteristics were individually potential determinants of the above referred indoor air pollutants, in both non-occupancy and occupancy periods. Mean values of T and RH for all sampling occupancy and non-occupancy periods in each studied microenvironment (classroom and season) were also considered as potential determinants. Moreover, CO_2, $PM_{2.5}$ and PM_{10} concentrations in non-occupancy periods were evaluated as potential determinants during occupancy periods. As a proxy of air change rate, CO_2 concentrations were also evaluated as potential determinants of $PM_{2.5}$ and PM_{10} in both occupancy and non-occupancy periods. These results were summarized in Table 6.2.

Table 6.2 - Summary of bivariate analysis (*p*-value), resulting from Kruskall-Wallis or Wilcoxon rank sum tests for categorical variables, and ANOVA for continuous variables.

Categorical variables	**CO_2 non-occupancy**	**CO_2 occupancy**	**$PM_{2.5}$ non-occupancy**	**$PM_{2.5}$ occupancy**	**PM_{10} non-occupancy**	**PM_{10} occupancy**
Site location	0.90	0.25	**0.07**	0.67	**0.08**	0.72
Age group of children	**0.07**	**0.10**	**0.07**	0.20	**0.02***	**0.01***
Season of sampling	**<0.01***	**<0.01***	**<0.01***	**0.05**	**0.02***	0.26
Type of management	**<0.01***	0.59	0.29	**0.03***	**0.11**	**<0.01***
Date of construction	**0.12**	**0.15**	0.25	0.64	0.30	0.49
Traffic in the near road	**0.13**	**<0.01***	**0.05**	0.85	**0.04***	0.85
Floor	**0.07**	**<0.01***	0.41	0.64	0.25	0.36
Ventilation	0.26	0.24	**0.08**	**0.13**	**0.05**	**0.03***
Heating	0.26	**0.06**	0.41	0.76	0.85	0.67
Signs of dampness	0.29	0.25	0.28	0.98	**0.14**	0.55
Flooring material	**0.03***	**<0.01***	0.62	**0.06**	0.52	**0.13**
Chalkboard	0.21	0.74	**0.02***	**0.04***	**0.02***	**0.04***
Cleaning frequency	**0.05**	0.64	**0.09**	0.77	**0.05**	0.30
Cleaning schedule	**0.06**	0.38	0.77	0.39	0.76	0.53
Dust cleaning method	0.31	**0.02***	0.27	0.72	0.23	**0.18**
Continuous variables	**CO_2 non-occupancy**	**CO_2 occupancy**	**$PM_{2.5}$ non-occupancy**	**$PM_{2.5}$ occupancy**	**PM_{10} non-occupancy**	**PM_{10} occupancy**
Occupant density	NA	0.61	NA	0.70	NA	0.38
T non-occupancy	**<0.01***	NA	**0.04***	NA	**0.02***	NA
T occupancy	NA	**<0.01***	NA	0.92	NA	0.74
RH non-occupancy	**0.02***	NA	**0.05**	NA	**0.01***	NA
RH occupancy	NA	**<0.01***	NA	**0.05**	NA	**0.03***
CO_2 non occupancy	NA	**<0.01***	**<0.01***	NA	**<0.01***	NA
CO_2 occupancy	NA	NA	NA	**0.18**	NA	**0.12**
$PM_{2.5}$ non-occupancy	NA	NA	NA	**<0.01***	NA	NA
PM_{10} non-occupancy	NA	NA	NA	NA	NA	**<0.01***

NA – not applicable; T – temperature; RH – relative humidity; * statistically significant (*p*-value < 0.05); in bold are those relevant to feed the multivariate analysis (*p*-value < 0.20)

Age group of children in the classroom, representing different occupancy and activity patterns, was significantly associated with PM_{10} ($p < 0.05$), while season of sampling was significantly associated with all indoor air pollutants outcomes considered ($p < 0.05$), excepting for PM_{10} occupancy ($p = 0.26$). Type of management was significantly associated with CO_2 and $PM_{2.5}$ background (non-occupancy) concentrations, as well as to PM_{10} occupancy concentrations ($p < 0.05$). Traffic in the near road was significantly associated with CO_2 in occupancy and PM_{10} in non-occupancy ($p < 0.05$). Classroom floor in the building, flooring material and dust cleaning method were significantly associated with CO_2 occupancy concentrations ($p < 0.05$). Ventilation was only significantly associated with PM_{10} occupancy concentrations ($p < 0.05$). The utilization of chalkboard in the classroom was statistically significant for both background and occupancy concentrations of $PM_{2.5}$ and PM_{10} ($p < 0.05$). Occupant density (number of occupants per area of the classroom) did not show relevant associations with any of the indoor air pollutants outcomes considered. T was significantly associated with both CO_2 concentrations and with $PM_{2.5}$ and PM_{10} background concentrations, while RH seemed significantly associated with all the indoor air pollutants outcomes considered ($p < 0.05$). In all these indoor air pollutants, background concentrations were significantly associated with occupancy concentrations ($p < 0.05$). Although not statistically significant, other cases in which $p < 0.20$ were selected to enter multivariate analysis (stepwise process).

Tables 6.3 and 6.4 summarize the explained variability (adjusted R^2) and relative importance of each predictor of the eight final multivariate linear regression models (same outcomes as the bivariate analysis). Those full models were detailed in Appendix B (B5 to B12). Models to assess the influence of $PM_{2.5}$ on PM_{10} concentrations in both occupancy and non-occupancy periods were also considered (models with $PM_{2.5}$ influence). Final models presented were the "best" models (based on AIC) after the stepwise process. Final models for occupancy periods had higher explained variability ($R^2 = 0.64$, 0.57 and 0.47, respectively, for CO_2, $PM_{2.5}$ and PM_{10}) than models for non-occupancy, except in those considering $PM_{2.5}$ influence on PM_{10} (0.97 and 0.94, respectively). In fact, $PM_{2.5}$ had a significantly high influence in PM_{10} models (80.4% and 72.8%, respectively, for non-occupancy and occupancy), and CO_2 (here considered as a proxy of air change rate) was also a statistically significant predictor of PM_{10} in both periods. Models for $PM_{2.5}$ and PM_{10} during occupancy had the same predictors, which was not observed for non-occupancy.

Table 6.3 - Explained variability (adjusted R^2) of the final multivariate linear regression models for CO_2 and $PM_{2.5}$ and relative importance of each predictor

	CO_2 non-occupancy	**CO_2 occupancy**	**$PM_{2.5}$ non-occupancy**	**$PM_{2.5}$ occupancy**
Explained variability (R^2)	**0.31**	**0.64**	**0.27**	**0.57**
Site location	a	a	**13.4%**	a
Age group of children	b	**5.3%**	b	a
Season of sampling	14.7%	6.4%	**45.0%**	6.1%
Type of management	17.6%	a	a	**8.8%**
Date of construction	**14.1%**	b	a	a
Traffic in the near road	b	b	b	a
Floor	b	b	a	a
Occupant density	NA	a	NA	a
Ventilation	a	a	b	b
Heating	a	6.7%	a	a
Signs of dampness	a	a	a	a
Flooring material	b	**17.0%**	a	**13.9%**
Chalkboard	a	a	b	b
Cleaning frequency	6.8%	a	b	a
Cleaning schedule	**15.8%**	a	a	a
Dust cleaning method	a	b	a	a
T	**31.0%**	b	b	a
RH	b	**21.1%**	b	b
CO_2 (non-occupancy)	NA	**43.5%**	**41.6%**	NA
CO_2 (occupancy)	NA	NA	NA	b
$PM_{2.5}$ (non-occupancy)	NA	NA	NA	**71.2%**
$PM_{2.5}$ (occupancy)	NA	NA	NA	NA
PM_{10} (non-occupancy)	NA	NA	NA	NA

a – excluded by bivariate analysis results (p-value < 0.20); b – excluded at stepwise process; NA – not applicable; T – temperature; RH – relative humidity; in bold are those statistically significant (p-value < 0.05)

Table 6.4 - Explained variability (adjusted R^2) of the final multivariate linear regression models for PM$_{10}$ and relative importance of each predictor

	PM$_{10}$ non-occupancy	**PM$_{10}$ occupancy**	**PM$_{10}$ non-occupancy (with PM$_{2.5}$ influence)**	**PM$_{10}$ occupancy (with PM$_{2.5}$ influence)**
Explained variability (R^2)	**0.31**	**0.47**	**0.97**	**0.94**
Site location	**12.1%**	a	b	a
Age group of children	b	b	**3.9%**	**4.1%**
Season of sampling	**25.1%**	3.8%	**4.9%**	**1.6%**
Type of management	b	**15.2%**	b	b
Date of construction	a	a	a	a
Traffic in the near road	b	a	b	a
Floor	a	a	a	a
Occupant density	NA	a	NA	a
Ventilation	b	b	b	b
Heating	a	a	a	a
Signs of dampness	b	a	**0.9%**	a
Flooring material	a	**13.9%**	a	b
Chalkboard	b	b	b	b
Cleaning frequency	11.6%	a	b	a
Cleaning schedule	a	a	a	a
Dust cleaning method	a	b	a	b
T	b	a	b	a
RH	b	b	b	b
CO$_2$ (non-occupancy)	**51.3%**	NA	**10.0%**	NA
CO$_2$ (occupancy)	NA	b	NA	**2.9%**
PM$_{2.5}$ (non-occupancy)	NA	NA	**80.4%**	NA
PM$_{2.5}$ (occupancy)	NA	NA	NA	**72.8%**
PM$_{10}$ (non-occupancy)	NA	**67.2%**	NA	**18.7%**

a – excluded by bivariate analysis results (*p*-value < 0.20); b – excluded at stepwise process; NA – not applicable; T – temperature; RH – relative humidity; in bold are those statistically significant (*p*-value < 0.05)

Flooring material was a statistically significant predictor for both CO_2, $PM_{2.5}$ and PM_{10} during occupancy periods. Regarding the influence of comfort parameters, T was a significant predictor ($p < 0.05$) only for CO_2 during non-occupancy, while RH was a significant predictor only for CO_2 during occupancy. CO_2 was a significant predictor for both $PM_{2.5}$ and PM_{10}, but only in non-occupancy. When considering $PM_{2.5}$ influence on PM_{10}, CO_2 was a significant predictor for both periods. Concentrations during non-occupancy had a major importance in all the models for occupancy periods.

Considering final models, the highest Cook's D value was 0.49 (for PM_{10} during non-occupancy with $PM_{2.5}$ influence model), indicating that there were no potential influential outliers in the predictor values. VIFs ranged from 1.00 (for $PM_{2.5}$ and non-occupancy model) to 2.23 (for PM_{10} occupancy model with $PM_{2.5}$ influence), indicating none or little collinearity between the predictors in each model.

6.3 Discussion

Continuous sampling of both indoor air pollutants and comfort parameters, for occupancy and non-occupancy periods as well as for weekdays and weekend, considering different scholar indoor microenvironments (classrooms and canteens) and different seasons (cold and warm), allowed the quantification of indoor air pollutants determinants through a detailed IAQ characterization in nursery and primary schools, in both urban and rural context. Nevertheless, comparisons with other studies were limited by the scarce literature on quantifying determinants of indoor air pollutants in nursery and primary schools.

Pollutants and parameters levels during occupancy periods, when children are exposed, were higher than in non-occupancy periods due to children's activities. This was also supported by Wierzbicka et al. (2015), which also indicated that only concentrations from occupancy periods should be used for exposure assessment and for estimating health effects in epidemiological and toxicological studies. Due to different occupancy patterns and activities, classrooms and canteens showed different IAQ patterns, with outdoor related air pollutants like NO_2 and O_3 having higher concentrations in canteens, while air pollutants from indoor sources like CO_2, formaldehyde and TVOC having higher concentrations in classrooms. In one hand, gas stoves in the kitchens contiguous to canteens could partly explain higher NO_2 concentrations in canteens. On the other hand, as not all the canteens have contiguous kitchens using gas stoves, those spaces are usually more open to outdoors than classrooms, which may explain higher concentrations of air pollutants from outdoor sources (NO_2 and O_3). Indoor/outdoor (I/O) ratios obtained for NO_2 and O_3 in two previous studies from the authors (Branco et al., 2015a; Nunes et al., 2016) supported these findings.

Significant seasonal variations found in almost all indoor air pollutants and parameters indicated that IAQ studies in scholar environments need to account for seasonal variations, otherwise important biases could be introduced, especially when assessing children's exposure. Jung et al. (2010) have previously concluded the importance of seasonal variations in residential exposure levels to indoor air pollutants. Higher values of CO_2, O_3, $PM_{2.5}$ and RH were found in cold season, while higher values of CO, NO_2, TVOC and T were found in warm season. T and RH are highly dependent on outdoor meteorological conditions, thus the results were expected. As the majority of the classrooms analysed had predominantly natural ventilation and did not have any heating system, windows to outdoor were usually closed in cold season to avoid heat losses making air change rate lower than in warm season, which might have led to a greater accumulation of indoor air pollutants, especially CO_2 and $PM_{2.5}$. Furthermore, in warm season the absence of air conditioning systems led to open doors and windows, thus to higher outdoor air penetration, which might have contributed to higher concentrations of traffic-related air pollutants like CO and NO_2.

Significant differences found between school buildings located in urban and rural sites were possibly due to both different outdoor conditions influencing indoor air, as previously described (Nunes et al., 2016; Nunes et al., 2015), and different children's routines and activities inside schools. Thus, it is important to take site location into consideration in IAQ schools' characterization.

Activities inside classrooms usually vary with the age of children (occupants). Activities in primary schools' classrooms are often limited to reading and writing/painting (light or moderate activity), while infants and pre-schoolers activities' usually have both vigorous (playing, physical activities), light/moderate (painting), and rest activities (nap) inside the same room. This contributed to the observed concentrations, especially CO_2, NO_2, TVOC and particulate matter, as well as T and RH in classrooms. This is why it is important to ensure that children's exposure assessment studies on school indoor environments must consider both nursery and primary schools.

Thermal discomfort was common in the majority of the studied classrooms in both nursery and primary schools, usually with higher temperatures than recommended (ASHRAE, 2007), especially in warm season and in classrooms with higher physical activity of the occupants (classrooms for pre-schoolers). Besides thermal discomfort, higher temperatures than recommended can have negative effects on the performance of schoolwork (Porras-Salazar et al., 2018). A poor RH control was also common in the classrooms studied. Although some situations of low RH were found in warm season, which could cause sensory irritation in eyes and airways and affect perceived comfort and students' and teachers' performance (Wolkoff, 2018; Wolkoff and Kjaergaard, 2007), high RH was often found, which can provide the optimal conditions for bacteria, fungi and viruses proliferation (Alves et al., 2015). These results confirmed previous conclusions from Chapter 3.

In the absence of any known indoor source, and due to I/O ratios lower that 1 previously reported in some of these nursery and primary schools (Chapter 4), CO, NO_2 and O_3 are expected to be originated from outdoor air. In this study, CO, NO_2 and O_3 concentrations are not expected to be of concern for IAQ and health as they never exceeded limit and guideline values.

On the other hand, in some classrooms, formaldehyde and TVOC concentrations were above the recommended limits in the Portuguese legislation (Portaria nº 353-A/2013) (respectively 100 µg m^{-3} and 600 µg m^{-3}, plus 100% of MT if no mechanical ventilation system was working in the room). Those concentrations were expected to be mainly originated indoors emitted from furniture, building materials, and products like paints and glues used by children in their activities, because results showed dependency on season and on the age group of classroom's occupants. Those sources of TVOC indoor scholar environments were also pointed out by other authors (Paciência et al., 2016; Zhong et al., 2017). The considerable variations along the occupancy periods (by non-constant "peaks" along the day) also supports this explanation. This is one of the reasons why the use of non-continuous sampling should be avoided in IAQ and exposure studies.

Problematic situations were more often found in nursery and primary schools located in urban areas, and CO_2 and particulate matter, especially finer fraction $PM_{2.5}$, presented the major IAQ problems. Overcrowded classrooms (> 25 occupants / 100 m^2), plus a probable deficit of air renovation led to CO_2 accumulation. This is a very common problem in classrooms, previously reported (Mainka et al., 2015), and it can lead to children's deficit of attention, affecting their school productivity. They could also indicate the accumulation of other indoor air pollutants, although it cannot be considered as a unique IAQ indicator. Previous studies showed evidence that increasing classrooms ventilation rates can be effective in decreasing the concentrations of some indoor-generated pollutants (Rosbach et al., 2016), and can decrease illness absenteeism and produce economic benefits (Mendell et al., 2013). Nevertheless, Ramalho et al. (2015) concluded that even in good ventilation conditions (i.e. low CO_2 levels), the reduction of pollutant sources is still necessary to achieve a satisfactory IAQ.

In most of the classrooms analysed, $PM_{2.5}$ concentrations were above the protection limits for IAQ and health. In fact, very high $PM_1/PM_{2.5}$ ratios indicated that most of $PM_{2.5}$ particles were finer, with less than 1 µm diameter. Coarser fraction (PM_{10}) observed concentrations were less problematic, although it should not be neglected, especially because, during occupation periods, the increase of coarser PM fractions was higher than of finer ones (lower $PM_{2.5}/PM_{10}$ and PM_{10}/TSP ratios in those periods). Poor IAQ caused by high particulate matter were also previously reported in the literature, for scholar environments in both urban and rural sites (Mainka and Zajusz-Zubek, 2015; Nunes et al., 2015). Indoor sources and inefficient cleaning led to resuspension phenomena due to children's activities, which caused high levels of $PM_{2.5}$ and PM_{10}. Although not knowing their composition, the levels found on these fraction sizes could be harmful for children's health. Besides children, health impacts on teachers are also important to consider (Muscatiello et al., 2015), as they are exposed to the same levels as children but for a longer period in life.

As CO_2 and particulate matter represented the worst cases of indoor air pollutants, multivariate linear regression models were performed to quantify their main determinants in both non-occupancy and occupancy periods. The final models obtained complied with the linear regression assumptions. Models for non-occupancy period showed low ability to predict CO_2, $PM_{2.5}$ and PM_{10} outcomes, while models for occupancy period showed a higher ability to predict those outcomes. Age group of the occupants, representing children's occupancy and activity patterns in the classroom, heating, flooring material, RH and concentrations in non-occupancy, adjusted for season of sampling, were the predictors of CO_2 concentrations during occupancy. Type of school management (if private or public school), flooring material and concentrations during non-occupancy periods, adjusted for season of sampling, were the main predictors of $PM_{2.5}$ and PM_{10} concentrations during occupancy. In fact, results showed that being a public managed school, as well as having hardwood flooring in classrooms, significantly contributed to the increase in both $PM_{2.5}$ and PM_{10} concentrations during occupancy. These two factors might be connected, because public schools usually have less available resources (staff, materials and budget) and usually face more obstacles to get them, which would certainly lead to a lower investment in maintenance, repair and renovation building works. When considering $PM_{2.5}$ as a predictor of PM_{10} concentrations, age group of the occupants, representing children's occupancy and activity patterns in the classroom, and CO_2 concentrations were the other predictors on occupancy period. Age group of occupants was a crucial determinant especially for CO_2 and for the coarser fraction of PM during occupancy periods, confirming that different types of activities and different occupation patterns from different age groups of children have different impacts on indoor air pollutants in nursery and primary schools.

Although results showed occupant density as a non-significant determinant of indoor air pollutants, it does not mean that it was meaningless to IAQ. In fact, these results should be carefully interpreted because almost all the classrooms were overcrowded, thus quantifying occupant density real influence on IAQ was not possible. Another limitation of this study was using CO_2 concentrations as a proxy of air change rate, instead of quantifying it. Also due to a limited number of schools, the main analysis was not stratified by age group of children (infants, pre-schoolers, primary school children) neither by outdoor environment (urban and rural).

6.4 Conclusions

In short, children usually faced thermal discomfort and high humidity, were exposed to high levels of indoor air pollutants in nursery and primary schools, more in urban than in rural sites, and significantly depending on season and on children's occupancy and activity patterns (different age groups have different occupancy and activity patterns). The major concerning indoor air pollutants for children's exposure were $PM_{2.5}$ and CO_2, with several building and classroom's characteristics as significant determinants of their levels, including heating, flooring material, indoor thermal conditions (T and RH), type of school management, and background concentrations (non-occupancy periods).

Chapter 7

Children's exposure to radon in nursery and primary schools[*]

This study aimed to evaluate indoor radon concentrations to which children were exposed in nursery and primary schools from two different districts in Portugal (Porto and Bragança), considering different influence factors (occupation patterns, classroom floor levels, year of buildings' construction and soil composition of the building site), as well as the comparison with IAQ standard values for health protection.

7.1 Methodology

7.1.1 Site description

This study was carried out in fifteen different school buildings in Northern Portugal, of which seven were located in Porto district — an urban radon-prone area, and the remaining eight were located in the Bragança district — a rural area that is not considered mandatory for indoor radon measurements according to Portuguese IAQ legislation (Portaria nº 353-A/2013). A total of five nursery schools for infants (children aged under 3) and twelve for pre-schoolers (3–5 years old) were studied, as well as eight primary schools (children aged 6–10 years old). One or more classrooms in each nursery and primary school were considered for this study. Lunch rooms were always sampled. A prior inspection (through direct observations and interviews with the staff) was performed to capture relevant information on timetables, activities and occupation, ventilation and other building characteristics that could be relevant to analyse the results obtained in this study. Table 7.1 summarizes the characterization of the studied microenvironments, regarding the distribution of the buildings per year of construction and the

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[*] adapted from: Branco PTBS, Nunes RAO, Alvim-Ferraz MCM, Martins FG, Sousa SIV, 2016. Children's Exposure to Radon in Nursery and Primary Schools. *International Journal of Environmental Research and Public Health* 13: 386

soil composition, namely its predominant types of rocks in the soil according to the Geological Map of Portugal (LNEG, 2013). Table 7.2 summarizes the number of classrooms per floor level in the building, with the according occupation in each one, for both districts. Regarding occupation, three different subsets were considered according to the age of the children (occupants): infants, pre-schoolers and primary school children.

Table 7.1 - Characterization of the studied buildings according to the year of construction and the type of predominant rocks in the soil (main soil composition).

Occupation	**Total**	**Year of Construction**		**Predominant Rock Type in the Soil**		
		<2006	**≥2006**	**Magmatites**	**Metamorphites**	**Sediments**
Porto district	7 [a]	3 [a]	4 [a]	5 [a]	1 [a]	1 [a]
Infants	3	1	2	2	0	1
Pre-schoolers	7	3	4	5	1	1
School children	5	3	2	4	1	0
Bragança district	8 [a]	2 [a]	6 [a]	3 [a]	5 [a]	0[a]
Infants	2	1	1	0	2	0
Pre-schoolers	5	2	3	2	3	0
School children	3	1	2	1	2	0

[a] There are situations in which both classrooms for infants and pre-schoolers, and for pre-schoolers and school children were in the same building.

Table 7.2 – Characterization of the studied classrooms' according to floor level in the building.

Occupation	**Total**	**Classrooms' Floor Level**		
		Ground Floor	**1st Floor**	**2nd and Higher Floors**
Porto district	30	17	10	3
Infants	6	4	2	0
Pre-schoolers	13	7	5	1
School children	11	6	3	2
Bragança district	17	14	3	0
Infants	4	4	0	0
Pre-schoolers	7	7	0	0
School children	6	3	3	0

The majority of the buildings analysed were built before 2006, *i.e.*, before the implementation of the first Portuguese legislation on IAQ (transposition of the European Directive including a radon reference level), and some of them were even centenary. Although renovations had recently been performed in some nursery and primary schools, the analyses were performed considering the year of construction of the building (the only exception was a building in Porto district used as both a nursery and primary school initially built before 2006, but totally rebuilt recently).

The majority of the studied classrooms were located on the ground floor of the buildings, and natural ventilation was predominant. In fact, only four of the studied classrooms had predominant forced ventilation (mechanical ventilation): two in Porto district and another two in Bragança district, all used for infants.

The majority of the buildings studied in Porto district were placed on soils where magmatic rocks are predominant, but in Bragança district they were mainly located on soils with metamorphites as predominant rocks. There was only one building placed on a predominantly sedimentary soil—a nursery school used both for infants and pre-schoolers in Porto district. To the best of the authors’ knowledge, none of the studied buildings were built on slabs nor did they have a basement-like area.

7.1.2 Sampling

Radon measurements were made continuously (logging hourly means) using a Radim 5B radon monitor (SMM, Prague, Czech Republic), which measures the α-activity of radon decay products (^{218}Po and ^{214}Po) collected from the detection chamber on the surface of a semiconductor detector by an electric field (Figure 7.1).

Figure 7.1 – Radim 5B radon monitor

This radon monitor was calibrated by the manufacturer by placing it in a barrel (controlled atmosphere) next to a reference instrument (Radim 3, verified in the Metrological Institute of Czech Republic), and recording measurements with both instruments simultaneously for about 24 hours. The results of both instruments were compared and calibration factor of the calibrated equipment was modified (3.6%) to get the same result as in the reference instrument. Calibration precision was about 5%. The error of the equipment is 5% for concentrations above 80 Bq·m^{-3}, and 20% for concentrations below that.

The equipment was placed as close to the centre of the room as possible, far from windows, doors and room’s corners, approximately at the same height of children’s breath (1.5 ± 0.5 m). Depending on secured permissions, and due to financial constraints, short-term samplings were performed from 2 to 9 consecutive days in each room (not simultaneously) in nursery schools, and for at least 24 hours in primary schools, and, in some circumstances, both on weekdays and weekends.

7.1.3 Data analysis

Descriptive statistics were initially determined, namely mean, median, minimum, maximum and standard deviation. Histograms were drawn to take a look at data and normality of the distributions was assessed through Kolmogorov-Smirnov, Shapiro-Wilk and Anderson-Darling normality tests. Distributions were assessed for log-normality using the same normality tests applied after a logarithmic data transformation.

The non-parametric Wilcoxon Rank Sum Test (also called Mann-Whitney *U* test) was used to test the significance of the differences between two samples, and the non-parametric Kruskal-Wallis test was used when comparing the significance of the differences between three samples.

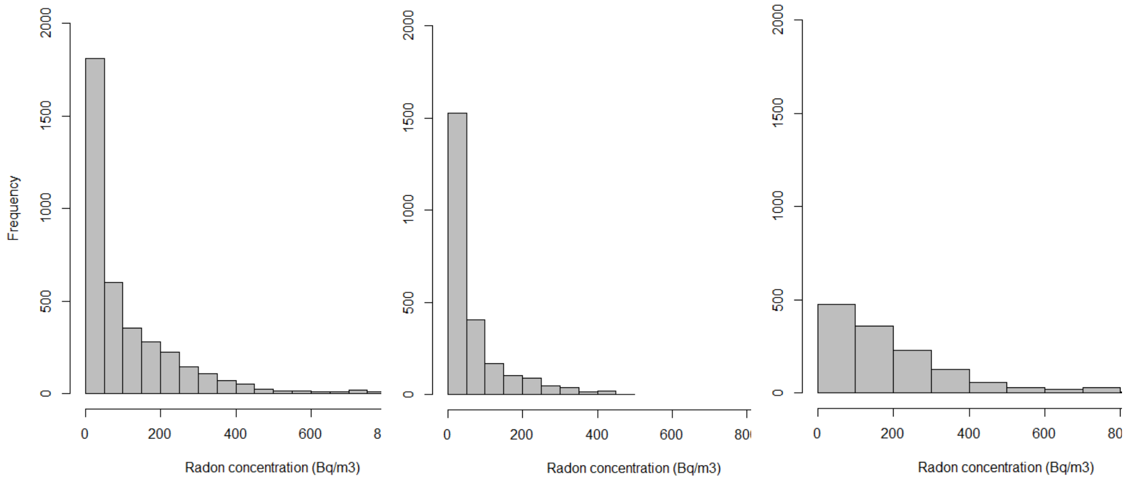
Descriptive statistics were calculated using MS Excel® (Microsoft Corporation, Redmond, WA, USA), and other statistical analyses were determined using R software, version 3.1.2 (R Foundation for Statistical Computing, 2014).

Although the mean radon indoor concentrations measured were preliminary, as they result from short-term sampling (screening), they were compared with IAQ standards and guidelines for health protection (annual) attempting to preliminarily evaluate exceedances. Comparisons were performed considering international references, namely: (a) WHO reference values of 100 Bq m^{-3} and 300 Bq m^{-3} (WHO, 2009); (b) USEPA reference value of 4 pCI L^{-1} (148 Bq m^{-3}) (USEPA, 2003); (c) EU reference value of 300 Bq m^{-3} (EU, 2013); and d) Portuguese reference value of 400 Bq m^{-3} (Portaria nº 353-A/2013).

7.2 Results and discussion

In the studied nursery and primary schools in Porto district, indoor radon concentrations varied from 0 to 459 Bq m^{-3} (N = 2429), with an average ± SD of 62 ± 86 Bq m^{-3}. In the studied nursery and primary schools in Bragança district, concentrations varied from 0 to 888 Bq m^{-3} (N = 1342), with an average ± SD of 193 ± 174 Bq m^{-3}.

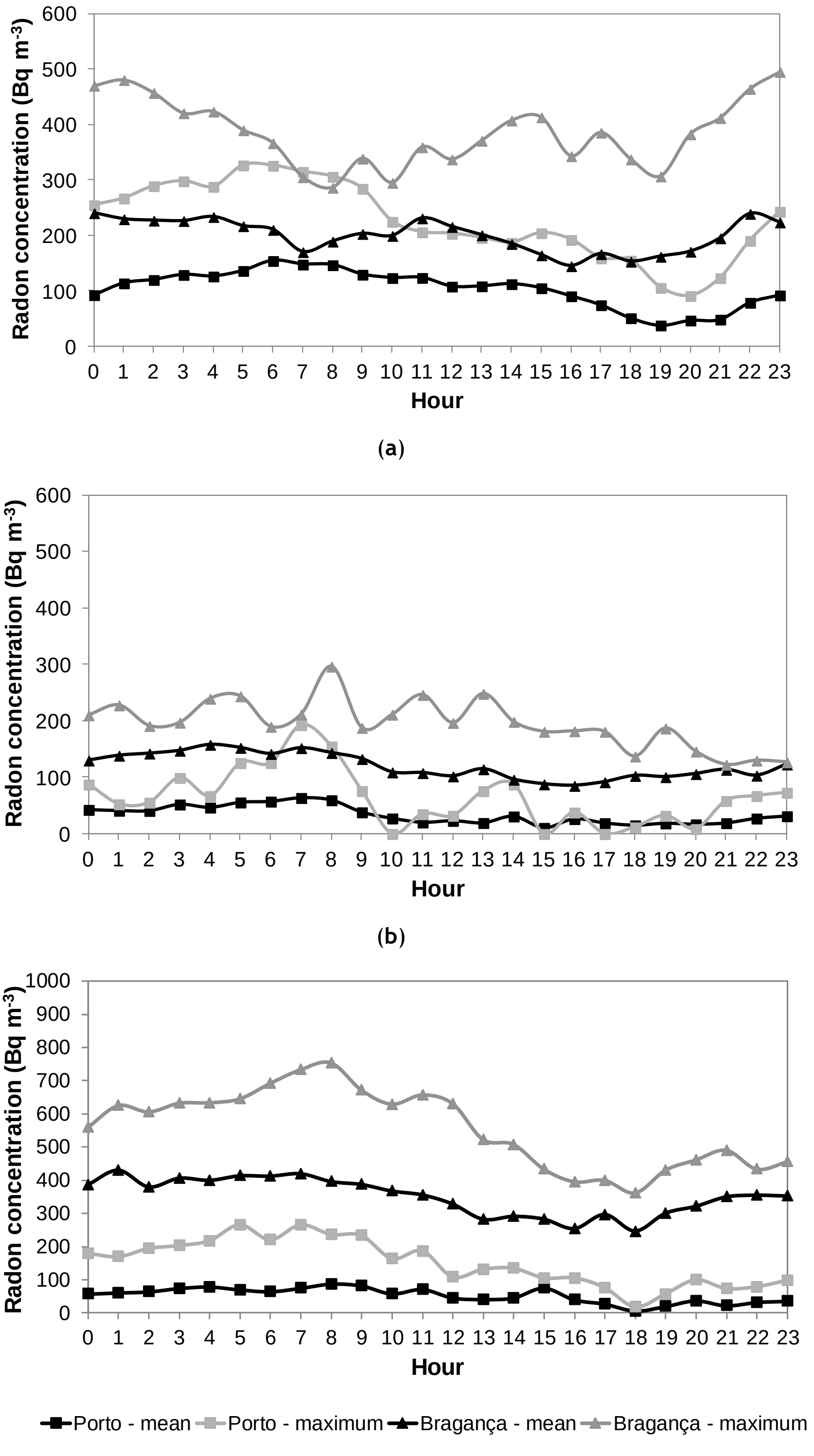
Indoor radon concentrations were found to be significantly higher in the nursery and primary schools in Bragança than in Porto district ($p < 0.05$). Figure 7.2 represents the frequency distribution of the hourly indoor radon concentrations obtained in each studied classroom of: (a) all the studied buildings, (b) buildings in Porto district, and (c) buildings in Bragança district. Low concentrations were the most common, and the highest indoor concentrations were found in the studied microenvironments in Bragança district. Figure 7.2 data distributions look like log-normal ones, nevertheless, results from Kolmogorov-Smirnov, Shapiro-Wilk and Anderson-Darling normality tests (after a logarithmic data transformation) for the data from nursery and primary schools in Porto and Bragança districts showed that data did not follow a normal distribution ($p < 0.05$).



(a) (b) (c)

Figure 7.2 - Frequency distribution of the hourly indoor radon concentrations measured in (a) all the studied buildings, (b) Porto district and (c) Bragança district.

Continuous sampling allowed assuming an average scenario, *i.e.*, hourly mean concentrations between two or more consecutive days were calculated, allowing the representation of the mean daily profile. As an example, Figure 7.3 shows two different scenarios for daily profiles considering ground floor classrooms for: (a) infants, (b) pre-schoolers, and (c) primary school children, each one representing: (i) the mean concentrations (daily mean scenario, in black); and (ii) the classroom with the highest mean concentrations found (daily maximum scenario, in grey). From Figure 7.3 it was possible to observe a similar pattern in the daily mean profiles of indoor radon concentrations in all the studied microenvironments: an increase of indoor concentration at the end of the day resulting in higher concentrations during night and dawn, followed by a decrease along the day.



(a)

(b)

(c)

Figure 7.3 - Daily mean and maximum scenarios of indoor radon concentrations in ground floor classrooms in Porto and Bragança districts for (a) infants, (b) pre-schoolers, and (c) primary school children.

Occupation patterns seemed to be responsible for those profiles, with higher concentrations at night caused by the absence of air renovation (accumulation), and with lower concentrations along the day due to a higher air turnover (through natural or mechanical ventilation). These patterns are in accordance with the typical daily patterns found in the literature for dwellings (WHO, 2009). Indoor radon concentrations were grouped according to some of the main influence factors, namely occupation, classroom floor level, year of buildings’ construction and soil composition of the building site. Figure 7.4 presents the distribution of radon concentrations in the studied microenvironments in both Porto and Bragança districts per subsets: (a) occupation, (b) classroom floor level. Figure 7.5 presents the same distribution per: (a) year of buildings’ construction, and (b) soil composition of the building site.

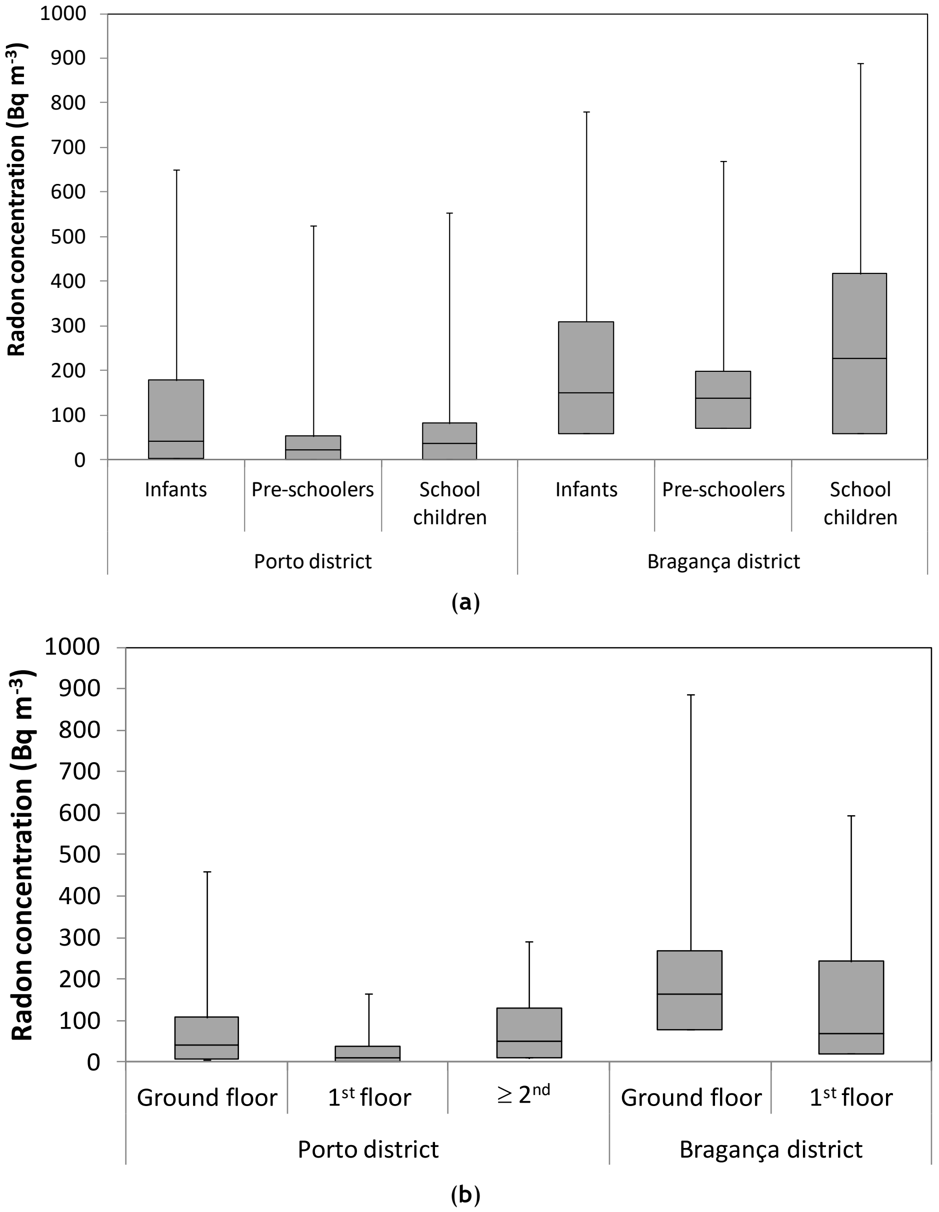
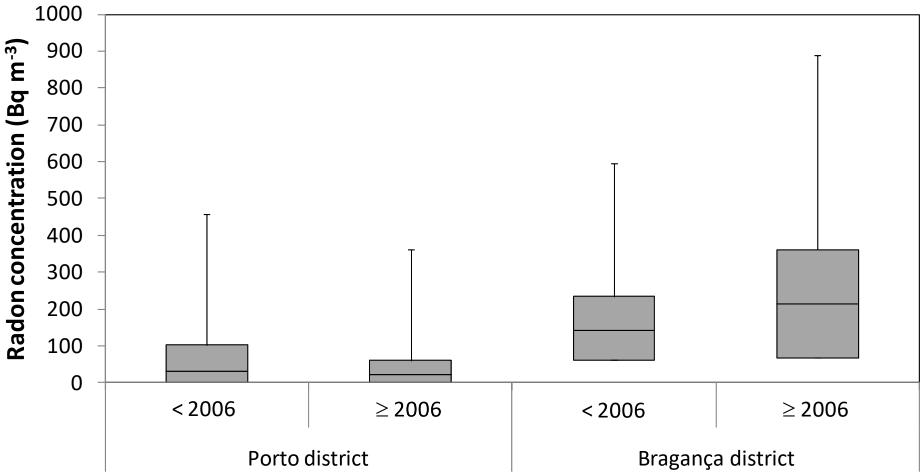
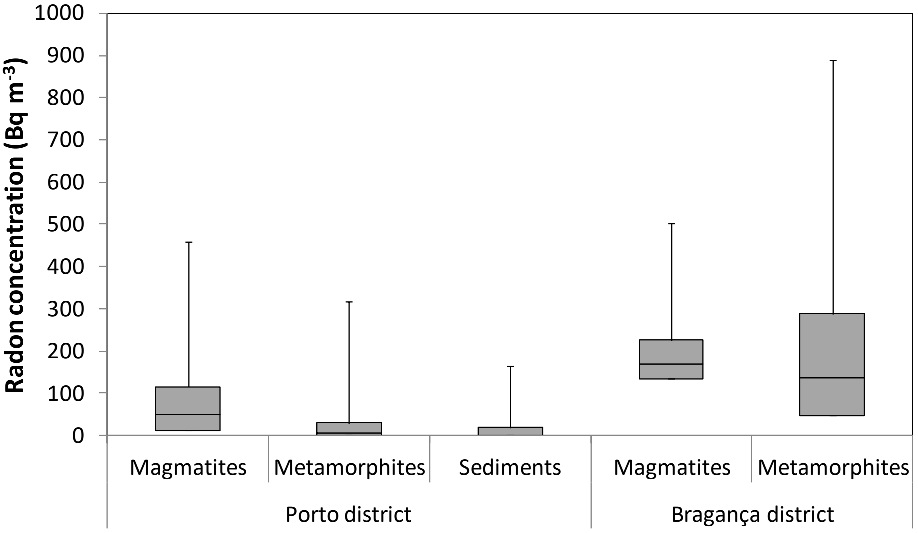


Figure 7.4 - Distribution of radon concentrations in the studied microenvironments in both Porto and Bragança districts per (a) occupation, and (b) classroom floor.



(a)



(b)

Figure 7.5 - Distribution of radon concentrations in the studied microenvironments in both Porto and Bragança districts per (a) year of buildings' construction, and (b) soil composition of the building site.

While indoor radon concentrations in the studied microenvironments in Porto district were found to be higher in the classrooms occupied by infants and lower in the classrooms occupied by pre-schoolers, in the studied microenvironments in Bragança they were found to be higher in the primary schools' classrooms and lower in the classrooms for pre-schoolers. Results indicated statistically significant differences between indoor radon concentrations in the classrooms depending on the occupation both in the classrooms studied in Porto and Bragança districts ($p < 0.05$). This seemed to be caused by the different activity patterns in classrooms which are highly dependent of the childrens' development stage: infancy, pre-school age or primary school age. Therefore, it is expected to find different results when assessing indoor radon concentrations in classrooms for infants, pre-schoolers or primary school children and it should be considered when assessing indoor radon concentrations in scholar buildings. In fact, in the studied nursery schools in Porto district, infants are expected to be exposed to higher radon concentrations than older children (pre-schoolers and primary school children), although in those in the Bragança district the results indicated that the highest concentrations are expected to be inhaled by primary school children, followed by infants and pre-schoolers.

All differences found between measurements in the different floor levels were found to be statistically significant ($p < 0.05$). As expected, higher indoor radon concentrations were found in the ground floor classrooms in both districts, which is the closest floor to the soil — the main source of radon in indoor air. It is important to take this into account when assigning rooms usage in school buildings. Nevertheless, indoor radon concentrations in the studied microenvironments in Porto district were found to be higher in the 2nd and higher floors classrooms than in the 1st floor classrooms. This might be associated with the limited data in this particular case — a one-off case where higher values occurred in a 2nd or higher classroom due to radon flow through cracks in the building.

Statistically significant differences ($p < 0.05$) were always found between indoor radon concentrations in the studied buildings built before 2006 and those built after 2006, both in the Porto and Bragança districts. In Porto district, the older buildings studied (built before the promulgation of the first IAQ Portuguese legislation) registered higher indoor radon concentrations than the newer ones (built in 2006 and afterwards). This might indicate that the introduction of the IAQ Portuguese legislation (introduction of a limit value for radon in indoor air) had an important role in reducing indoor radon concentrations inside buildings. On the other hand, in Bragança district the newer buildings studied (built in 2006 and after) registered the highest indoor radon concentrations, which might indicate that, despite the introduction of the IAQ Portuguese legislation, as indoor radon measurements were not mandatory in Bragança district nothing seemed to have been done to prevent high concentrations inside the buildings in that district.

Nursery and primary schools from Porto district built upon soils where magmatites were predominant registered higher indoor radon concentrations than those where metamorphites were predominant, which in turn registered higher indoor radon concentrations than those where sediments prevailed. These results are in agreement with what was initially expected (Sundal et al., 2004). However, in Bragança district, the studied nursery and primary schools built upon soils where metamorphites predominate registered higher indoor radon concentrations than those where magmatites prevailed. All the differences were found to be statistically significant ($p < 0.05$). Since the results were the opposite in the studied buildings in the two districts, without a deeper analysis it is not possible to understand the real influence that soil composition of the building site has on the indoor radon concentrations found. Thus, it could be unwise to limit indoor radon assessment to buildings constructed in a specific type of soil. The influence of other factors in the radon indoor concentrations, like building materials

(Sahoo et al., 2011), could also be important, but it was not performed in this study because data was not available.

Although the mean radon indoor concentrations measured were preliminary, as they result from short-term sampling (screening) — attempting to preliminarily evaluate exceedances, indoor radon mean concentrations during occupation periods in the studied microenvironments were compared with the reference values for IAQ and health protection referred in Section 7.1.3. Exceedances were calculated (*i.e.*, the number of classrooms where the mean indoor concentration during occupation period was above the reference value).

In Porto district, the majority of the classrooms assessed (25/30) did not exceed the reference values considered, while in Bragança district only some of the studied classrooms did not show exceedances (6/17). In fact, indoor radon concentrations found in the studied nursery and primary schools in Porto district never exceeded the reference radon indoor concentration from the Portuguese national legislation on IAQ (the least restrictive of all the reference values here considered). In Bragança district two classrooms exceeded the reference values — one from a nursery and the other from a primary school. Classrooms for pre-school children in Porto never exceeded any of the reference values, and only two classrooms of primary schools exceeded WHO reference value of 100 Bq m^{-3} (the most restrictive). In the case of classrooms for infants, only three exceeded both WHO and USEPA reference values (100 and 148 Bq m^{-3}, respectively). In Bragança district, three of the classrooms for infants exceeded WHO reference value of 100 Bq m^{-3}, two of them also exceeded USEPA reference value and only one of them exceeded both WHO and EU reference values of 300 Bq m^{-3} as well as the Portuguese legislation. Four of the studied classrooms for pre-schoolers exceeded WHO reference value of 100 Bq m^{-3} and two of them also exceeded USEPA reference value. Four of the primary schools' classrooms analysed exceeded the WHO guideline of 100 Bq m^{-3}, three of them also exceeded USEPA reference value, and one of them also exceeded both WHO and EU reference of 300 Bq m^{-3}, as well as the Portuguese legislation.

Although indoor radon concentrations were in general within the Portuguese legislation for IAQ, a considerable number of exceedances to the international reference values for IAQ and health protection were found, which is a concerning situation as there is no known threshold below which radon inhalation exposure does not present any risk to human health (WHO, 2009).

Eighteen studies published from 2009 to 2014 were found in the literature regarding radon levels in the indoor air of school microenvironments. Table 7.3 summarizes the main characteristics of those studies and the mean radon indoor concentrations that they reported.

Table 7.3 - Summary of the main results of most recent studies (from 2009 to 2014) regarding radon in indoor air of school microenvironments.

Location	Type of Schools	Concentration (Bq m^{-3})	References
Bulgaria (Kremikovtsi)	Nursery and primary schools	339 (short term)	Vuchkov et al. (2013)
		694 (long term)	
Saudi Arabia (Zulfi)	Primary schools	80.0	Al-Ghamdi et al. (2011)
	Nursery schools	80.1	
Greece	Primary schools	149	Clouvas et al. (2011)
Italy (South-East)	Primary schools	218	Trevisi et al. (2012)
	Nursery schools	246	
Turkey (Batman)	Primary schools	46	Damla and Aldemir (2014)
Poland (Kalisz)	Nursery and primary schools	46.0	Bem et al. (2013)
Poland (Ostrów Wielkopolski)	Nursery and primary schools	48.9	
Serbia (Southern)	Primary schools	119	Bochicchio et al. (2014)
	Primary schools	118	Zunic et al. (2013)
Canada (Province of Quebec)	Primary schools	56	Poulin et al. (2012)
Slovenia	Nursery schools	145 to 794	Vaupotic et al. (2012)
	Primary schools	70 to 770	
Bulgaria (Sofia)	Nursery schools	132	Ivanova et al. (2014)
Republic of Macedonia	Primary schools	88	Stojanovska et al. (2014)
Czech Republic	Nursery schools	204 (reconstruction) 149 (non-reconstruction)	Fojtikova and Navratilova Rovenska (2014)
Korea (Some provinces)	Primary schools	23 to 1414	Chang et al. (2011)
Korea (National survey)	Primary schools	98.4	Kim et al. (2011)
Pakistan (Punjab)	Primary schools	52	Rahman et al. (2010)
Pakistan (Urban area)	Primary schools	39	Rahman et al. (2009)
Pakistan (Rural area)	Primary schools	47	
Romania (3 counties)	Primary schools	215	Burghele and Cosma (2012)
Portugal (Porto district)	Nursery schools (infants)	101	This study
	Nursery schools (pre-schoolers)	37	
	Primary schools	57	
Portugal (Bragança district)	Nursery schools (infants)	189	
	Nursery schools (pre-schoolers)	138	
	Primary schools	275	

Indoor mean radon concentrations reported in recent literature for nursery schools from Italy (Trevisi et al., 2012), Bulgaria (Vuchkov et al., 2013), Slovenia (Vaupotic et al., 2012) and Czech Republic (Fojtikova and Navratilova Rovenska, 2014) were usually higher than those found in the present study, in both school microenvironments in the Porto and Bragança districts, which in turn were higher than those found in nursery schools from Saudi Arabia (Al-Ghamdi et al., 2011) and Poland (Bem et al., 2013).

On the other hand, indoor radon concentrations found in schools from Porto district were lower than the majority of those found in recent literature, except when comparing with the results from Turkish (Damla and Aldemir, 2014), Canadian (Poulin et al., 2012) and Pakistani schools (Rahman et al., 2009; Rahman et al., 2010). Indoor radon concentrations found in schools from Bragança district were higher than the majority of the ones reported in the literature, except for those in Bulgaria (Vuchkov et al., 2013) and Slovenia (Vaupotic et al., 2012), which enhance the concerns about the results here found for Bragança district.

Despite the limitations of this new preliminary approach, this study shows that the results found were quite concerning from the children's health point of view, especially in Bragança district, because radon is a carcinogenic compound and its inhalation has been associated with lifetime lung cancer risk. It also points out the need of assessing indoor radon concentrations not only in primary schools, but also in nursery schools, since children are expected to be exposed to relevant concentrations from infancy in those microenvironments. These preliminary data will be useful for the future survey of the long-term radon concentrations measurements.

7.3 Conclusions

Continuous active sampling allowed understanding the daily profile of indoor radon concentrations in both nursery and primary schools from Porto and Bragança districts. Results showed higher concentrations during night and dawn caused by the absence of air renewal, and lower along the day due to a higher air renovation. These patterns were found to be in accordance with the typical daily patterns already reported in the literature for other types of dwellings.

Classroom occupation (determined by children's age, activities and number of occupants) influenced radon concentrations inside classrooms. Thus, different results can be expected when assessing indoor radon concentrations in scholar microenvironments occupied by infants, pre-schoolers or primary school children. Another significant factor was floor level, with higher concentrations registered in the lower floors (the closest to the soil which is the main source of indoor radon). Consequently, floor level should be considered when assigning rooms usage in school buildings. The year of a building's construction, namely before or after 2006 (introduction of the IAQ Portuguese legislation), seemed to have had an important role in reducing indoor radon concentrations inside the studied buildings in Porto district. Limiting indoor radon assessment based upon buildings constructed in a specific type of soil will be difficult, because the results did not allow understanding the real influence that soil composition of the building site has in the indoor radon concentrations and in the radon children's exposure in the nursery and primary schools. These results point out the need of assessing indoor radon concentrations not only in primary schools, but also in nursery schools, since children are expected to be exposed to relevant concentrations from infancy in those microenvironments. Radon is a carcinogenic compound and its inhalation has been associated with lifetime lung cancer risk and, in fact, there is no known threshold below which radon inhalation exposure does not present risk to human health, so the results were quite concerning, especially in the studied nursery and primary schools from Bragança district.

Short-time measurements as well as a limited number of classrooms and buildings studied constituted a study limitation, thus this study is considered a preliminary assessment. Nevertheless, these preliminary data will be useful for the future survey of the long-term radon concentrations measurements, as recommended by the International Commission on Radiological Protection (ICRP, 2014) and by the European Commission (EU, 2013).

PART III

IMPACT ON CHILDHOOD ASTHMA

Asthma is the commonest and most important chronic non-infectious disease of childhood and it is estimated that actually more than 300 million people are affected worldwide (Bjerg et al., 2015; Strina et al., 2014). The prevalence of asthma has increased over the past few decades (it is currently approximately 10% globally) and today is a serious public health issue with a considerable impact on health economics (Bjerg et al., 2015; Lawson et al., 2014; Van Den Akker-van Marle et al., 2005). Its incidence is higher during childhood (Bjerg-Backlund et al., 2006; Bjerg et al., 2015). Prevalence is a frequently used epidemiological measure of how commonly a disease occurs in a population. It measures how much of some disease or condition there is in a population at a particular point in time. The prevalence of asthma varies considerably from country to country.

In Portugal, research on childhood asthma is still limited, although it has been gaining more importance. From the Portuguese national asthma survey (Sa-Sousa et al., 2012) it was not possible concluding about asthma prevalence of pre- and primary schoolchildren. As far as known, eight original research studies were published regarding childhood asthma prevalence and/or risk factors in Portugal, considering young children (pre- and primary school age). All those studies were cross-sectional, and they were conducted in big urban areas of the country (Lisbon (Constant et al., 2011; Khan et al., 2007; Pegas et al., 2011), Porto (Alvim-Ferraz et al., 2005), and Coimbra (Muc et al., 2014; Muc et al., 2013)). Only one was performed in the rural areas (Bragança district) (Sousa et al., 2009; Sousa et al., 2011). High population densities and easier availability of material and human resources (researchers, medical doctors and technicians) encouraged the development of studies for urban areas, although rural areas should not be forgotten as significant differences on asthma prevalence and morbidity can be found (Lawson et al., 2011; Valet et al., 2011). The study population (mainly primary school children) varied from 313 to 1037, and only one study included pre-school children under 7 years old as sub-group of the study population (de Sousa et al., 2011). Asthma studies on pre-schoolers are rare due to methodological constraints, namely to obtain precise health information and to perform medical exams to confirm symptoms (Santos et al., 2013). Children were usually recruited from schools to participate in the studies, and validated questionnaires based on the International Study of Asthma and Allergies in Childhood (ISAAC) were the most common way to obtain children's health information, although other options were found (Constant et al., 2011; de Sousa et al., 2011). The use of ISAAC-derived questionnaires allowed asthma prevalence estimation, through asthma diagnosis based on symptoms and asthma previously diagnosed. However, in some cases there was not information about the criteria used for asthma diagnosis (Khan et al., 2007; Pegas et al., 2011), and even when that information is present, different criteria were considered for asthma diagnosis, namely: i) previously diagnosed asthma (Constant et al., 2011); ii) at least one asthma episode in a defined lifetime (Muc et al., 2014; Muc et al., 2013); iii) wheezing and dyspnoea symptoms simultaneously mentioned in the absence of upper respiratory infections (Alvim-Ferraz et al., 2005; Sousa et al., 2009); and iv) combination of answers given by the patient about respiratory symptoms and physician's best knowledge of the patient's asthma status (de Sousa et al., 2011). Medical exams for asthma confirmation were only performed in three cases: for two of them by spirometry (Constant et al., 2011; Sousa et al., 2011) and for the third one by tests of bronchial reactivity with methacoline (Alvim-Ferraz et al., 2005). In none of these cases, medical exams of confirmation were performed in pre-school aged children.

All the above referred studies in Portugal reported lower values of asthma prevalence than what was expected by the Portuguese Directorate-General of Health for children aged 6-7 years old (11%) (Saúde, 2012). They were also lower than the reported as active asthma for the same population (12.9%) in the ISAAC study (Pinto, 2011), which in turn was also the same value reported for 13 years old Portuguese adolescents (Falcão et al., 2008). For example, de Sousa et al. (2011) reported a prevalence of asthma of 9.56% in the young children aged 6 months to 7 years old, which was lower than expected due to diagnostic problems (the diagnostics procedures were based on a combination of the answers given by the patient on respiratory symptoms and the physician’s best knowledge of the patient’s asthma status). Constant et al. (2011) also suspected of under-estimation of asthma prevalence (4%) in the studied population. In fact, different asthma prevalence values were found in the different Portuguese studies, which should be interpreted with caution, because it could possibly be due to different methodologies used and different criteria considered for asthma diagnosis. Moreover, other factors like children’s age and environmental contexts were also different, which could contribute to differences in the prevalence results.

Traditionally, asthma prevalence surveys were based on ISAAC questionnaire and mainly focused on children aged 6-7 and 13-14 years old (Akcay et al., 2014; Muc et al., 2014; Strina et al., 2014). However, most asthma develops before 6 years old (Bousquet et al., 2007; Weichenthal et al., 2007). Although in pre-school age is difficult to make a definite diagnosis of asthma, it is worth determining the prevalence and analyzing risk factors for this phenomenon among pre-school aged children (Patelarou et al., 2015; van der Mark et al., 2014; Yeh et al., 2011). Risk factors for asthma and allergy may be categorized as: i) host; or ii) environmental (Annesi-Maesano et al., 2013). Host factors might include heredity, gender, race, and age, with heredity being by far the most important. Four major environmental candidates are alterations in exposure to infectious diseases during early childhood, environmental pollution, allergen levels, and dietary changes. Many risk factors for childhood asthma have been identified, including allergic sensitisation, family history of asthma, severe respiratory tract infections, low birth weight, and pollutants such as parental tobacco smoke (Anto, 2012; Bjerg-Backlund et al., 2006; Sousa et al., 2013; Sousa et al., 2011; Strina et al., 2014). However, their impact on prevalence trends in pre-school age has rarely been studied (Patelarou et al., 2015; Strina et al., 2014).

In fact, studying factors that may increase the risk of asthma on childhood is complicated by their multiplicity and difficulty of defining asthma as an outcome. Asthma diagnosis is usually based only on reported previous diagnosis and/or parent-reported symptoms on questionnaires derived from ISAAC. In one hand, questionnaires are an affordable method to obtain reported symptoms, and personal and environmental information on factors that may influence the risk of asthma; on the other hand, reported symptoms must be confirmed by medical examination to produce a more accurate diagnose of asthma. Pulmonary function tests (PFT), usually under-utilized, are fundamental to make a confident asthma diagnosis. Spirometry is the most frequent method used for measuring lung function, commonly performed on adults and school-aged children, but rarely used on pre-schoolers, although feasible (Kampschmidt et al., 2016). When used, it has also the advantage of allowing longitudinal studies by monitoring individuals from pre-school age to adulthood (Beydon et al., 2007). Moreover, it is the recommended method for measuring airflow limitation and reversibility to establish an asthma diagnosis (GINA, 2018).

Although literature reported several risk factors for childhood asthma, a better understanding of their impact on childhood asthma is needed towards primary prevention (Beasley et al., 2015), especially in pre-school age (Strina et al., 2014). Moreover, on risk factors' studies, asthma was usually diagnosed by reported symptoms and/or reported previous physician-diagnosis, neglecting the latest clinical guidelines and recommendations from GINA (GINA, 2018), and European Respiratory Society (ERS) and American Thoracic Society (ATS) namely through the most recent Global Lung Initiative (GLI) (Quanjer et al., 2012; Stanojevic, 2018). Furthermore, the assessment of combined risk effects between a wide variety of host and environment factors is usually limited, thus neglecting confounding effects.

While the impacts of home environment on childhood asthma have been extensively studied (Breysse et al., 2010), school was usually less studied although it is the most important indoor environment for children apart from home, as well as their first place for social activity. Besides, children are frequently physically active in school, increasing their ventilation rate and thus the inhaled dose of pollutant concentrations, and schools usually suffer from inadequate building maintenance (Hauptman and Phipatanakul, 2015).

Until 1999, peer-reviewed literature on this subject was sparse, although there was a clear indication that classroom ventilation was typically inadequate (high CO_2 and low ventilation rates). The most commonly measured pollutants in schools were TVOC, formaldehyde and microbial contaminants, but in most cases health symptoms were not determined (Daisey et al., 2003). Latter, Zuraimi et al. (2007) suggested that different ventilation strategies employed by childcare centres could cause significant variations in IAQ and prevalence of asthma, allergies and respiratory symptoms of attending children. On the other hand, Zhao et al. (2008) suggested that exposure at school to chemical air pollutants such as SO_2, NO_2, and formaldehyde were associated with asthmatic symptoms. In fact, poor IAQ in schools have been often reported and related to: i) respiratory disturbances, namely affecting nasal patency (Simoni et al., 2010); ii) increased prevalence of clinical manifestations of asthma and rhinitis, the risk being higher for children with a background of allergies (Annesi-Maesano et al., 2012); and iii) wheezing and lung function abnormality in pre-schoolers, especially related with exposures to PM, TVOC and CO (Rawi et al., 2015).

Although poor IAQ in scholar indoor environments have been frequently reported, relationships between IAQ in schools and the allergic and respiratory health of schoolchildren have been insufficiently explored (Annesi-Maesano et al., 2013; Annesi-Maesano et al., 2012; Patelarou et al., 2015). Moreover, published studies regarding the relationship between IAQ in schools and children's allergies and respiratory health, in particular childhood asthma, usually presented at least one the following limitations: i) focus only on urban areas, neglecting rural sites where both children's time-activity-patterns and outdoor air concentrations are expected to differ; ii) studied population was usually primary school aged or even older, despite the fact that childhood asthma usually develops early in life (pre-school age); iii) classrooms' concentrations were usually assumed as exposure, not considering children's time-location patterns and neglecting other relevant indoor microenvironments (canteens, bedrooms); iv) inhalation exposure models were commonly used, despite the fact that they did not strictly take into account the inhaled dose of airborne compounds, but only the presence of air pollutants near the breathing zone of a person; v) consider single or few pollutants individually, neglecting their combined effects; vi) respiratory health data, especially asthma related, is usually parent-reported in a survey, instead of measured and confirmed by a physician.

To overcome the lacks described, the work specifically developed in this thesis and reported in the following chapters goes further on this field, by evaluating IAP impacts on childhood asthma prevalence in urban and rural sites. It starts by estimating asthma prevalence and risk factors in early childhood (children under 6 years old attending nursery school) based only on reported information from validated questionnaires (Chapter 8). After that, and based on physical diagnosis according to the latest guidelines, asthma prevalence is calculated in pre- and primary schoolchildren attending nursery and primary schools, and it was evaluated whether host and environmental reported factors have an independent or combined risk effect on childhood asthma (Chapter 9). Lastly, this part reports the quantification of children's exposure to, and inhaled dose of, indoor air pollutants in nursery and primary schools, evaluating their associations with childhood asthma prevalence and other asthma-related outcomes (Chapter 10).

Chapter 8

Asthma prevalence and risk factors in early childhood at Northern Portugal*

The present chapter aimed to assess asthma prevalence and associated risk factors, namely demographic, environmental, psychosocial and clinical risk factors for infants and pre-schoolers living in Northern Portugal.

8.1 Methodology

Study population consisted of 1042 children attending the 17 nursery schools involved in the INAIRCHILD project. These nursery schools were located in urban and suburban contexts in Porto district and in rural context in Bragança district (both in northern region of Portugal). In Porto district, 3 and 7 nursery schools were considered, for infants (children aged under 3) and pre-schoolers (3-5 years old) respectively; in Bragança district, there were 2 and 5 nursery schools considered, for infants and pre-schoolers respectively.

Data concerning asthma prevalence were collected through ISAAC-derived questionnaires, distributed in 2013/2014 academic year to all the children attending the nursery schools involved (Appendix C). The questionnaire included questions concerning sex, age, height, weight, distance from home to school, socioeconomic status (SES), tobacco smoke exposure, family asthma history and health symptoms related to asthma prevalence: asthma previously diagnosed, wheezing, dyspnea and their severity through asthma attacks (number in the previous year, speech-limiting attacks, nocturnal and induced by exercise). Parents or guardians signed participation consent (Appendix D) according to the Helsinki Declaration

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* adapted from: Branco PTBS, Nunes RAO, Alvim-Ferraz MCM, Martins FG, Ferraz C, Vaz LG, Sousa SIV, 2016. Asthma prevalence and risk factors in early childhood at Northern Portugal. *Revista Portuguesa de Pneumologia* (English Edition) 22(3):146-150.

developed by the World Medical Association, and completed the questionnaire. Uncompleted questionnaires were excluded. Questionnaires and their evaluation were validated by medical doctors.

Logistic regression models were used to calculate odds ratios (OR). The level of statistical significance was set at 0.05. Statistical analyses were performed using *epicalc* package (Chongsuvivatwong, 2009) in R software, version 3.1.2 (R Development Core Team 2014).

8.2 Results and discussion

From the 1042 ISAAC-derived questionnaires distributed, a total of 497 questionnaires were considered complete for this study (response rate of 48%). Out of those, 197 questionnaires were from children attending nursery schools in Bragança district - rural context, and 160 and 140 questionnaires were from children attending nursery schools in Porto district - urban and suburban context, respectively. The studied population (mean age 3.6 years old) is characterized in Table 8.1. Around 52% of the studied children presented at least one of the respiratory symptoms investigated (wheeze, dyspnoea and cough) in the absence of upper respiratory infections. The prevalence of wheezing for lifetime period and for the past year was 30.4% and 17.1%, respectively.

Based on the answers from the questionnaires, children were considered asthmatic if wheezing and dyspnoea were reported simultaneously, or if previously diagnosed asthma was self-reported (Alvim-Ferraz et al., 2005; Sousa et al., 2009). The studied population registered a global asthma prevalence of 10.7%, which is similar to the estimated prevalence (11.0%) for Portuguese children population aged 6-7 years old (Direção Geral da Saúde, 2013), showing that an early diagnosis might be possible and would surely be beneficial for the mitigation of childhood asthma.

In Chicago, United States of America (USA), Grant et al. (1999) obtained from ISAAC-derived questionnaires a prevalence of asthma of 10.8% among inner-city kindergarten children (mean age 5.7 years), which was found similar to that found in the present study for the same age (pre-schoolers). Also in the USA, and using a different methodology to obtain data on asthma prevalence (3 national surveys), Akinbami et al. (2009) reported asthma prevalence in children aged 0-4 years old, lower than in the present study (6.2%) in the period of 2004-2005. In Los Angeles (USA), from new born to 5 years old, asthma prevalence was estimated to be 5.9% (The Los Angeles County Department of Health Services, 2004), lower than that found in the present study; this age group had the lowest asthma prevalence in comparison with the other groups studied (6-11 and 12-17 years old), however having the highest number of emergency room or urgent care visits. In the New York State (USA) (Public Health Information Group, 2013), asthma prevalence for the age group 0-4 years old (7.3%) was also the lowest estimated (compared with 5-9, 10-14 and 15-17 years old groups).

Table 8.1 - Characterization of the studied children and prevalence of asthma symptoms, with confidence intervals (CI).

	%	95% CI
Sex		
Female	47.9	43.5-52.3
Male	52.1	47.7-56.5
Lifetime prevalence		
Wheeze	30.4	26.3-34.4
Dyspnoea	11.7	8.8-14.5
Asthma (previously diagnosed)	3.8	2.1-5.5
Prevalence in the past year		
Wheeze		
Spontaneous	17.1	13.8-20.4
Attacks number		
None	6.0	3.9-8.1
1-3	13.3	10.3-16.3
4-12	3.6	2.0-5.3
≥12	0.4	0.0-1.0
Nocturnal attacks number		
None	13.7	10.7-16.7
<1 night/week	7.4	5.1-9.8
≥1 night/week	2.2	0.9-3.5
Exercise-induced	3.4	1.8-5.0
Speech-limiting attacks	2.4	1.1-3.8
Dyspnoea		
Attacks number		
None	13.3	10.3-16.3
1-3	7.4	5.1-9.8
4-12	1.4	0.4-2.4
>12	0.2	0.0-0.6
Nocturnal attacks number		
None	16.3	13.1-19.5
<1 night/week	3.6	2.0-5.3
≥1 night/week	1.4	0.4-2.4
Nocturnal cough (without infection)	38.0	33.8-42.3

Zhao et al. (2010) studied children in the 3 major cities of China applying also ISAAC-based questionnaires, and registered lower asthma prevalence (3.15% in Beijing, 7.45% in Chongqing, and 2.09% Guangzhou). In a Portuguese study based on a similar methodology, de Sousa et al. (2011) reported an asthma prevalence of 9.56% for children aged 0-7 years old from Matosinhos (a suburban area in Porto district), slightly lower than the prevalence estimated for the suburban area studied in the present study (also in Porto district).

Table 8.2 shows the distribution of asthma risk factors for the studied children, determined using univariate logistic regression analysis. OR and respective 95% confidence interval (CI) are also presented. In the studied population, asthma prevalence was higher for boys than for girls and body mass index (BMI) seemed to be a risk factor for asthma prevalence, with higher risk for obese children (OR = 1.32), all results consistent with the literature (Akinbami et al., 2009; Public Health Information Group, 2013). Children attending nursery schools located in non-rural areas (urban and suburban areas) were found to have a greater risk (OR = 1.90 and 2.49) than in rural areas. Zhu et al. (2015) also registered lower asthma prevalence in Chinese children aged 5 years old or younger from rural areas (1.33%) than in those from urban areas (2.83%) of Beijing, although both lower than in the present study. In Tennessee (USA), Valet et al. (2011) studied asthma prevalence in children under 6 years old between 1995 and 2000, and found it higher in rural context (13%) than in suburban (12%) or in urban (11%), which is the opposite from the findings in the present study (6.6%, 11.9% and 15.0%, respectively). However, these comparison should be made with caution, not only because the methodology for obtaining prevalence in data in that study was different (asthma diagnosis was based on hospital databases and pharmacy claims), but also because the classification of rural context could be different. On the other hand and contrary to what was found in previous studies (Zhao et al., 2010), an increase in asthma prevalence with the age was not found. Additionally, asthma prevalence did not seem to be dependent on distance from home to nursery school. Although SES is a measure of the family’s economic and social position in relation to others, based on income, education and occupation (Green, 1970), the questionnaires did not provide information about income. So, in the present study, SES was estimated merely based on education and parents’ occupation which constitutes a limitation. Results showed higher prevalence for children with high SES, but literature findings suggested the opposite (Anto, 2012). However, the limitations in the results make them uncertain and its interpretation tricky. Although asthma is one of the diseases showing the largest burden due to ETS (Anto, 2012), results globally showed that living with smokers did not constitute a risk factor for asthma prevalence, which might have been due to the tendency of adults to avoid smoking in the presence of young children. In fact, Yeh et al. (2011) concluded that parental smoking was not related to asthma development in early childhood.

The factor with higher risk (OR = 4.89) was having at least one parent with asthma, confirming asthma family history as an evident risk factor for infants and pre-schoolers (Strina et al., 2014).

Table 8.2 – Distribution of asthma risk factors for the children studied.

	Asthmatics (%)	OR	95% CI
Sex			
Female	9.7	1	-
Male	11.6	1.22	0.66-2.28
Age (years)			
<3	10.5	1	-
3-6	10.7	1.03	0.47-2.49
BMI[a]			
Healthy weight	13.1	1	-
Underweight	6.1	0.43	0.05-1.89
Overweight	7.1	0.51	0.14-1.45
Obese	16.7	1.32	0.56-2.97
Nursery school location			
Rural	6.6	1	-
Urban	11.9	1.90	0.86-4.35
Suburban	15.0	2.49	1.14-5.64
Distance home-school[b] (km)			
0-10	10.9	1	-
10-20	10.0	0.91	0.27-2.48
≥20	11.5	1.07	0.20-3.78
Socioeconomic status			
High	14.9	1	-
Medium	9.1	0.57	0.22-1.65
Low	12.8	0.84	0.31-2.55
Living with a smoker			
No	10.6	1	-
1 smoker	10.9	1.04	0.49-2.08
2 or more smokers	10.5	0.99	0.32-2.57
Family asthma history			
No parents with asthma	7.7	1	-
Parent with asthma	29.0	4.89	2.45-9.53

[a] BMI – body mass index (N = 350 children); [b] N = 453 children

8.3 Conclusions

Results showed high estimated asthma prevalence in early childhood at Northern Portugal, comparable to that of Portuguese schoolchildren (6-7 years old) reported by the national Directorate-General of Health, thus showing that an early diagnosis might be possible and helpful for the reduction of childhood asthma. Environmental context (urban, suburban or rural), gender and family asthma history showed clear associations with asthma prevalence, namely non-rural location, male gender, and being the child of an asthmatic parent were found to be risk factors.

Chapter 9

Asthma in urban and rural pre- and primary schoolchildren according to the latest GINA definition*

The present chapter aimed to assess childhood asthma prevalence and to evaluate whether host and environmental reported factors have an independent or combined risk effect on childhood asthma, by: i) considering a sample of the general population of pre- and primary school children from both urban and rural sites; and ii) following the newest GINA guidelines and recommendations to asthma diagnosis based on reporting history of characteristic respiratory symptoms and demonstrating variable expiratory airflow limitation by spirometry with reversibility test.

9.1 Methodology

9.1.1 Study population, selection and recruitment

This study involved pre-schoolers (3-5 years old), and primary school children (6-10 years old) recruited from nursery and primary schools, from both urban and rural areas of northern Portugal, involved in INAIRCHILD project (Sousa et al., 2012a), in the academic years of 2013/2014 (campaign 1) and 2015/2016 (campaign 2, to increase sample size). Parents or guardians signed an informed consent (Appendix D) according to the Helsinki Declaration developed by the World Medical Association. At any stage of the study, the potential children's dissent was always respected.

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* adapted from: Branco PTBS, Alvim-Ferraz MCM, Martins FG, Ferraz C, Vaz LG, Sousa SIVS. Asthma in urban and rural pre- and primary schoolchildren according to the latest GINA guidelines. *Submitted.*

9.1.2 Data collection and asthma diagnosis

The same ISAAC-derived questionnaire (Appendix C) as in the previous chapter accompanied by an explanatory letter were distributed to all children attending INAIRCHILD nursery and primary schools, including questions about personal characteristics, SES, exposure to second-hand tobacco smoke, lifestyle and nutritional habits, family asthma history and health symptoms related to asthma and wheezing. This allowed obtaining information on relevant reported host and environmental factors that may influence the risk of having asthma. Medical doctors validated all questionnaires. Questionnaires missing signed consent, sex or date of birth were excluded.

According to the most recent GINA guidelines and recommendations (GINA, 2018), asthma diagnosis was based on reporting history of characteristic respiratory symptoms and demonstrating variable expiratory airflow limitation by spirometry with reversibility test. Thus, children who were reported being asthmatic in the questionnaire (asthma previously diagnosed by a medical doctor) and those who reported at least one asthmatic symptom (wheezing, dyspnoea or nocturnal cough in the absence of upper respiratory infection) were selected for PFT.

Spirometry pre and post bronchodilator administration (200 μg of salbutamol) was used to perform the PFT according to the latest guidelines and recommendations from ERS/ATS and GINA (GINA, 2018; Thurston et al., 2017). A Vitalograph ALPHA Track (Vitalograph, UK) was used at one specific room of each school to where medical doctors brought the necessary equipment. That room was specifically chosen to avoid confounding effects related to weather and other indoor environmental conditions. Children were instructed how to do the manoeuvres, repeating them at least three times until the reproducibility was reached. As the majority of children was doing this test for the first time, a training period was considered to familiarize with the equipment and technician. Flow- and volume-driven interactive computerized incentives were used to encourage manoeuvres. Children were seated and no nose clip was used. Flow-volume and volume-time traces were visually inspected to exclude visibly inadequate manoeuvers. Pulmonary function indexes were measured in each attempt and predicted for each individual using the latest recommendations (Quanjer et al., 2012), namely: i) forced expiratory volume in 1 second (FEV_1) which is the volume exhaled during the first second of a forced expiratory manoeuvre started from the level of total lung capacity; and ii) forced vital capacity (FVC) which is the volume of air that can forcibly be blown out after full inspiration.

Asthma was diagnosed, based on the newest GINA guidelines and recommendations (GINA, 2018): if at least one asthmatic symptom (wheezing, dyspnoea or nocturnal cough in the absence of upper respiratory infection) was reported simultaneously with spirometry results revealing both airflow limitation (obstruction) and excessive variability in lung function. Airflow limitation is associated with a reduced FEV_1/FVC (< 0.90) and excessive variability in lung function is associated with a positive bronchodilator reversibility test with an increase in FEV_1 higher than 12% predicted, with or without reporting a previous diagnosis. The Global Lung Initiative (GLI) 2012 equations were used to predict lower limits of normal for spirometric indices (Quanjer et al., 2012; Quanjer and Weiner, 2014).

9.1.3 Data analysis

Descriptive statistics were used to express cohort's characteristics. Prevalence rate was calculated as the ratio between the number of cases and the total number of individuals considered. Statistical significance of differences was assessed by the Chi-square test, and phi coefficient was used to measure the degree of association between two binary variables. Several host and environmental reported factors that may influence the risk of developing asthma were obtained from the ISAAC-derived questionnaire. Separate bivariate and multivariate logistic regressions were used to analyse respectively those individual and combined risk effects. Variables with more than 50% of missing data were excluded. To avoid bias by losing individuals, other variables with missing data were imputed by using Multivariate Imputation by Chained Equations based on logistic regression for binary variables and polytomous logistic regression for other unordered categorical variables (Buuren and Groothuis-Oudshoorn, 2011). Missing values in the outcome were not imputed, and 20 imputed datasets were created.

To obtain the final multivariate logistic regression model, an automatic model selection after multiple imputation approach based on AIC and based on Rubin's rules was used (M. et al., 2008; Schomaker and Heumann, 2014). In the final model, adjusted OR and their 95% CI were used for the interpretation of results. Statistical computations were performed with R software version 3.4.3. The level of statistical significance was set at 0.05.

9.2 Results

9.2.1 Study population characteristics and asthma prevalence

This study involved 1261 children (Figure 9.1) from nursery (pre-schoolers) and primary schools (516 and 745, respectively), both from urban (56.8%) and rural areas (43.2%). Mean age (SD) of the study population was 6.0 (2.1) years old. Mean age (SD) of pre- and primary school children was respectively 4.0 (0.9) and 7.4 (1.3). Tables 9.1 and 9.2 summarize main characteristics and prevalence of asthma-related symptoms of this study population. The majority of children was from urban sites (56.8%), had normal BMI and was born in Portugal (95.5%). Living with a smoker was common (40.2%), especially in rural areas, and 13.7% of children had at least one asthmatic parent, being in urban areas (18.1%) more than double than those in rural areas (7.9%).

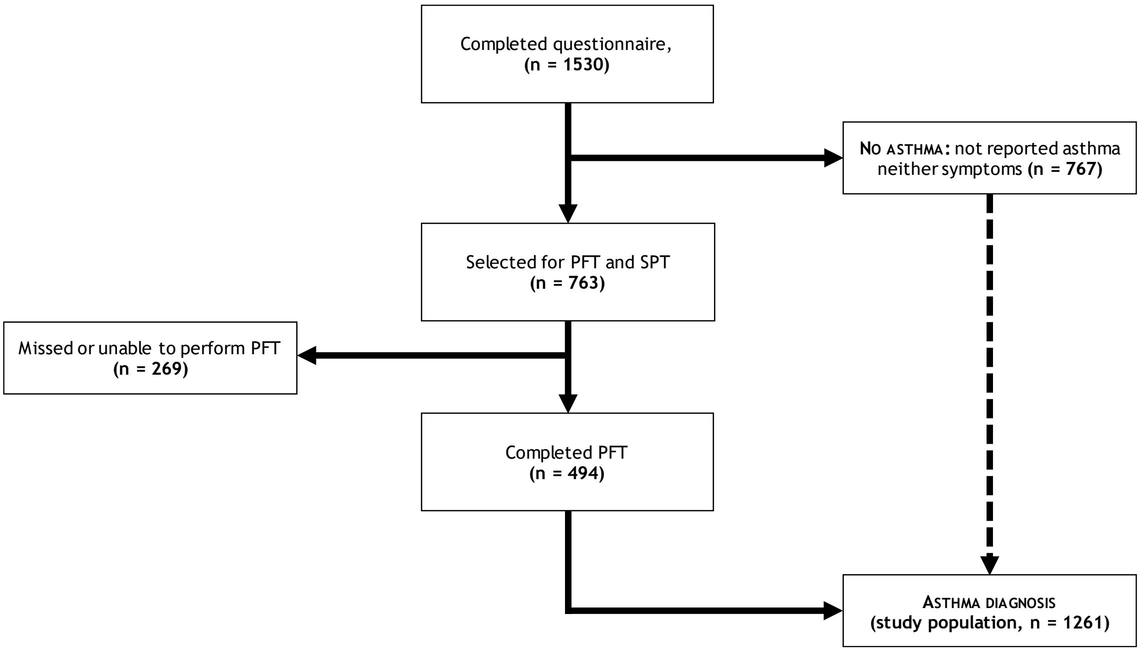


Figure 9.1 – Flowchart of the study population considered for asthma diagnosis

Ever wheezing was reported by 30.1% of the population, while active wheezing (wheezing in the previous year) was merely reported by 10.4%, higher in urban areas and decreasing with age, predominantly occurring during the day and with a moderate frequency (1-3 times/year). Although reduced, exercise-induced wheezing and speech-limiting attacks were also higher in urban areas, as well as active dyspnoea. Nocturnal cough without cold or respiratory infection was the most prevalent active symptom (36.0%). At least one active asthmatic symptom (wheeze, dyspnoea or cough) was reported by 48.9%.

Following the newest GINA guidelines and recommendations (GINA, 2018), asthma was diagnosed in 5.5% of the population. It was higher in primary school children (6.4%) than in pre-schoolers (4.4%), although the difference was not statistically significant (p = 0.23). Moreover, diagnosed asthma was higher in children from urban locations (6.0%) when compared with those from rural sites (4.8%), although the difference was not also statistically significant (p = 0.41).

Previously diagnosed asthma was reported in 4.3% of the study population, higher in older children and in urban areas. From those that were diagnosed asthmatic in this study, 23.2% have not been diagnosed before. In fact, 1.2% of the study population were undiagnosed asthmatics, i.e. children that did not report being asthmatics although they were diagnosed in this study. This under-diagnosing of asthma was higher among primary school children, as well as higher in urban areas.

Table 9.1 – Characterization of the study population (with 95% confidence intervals), in the whole population and divided by age and by location

	Population (n=1261)		**by children's age**				**by site location**			
			Pre-schoolers (n=516)		**Primary school (n=745)**		**Urban (n=716)**		**Rural (n=545)**	
	%	**95% CI**	%	**95% CI**	%	**95% CI**	%	**95% CI**	%	**95% CI**
Sex										
Female	50.4	(47.6-53.1)	46.5	(42.2-50.8)	53.0	(49.4-56.6)	49.3	(45.6-53.0)	51.7	(47.5-55.9)
Male	49.6	(46.9-52.4)	53.5	(49.2-57.8)	47.0	(43.4-50.6)	50.7	(47.0-54.4)	48.3	(44.1-52.5)
Location										
Rural	43.2	(40.5-46.0)	54.7	(50.4-58.9)	41.7	(38.2-45.3)	-	-	-	-
Urban	56.8	(54.0-59.5)	45.3	(41.1-49.6)	58.3	(54.7-61.8)	-	-	-	-
BMI classification										
Normal	58.3	(55.1-61.5)	55.9	(50.9-61)	60.0	(55.8-64.1)	58.5	(54.4-62.7)	58.0	(52.9-63.1)
Underweight	7.4	(5.7-9.1)	9.5	(6.5-12.4)	6.0	(4-8)	5.1	(3.3-6.9)	10.9	(7.7-14.2)
Overweight	16.1	(13.7-18.5)	14.9	(11.2-18.5)	16.9	(13.8-20.1)	17.5	(14.3-20.6)	14.0	(10.4-17.6)
Obese	18.2	(15.7-20.7)	19.7	(15.7-23.8)	17.1	(13.9-20.3)	18.9	(15.6-22.2)	17.1	(13.2-21)
SES classification										
Class 1	22.0	(19.7-24.3)	25.1	(21.3-28.8)	19.9	(17-22.8)	27.9	(24.6-31.2)	14.4	(11.4-17.3)
Class 2	15.4	(13.4-17.3)	15.2	(12.1-18.3)	15.5	(12.9-18.1)	19.3	(16.4-22.2)	10.1	(7.6-12.7)
Class 3	13.1	(11.3-15.0)	11.9	(9.1-14.7)	14.0	(11.5-16.5)	14.6	(12.0-17.2)	11.2	(8.6-13.9)
Class 4	30.5	(28.0-33.1)	29.8	(25.8-33.7)	31.1	(27.8-34.4)	23.1	(20.0-26.2)	40.3	(36.2-44.5)
Class 5	13.4	(11.6-15.3)	14.2	(11.2-17.2)	12.9	(10.5-15.3)	10.2	(8.0-12.4)	17.7	(14.5-20.9)
Class 6	5.5	(4.2-6.7)	3.9	(2.2-5.6)	6.6	(4.8-8.4)	4.9	(3.3-6.5)	6.3	(4.2-8.3)
Born in Portugal, no	4.5	(3.3-5.6)	3.3	(1.8-4.9)	5.3	(3.7-6.9)	1.8	(0.8-2.8)	8.0	(5.7-10.3)
Living with a smoker, yes	40.2	(37.5-42.9)	40.8	(36.5-45)	39.8	(36.3-43.3)	38.5	(34.9-42.1)	42.4	(38.2-46.6)
Asthmatic parent, yes	13.7	(11.8-15.6)	13.0	(10.1-15.9)	14.2	(11.7-16.7)	18.1	(15.3-21.0)	7.9	(5.7-10.2)

CI – Confidence interval; BMI – Body Mass Index; SES – Socioeconomic status

Table 9.2 – Characterization and prevalence of asthma symptoms (with 95% confidence intervals), in the whole population and divided by age and by location

	Population (n=1261)		by children's age				by site location			
			Pre-schoolers (n=516)		Primary school (n=745)		Urban (n=716)		Rural (n=545)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Reported lifetime prevalence										
Wheezing	24.6	(22.1-27.0)	22.6	(19-26.2)	24.4	(21.3-27.5)	25.2	(22-28.4)	21.6	(18.1-25.1)
Dyspnoea	10.3	(8.6-12.0)	8.0	(5.7-10.4)	11.2	(8.9-13.5)	10.1	(7.9-12.3)	9.7	(7.2-12.2)
Asthma (previously diagnosed)	4.3	(3.2-5.5)	3.1	(1.6-4.6)	4.9	(3.3-6.4)	4.5	(3.0-6.0)	3.7	(2.1-5.3)
Reported prevalence in the past year										
Wheezing										
Spontaneous	10.4	(8.6-12.1)	11.6	(8.8-14.4)	8.9	(6.8-10.9)	11.1	(8.8-13.4)	8.5	(6.1-10.8)
Attacks number										
None	0.3	(0.0-0.7)	0.4	(0.0-0.9)	0.3	(-0.1-0.7)	0.3	(0.0-0.7)	0.4	(0.1-0.9)
1-3	7.6	(6.1-9.1)	9.4	(6.9-12)	5.9	(4.2-7.6)	8.2	(6.2-10.2)	6.2	(4.2-8.3)
4-12	2.3	(1.4-3.1)	1.8	(0.6-2.9)	2.5	(1.3-3.6)	2.4	(1.3-3.5)	1.9	(0.7-3)
≥12	0.3	(0.0-0.5)	0.2	(0.0-0.6)	0.3	(-0.1-0.7)	0.3	(0.0-0.7)	0.2	(0.2-0.6)
Nocturnal attacks number										
None	4.3	(3.1-5.4)	5.3	(3.4-7.3)	3.3	(2-4.6)	4.8	(3.2-6.4)	3.2	(1.7-4.7)
<1 night/week	4.3	(3.1-5.4)	4.7	(2.9-6.6)	3.7	(2.3-5)	4.5	(3-6)	3.6	(2-5.1)
≥1 night/week	1.8	(1.1-2.6)	1.8	(0.6-2.9)	1.8	(0.8-2.7)	1.7	(0.7-2.6)	1.9	(0.7-3)
Exercise-induced	3.1	(2.1-4.1)	1.8	(0.6-2.9)	3.8	(2.4-5.2)	3.4	(2.1-4.7)	2.4	(1.1-3.8)
Speech-limiting attacks	1.3	(0.6-1.9)	1.2	(0.2-2.1)	1.2	(0.4-2)	1.5	(0.6-2.5)	0.8	(0.0-1.5)
Dyspnoea										
Attacks number										
None	3.5	(2.4-4.5)	2.5	(1.2-3.9)	3.9	(2.5-5.3)	3.5	(2.2-4.9)	3.2	(1.7-4.6)
1-3	5.6	(4.3-6.8)	4.7	(2.9-6.5)	5.8	(4.1-7.5)	5.9	(4.2-7.6)	4.6	(2.9-6.4)
4-12	1.2	(0.6-1.8)	0.8	(0.0-1.5)	1.4	(0.5-2.2)	0.7	(0.1-1.3)	1.7	(0.6-2.8)
>12	0.3	(0-0.7)	0.4	(0.0-0.9)	0.3	(-0.1-0.6)	0.1	(0.0-0.4)	0.6	(0.0-1.2)
Nocturnal attacks number										
None	6.9	(5.5-8.3)	4.9	(3-6.8)	7.8	(5.9-9.8)	7.9	(5.9-9.8)	5.0	(3.2-6.9)
<1 night/week	2.6	(1.7-3.5)	2.2	(0.9-3.4)	2.7	(1.5-3.9)	1.7	(0.7-2.6)	3.5	(2-5.1.0)
≥1 night/week	0.9	(0.4-1.4)	1.2	(0.2-2.1)	0.7	(0.1-1.3)	0.7	(0.1-1.3)	1.1	(0.2-2.0)
Nocturnal cough (without infection)	28.3	(25.8-30.8)	31.0	(26.9-35)	26.5	(23.3-29.7)	27.0	(23.7-30.3)	30.0	(26.2-33.9)

CI – Confidence interval; BMI – Body Mass Index; SES – Socioeconomic status

9.2.2 Risk factors

Information collected from the ISAAC-derived questionnaires allowed building 49 variables (factors) to assess their influence on childhood asthma Appendix E (E1). For each factor, bivariate analysis allowed assessing individual risk effect on the outcome – diagnosed asthma Appendix E (E2). Multivariate analysis based on multiple imputed datasets allowed assessing combined effects of all the factors on asthma (full model). One variable ("sports location") was dropped out for having more than 50% of missing data (Appendix E (E3)), and another one was dropped out due to high correlation with other ("number of smokers in family", highly correlated with "living with a smoker": 0.95). Campaign was included as a factor to understand differences in time and to account for them. However, it was not statistically significant. Results from the full multivariate logistic regression model are detailed in Table 9.3. From the full set of candidate models, the model selection methodology used allowed obtaining the final ("best") model according to AIC, which was summarized in Figure 9.2.

Table 9.3 – Summary of the combined risk effects on asthma prevalence: results of the full multivariate logistic regression models, presented as adjusted odds ratio (aOR) and their 95% confidence intervals (95%CI)

Factors	**aOR (95%CI)**	***p*-value**
Campaign C2 vs. C1	1.12 (0.60-2.11)	0.72
Host factors	**aOR (95%CI)**	***p*-value**
Male vs. Female	2.14 (1.18-3.86)	**0.01***
Pre-schooler vs. Primary school children	0.48 (0.24-0.93)	**0.03***
BMI classification: Underweight	0.93 (0.26-3.36)	0.91
BMI classification: Overweight	1.04 (0.38-2.84)	0.94
BMI classification: Obese	1.27 (0.57-2.83)	0.56
Low birthweight	0.93 (0.39-2.19)	0.86
Older brothers: 1 vs. 0	0.65 (0.33-1.26)	0.20
Older brothers: 2 or more vs. 0	0.40 (0.14-1.17)	0.09
Younger brothers: 1 vs. 0	0.56 (0.27-1.16)	0.12
Younger brothers: 2 or more vs. 0	1.04 (0.22-4.78)	0.96
Born in Portugal: No	0.96 (0.19-4.70)	0.96
Parental history of asthma	3.96 (2.10-7.48)	**<0.01***

aOR – adjusted odds ratio; CI – confidence interval; NA – not applicable; BMI – Body Mass Index; SES – Socioeconomic status; * statistically significant ($p < 0.05$)

Table 9.3 (cont.) – Summary of the combined risk effects on asthma prevalence: results of the full multivariate logistic regression models, presented as adjusted odds ratio (aOR) and their 95% confidence intervals (95%CI)

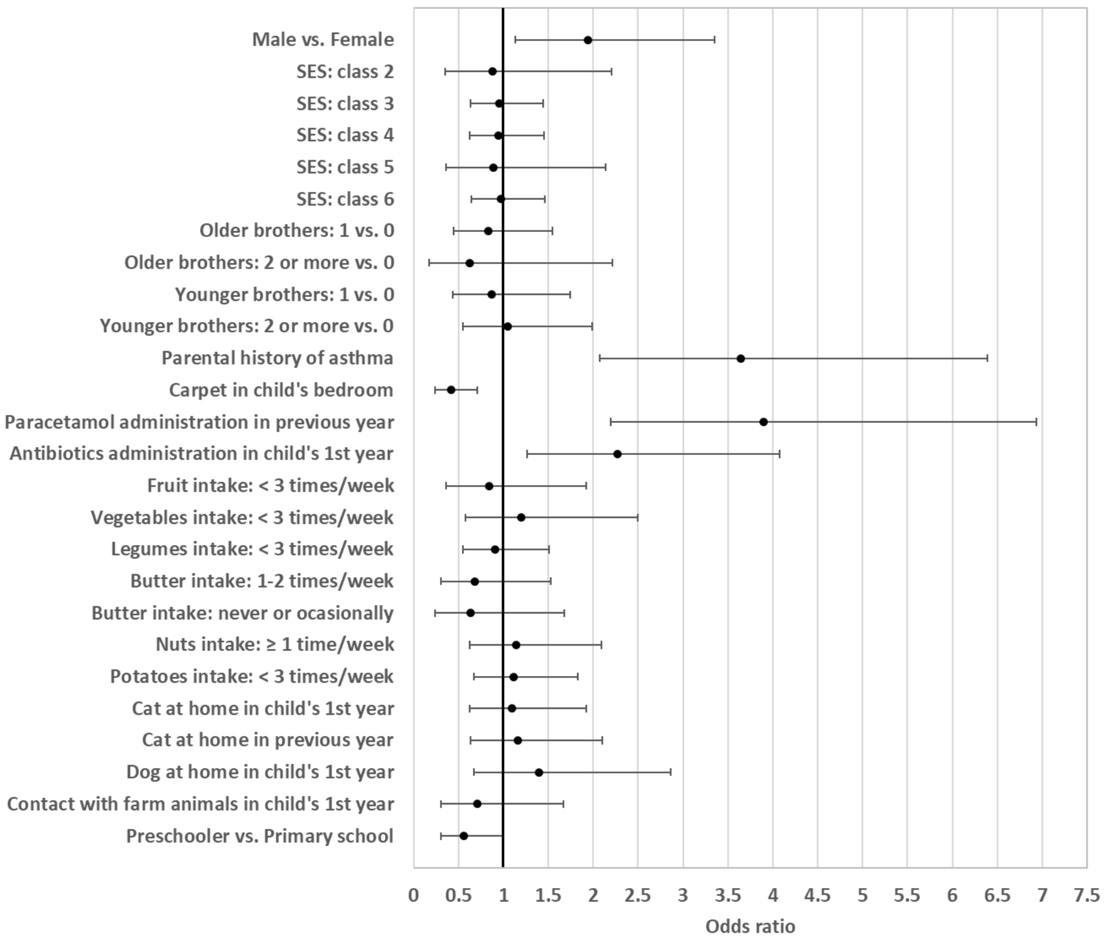
Environmental factors	**aOR (95%CI)**	***p*-value**
Rural vs. Urban	0.98 (0.44-2.18)	0.96
SES: class 2	0.29 (0.09-0.91)	**0.03***
SES: class 3	0.63 (0.21-1.96)	0.43
SES: class 4	0.63 (0.20-1.99)	0.43
SES: class 5	0.36 (0.09-1.42)	0.14
SES: class 6	0.87 (0.19-3.90)	0.85
Maternal education: Low	0.98 (0.44-2.17)	0.96
Maternal education: High	1.23 (0.45-3.32)	0.69
Living with a smoker	1.30 (0.69-2.42)	0.42
Mother smoking during pregnancy	0.68 (0.28-1.62)	0.38
Sports practice	1.01 (0.54-1.86)	0.99
Breath limiting physical activities	0.81 (0.42-1.56)	0.52
Energy to cook: Gas vs. Electricity	1.04 (0.55-1.97)	0.90
Energy to heat: gas, kerosene, paraffin vs. electricity	0.78 (0.33-1.88)	0.58
Energy to heat: wood, coal, oil vs. electricity	0.82 (0.39-1.74)	0.61
Energy to heat: none vs. electricity	1.61 (0.28-9.42)	0.60
Carpeted house	NA	NA
Carpet in child's bedroom	0.38 (0.21-0.68)	**<0.01***
Traffic near home (week): often vs. all day	0.79 (0.31-2.01)	0.62
Traffic near home (week): rarely vs. all day	1.08 (0.31-3.76)	0.91
Traffic near home (weekend): often vs. all day	1.01 (0.38-2.67)	0.99
Traffic near home (weekend): rarely vs. all day	0.90 (0.24-3.33)	0.88
Paracetamol administration in child's 1st year	0.86 (0.44-1.68)	0.65
Paracetamol administration in previous year	4.70 (2.46-8.98)	**<0.01***
Antibiotics administration in child's 1st year	2.25 (1.17-4.34)	**0.02**
Meat intake: < 3 times/week	0.97 (0.47-2.00)	0.93
Fish intake: < 3 times/week	1.30 (0.65-2.60)	0.47
Fruit intake: < 3 times/week	0.49 (0.17-1.39)	0.18
Vegetables intake: < 3 times/week	2.00 (0.92-4.35)	0.08
Legumes intake: < 3 times/week	0.68 (0.35-1.32)	0.26
Cereals intake: < 3 times/week	0.80 (0.28-2.29)	0.68

aOR – adjusted odds ratio; CI – confidence interval; NA – not applicable; BMI – Body Mass Index; SES – Socioeconomic status; * statistically significant ($p < 0.05$)

Table 9.3 (cont.) – Summary of the combined risk effects on asthma prevalence: results of the full multivariate logistic regression models, presented as adjusted odds ratio (aOR) and their 95% confidence intervals (95%CI)

Environmental factors	**aOR (95%CI)**	***p*-value**
Pasta intake: < 3 times/week	0.78 (0.36-1.71)	0.54
Rice intake: < 3 times/week	1.18 (0.53-2.66)	0.69
Butter intake: 1-2 times/week	0.51 (0.26-1.01)	0.05
Butter intake: never or occasionally	0.45 (0.19-1.05)	0.06
Margarine intake: < 3 times/week	0.80 (0.41-1.58)	0.52
Nuts intake: ≥ 1 time/week	1.58 (0.76-3.28)	0.22
Potatoes intake: < 3 times/week	1.25 (0.65-2.39)	0.50
Milk intake: < 3 times/week	1.10 (0.40-3.00)	0.86
Eggs intake: 1-2 times/week	0.69 (0.29-1.65)	0.40
Eggs intake: never or occasionally	1.37 (0.63-2.97)	0.43
Fast food intake: ≥ 1 time/week	1.46 (0.66-3.23)	0.35
Cat at home in child's 1st year	1.42 (0.58-3.50)	0.45
Cat at home in previous year	1.38 (0.65-2.94)	0.40
Dog at home in child's 1st year	1.61 (0.75-3.43)	0.22
Dog at home in previous year	0.91 (0.43-1.91)	0.80
Contact with farm animals in child's 1st year	0.53 (0.17-1.62)	0.26
Contact with farm animals during pregnancy	1.17 (0.38-3.58)	0.79
Breastfeeding time: < 4 months vs. > 4 months	0.89 (0.44-1.79)	0.74
Breastfeeding time: No vs. > 4 months	1.71 (0.79-3.71)	0.17
Daily time watching TV: 1-3h vs. < 1h	0.61 (0.32-1.14)	0.12
Daily time watching TV: > 3h vs. < 1h	0.37 (0.12-1.13)	0.08

aOR – adjusted odds ratio; CI – confidence interval; NA – not applicable; BMI – Body Mass Index; SES – Socioeconomic status; * statistically significant ($p < 0.05$)



SES – Socioeconomic Status

Figure 9.2 – Forest plot of the final ("best") multivariate logistic regression model selected after multiple imputation approach based on Akaike's Information Criterion (AIC) and based on Rubin's rules: adjusted odds ratio and their 95% confidence.

It was possible to highlight four factors having both individual and combined statistically significant risk effects on asthma, namely two host risk factors (being male and child's mother and/or father asthmatic), and two environmental (child's paracetamol administration in the previous year and antibiotics administration in child's first year of life). Although not statistically significant individually (bivariate analysis), primary school age, when compared to pre-school age, was also found to be a relevant risk factor for asthma, as it was statistically significant combined with the other factors (multivariate analysis), and selected to be included in the final model. Although statistically significant in the bivariate analysis, some factors were not significant in multivariate analysis, namely paracetamol administration in child's first year of life, cat or dog at child's household in the 1st year of life and cat in the previous year. Other factors were selected for the best model although not statistically significant in the multivariate model, namely: SES classification, the number of older and younger brothers, having cat or dog at child's household in the 1st year of life and cat in the previous year, child's mother in regular contact with farm animals during pregnancy, and weekly frequency of intake of some food (fruits, vegetables, legumes, butter, nuts and potatoes). The other factors studied were not statistically significant in bivariate, in multivariate analysis and not selected for the final model. It is important to highlight that living with a smoker, frequency fast food intake and having cat at child's household in previous year indicated a positive (although not statistically significant) association with the studied outcomes, while carpet in child's bedroom seemed to be an important protective factor.

9.3 Discussion

Despite the scientific relevance, comparing results for asthma prevalence between different studies is usually complex due to the different asthma definitions or different methodologies used for asthma diagnosis. Although less expensive, thus more suitable to large epidemiological studies, asthma diagnosed merely based on reported information can introduce important biases and may lead to inadequate conclusions. Considering that objective asthma diagnosis following the latest clinical guidelines and recommendations from GINA and ERS/ATS (GINA, 2018) is the most accurate method to diagnose asthma, its use should be favoured. Thus, this study considered asthma diagnosed following the latest clinical guidelines and recommendations.

This is a study in a sample of the general population of pre- and primary school children, which is a major strength of this study as no selection criteria for respiratory disease was considered for subjects' recruitment. In fact, as suggested by Oluwole et al. (2018), this study population included children from both urban and rural sites, and results showed higher prevalence of reported asthmatic symptoms and asthma in urban sites as expected, as well as higher reported parental history of asthma. This study population also included children from different age groups, which allowed understanding differences of asthma prevalence at different childhood stages. Asthma is usually easily and more frequently diagnosed in older children, which explains why reported asthma increased with age, although it can also be explained by the asthma prevalence continuous increase during primary school ages (Bjerg-Backlund et al., 2006). On the other hand, wheezing is usually more common in younger children, confirming the results achieved of active wheezing decrease with age. Furthermore, many children may wheeze once in their lifetime and not wheeze again, which might explain the difference found between ever and active wheezing. The non-significant difference between asthma diagnosed in pre- and primary schoolchildren confirmed that asthma develops at early ages, thus it should be correctly diagnosed as earlier as possible. In fact, this study provided evidence of under-diagnosed asthma in both pre- and primary school children, which were in accordance to what Aaron et al. (2018) reviewed for schoolchildren worldwide. Also, the present study provided evidence of under-diagnosed asthma in both settings (urban and rural), confirming that asthma diagnosis merely based on reported symptoms may be underestimating the real prevalence of this disease, as previously reported in the literature (Oluwole et al., 2018). Children with undiagnosed asthma may suffer poorer health-related quality of life and more school absenteeism. This led also to conclude that future studies should have a special focus on the urban environment when studying asthma development.

There were both host and environmental factors that had a risk effect on asthma. Results from bivariate analysis were also different from multivariate analysis, thus enhancing the importance of studying combined risk factors instead of studying them individually. Besides, results for campaign factor confirmed that differences in time (between the two recruitment campaigns) were not relevant. Host factors that mainly predispose a child to develop asthma included being male, older age and having at least one asthmatic parent; environmental factors included paracetamol administration in the previous year (currently), and antibiotics administration in child's first year of life. On the other hand, carpet in child's bedroom seemed to have a protective effect. These results were consistent with recently published findings. Bjerg et al. (2015) also reported that non-environmental risk factors parental asthma and male sex had an increasing or constant importance for current asthma in 7-8 years old children in Sweden. In fact, parental history of asthma and being male have been commonly reported as risk factors for asthma on childhood (Caminati et al., 2015; Milligan et al., 2016; Strina et al., 2014). Children being administered antibiotics and paracetamol in the first year of life and on late childhood were also reported to increase the risk of developing asthma and asthmatic symptoms in children (Beasley et al., 2008; Marra et al., 2009). Other factors here studied, yet not significant for asthma diagnosed outcome, pointed in the same direction as other recently published findings, including the positive association of obesity (Forno et al., 2015; Papoutsakis et al., 2013) and exposure to ETS (Anto, 2012) on childhood asthma.

9.4 Conclusions

In summary, when studying asthma prevalence on childhood it is crucial to clearly define asthma outcome by favouring the latest clinical guidelines and recommendations, as well as to include younger children (pre-school aged), and from both urban and rural sites. Information from the most relevant reported host and environmental risk factors should also be taken into account, especially sex, parental history of asthma, and early-life and current (previous year) paracetamol and antibiotics administration.

Chapter 10

Impact of indoor air pollution in nursery and primary schools on childhood asthma[*]

This chapter mainly aimed to evaluate the associations between children's exposure/inhaled dose to indoor air pollutants and childhood asthma in nursery and primary schools, by: i) considering both urban and rural sites, and including children from two different age groups (pre- and primary school children); ii) using a microenvironmental modelling approach to estimate indoor air pollutants' exposures and inhaled doses, considering classrooms, but also other different indoor scholar environments; iii) analysing several major indoor air pollutants, individually and combined; and iv) diagnosing asthma based on medical doctors' physical examinations according to the most recent guidelines. Two complementary hypothesis were tested: i) if exposures/inhaled doses of indoor air pollutants in nursery and primary schools are associated with childhood asthma prevalence, reported respiratory symptoms and/or changes in lung function; and ii) if children's sensitisation (to the most common aeroallergens) influence on that association, i.e., associations between indoor air pollutants exposures/inhaled doses and childhood asthma differences among sensitised and non-sensitised children.

10.1 Materials and methods

10.1.1 Study population and health assessment

This cross-sectional study involved children recruited from the nursery and primary schools (urban and rural) participating in the INAIRCHILD project in the academic year of 2013/2014 (campaign 1) and 2015/2016 (campaign 2, to increase sample size), except infants (children under 3 years old). The governance bodies from all the nursery and primary schools involved in

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[*] adapted from: Branco PTBS, Alvim-Ferraz MCM, Martins FG, Ferraz C, Vaz LG, Sousa SIVS. Impact of indoor air pollution in nursery and primary schools on childhood asthma. *Submitted.*

this study consent to perform this study. Parents or guardians signed an informed consent (Appendix C) according to the Helsinki Declaration developed by the World Medical Association and completed the same ISAAC-derived questionnaire described in the two previous chapters to obtain information about child's personal, family socio-economic status and lifestyle characteristics, including respiratory health information, exposure to tobacco smoke at home and parental history of asthma. Medical doctors validated all questionnaires. At any stage of the study, the potential children's dissent was always respected.

According to GINA (GINA, 2018), asthma diagnosis should be based on the history of characteristic respiratory symptoms and the demonstration of variable expiratory airflow limitation. Thus, children who were reported being asthmatic on the questionnaire and those who reported at least one asthmatic symptom (wheezing, dyspnoea, or nocturnal cough in the absence of upper respiratory infection) were selected for PFT.

Spirometry pre and post bronchodilator administration (200 µg of salbutamol) was used to perform the PFT according to the latest guidelines from ERS/ATS and GINA (GINA, 2018; Thurston et al., 2017); a Vitalograph ALPHA Track (Vitalograph, UK) was used at one specific room of each school to where medical doctors brought the necessary equipment. Spirometry procedures and pulmonary function indexes obtained were described in detail in the previous section 9.1.2. FEV_1/FVC ratio was calculated.

Asthma was diagnosed based on GINA guidelines (GINA, 2018), if at least one asthmatic symptom (wheezing, dyspnea or nocturnal cough in the absence of upper respiratory infection) was reported simultaneously with spirometry results revealing both airflow limitation (obstruction) and excessive variability in lung function (positive bronchodilator reversibility test with an increase in FEV_1 higher than 12% predicted), with or without reporting a previous diagnosis.

Those who completed PFT were also selected to perform medical skin prick tests (SPT) for evaluating allergen sensitisation to common aeroallergens (Migueres et al., 2014; Viegi et al., 2004), namely: i) house dust mites (*Dermatophagoides pteronyssinus* (Dp), *Dermatophagoides farinae* (Df) and *Lepidoglyphus destructor* (Ld)); ii) pollens (wild grasses composed by a mixture of *Agrostis*, *Anthoxanthum odoratum*, *Dactylis glomerata*, *Festuca pratensis*, *Holcus lanatus*, *Lolium perenne, Phleum pratense* and *Poa pratensis*, sown grasses composed by a mixture of *Secale cereale*, *Hordeum vulgare* and *Triticum*, and tree pollen composed by a mixture of *Fraxinus excelsior, Populus* and *Salix*); and iii) animal dander – dog (Canis familiaris) and cat (*Felis domesticus*). The allergens used were obtained from Bial (Aristegui, Produtos Farmacêuticos S.A., Portugal). The SPT were performed on the anterior face of the child's forearm, using the tip of a metallic lancet. Skin reaction confirmed allergen sensitisation depending on the skin wheal size and flare reaction in comparison with positive control (histamine solution) and negative control (saline control). Children were considered sensitised, if revealed positive to at least one of the studied aeroallergens.

Figure 10.1 shows the flowchart with the study population for each step of the methodology. For the association with IAQ, this study considered five health outcomes: i) reported active wheezing – if reported wheezing in the last 12 months; ii) reported asthma, if answered "Yes" to the question "Does the child have or ever had asthma?"; iii) diagnosed asthma, when asthma was diagnosed based on GINA guidelines above referred; iv) obstructive disorder, which is an airflow limitation (obstruction) associated with reduced FEV_1/FVC (< 0.90); and v) dysfunction, which is a reduced FEV_1 (< 80% predicted). Moreover, this study also classified children as having asthma with AS (if diagnosed both asthma and sensitization), asthma without AS (if diagnosed asthma, but not sensitization), or no asthma (if not asthmatic).

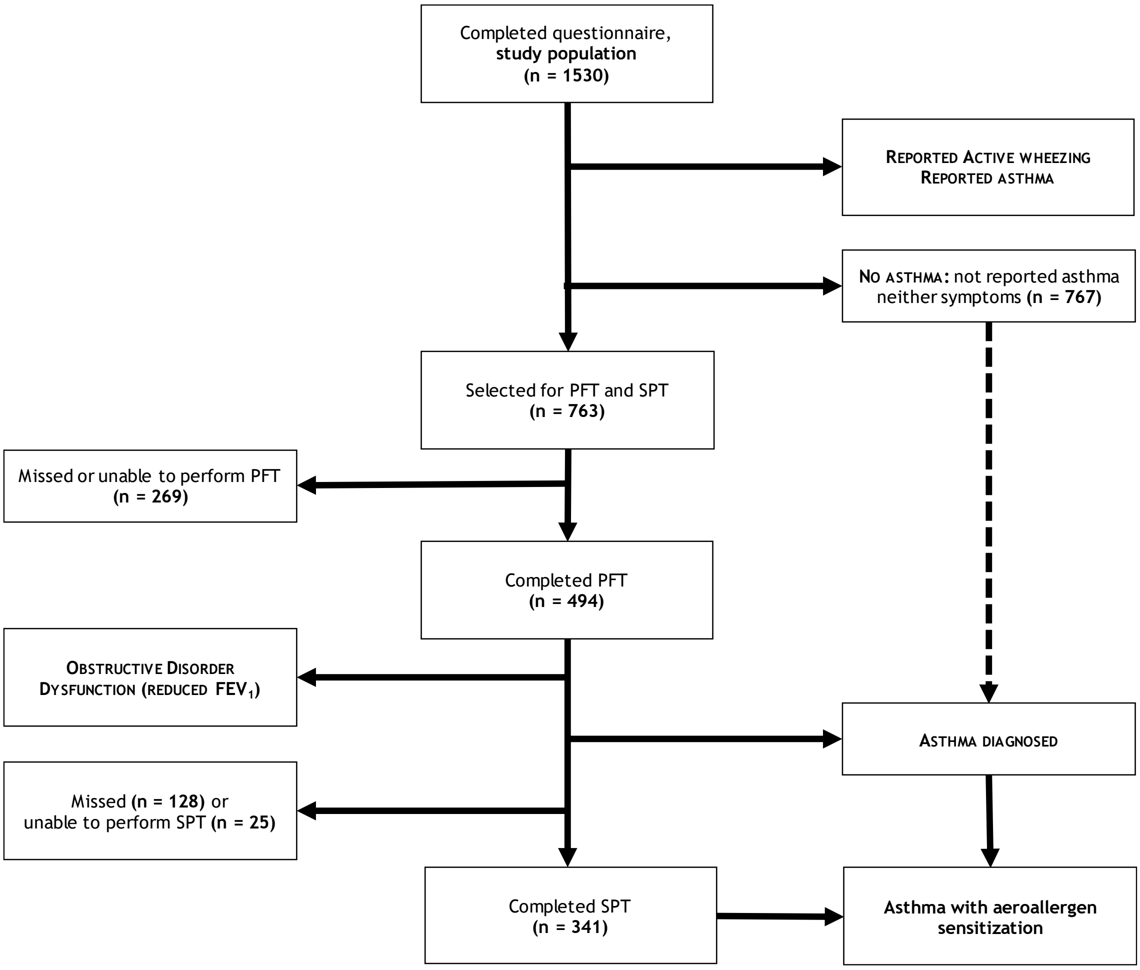


Figure 10.1 - Flowchart including the study population in the different steps of the methodology

10.1.2 Exposure and inhaled dose assessment

Children's daily exposure to indoor air pollutants in nursery and primary school was estimated based on a microenvironmental modelling approach, according to equation 2.1 (in section 2.2.2). From all the nursery and primary schools involved in INAIRCHILD project (Chapter 6), nursery schools for infants (children aged under 3) were excluded. Thus, this study considered the main indoor microenvironments (classrooms, canteens and bedrooms used for naps after lunch when applicable) from 17 nursery schools for pre-schoolers (children usually aged 3-6) and 8 primary schools (children usually aged 6-10). The governance bodies from all the schools involved in this study consent to perform this study.

Indoor concentrations of CO_2, CO, formaldehyde, NO_2, O_3, TVOC, $PM_{2.5}$ and PM_{10} were continuously monitored from at least 24 hours to 9 consecutive days (not simultaneously) in each studied room. Sampling methods and main characteristics of each sensor were previously described in detail in previous sections 3.1.2, 4.1.1, 5.1, and 6.1.2. indoor air pollutants samplings occurred in 69 classrooms and 15 canteens, having been selected one or more representative classrooms and canteens in each nursery and primary school building. Although samplings occurred twice in some rooms, namely during cold season (October to March) and warm season (April to September), they cannot be considered repeated measurements as they occurred in distinct academic years (from 2013 to 2016), corresponding to the two recruitment campaigns, thus with distinct occupants, occupancy and activities' conditions. This study assumed that each participant had lunch at the school canteen. For exposure estimates, when the indoor ME of the participating child were not sampled, indoor air pollutants concentrations were obtained from the most similar room (similar room characteristics, occupancy and activity patterns patterns).

Time spent by each child in different indoor school ME and the correspondent activity were initially obtained from a parent-reported daily diary (a typical 24-hour weekday divided into log periods of 30-min), then confirmed by information from the school timetable, and after validated by the educator/teacher of the class. A total of 507 complete daily diaries were considered (174 from pre-schoolers and 333 from primary school children).

Exposure does not strictly take into account the inhaled dose of indoor air pollutants, but only the presence of them near the breathing zone of a person. Thus, for each child i, daily inhaled dose (D_i) in school indoor ME was estimated based on the time-averaged exposure (E_i), inhalation rate (IR_k) adopted for each activity k from the US EPA approach (U.S. Environmental Protection Agency (EPA), 2011), and child's body weight (BW_i) obtained from the questionnaire, by using the Equation 10.1.

$$D_i = \sum_{k=1}^{K} (E_{ik} \,.\, IR_k)/BW_i \qquad (10.1)$$

10.1.3 Data analysis

Continuous measurements (logged each minute) allowed calculating hourly means for each indoor air pollutant. For each participating child, daily exposures to indoor air pollutants in school, and correspondent inhaled doses were calculated. Prevalence rates were calculated as the ratio between the number of cases and the total number of individuals considered. Descriptive statistics were used to express the characteristics of both health outcomes, exposures and inhaled doses. Phi coefficient (mean square contingency coefficient) was used as a measure of association between the studied binary outcomes.

As all the respiratory health outcomes considered were binary variables, multivariate logistic regression models were used to assess the association between exposure/inhaled dose and each outcome considered.

Firstly, independent models were built for each indoor air pollutant (unipollutant models) to understand the individual influence of each, by considering continuous exposure/inhaled dose scaled by IQR – scaled OR were obtained representing outcome change relative to an interquartile change in each exposure/inhaled dose metric. The same models were also applied to different types of transformation in the exposure variables, namely: i) dichotomized into ‘high’ and ‘low’ by using median as cutoff; ii) dichotomized into ‘high’ and ‘low’ by using Portuguese legislation (Portaria nº 353-A/2013) or World Health Organization (WHO, 2010) limit values as cutoff; and iii) dichotomized into ‘at risk’ and ‘not at risk’ by considering ‘at risk’ children attending rooms where concentrations exceeded the limit values. As there were no reference values for inhaled doses, these variables were only factorized into ‘high’ and ‘low’ by using median as cutoff.

Secondly, in order to understand the combined influence exposure/inhaled dose of all the studied gaseous indoor air pollutants and $PM_{2.5}$, multipollutant logistic regression models were built, also by considering continuous exposure/inhaled dose to all the studied indoor air pollutants scaled by IQR. The same models were also applied to the different types of transformations in the exposure variables considered in unipollutant models.

Finally, multinomial logistic regression models were used to estimate the effect of indoor air pollutants exposure/inhaled dose on the probability that the outcome (asthma diagnosed) is: no asthma, asthma with AS or asthma without AS. No asthma was chosen as the comparison level, and 2 regression coefficients, corresponding to each other outcome levels, were estimated for each exposure variable in these regression models. These models were built by considering the same exposure/inhaled dose transformations as in the previous analyses.

Previous knowledge was considered to define potential adjustment for confounders. Thus, all models were adjusted for site location (if urban or rural), recruitment campaign (1 or 2), mother education as a measure of the family SES, exposure to tobacco smoke at home (living with a smoker), sex, age group (pre- or primary school children), BMI and parental history of asthma. Multinomial logistic regression models were also adjusted for child's contact with farm animals in the first year of life, and with pets (cat or dog) at home in the previous year and/or in the first year of life.

Statistical computations were performed with R software version 3.4.3. The level of statistical significance was set at 0.05, except when stated otherwise.

10.2 Results

10.2.1 Characterization of the study population and health outcomes' prevalence

This study involved 1530 children attending nursery (648 pre-schoolers) and primary schools (882 primary school children), both from urban (59.8%) and rural areas (40.2%). Mean age (SD) of this study population was 6.0 (2.1) years old, and 51.0% were females. More than 95% of this population were born and always lived in Portugal, 41.1% lived with a smoker, and 15.1% of children had an asthmatic parent - in urban sites (19.5%) more than the double of rural ones (8.7%). Study population had a mean (SD) BMI of 17.0 (3.0), being the majority (59.5%) of them classified with normal BMI, although 33.2% were overweight or obese. Main personal characteristics and prevalence of respiratory health outcomes considered are detailed in Tables 10.1 and 10.2.

Table 10.1 - Characterization of the study population (with 95% confidence intervals), in the whole population and divided by age and by location

Characteristics	Population (n=1530)		by children's age				by location			
			Pre-schoolers (n = 648)		Primary school children (n=882)		Urban (n=915)		Rural (n=615)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Sex										
Female	51.0	(48.5-53.5)	49.7	(45.8-52.2)	51.9	(48.6-55.2)	50.1	(46.8-52.6)	52.4	(48.4-56.3)
Male	49.0	(46.5-51.5)	50.3	(46.5-52.8)	48.1	(44.8-51.4)	49.9	(46.7-52.5)	47.6	(43.7-51.6)
Age group										
Pre-schooler	42.4	(39.9-44.8)	-	-	-	-	42.4	(39.2-44.9)	42.3	(38.4-46.2)
Primary school children	57.6	(55.2-60.1)	-	-	-	-	57.6	(54.4-60.1)	57.7	(53.8-61.6)
Location										
Rural	40.2	(37.7-42.7)	40.1	(36.3-42.6)	40.2	(37.0-43.5)	-	-	-	-
Urban	59.8	(57.3-62.3)	59.9	(56.1-62.3)	59.8	(56.5-63.0)	-	-	-	-
BMI classification										
Normal	59.5	(56.7-62.4)	56.9	(52.4-59.8)	61.5	(57.7-65.3)	59.6	(56.0-62.5)	59.5	(54.7-64.3)
Underweight	7.2	(5.7-8.8)	10.0	(7.3-11.8)	5.2	(3.5-6.9)	5.5	(3.9-6.9)	10.2	(7.2-13.2)
Overweight	15.8	(13.7-18.0)	14.9	(11.7-17.0)	16.5	(13.6-19.4)	16.9	(14.2-19.1)	13.9	(10.5-17.3)
Obese	17.4	(15.1-19.6)	18.1	(14.6-20.4)	16.8	(13.9-19.7)	17.9	(15.1-20.2)	16.4	(12.8-20)
Mother education										
Medium	31.9	(29.5-34.3)	31.2	(27.6-33.5)	32.4	(29.3-35.6)	28.2	(25.3-30.5)	37.6	(33.7-41.5)
Low	28.5	(26.2-30.8)	24.3	(21.0-26.5)	31.6	(28.5-34.7)	22.7	(20.0-24.8)	37.5	(33.6-41.4)
High	39.6	(37.1-42.1)	44.5	(40.7-47.0)	35.9	(32.7-39.1)	49.1	(45.9-51.7)	24.9	(21.4-28.4)
Born in Portugal, no	4.5	(3.5-5.6)	3.9	(2.4-4.8)	5.0	(3.6-6.5)	2.1	(1.2-2.8)	8.2	(6.0-10.4)
Living with a smoker, yes	41.1	(38.6-43.6)	41.0	(37.2-43.4)	41.2	(38-44.5)	39.2	(36.0-41.7)	43.9	(40.0-47.9)
Asthmatic parent, yes	15.1	(13.3-16.9)	14.4	(11.7-16.2)	15.7	(13.2-18.1)	19.5	(16.9-21.5)	8.7	(6.4-10.9)

CI – confidence interval; BMI – body mass index

Table 10.2 - Characterization and prevalence of respiratory health outcomes considered (with 95% confidence intervals), in the whole population and divided by age and by location

Health outcomes	Population (n=1530)		by children's age Pre-schoolers (n = 648)		Primary school children (n=882)		by location Urban (n=915)		Rural (n=615)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Reported asthma	5.9	(4.7-7.0)	4.0	(2.5-5.5)	7.2	(5.5-8.9)	6.9	(5.3-8.6)	4.3	(2.7-5.9)
Active wheezing	13.6	(11.9-15.3)	16.3	(13.4-19.1)	11.7	(9.5-13.8)	16.0	(13.6-18.4)	10.0	(7.6-12.4)
Selected for PFT and SPT	49.9	(47.4-52.4)	53.1	(49.2-55.6)	47.5	(44.2-50.8)	52.2	(49.0-54.7)	46.3	(42.4-50.3)
Obstructive disorder [a]	36.4	(32.2-40.7)	27.4	(21.4-33.4)	43.3	(37.5-49.0)	36.9	(31.3-42.6)	35.8	(29.4-42.2)
Dysfunction [a]	23.1	(19.4-26.8)	17.0	(11.9-22.0)	27.7	(22.4-32.9)	15.1	(10.9-19.2)	33.5	(27.2-39.8)
Dysfunction degree [a]										
Normal	76.9	(73.2-80.6)	83.0	(78.0-88.1)	72.3	(67.1-77.6)	84.9	(80.8-89.1)	66.5	(60.2-72.8)
Mild	18.0	(14.6-21.4)	16.0	(11.1-21.0)	19.5	(14.9-24.1)	14.7	(10.5-18.8)	22.3	(16.8-27.9)
Moderate	4.9	(3.0-6.8)	0.9	(0.0-2.2)	7.8	(4.7-10.9)	0.4	(-0.3-1.1)	10.7	(6.6-14.8)
Severe	0.2	(0.0-0.6)	0.0	(0.0-0.0)	0.4	(0.0-1.0)	0.0	(0-0)	0.5	(0.0-1.4)
Asthma diagnosed	5.5	(4.2-6.7)	4.5	(2.7-6.2)	6.2	(4.4-7.9)	6.0	(4.3-7.7)	4.8	(3.0-6.6)
Sensitised to aeroallergens [b]	35.2	(30.1-40.3)	25.6	(19.5-30.3)	40.2	(33.3-45.4)	40.3	(33.4-45.5)	28.3	(20.9-35.6)
Allergy and asthma										
Asthma with AS	2.5	(1.4-3.5)	0.7	(0.0-1.2)	3.5	(1.9-4.7)	3.0	(1.5-4.1)	1.7	(0.4-3.1)
Asthma without AS	2.9	(1.8-4.1)	2.3	(1.0-3.3)	3.3	(1.7-4.5)	3.2	(1.6-4.3)	2.6	(0.9-4.3)
No asthma	94.6	(93.1-96.1)	97.1	(95.6-98.2)	93.2	(91-94.9)	93.9	(91.8-95.5)	95.7	(93.5-97.8)

[a] these outcomes represent the prevalence in symptomatic children who completed spirometry for pulmonary function test; [b] these outcomes represent prevalence in children who completed spirometry and skin prick tests for aeroallergen sensitisation assessment; AS - aeroallergen sensitisation; CI - confidence interval; PFT - pulmonary function test; SPT - skin prick test

Wheezing on the previous 12 months (here considered as active wheezing) was reported by 13.6% of the children, higher in pre-school age and in urban sites, while 5.9% reported being previously diagnosed as asthmatic (reported asthma), also higher in urban sites but for older children (primary schoolers).

Based on respiratory symptoms and reported asthma, half of the population (49.9%) was selected for PFT and SPT to confirm asthma diagnosis and to obtain information on lung function, as well as to evaluate sensitisation to common aeroallergens. The number of symptomatic children was higher among the youngest (pre-schoolers) and among those from urban sites. From those who completed PFT, 36.4% were found to have an obstructive disorder, while 23.1% of them presented a reduced FEV_1 (dysfunction), with mild, moderate and severe dysfunction affecting, respectively, 18.0%, 4.9% and 0.2% of them. Asthma was diagnosed in 5.5% of the study population, being higher in primary school children (6.2%) than in pre-schoolers (4.5%), and higher in urban (6.0%) than in rural sites (4.8%). To understand if there was an association between the studied health outcomes, phi coefficients were used showing weak or negligible positive associations in most cases ($0.01 < \text{phi} < 0.38$), except between reported and diagnosed asthma ($\text{phi} = 0.87$). Still, all outcomes were considered independently for the following analyses.

From those who were selected for PFT and SPT, 67.0% completed SPT (of those, 57.1% were pre-schoolers and 73.7% primary school children, 57.6% were from urban sites and 85.8% from rural ones). From those, 35.2% were sensitised to at least one of the studied aeroallergens. Sensitisation to aeroallergens was higher in older children and in urban sites. From this study population, 2.5% had asthma with AS, while 2.9% had asthma without AS, meaning that about 46% of the asthmatics had AS. In primary school children, there were more asthmatics with AS than asthmatics without it, while with the youngest (pre-schoolers) occurred the opposite. Results from aeroallergen sensitisation are detailed in Appendix F (F1). Sensitisations to dust mites were the most commonly found (25%), followed by animal dander (15%) and pollens (11%). Sensitisations to dust mites were higher in primary school children than in younger ones, while sensitisations to pollens were the opposite. Sensitisations to dust mites and pollens were both higher in children from urban sites, while sensitisations to animal dander were higher in rural individuals.

10.2.2 Time-location-activity patterns, IAP exposure and inhaled dose estimation

Data collected from the parent-reported daily diaries allowed estimating daily patterns for locations in a typical weekday (24-hour) for both pre- and primary school children, from urban and rural sites, considering the major ME: home indoor, home outdoor, school indoor, school outdoor, in transport and others. Time spent in these MEs are summarized in Figure 10.2, and proportions of time in a typical weekday (24 hours) are detailed in Appendix F (F2). More than half of a weekday was usually spent inside home. Outdoors (home and school) represented less than 10% of the day, and less than 1 hour of the day was usually spent in transport (commuting). These data confirmed that children spent most of their time indoors being a significant portion inside school (more than 6 hours in average, representing 24-28% of the day). That portion was higher in rural than in urban sites, and higher for pre-schoolers than for primary school children in urban sites.

School timetable in each class allowed to obtain more detailed information on the time spent in each specific ME inside the schools. Although classroom was the major indoor school ME, children usually spent 1-2 hours in canteen; in some cases, the youngest also spent 1-3 hours in bedroom after lunch (nap). For exposure estimation in each child, the time spent in each of those specific indoor school ME was considered when there were indoor air pollutants samplings available.

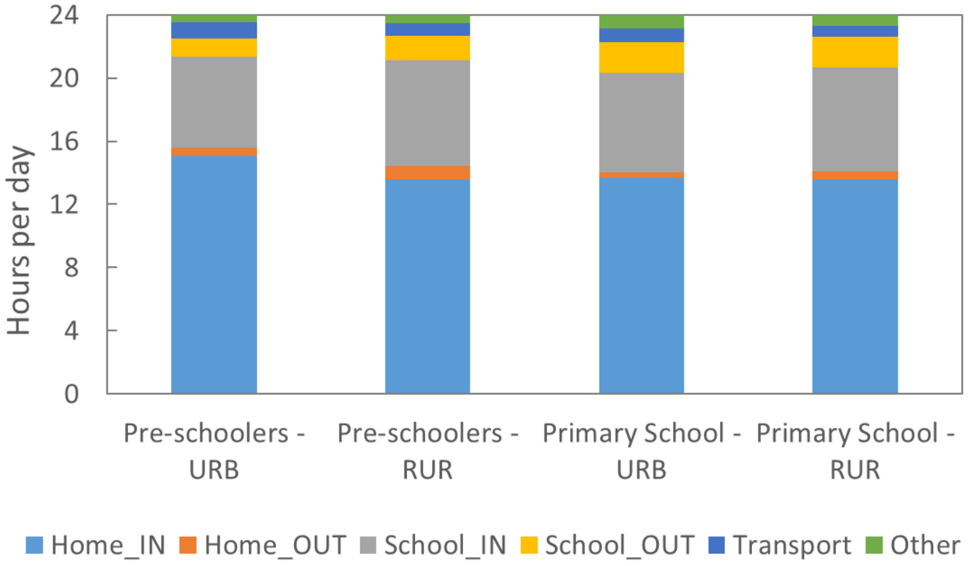


Figure 10.2 - Time spent in each major microenvironment, on a typical weekday, by pre-schoolers and primary school children, from both urban and rural sites

Parent-reported daily diaries also allowed obtaining information on the specific activities to build time-activity patterns for both pre- and primary school children, from both urban and rural sites. Indoor school activities reported by parents were then confirmed in the class timetables and validated by the educators/ teachers. Time-activity patterns are represented in Figure 10.3, and proportions are detailed in Appendix F (F3). Activities were classified into rest (sleep/ nap or sedentary/ passive), light intensity, moderate intensity and heavy (high intensity) according to the literature (U.S. Environmental Protection Agency (EPA), 2011). Rest activities occurred mainly during night at home (sleep), while light activities dominated the period of time indoor school. Although some moderate and heavy activities occurred during periods indoor schools, mainly associated with playing activities, they usually occurred associated with extracurricular activities. Those moderate and heavy activities were more common in children from urban sites. For each individual, short-term IR were obtained from the literature (U.S. Environmental Protection Agency (EPA), 2011), depending on the child's age and on the type of activity. Then a mean IR was calculated for each age group of children in each site (pre-schoolers at urban sites, pre-schoolers at rural sites, primary school children at urban sites, and primary school children at rural sites). Those IR were then used to estimate daily dose inhaled by each child, and they are represented in Appendix F (F4).

Children's exposure to indoor air pollutants and inhaled doses in the studied nursery and primary schools were estimated and summarized in Table 10.3, allowing to evidence important results. Usually, pre-schoolers were exposed to higher CO_2 levels and with higher variability, and inhaled higher doses of this gas, when compared to children from primary schools. Results from both formaldehyde and TVOC also revealed a higher variability of these pollutants' exposures and inhaled doses among the studied pre-schoolers. Regarding indoor air pollutants predominantly from outdoor sources (CO and O_3), both exposures and inhaled doses were higher at urban sites. Moreover, for NO_2 the age group seemed to have a greater influence than the location in both exposures and inhaled doses, being usually higher in pre-schoolers. Regarding particulate matter ($PM_{2.5}$ and PM_{10}), at urban sites daily exposures were usually higher at nursery schools (pre-schoolers), while at rural sites daily exposures were usually higher at primary school. However, at both site locations, pre-schoolers inhaled higher $PM_{2.5}$ and PM_{10} doses when compared to the studied primary school children.

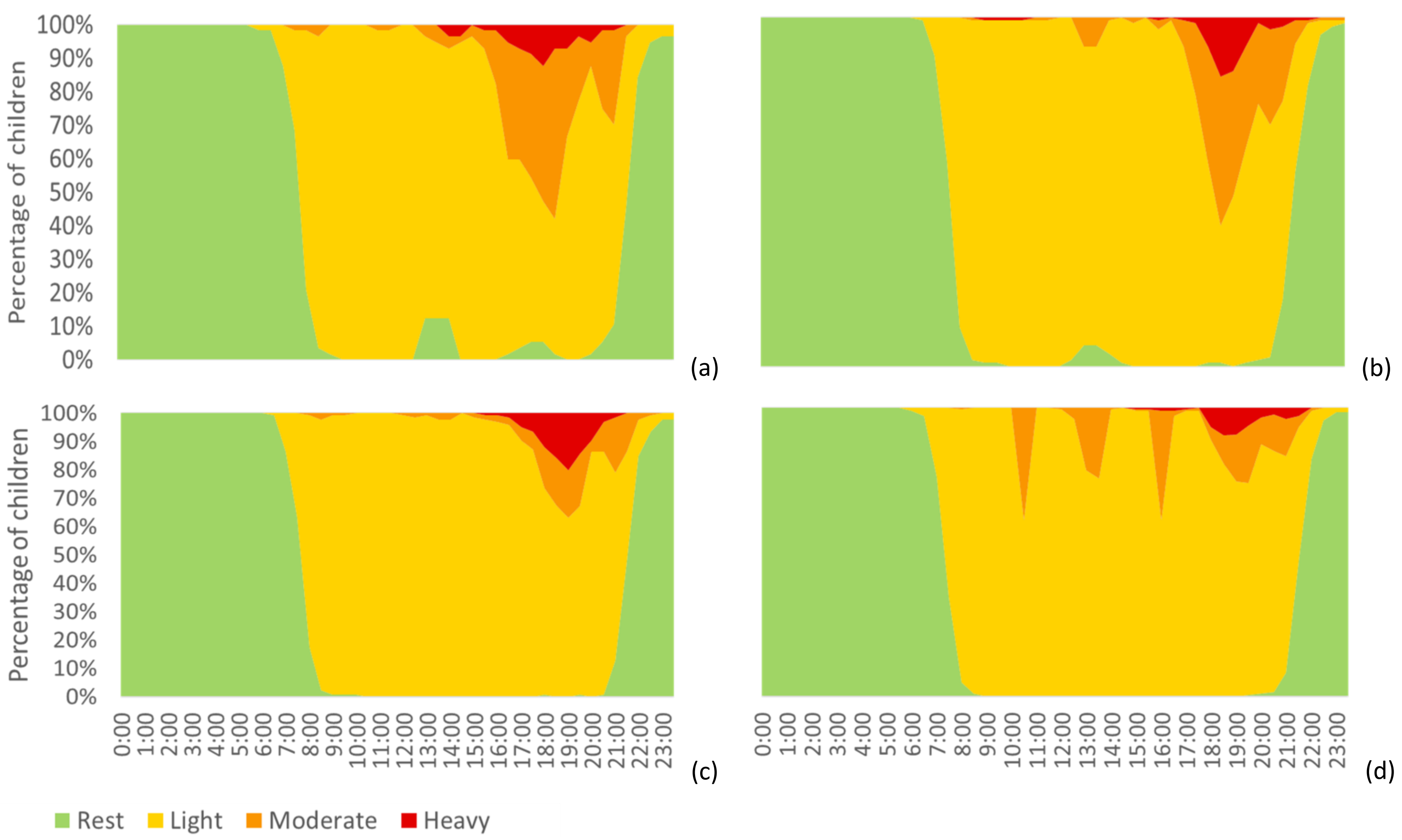


Figure 10.3 – Daily time-activity patterns of a typical weekday (24-hour) of: (a) Pre-schoolers from urban sites; (b) Pre-schoolers from rural sites; (c) Primary school children from urban sites; and (d) Primary school children from rural sites.

Table 10.3 – Descriptive statistics of daily children's exposure to indoor air pollutants' and inhaled dose in the studied nursery and primary schools, from both urban and rural sites

Exposure	**CO_2 (mg m^{-3})**	**CO (μg m^{-3})**	**CH_2O (μg m^{-3})**	**NO_2 (μg m^{-3})**	**O_3 (μg m^{-3})**	**TVOC (μg m^{-3})**	**$PM_{2.5}$ (μg m^{-3})**	**PM_{10} (μg m^{-3})**
Population								
Median	2211.8	2245.5	22.5	4.6	10.1	34.2	44.1	70.0
IQR	1025.1	2857.5	62.9	44.2	10.7	169.9	27.4	52.3
Pre-schoolers from urban sites								
Median	1915.2	2536.0	27.4	26.9	12.2	10.7	52.2	70.3
IQR	1313.6	1880.6	40.0	115.3	17.2	137.2	23.8	60.9
Pre-schoolers from rural sites								
Median	2242.0	1900.6	17.6	47.7	7.4	29.6	34.5	49.7
IQR	1619.8	3024.0	52.0	45.0	6.9	242.0	52.5	72.8
Primary school children from urban sites								
Median	2658.0	2874.0	2.4	0.0	11.3	76.7	42.9	67.0
IQR	915.8	2814.1	77.2	20.3	12.9	118.3	25.5	27.1
Primary school children from rural sites								
Median	2204.0	1439.7	51.7	3.0	2.0	34.2	45.6	79.8
IQR	453.5	4493.8	71.2	41.6	8.5	23.6	57.6	72.6
Inhaled dose	**CO_2 (mg kg^{-1} d^{-1})**	**CO (μg kg^{-1} d^{-1})**	**CH_2O (μg kg^{-1} d^{-1})**	**NO_2 (μg m^{-3} d^{-1})**	**O_3 (μg m^{-3} d^{-1})**	**TVOC (μg kg^{-1} d^{-1})**	**$PM_{2.5}$ (μg kg^{-1} d^{-1})**	**PM_{10} (μg kg^{-1} d^{-1})**
Population								
Median	63.1	67.4	0.7	0.1	0.3	0.9	1.3	2.1
IQR	39.9	94.7	1.5	1.3	0.3	3.9	1.2	1.8
Pre-schoolers from urban sites								
Median	71.5	96.8	0.9	1.1	0.4	0.4	2.0	3.0
IQR	47.8	84.6	1.7	4.0	0.7	5.0	1.2	2.4
Pre-schoolers from rural sites								
Median	85.1	81.3	0.6	1.8	0.3	1.1	1.4	2.2
IQR	79.2	101.5	2.0	1.9	0.3	8.6	2.0	2.6
Primary school children from urban sites								
Median	64.0	65.2	0.1	0.0	0.3	2.1	1.0	1.6
IQR	35.7	69.8	1.1	0.4	0.3	3.3	0.5	0.7
Primary school children from rural sites								
Median	54.1	25.7	1.1	0.1	0.0	0.9	1.2	2.1
IQR	23.0	66.6	1.6	0.8	0.2	0.9	1.3	1.6

IQR – interquartile range; CH_2O – formaldehyde; TVOC – total volatile organic compounds

10.2.3 Associations between IAP and childhood asthma

To assess associations between exposures/ inhaled doses and children's respiratory health, multivariate logistic regression models were built. Initially, an independent model for each indoor air pollutant (unipollutant) was built, by considering continuous exposure/inhaled dose scaled by IQR. Summary of the OR and respective 95% CI for each indoor air pollutant exposure and inhaled dose for each model were summarized in Tables 10.4 and 10.5, respectively. The same models were applied to other different types of transformation in the exposure variables (dichotomized by median, dichotomized by threshold, dichotomized by risk), being summarized in Appendix F (F5 to F8).

Results did not show statistically significant association between exposure or inhaled dose to any of the specific indoor air pollutants and diagnosed asthma. However, results showed that each IQR increase in the NO_2 and O_3 exposure were associated with an odds increase of obstructive disorder in studied pre- and primary school children (OR = 1.33, $p = 0.047$, and OR = 1.46, $p = 0.060$, respectively), although those indoor air pollutants never exceeded the reference thresholds (from the Portuguese legislation (Portaria nº 353-A/2013) and the World Health Organization (WHO, 2010) limit values) in the studied sites. Each IQR increase in O_3 inhaled dose was also associated with an odds increase of obstructive disorder (OR = 1.38, $p = 0.080$). Results also showed that each IQR increase in both O_3 and particulate matter ($PM_{2.5}$ and PM_{10}) children's exposure and inhaled dose were significantly associated with an odds increase of a reduced FEV_1 (dysfunction). Children exposed to high NO_2 concentrations (higher than the median, 4.6 µg m^{-3}), had significantly increased odds of an active wheezing (OR = 1.62, $p = 0.017$). The same, although not statistically significant, happened for each IQR increase (OR = 1.17, $p = 0.120$). Children exposed to high formaldehyde concentrations (higher than the median, 22.5 µg m^{-3}) had also significantly increased odds of an obstructive disorder (OR = 1.87, $p = 0.028$), although that was not found when children were exposed to formaldehyde levels higher than the threshold, or when they were exposed at risk (in this study defined as occupying rooms where that threshold was exceeded). On the other hand, occupying rooms exceeding both $PM_{2.5}$ and PM_{10} thresholds significantly increased the odds of having dysfunction (respectively OR = 2.08, $p = 0.034$, and OR = 3.19, $p < 0.001$). Individually, CO_2 exposure and inhaled dose did not present statistically significant associations with any of the studied health outcomes. CO and TVOC exposures and inhaled doses did not show statistically significant association with increased odds of the studied health outcomes. Analysis for exposures and inhaled doses led to similar results.

Multipollutant multivariate logistic regression models were built to quantify the combined effects of exposure/ inhaled dose of all the studied gaseous indoor air pollutants and $PM_{2.5}$. OR and respective 95% CI are represented in Figures 10.4 and 10.5, by considering continuous exposure/inhaled dose to all the studied indoor air pollutants scaled by IQR. Results from the same models applied to the other transformations (dichotomized by median, dichotomized by threshold, dichotomized by risk) in the exposure variables were summarized (OR and 95% CI) in Appendix F (F9 and F10).

Table 10.4 - Summary results of each unipollutant multivariate exposure model: adjusted odds ratio (aOR) for pollutant exposure, its 95% confidence interval, and significance (*p*-value)

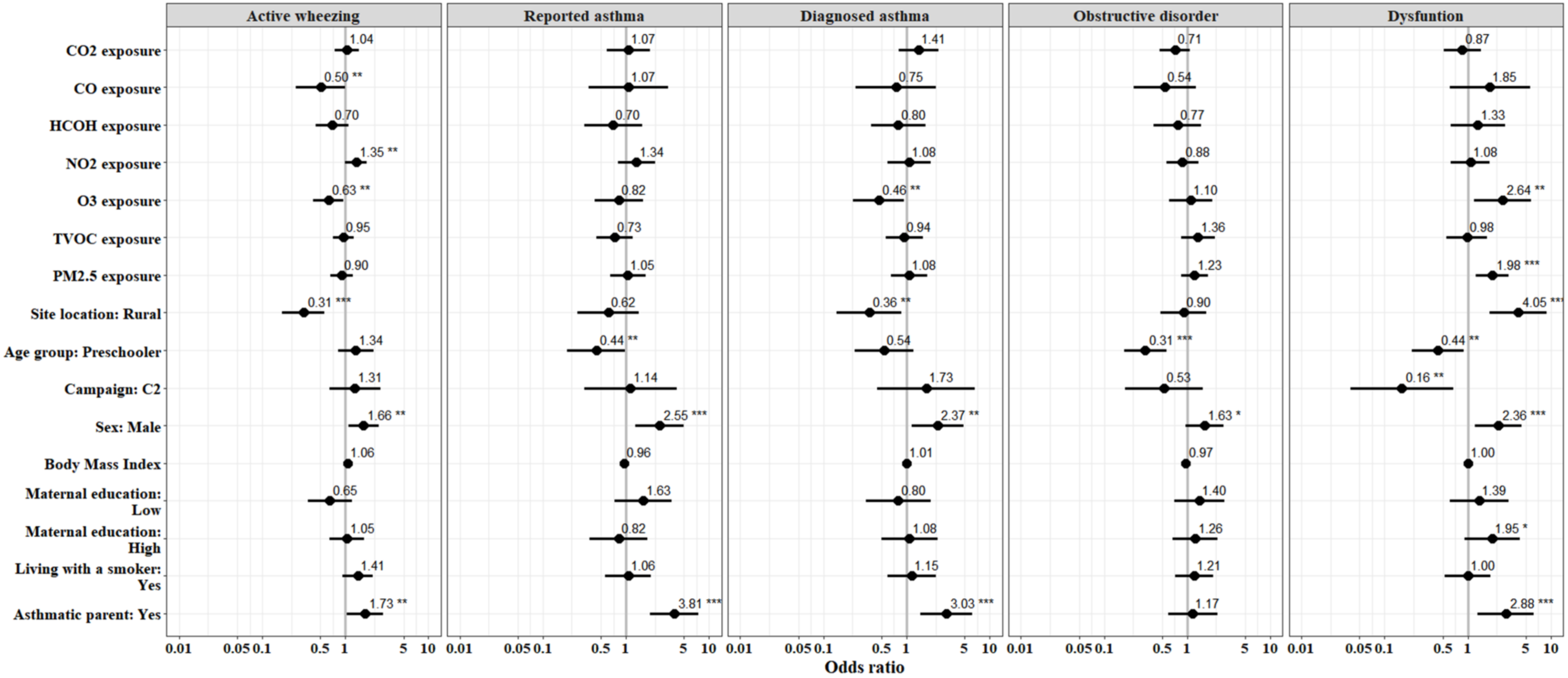
Exposure model	**Active wheezing**		**Reported asthma**		**Diagnosed asthma**		**Obstructive disorder**		**Dysfunction**	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
CO_2	0.90 (0.69,1.16)	0.406	0.69 (0.45,1.06)	0.082*	0.94 (0.61,1.46)	0.797	0.85 (0.63,1.15)	0.293	0.99 (0.69,1.41)	0.951
CO	0.69 (0.46,1.03)	0.069*	1.03 (0.57,1.85)	0.927	0.75 (0.40,1.39)	0.359	0.59 (0.38,0.91)	**0.015****	0.49 (0.30,0.81)	**0.005***
Formaldehyde	0.69 (0.50,0.96)	**0.019****	0.41 (0.20,0.82)	**0.003*****	0.66 (0.37,1.21)	0.148	0.82 (0.53,1.26)	0.351	1.05 (0.63,1.73)	0.863
NO_2	1.17 (0.96,1.42)	0.120	1.03 (0.70,1.52)	0.882	0.89 (0.58,1.34)	0.560	1.33 (1.01,1.75)	**0.047****	1.30 (0.89,1.91)	0.185
O_3	1.06 (0.80,1.41)	0.668	1.16 (0.73,1.83)	0.537	0.82 (0.51,1.33)	0.426	1.46 (0.98,2.19)	0.060*	2.71 (1.54,4.75)	**< 0.001*****
TVOC	1.12 (0.90,1.40)	0.330	0.69 (0.44,1.11)	0.098*	0.83 (0.53,1.28)	0.379	1.15 (0.84,1.58)	0.373	0.90 (0.59,1.37)	0.615
$PM_{2.5}$	0.92 (0.72,1.17)	0.486	0.93 (0.63,1.36)	0.702	1.04 (0.70,1.54)	0.850	1.21 (0.93,1.59)	0.162	1.82 (1.34,2.48)	**< 0.001*****
PM_{10}	0.87 (0.64,1.17)	0.339	0.94 (0.58,1.52)	0.800	1.08 (0.66,1.75)	0.768	1.11 (0.78,1.58)	0.566	2.13 (1.42,3.18)	**< 0.001*****

aOR – adjusted odds ratio; CI – confidence interval; * significant at *p*-value < 0.10; ** significant at *p*-value < 0.05; *** significant at *p*-value < 0.01

Table 10.5 - Summary results of each unipollutant multivariate inhaled dose model: adjusted odds ratio (aOR) for pollutant inhaled dose, its 95% confidence interval, and significance (*p*-value)

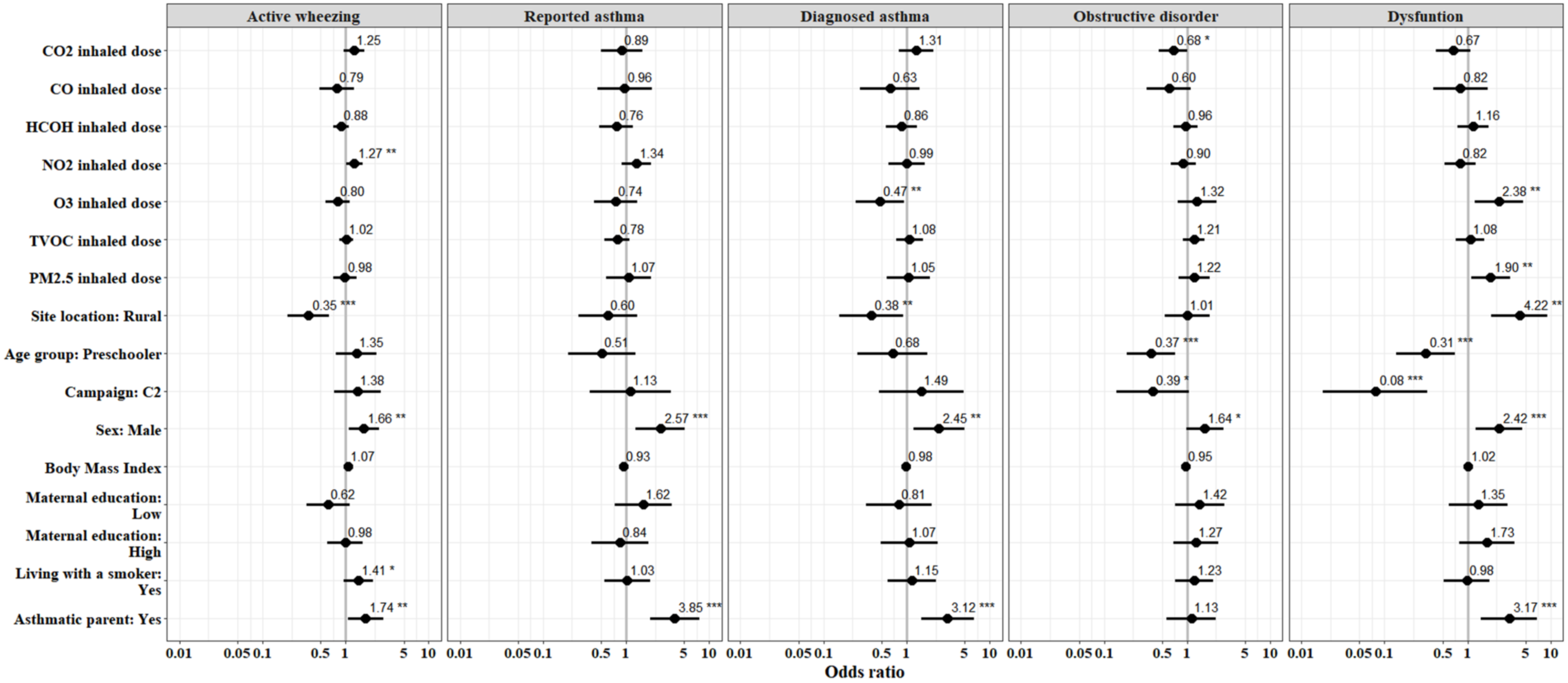
Inhaled dose model	**Active wheezing**		**Reported asthma**		**Diagnosed asthma**		**Obstructive disorder**		**Dysfunction**	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
CO_2	1.13 (0.90,1.43)	0.299	0.67 (0.43,1.06)	0.072*	1.02 (0.68,1.52)	0.936	0.88 (0.67,1.14)	0.326	1.07 (0.79,1.44)	0.663
CO	0.85 (0.59,1.23)	0.396	1.06 (0.61,1.86)	0.837	0.78 (0.42,1.44)	0.419	0.62 (0.40,0.94)	**0.023****	0.43 (0.25,0.73)	**0.001*****
Formaldehyde	0.88 (0.73,1.05)	0.133	0.54 (0.31,0.93)	**0.005*****	0.80 (0.54,1.18)	0.206	0.92 (0.72,1.17)	0.463	1.06 (0.79,1.42)	0.723
NO_2	1.15 (0.99,1.33)	0.071*	1.04 (0.78,1.39)	0.779	0.89 (0.64,1.24)	0.486	1.16 (0.94,1.43)	0.158	1.13 (0.84,1.52)	0.416
O_3	1.14 (0.90,1.45)	0.287	1.05 (0.69,1.60)	0.834	0.85 (0.54,1.33)	0.469	1.38 (0.96,1.99)	0.080*	2.85 (1.70,4.77)	**< 0.001*****
TVOC	1.10 (0.95,1.28)	0.192	0.80 (0.58,1.11)	0.156	0.95 (0.71,1.25)	0.698	1.08 (0.90,1.31)	0.411	0.93 (0.72,1.20)	0.547
$PM_{2.5}$	0.98 (0.75,1.29)	0.904	0.84 (0.53,1.34)	0.461	0.99 (0.61,1.60)	0.975	1.08 (0.79,1.48)	0.612	1.94 (1.36,2.76)	**< 0.001*****
PM_{10}	0.95 (0.74,1.22)	0.658	0.87 (0.56,1.34)	0.523	1.01 (0.65,1.57)	0.962	0.96 (0.70,1.33)	0.819	1.86 (1.31,2.65)	**< 0.001*****

aOR – adjusted odds ratio; CI – Confidence interval; * significant at *p*-value < 0.10; ** significant at *p*-value < 0.05; *** significant at *p*-value < 0.01



* *p*-value < 0.10; ** *p*-value < 0.05; *** *p*-value < 0.01

Figure 10.4 – Results from the multipollutant multivariate logistic regression models (adjusted odds ratio and 95% confidence intervals), when considering exposure to indoor air pollutants scaled by interquartile range and all the studied respiratory health outcomes (active wheezing, reported asthma, diagnosed asthma, obstructive disorder and dysfunction).



* *p*-value < 0.10; ** *p*-value < 0.05; *** *p*-value < 0.01

Figure 10.5 - Results from the multipollutant multivariate logistic regression models (adjusted odds ratio and 95% confidence intervals), when considering inhaled dose of indoor air pollutants scaled by interquartile range and all the studied respiratory health outcomes (active wheezing, reported asthma, diagnosed asthma, obstructive disorder and dysfunction).

In these models, each IQR increase of exposure or inhaled dose was not associated with the odds increase of either reported/diagnosed asthma, or obstructive disorder. Nevertheless, in these multipollutant models, each IQR increase of NO_2 exposure (OR = 1.35, $p = 0.05$) and inhaled dose (OR = 1.27, $p = 0.03$) were both significantly associated with increased odds of active wheezing, while each IQR increase of both O_3 and $PM_{2.5}$ exposures (OR = 2.64, $p = 0.01$, and OR = 1.98, $p < 0.01$, respectively) and inhaled doses (OR = 2.38, $p = 0.01$, and OR = 1.90, $p = 0.02$, respectively) were significantly associated with reduced FEV_1 (dysfunction). In the same multipollutant approach, and although not always statistically significant, high (above the median) indoor air pollutants exposures seemed to be associated with: i) active wheezing, namely due to NO_2 and TVOC; ii) diagnosed asthma, namely due to CO_2 and formaldehyde; iii) obstructive disorder, namely due to formaldehyde and O_3 exposures (and TVOC inhaled dose, although not exposure); and iv) dysfunction, namely due to CO_2, CO, formaldehyde, O_3 and $PM_{2.5}$ exposures (the same except CO_2 in the case of inhaled doses). Although not exactly the same, results from exposure and inhaled dose models of association were similar for active wheezing, obstructive disorder and dysfunction outcomes, while results were different for reported or diagnosed asthma outcomes. Regarding covariates in these multipollutant models, site location had a statistically significant contribution in most associations, with urban areas increasing the odds of all the studied health outcomes except for dysfunction. Being male and having at least one asthmatic parent also increased the odds of all outcomes. Age group was also relevant, especially in obstructive disorder and dysfunction in which primary school children had statistically significant increased odds of having those outcomes when compared with pre-schoolers.

Multinomial logistic regression models were used to estimate the effect of indoor air pollutants exposure/ inhaled dose on the probability that asthma diagnosed is in particular category: no asthma (as reference), asthma with aeroallergen sensitisation and asthma without aeroallergen sensitisation. These results are summarized in Table 10.6. Although not statistically significant, each IQR increase in particulate matter exposure was associated with a higher increase in the odds of having asthma diagnosed with AS (OR = 1.83 and $p = 0.097$ for $PM_{2.5}$; OR = 2.06 and $p = 0.118$ for PM_{10}) than of having asthma diagnosed without AS (OR = 1.08 and $p = 0.804$ for $PM_{2.5}$; OR = 1.18 and $p = 0.667$ for PM_{10}). There were some covariates that showed different influence in the two studied categories of the outcome (diagnosed asthma with AS, and diagnosed asthma without AS). In some cases, they had significantly higher influence on asthma without AS than in asthma with AS, namely: i) having at least one asthmatic parent (OR = 4.36, $p = 0.013$, and OR = 2.36, $p = 0.202$, respectively); and ii) having a dog at home in child’s first year of life (OR = 5.35, $p = 0.011$, and OR = 0.38, $p = 0.401$, respectively). In other cases, those covariates had significantly higher influence on asthma with AS than on asthma without AS, namely: i) being pre-schooler (OR = 0.05, $p = 0.040$, and OR = 1.50, $p = 0.483$, respectively); and ii) being male (OR = 3.99, $p = 0.040$, and OR = 1.50, $p = 0.483$, respectively). Identical results were obtained for inhaled dose models.

Table 10.6 - Results from the multinomial logistic regression models for $PM_{2.5}$ and PM_{10} exposure and inhaled dose: adjusted odds ratio (aOR) for pollutant exposure, 95% confidence interval, and significance (*p*-value)

Predictors	Exposure models				Inhaled dose models			
	Category 1 (asthma with aeroallergen sensitisation)		Category 2 (asthma without aeroallergen sensitisation)		Category 1 (asthma with aeroallergen sensitisation)		Category 2 (asthma without aeroallergen sensitisation)	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
$PM_{2.5}$ exposure / inhaled dose	1.83 (0.90-3.73)	0.097*	1.08 (0.58-2.00)	0.804	1.81 (0.73-4.51)	0.202	1.11 (0.52-2.36)	0.786
Site location: Rural	0.27 (0.06-1.24)	0.093*	0.85 (0.24-2.96)	0.799	0.33 (0.08-1.36)	0.125	0.86 (0.25-2.95)	0.805
Age group: Pre-schooler	0.05 (0.01-0.46)	**0.008*****	0.83 (0.26-2.68)	0.753	0.04 (0.00-0.43)	**0.008*****	0.78 (0.22-2.84)	0.711
Maternal education: Low	2.43 (0.55-10.79)	0.243	0.38 (0.09-1.55)	0.175	2.44 (0.55-10.79)	0.241	0.37 (0.09-1.55)	0.174
Maternal education: High	1.19 (0.27-5.30)	0.816	0.35 (0.10-1.30)	0.117	1.20 (0.27-5.35)	0.807	0.35 (0.10-1.29)	0.115
Living with a smoker: Yes	1.18 (0.36-3.87)	0.785	1.68 (0.55-5.12)	0.363	1.12 (0.35-3.62)	0.852	1.67 (0.55-5.11)	0.365
Sex: Male	3.99 (1.06-14.95)	**0.040****	1.50 (0.48-4.70)	0.483	4.09 (1.09-15.42)	**0.037****	1.51 (0.48-4.71)	0.482
Body Mass Index	0.92 (0.76-1.12)	0.424	1.07 (0.90-1.28)	0.414	0.94 (0.77-1.16)	0.590	1.08 (0.91-1.29)	0.389
Asthmatic parent: Yes	2.36 (0.63-8.83)	0.202	4.36 (1.36-14.0)	**0.013****	2.10 (0.58-7.61)	0.258	4.34 (1.35-13.95)	**0.014****
Cat at home in child's 1st year	1.23 (0.22-6.96)	0.814	0.55 (0.10-3.14)	0.499	1.14 (0.20-6.38)	0.882	0.55 (0.10-3.14)	0.500
Cat at home in previous year	1.54 (0.38-6.19)	0.546	2.51 (0.71-8.84)	0.152	1.62 (0.41-6.46)	0.494	2.51 (0.71-8.84)	0.153
Dog at home in child's 1st year	0.38 (0.04-3.64)	0.401	5.35 (1.46-19.52)	**0.011****	0.38 (0.04-3.63)	0.401	5.33 (1.46-19.44)	**0.011****
Dog at home in previous year	0.49 (0.09-2.69)	0.409	0.97 (0.27-3.46)	0.962	0.48 (0.09-2.62)	0.396	0.98 (0.27-3.53)	0.978
Contact with farm animals in child's 1st year	1.47 (0.34-6.39)	0.605	0.33 (0.06-1.75)	0.195	1.64 (0.38-7.05)	0.507	0.33 (0.06-1.75)	0.194
PM_{10} exposure / inhaled dose	2.06 (0.83-5.09)	0.118	1.18 (0.55-2.55)	0.667	1.59 (0.68-3.69)	0.281	1.15 (0.57-2.32)	0.688
Site location: Rural	0.30 (0.07-1.27)	0.103	0.84 (0.24-2.92)	0.783	0.36 (0.09-1.42)	0.145	0.85 (0.25-2.94)	0.802
Age group: Pre-schooler	0.05 (0.01-0.47)	**0.008*****	0.83 (0.26-2.68)	0.756	0.04 (0.00-0.47)	**0.009*****	0.77 (0.22-2.71)	0.685
Maternal education: Low	2.42 (0.55-10.74)	0.244	0.37 (0.09-1.52)	0.168	2.42 (0.55-10.7)	0.244	0.36 (0.09-1.53)	0.167
Maternal education: High	1.15 (0.26-5.13)	0.855	0.35 (0.10-1.30)	0.117	1.17 (0.26-5.22)	0.838	0.35 (0.10-1.28)	0.114
Living with a smoker: Yes	1.12 (0.34-3.64)	0.854	1.68 (0.55-5.13)	0.362	1.08 (0.34-3.50)	0.894	1.68 (0.55-5.11)	0.363
Sex: Male	3.91 (1.04-14.67)	**0.043****	1.50 (0.48-4.69)	0.487	4.03 (1.07-15.13)	**0.039****	1.50 (0.48-4.70)	0.485
Body Mass Index	0.92 (0.76-1.13)	0.433	1.08 (0.91-1.28)	0.399	0.94 (0.76-1.15)	0.543	1.09 (0.91-1.30)	0.368
Asthmatic parent: Yes	2.18 (0.59-8.01)	0.242	4.35 (1.35-14.0)	**0.014****	1.99 (0.55-7.14)	0.291	4.33 (1.35-13.93)	**0.014****
Cat at home in child's 1st year	1.26 (0.22-7.12)	0.794	0.55 (0.10-3.15)	0.500	1.16 (0.21-6.45)	0.869	0.55 (0.10-3.15)	0.502
Cat at home in previous year	1.61 (0.40-6.47)	0.500	2.54 (0.72-8.98)	0.148	1.66 (0.42-6.62)	0.470	2.53 (0.72-8.94)	0.150
Dog at home in child's 1st year	0.39 (0.04-3.71)	0.412	5.35 (1.47-19.53)	**0.011****	0.39 (0.04-3.69)	0.411	5.33 (1.46-19.40)	**0.011****
Dog at home in previous year	0.48 (0.09-2.62)	0.394	0.98 (0.27-3.49)	0.972	0.47 (0.09-2.58)	0.387	0.99 (0.28-3.57)	0.992
Contact with farm animals in child's 1st year	1.51 (0.35-6.55)	0.581	0.33 (0.06-1.73)	0.190	1.65 (0.38-7.13)	0.501	0.33 (0.06-1.74)	0.192

aOR - adjusted odds ratio; CI - Confidence interval; * significant at *p*-value < 0.10; ** significant at *p*-value < 0.05; *** significant at *p*-value < 0.01

10.3 Discussion

This study allowed obtaining relevant results on the associations between children's indoor air pollutants exposure/inhaled dose and reported respiratory symptoms, changes in lung function and/or childhood asthma in nursery and primary schools, both in urban and rural areas. This study also allowed understanding the influence of children's sensitisation to the most common aeroallergens on that association.

Questionnaire results showed more asthmatic symptoms in pre-schoolers, with a special highlight in active wheezing. Nevertheless, results showed higher asthma prevalence both reported and diagnosed in older children (primary school age). For younger ages (pre-schoolers), respiratory symptoms are frequent, but may indicate other pathologies rather than asthma (Yeh et al., 2011). Although results showed high correlation between reported and diagnosed asthma, the highest reported asthma prevalence indicated a misdiagnosed asthma in the study population. Asthma reported in these study questionnaires was either previously diagnosed based on out of date criteria to diagnose asthma in children, or merely based on reported symptoms without any complementary PFT. There were a limited number of studies in the literature comparing urban with rural areas, but, in general, children from urban sites presented higher asthma prevalence and asthma-like symptoms (Oluwole et al., 2018), as in the present study.

Time-location and time-activity patterns confirmed that these children spent most of their day indoors, and a significant portion inside scholar environment. Differences in patterns between age groups and site location indicated that these two factors played an important role in children's exposure to IAP in those microenvironments. Inhalation doses were estimated, allowing a deeper analysis of the impact of IAP on children, as exposure did not consider either the activities nor the individual characteristics of the child (namely sex, age and body weight). High CO_2 inhaled exposures and doses inside scholar indoor microenvironments were in agreement with results from the previous chapters 3 and 6 and previous studies reporting high levels of CO_2 in classrooms (Mainka and Zajusz-Zubek, 2015). They could be mainly caused by overcrowding and deficit air renovation (insufficient ventilation). In the absence of indoor sources, exchange with outdoor air may have been the cause for higher CO and O_3 inhaled exposures and doses in urban sites. In general, pre-schoolers were exposed to and inhaled higher doses of indoor air pollutants, including particulate matter. Their classrooms were usually more overcrowded and less ventilated to keep the thermal comfort – to prevent heat loss in cold season and heat incoming during warm season. As younger children are more susceptible to temperature changes, there are usually more concerns about thermal comfort with them than with older ones. Younger children have also activities with greater mobility, thus contributing to higher exposures to particulate matter and higher inhalation rates, concomitantly with a lower body weight, leading to higher inhalation doses.

To estimate associations between air pollution and health outcomes, independent models for each specific studied pollutant (unipollutant) were built. However, in real world indoor air is a complex mixture of several indoor air pollutants, which this study tried to represent by using multipollutant models to evaluate the association. The odds ratios obtained are difficult to compare with those reported in previous studies because each study examined a different study population, under a different setting, using a different statistical analysis method and adjusting the odds ratios for a different set of confounding factors. Continuous data of inhaled exposures and doses, obtained from active continuous IAQ sampling, were in the basis of this study and allowed performing different transformations on those exposure variables. This not only allowed expressing values relatively well-represented in the sample (when considering an IQR increment in exposure), but also allowed to consider individuals exposed to high or low levels of exposure/ dose in relation to the median of the sample or in relation to the recommended threshold.

Although not considered a pollutant *per se* in indoor environments, CO_2 is usually used as a useful global indicator of IAQ (Salthammer et al., 2016). However, CO_2 was not significantly associated with the increase on the odds of having any of the studied respiratory outcomes. For this reason, studies of association between IAP exposures in school environments and children's respiratory health should not be limited to CO_2.

The studied indoor air pollutants were not significantly associated with diagnosed asthma, neither individually nor combined (multipollutant). This indicated that inhaled exposures or doses to IAP in nursery and primary schools could not be *per se* associated with asthma prevalence. Although it was not possible to claim that inhaled exposures or doses to IAP in nursery and primary schools were associated with asthma prevalence, results showed statistically significant associations between IAP (NO_2) and reported active wheezing, and between IAP (O_3 and $PM_{2.5}$) and reduced lung function, namely dysfunction. In fact, although NO_2 and O_3 concentrations indoor the studied nursery and primary schools were always below Portuguese legislated thresholds, children's exposure seemed to be associated with an increased odd of having those respiratory health issues, during childhood. In accordance, Annesi-Maesano et al. (2012) reported a poor air quality in French primary schools, which varied significantly among schools and cities, related to an increased prevalence of clinical manifestations of asthma and rhinitis in schoolchildren. Moreover, previous findings from Rawi et al. (2015) indicated that the exposures to poor IAQ and increasing levels of indoor air pollutants concentrations in pre-schools in Malaysia were associated with a reduction in lung function and with increasing reports of respiratory symptoms among pre-school children, namely wheezing ($PM_{2.5}$, PM_{10}, VOC and CO). Another previous study, this time considering personal monitoring of 6-15 years old children living in the city of Rio de Janeiro, Brazil, also reported that even within acceptable levels most of the time, air pollution, especially PM_{10} and NO_2, was associated with a decrease in lung function (Castro et al., 2009). Mölter et al. (2013) findings also suggested that lifetime exposure to PM_{10} and NO_2 might be associated with reduced growth in FEV_1 in children when considering home, school and commuting between them. Ranzi et al. (2014) reported for outdoor air, a clear link between exposure to NO_2 (estimated by land-use regression modelling) and respiratory symptoms in young children during their first 7 years of life, but only weak associations that seemed to increase with age. Mölter et al. (2015) reported no statistically significant association between exposure to selected outdoor air pollution metrics (estimated by land-use regression modelling) and childhood asthma (although mainly positive associations were found) in a meta-analysis of five birth cohorts located in five large conurbations in Europe. In agreement, previous published studies reported that asthma exacerbation, severe respiratory symptoms and moderate airway obstruction on spirometry were observed in children due to various sources of IAP in households and schools (Liu et al., 2018).

Although studies on association were often merely based on indoor air pollutants concentrations or inhaled exposures, the differences on the results from the present study between inhaled exposures and doses association models show that the use of inhaled dose should be favoured in this type of studies. Inhalation exposure models do not strictly take into account the inhaled dose of compounds, but only the presence of air pollutants near the breathing zone of a person, thus neglecting inhalation rates and body weight of the individuals studied.

Results showed that sensitisation to at least one of the most common aeroallergens (dust mites, pollens and animal dander) was frequent in these children from nursery and primary schools. In fact, those aeroallergens were commonly found on desktop surfaces in pre-schools and elementary schools (Kanchongkittiphon et al., 2014). An increase in inhaled exposure and dose to particulate matter ($PM_{2.5}$ and PM_{10}) was associated with a higher increase in the odds of having asthma with AS than of having asthma without AS. This seemed to indicate that children sensitised to aeroallergens are more likely to develop childhood asthma due to IAP exposure in nursery and primary schools than those that are not sensitised. Previous studies in literature identified significant positive associations among $PM_{2.5}$ and NO_2 and sensitised asthmatics (Annesi-Maesano et al., 2012).

The objectives of this study were fulfilled, nevertheless, some limitations should be taken into account. Although sample size allowed to have an acceptable statistical power, a bigger sample size would allow performing stratifications of the study population, namely by site location (urban and rural) and by age group (pre- and primary school children). This study did not considered complete information about individual's atopy, as information about eczema, itchy rash or even parents' history of atopic disease were not collected. Aeroallergen sensitisation was only assessed (skin prick tests) in the first recruitment campaign, which limited the number of individuals in the study population in the multinomial logistic regression modelling. Lung function was only assessed (by spirometry) in children reporting symptoms or reporting previously diagnosed asthma in the questionnaires, which limited the analysis of the impact of IAP on both obstructive disorder and reduced FEV_1 (dysfunction). Although asthma was diagnosed by using the most recent guidelines, severity and control of asthma were not evaluated, limiting the quantification of the impact of IAP inhaled exposures and doses in the different asthma severity degrees and levels of control.

10.4 Conclusions

As far as the author's knowledge goes, this was the first study to evaluate the associations between indoor air pollutants children's inhaled exposure/dose in nursery and primary schools, in both urban and rural areas, and both childhood asthma, reported respiratory symptoms and/or changes in lung function, and evaluating also the influence of aeroallergens' sensitisation in that association. This study represented children's exposure to indoor air pollutants in nursery and primary schools by considering a microenvironmental modelling approach based on both continuous monitoring of indoor air pollutants in the distinct indoor microenvironments, and real data on time-activity-location patterns. As far as the authors' knowledge goes, this is also the first study in Portuguese nursery and primary school children populations estimating inhalation rates for each age group and site location, based on reported time-location and time-activity patterns. This allowed studying both inhaled exposures and doses, deepening the analysis of the impact of IAP on children, as exposure only take into account the presence of air pollutant near the breathing zone, neglecting activities and individual characteristics. Asthma-related symptoms were reported in a validated questionnaire intensively used worldwide, while asthma was diagnosed by medical tests according to the most recent GINA guidelines.

This study concluded that school indoor microenvironments play a relevant role in daily children's exposure to air pollution, especially classrooms. This study represented the complex mixture of several indoor air pollutants that occur in indoor air by considered multipollutant models of association. Although CO_2 is usually used as a good global IAQ indicator, the results from this study suggest that it should not be used alone as a proxy of IAP for epidemiological studies. Nevertheless, and although this study covered most of the considered major indoor air pollutants of the nursery and primary schools environments, overall it found no evidence of a significant association with the prevalence of childhood asthma. However, children's exposure to the levels of indoor air pollutants found were significantly associated with other asthma-related health outcomes, namely with an increase in the odds of having active wheezing due to NO_2, and abnormal lung function (reduced FEV_1) due to O_3 and $PM_{2.5}$. On one hand, although NO_2 and O_3 were always found below the thresholds in this study, and their exceedances were not common indoor scholar microenvironments, this study suggests that they could have a negative impact on children's respiratory health. On the other hand, $PM_{2.5}$ was usually found in high concentrations indoor scholar microenvironments, and often above the thresholds. Moreover, results from this study suggest that children sensitised to common aeroallergens are more likely to develop asthma during childhood due to exposure to particulate matter in nursery and primary schools' indoor air.

PART IV

CONCLUSIONS AND PROSPECTIVE WORK

Chapter 11

Main Conclusions and Suggestions for future work

This chapter summarises the main findings of this thesis, highlighting recommendations and suggestions for future work.

11.1 Summary of the main findings

The characterisation of IAQ in nursery and primary schools, from both urban and rural areas of northern Portugal, allowed obtaining the following main conclusions:

- Poor IAQ was commonly found in nursery and primary schools. Indoor concentrations of CO_2, $PM_{2.5}$ and PM_{10}, were often above the reference values (international guidelines and national legislation). Formaldehyde and TVOC also exceeded the reference values, although less frequently. In general, values of T and RH indicated that children were expected to experience thermal discomfort during classes. Indoor concentrations of O_3, CO and NO_2 never exceeded the reference values. Radon never exceed Portuguese legislation, but in some cases exceeded international guidelines.
- In the absence of indoor relevant sources, the influence of outdoor air seemed to be determinant on O_3, CO and NO_2 indoor concentrations. The observed formaldehyde and TVOC peak concentrations indicated the presence of specific indoor sources for these pollutants, which might include materials emitting formaldehyde (e.g. furnishing) and products emitting VOC associated with cleaning and children's specific activities (e.g. paints and glues). Children's age group, activities, number of occupants, classroom floor and year of building construction influenced the radon concentrations.
- Regarding the determinants of $PM_{2.5}$ and CO_2 , the major concerning indoor air pollutants for children's exposure, the most significant building and classroom's

characteristics were heating system, flooring material, indoor thermal conditions (T and RH), type of school management, and background concentrations (non-occupancy periods).

- Children were exposed to high levels of indoor air pollutants, more in urban than in rural sites, and in both areas significantly depending on season and on children's occupancy and activity patterns (different age groups have different occupancy and activity patterns).
- School indoor microenvironments, especially classrooms, played a relevant role in children's daily exposure to air pollution. Pre-schoolers had a higher exposure to, and inhaled dose of, indoor air pollutants than primary school children, as their classrooms were usually more crowded and less ventilated to keep thermal comfort.
- Although the number of children per class always complied with Portuguese legislation for educational purposes, overcrowded classrooms according to ASHRAE recommendations were commonly found. Mechanical ventilation systems were unusual in Portuguese nursery and primary schools, and high CO_2 concentrations seemed to indicate that natural ventilation provided insufficient air exchange rate as windows and doors were often closed during classes (exposure periods), mainly to prevent noise entering and heat loss. Thus, IAQ and ventilation aspects should be taken into account in the legislation for the number of children per class.

The study of childhood asthma prevalence and risk factors in Portuguese pre- and primary school children from both urban and rural areas, as well as the modelling of children's exposure to IAP in nursery and primary schools and their effects on childhood asthma allowed concluding that:

- From the initial estimation based on reported data from 497 ISAAC-derived questionnaires, 10.7% of the children attending nursery schools were asthmatics.
- In a larger population of 1261 pre- and primary school children attending nursery and primary schools in both urban and rural areas, asthma was diagnosed in 5.5% of children, following the newest GINA guidelines and recommendations.
- Although not significantly different, asthma prevalence was higher in primary school children than in pre-schoolers, and higher in children from urban locations when compared with those from rural sites. The non-significant difference between asthma diagnosed in pre- and primary school children confirmed that asthma develops at early ages, thus it should be correctly diagnosed as earlier as possible.
- This study provided evidence of under-diagnosed asthma in both pre- and primary school children, and in both settings (urban and rural) confirming that asthma diagnosis

merely based on reported symptoms might be underestimating the real prevalence of this disease.

- Results confirmed both host and environmental factors have a risk effect on asthma. Host factors that mainly predispose a child to develop asthma included being male, older age and having at least one asthmatic parent; environmental factors included paracetamol administration in the previous year (currently), and antibiotics administration in child's first year of life.
- In the whole study population (1530 children attending all the nursery and primary schools studied), prevalence of active wheezing, reported being previously diagnosed with asthma, diagnosed asthma, and asthma with aeroallergen sensitisation were 13.6%, 5.9%, 5.5% and 2.5% respectively. Regarding lung function in those who completed spirometry, 36.4% had obstructive disorder, and 23.1% presented respiratory dysfunction, here defined as reduced FEV_1.
- Overall, no evidence was found of a significant association between indoor air pollutants and the prevalence of childhood asthma. However, children's IAP exposure was significantly associated with other asthma-related outcomes, namely with an increase in the odds of having active wheezing due to NO_2, and abnormal lung function (reduced FEV_1) due to O_3 and $PM_{2.5}$. Although NO_2 and O_3 were always below the thresholds in this study, results suggest that they could have a negative impact on children's respiratory health that must not be neglected.
- Results suggest that children sensitised to common aeroallergens are more likely to develop asthma during childhood due to inhaled PM in nursery and primary schools' indoor air.

The findings from this thesis support the need for developing and implementing mitigation measures to reduce indoor air pollutants levels in nursery and primary schools, and prevention actions to avoid children's exposure to IAP. Those measures include: i) reducing the time spent indoors in the same microenvironment by doing more and/or longer breaks; ii) improving the air renovation rate through better ventilation habits, and more efficient control of indoor thermal conditions, by using correctly heaters and air conditioners where they exist; iii) changing cleaning activities schedule, to after the occupation period; iv) replacing materials emitting formaldehyde and better ventilation while using products emitting VOC; v) avoiding or making a better maintenance of hardwood flooring materials, chalkboard use and VOC emitting materials, and vi) considering room location (especially floor) when assigning rooms purpose in school buildings. Most of these measures are low-cost, thus they can easily be applied. Their application might bring significant improvements in both IAQ and children's health and quality of life. Nevertheless, the basis of IAQ improvement is raising awareness, i.e., to educate and to mobilize all the scholar community (children, staff, teachers, coordinators, and even parents/guardians) into these issues.

Besides the scientific outcomes, this thesis also provided IAQ reports for each nursery and primary school, that were delivered to the coordinators. An example can be seen in Appendix G. Moreover, individual reports containing the results and diagnosis from both the skin prick tests and the pulmonary function tests were delivered to the parents/caregivers of each child that completed the tests. An example can be seen in Appendix H.

11.2 Suggestions for future work

The relevant findings of this study opened new opportunities of research in the field of environmental epidemiology, particularly in the air quality impacts on childhood asthma.

Concerning the IAQ characterisation in nursery and primary schools, future studies should include: i) the quantification of air change rate; ii) the characterisation of PM composition (e.g. heavy metals, polycyclic aromatic hydrocarbons, allergens) – after being identified as the major IAQ problem in nursery and primary schools, characterising its composition will allow a better assessment of the toxicology and health impacts; iii) identification and quantification of individual VOC, to better understand their sources and health impacts; iv) quantification of microbiological compounds in the indoor air, namely bacteria and fungi; and v) conduct a national radon survey in nursery and primary schools, using long-term measurements in order to estimate the annual effective inhaled dose.

It is important to recognise that there are many aspects of the complex association between childhood asthma and exposure to IAP in nursery and primary schools not addressed in this study. Therefore, future studies must particularly consider: i) the inclusion of prenatal factors, exposures and gene-environment interactions; ii) the assessment of children’s exposure to aeroallergens and its impact on health, by quantifying aeroallergens in PM in nursery and primary schools; iii) the evaluation of asthma severity and control in the asthmatic population; and iv) the estimation of morbidity and costs associated with observed impacts (e.g. absenteeism, hospital visits, medication, among others).

Extending the study to other microenvironments identified in the daily time-activity-location patterns from this study could also be done in the future, in order to estimate the daily exposure impacts on childhood asthma. The primary health outcome of interest in this thesis was childhood asthma, although in the future other allergic and irritant-induced outcomes such as eczema and allergic rhinitis could be of interest for a similar analysis.

Besides implementing the suggested mitigation measures to reduce indoor air pollutants levels in nursery and primary schools, it could also be important in the future to quantify their impacts in both IAQ and children’s health. This could be done by involving all scholar community (coordinators, teachers/educators, staff, children and their parents/caregivers) in a citizenscience approach, providing them with proper training and tools like the emerging low-cost air quality sensing technologies.

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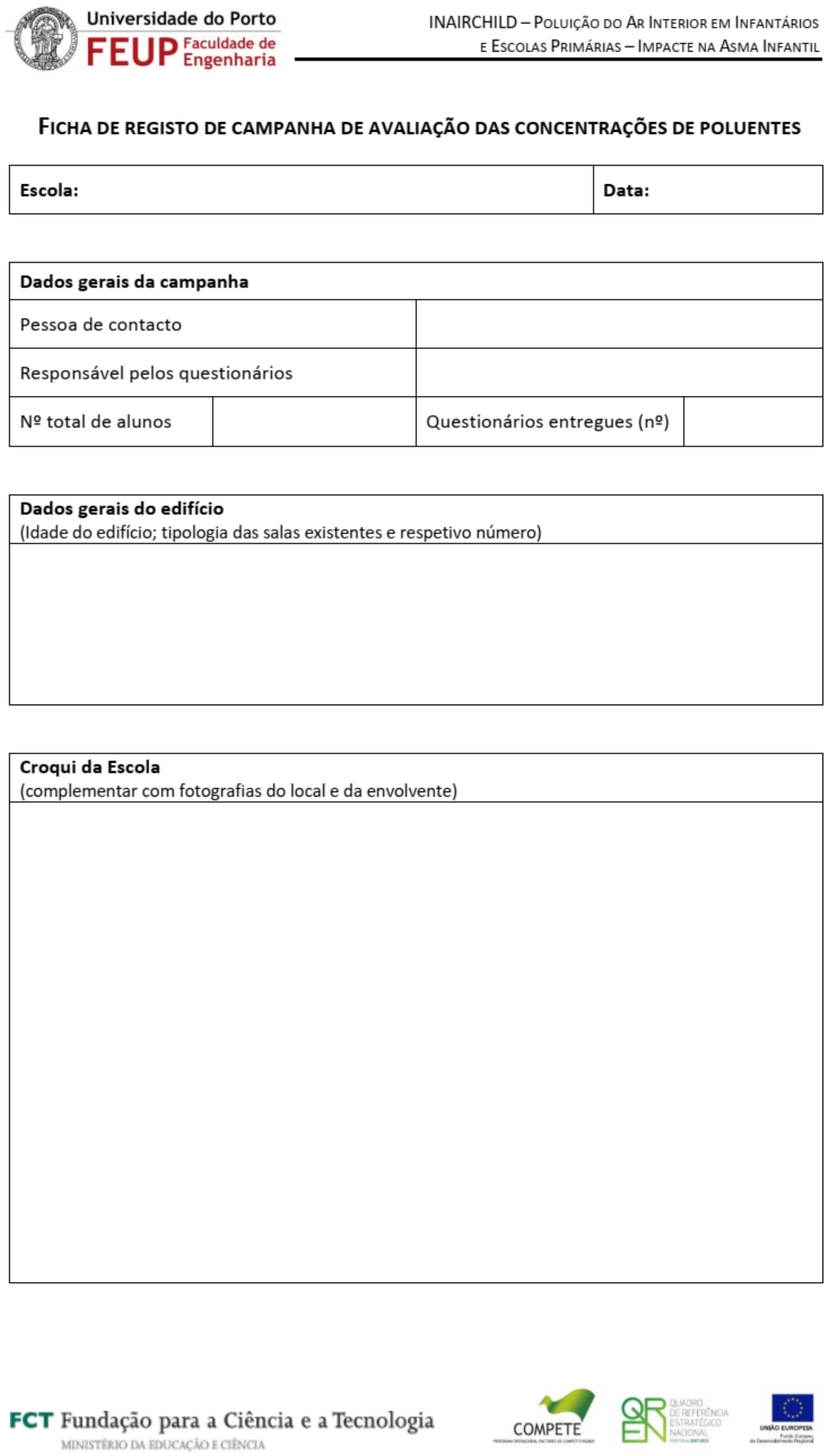
APPENDICES

APPENDIX A – Indoor characterization form



Universidade do Porto
FEUP Faculdade de Engenharia

INAIRCHILD – Poluição do Ar Interior em Infantários
e Escolas Primárias – Impacte na Asma Infantil

FICHA DE REGISTO DE CAMPANHA DE AVALIAÇÃO DAS CONCENTRAÇÕES DE POLUENTES

Escola:	**Data:**

Dados gerais da campanha			
Pessoa de contacto			
Responsável pelos questionários			
Nº total de alunos		Questionários entregues (nº)	

Dados gerais do edifício (Idade do edifício; tipologia das salas existentes e respetivo número)

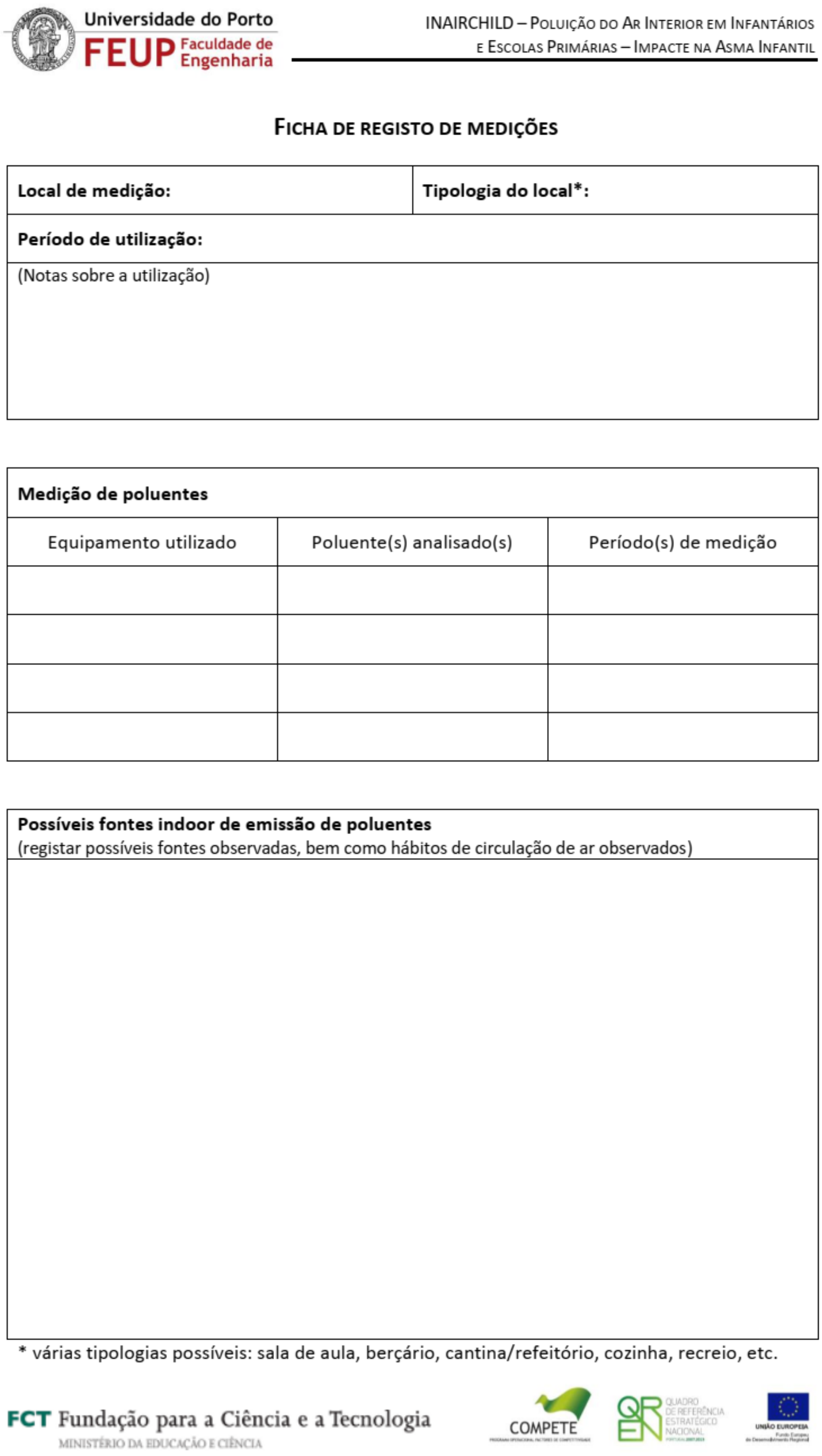
Croqui da Escola (complementar com fotografias do local e da envolvente)

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

COMPETE

QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL

UNIÃO EUROPEIA



Universidade do Porto
FEUP Faculdade de Engenharia

INAIRCHILD – POLUIÇÃO DO AR INTERIOR EM INFANTÁRIOS
E ESCOLAS PRIMÁRIAS – IMPACTE NA ASMA INFANTIL

FICHA DE REGISTO DE MEDIÇÕES

Local de medição:	**Tipologia do local*:**
Período de utilização:	
(Notas sobre a utilização)	

Medição de poluentes		
Equipamento utilizado	Poluente(s) analisado(s)	Período(s) de medição

Possíveis fontes indoor de emissão de poluentes (registar possíveis fontes observadas, bem como hábitos de circulação de ar observados)

* várias tipologias possíveis: sala de aula, berçário, cantina/refeitório, cozinha, recreio, etc.

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

COMPETE

QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL

UNIÃO EUROPEIA

Croqui do espaço (com referência à localização dos equipamentos de medição e possíveis fontes de emissão)

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA
COMPETE
QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
UNIÃO EUROPEIA

B1 – Detailed characteristics of all the studied microenvironments (n = 101): site location, age group, room type, season of sampling, traffic in the near road, area, number of occupants and occupant density

ID	Site location	Age group	Room type	Season of sampling	Type of management	Date of construction	Traffic in the near road	Area (m^2)	Number of occupants	Occupant density (occupants/100 m^2)
I_URB1_A1	Urban	Infants	classroom	cold	private	Before 2006	medium/large	38	19	50
I_URB1_A2	Urban	Infants	classroom	warm	private	Before 2006	medium/large	38	25	66
I_URB1_B1	Urban	Infants	classroom	cold	private	Before 2006	medium/large	41	21	51
I_URB1_B2	Urban	Infants	classroom	warm	private	Before 2006	medium/large	41	21	51
I_URB2_A2	Urban	Infants	classroom	warm	private	2006 or after	medium/large	48	12	25
I_URB2_A1	Urban	Infants	classroom	cold	private	2006 or after	medium/large	48	13	27
I_URB2_B2	Urban	Infants	classroom	warm	private	2006 or after	medium/large	40	20	50
I_URB2_B1	Urban	Infants	classroom	cold	private	2006 or after	medium/large	40	22	55
I_URB3_A2	Urban	Infants	classroom	warm	private	Before 2006	small	36	17	47
I_URB3_A1	Urban	Infants	classroom	cold	private	Before 2006	small	36	16	44
I_URB3_B2	Urban	Infants	classroom	warm	private	Before 2006	small	39	20	51
I_URB3_B1	Urban	Infants	classroom	cold	private	Before 2006	small	39	20	51
I_URB3_C1	Urban	Infants	classroom	cold	private	Before 2006	small	51	17	33
I_URB3_DA2	Urban	Infants	bedroom	warm	private	Before 2006	small	38	18	47
I_URB3_DA1	Urban	Infants	bedroom	cold	private	Before 2006	small	38	20	53
I_URB3_DB1	Urban	Infants	bedroom	cold	private	Before 2006	small	36	17	47
P_URB1_A1	Urban	Preschoolers	classroom	cold	private	Before 2006	medium/large	21	7	33
P_URB1_B1	Urban	Preschoolers	classroom	cold	private	Before 2006	medium/large	59	25	42
P_URB1_B2	Urban	Preschoolers	classroom	warm	private	Before 2006	medium/large	59	31	53
P_URB1_LR1	Urban	Preschoolers	canteen	cold	private	Before 2006	medium/large	38	47.5	125

B1 (*cont.*) – Detailed characteristics of all the studied microenvironments (n = 101): site location, age group, room type, season of sampling, traffic in the near road, area, number of occupants and occupant density

ID	Site location	Age group	Room type	Season of sampling	Type of management	Date of construction	Traffic in the near road	Area (m^2)	Number of occupants	Occupant density (occupants/100 m^2)
P_URB1_LR2	Urban	Preschoolers	canteen	warm	private	Before 2006	medium/large	38	47.5	125
P_URB2_A2	Urban	Preschoolers	classroom	warm	private	2006 or after	medium/large	50	27	54
P_URB2_A1	Urban	Preschoolers	classroom	cold	private	2006 or after	medium/large	50	28	56
P_URB2_LR2	Urban	Preschoolers	canteen	warm	private	2006 or after	medium/large	92	42.5	46
P_URB2_LR1	Urban	Preschoolers	canteen	cold	private	2006 or after	medium/large	92	100	109
P_URB3_A2	Urban	Preschoolers	classroom	warm	public	Before 2006	medium/large	45	25	56
P_URB3_B2	Urban	Preschoolers	classroom	warm	public	Before 2006	medium/large	36	37	103
P_URB3_LR2	Urban	Preschoolers	canteen	warm	public	Before 2006	medium/large	56	45	80
P_URB4_A1	Urban	Preschoolers	classroom	cold	public	2006 or after	medium/large	51	23	45
P_URB4_A2	Urban	Preschoolers	classroom	warm	public	2006 or after	medium/large	51	27	53
P_URB4_B1	Urban	Preschoolers	classroom	cold	public	2006 or after	medium/large	51	28	55
P_URB4_B2	Urban	Preschoolers	classroom	warm	public	2006 or after	medium/large	51	27	53
P_URB4_LR1	Urban	Preschoolers	canteen	cold	public	2006 or after	medium/large	104	240	231
P_URB4_LR2	Urban	Preschoolers	canteen	warm	public	2006 or after	medium/large	104	250	240
P_URB5_A2	Urban	Preschoolers	classroom	warm	public	2006 or after	small	63	25	40
P_URB5_B2	Urban	Preschoolers	classroom	warm	public	2006 or after	small	63	20	32
P_URB5_LR2	Urban	Preschoolers	canteen	warm	public	2006 or after	small	120	90	75
P_URB6_A2	Urban	Preschoolers	classroom	warm	private	Before 2006	small	39	24	62
P_URB6_B2	Urban	Preschoolers	classroom	warm	private	Before 2006	small	36	16	44
P_URB6_C2	Urban	Preschoolers	classroom	warm	private	Before 2006	small	38	24	63

B1 (*cont.*) – Detailed characteristics of all the studied microenvironments (n = 101): site location, age group, room type, season of sampling, traffic in the near road, area, number of occupants and occupant density

ID	**Site location**	**Age group**	**Room type**	**Season of sampling**	**Type of management**	**Date of construction**	**Traffic in the near road**	**Area (m^2)**	**Number of occupants**	**Occupant density (occupants/100 m^2)**
P_URB6_LRA2	Urban	Preschoolers	canteen	warm	private	Before 2006	small	148	70	47
P_URB6_LRA1	Urban	Preschoolers	canteen	cold	private	Before 2006	small	148	64	43
P_URB6_LRB2	Urban	Preschoolers	canteen	warm	private	Before 2006	small	NA	43	NA
P_URB7_A1	Urban	Preschoolers	classroom	cold	public	2006 or after	small	56	27	48
P_URB7_A2	Urban	Preschoolers	classroom	warm	public	2006 or after	small	56	27	48
S_URB1_A2	Urban	Primary	classroom	warm	private	Before 2006	medium/large	36	24	67
S_URB1_A1	Urban	Primary	classroom	cold	private	Before 2006	medium/large	36	26	72
S_URB1_B2	Urban	Primary	classroom	warm	private	Before 2006	medium/large	38	26	68
S_URB1_B1	Urban	Primary	classroom	cold	private	Before 2006	medium/large	38	26	68
S_URB1_C2	Urban	Primary	classroom	warm	private	Before 2006	medium/large	36	26	72
S_URB1_C1	Urban	Primary	classroom	cold	private	Before 2006	medium/large	36	27	75
S_URB1_D1	Urban	Primary	classroom	cold	private	Before 2006	medium/large	37	29	78
S_URB2_A2	Urban	Primary	classroom	warm	private	2006 or after	medium/large	48	18	38
S_URB2_A1	Urban	Primary	classroom	cold	private	2006 or after	medium/large	48	26	54
S_URB2_B1	Urban	Primary	classroom	cold	private	2006 or after	medium/large	53	21	40
S_URB3_A1	Urban	Primary school	classroom	cold	public	2006 or after	medium/large	51	22	43
S_URB3_A2	Urban	Primary school	classroom	warm	public	2006 or after	medium/large	51	21	41
S_URB3_B1	Urban	Primary school	classroom	cold	public	2006 or after	medium/large	51	24	47
S_URB3_B2	Urban	Primary school	classroom	warm	public	2006 or after	medium/large	51	20	39
S_URB4_A1	Urban	Primary school	classroom	cold	public	Before 2006	small	41	21	51

B1 (*cont.*) – Detailed characteristics of all the studied microenvironments (n = 101): site location, age group, room type, season of sampling, traffic in the near road, area, number of occupants and occupant density

ID	**Site location**	**Age group**	**Room type**	**Season of sampling**	**Type of management**	**Date of construction**	**Traffic in the near road**	**Area (m^2)**	**Number of occupants**	**Occupant density (occupants/100 m^2)**
S_URB4_B1	Urban	Primary school	classroom	cold	public	Before 2006	small	41	21	51
S_URB5_A1	Urban	Primary school	classroom	cold	public	2006 or after	small	55	22	40
S_URB5_A2	Urban	Primary school	classroom	warm	public	2006 or after	small	55	23	42
S_URB5_B1	Urban	Primary school	classroom	cold	public	2006 or after	small	57	24	42
S_URB5_B2	Urban	Primary school	classroom	warm	public	2006 or after	small	57	27	47
S_URB5_C1	Urban	Primary school	classroom	cold	public	2006 or after	small	55	23	42
S_URB5_C2	Urban	Primary school	classroom	warm	public	2006 or after	small	55	21	38
I_RUR1_A2	Rural	Infants	classroom	warm	private	2006 or after	small	23.5	25	106
I_RUR1_B2	Rural	Infants	classroom	warm	private	2006 or after	small	37.5	1	3
I_RUR1_LR2	Rural	Infants	canteen	warm	private	2006 or after	small	56	24	43
I_RUR2_A1	Rural	Infants	classroom	cold	private	2006 or after	small	17.1	11	64
I_RUR2_A2	Rural	Infants	classroom	warm	private	2006 or after	small	17.1	11	64
I_RUR2_B1	Rural	Infants	classroom	cold	private	2006 or after	small	20.6	17	83
I_RUR2_B2	Rural	Infants	classroom	warm	private	2006 or after	small	20.6	14	68
P_RUR1_A2	Rural	Preschoolers	classroom	warm	public	2006 or after	small	63	27	43
P_RUR1_B2	Rural	Preschoolers	classroom	warm	public	2006 or after	small	48	22	46
P_RUR1_LR2	Rural	Preschoolers	canteen	warm	public	2006 or after	small	104	200	192
P_RUR2_A2	Rural	Preschoolers	classroom	warm	private	Before 2006	small	32.5	16	49
P_RUR2_LR2	Rural	Preschoolers	canteen	warm	private	Before 2006	small	26	16	62
P_RUR3_A1	Rural	Preschoolers	classroom	cold	public	2006 or after	small	49.6	26	52

B1 (*cont.*) – Detailed characteristics of all the studied microenvironments ($n = 101$): site location, age group, room type, season of sampling, traffic in the near road, area, number of occupants and occupant density

ID	Site location	Age group	Room type	Season of sampling	Type of management	Date of construction	Traffic in the near road	Area (m^2)	Number of occupants	Occupant density (occupants/100 m^2)
P_RUR3_A2	Rural	Preschoolers	classroom	warm	public	2006 or after	small	49.6	29	58
P_RUR4_A1	Rural	Preschoolers	classroom	cold	private	2006 or after	small	50.2	25	50
P_RUR4_A2	Rural	Preschoolers	classroom	warm	private	2006 or after	small	50.2	27	54
P_RUR4_B1	Rural	Preschoolers	classroom	cold	private	2006 or after	small	50.2	19	38
P_RUR4_B2	Rural	Preschoolers	classroom	warm	private	2006 or after	small	50.2	25	50
P_RUR5_A1	Rural	Preschoolers	classroom	cold	public	Before 2006	small	88.6	26	29
P_RUR5_A2	Rural	Preschoolers	classroom	warm	public	Before 2006	small	88.6	22	25
S_RUR1_A1	Rural	Primary school	classroom	cold	public	2006 or after	small	59.8	17	28
S_RUR1_A2	Rural	Primary school	classroom	warm	public	2006 or after	small	59.8	17	28
S_RUR1_B1	Rural	Primary school	classroom	cold	public	2006 or after	small	73.6	28	38
S_RUR1_B2	Rural	Primary school	classroom	warm	public	2006 or after	small	73.6	28	38
S_RUR1_C1	Rural	Primary school	classroom	cold	public	2006 or after	small	47.6	19	40
S_RUR1_C2	Rural	Primary school	classroom	warm	public	2006 or after	small	47.6	19	40
S_RUR2_A1	Rural	Primary school	classroom	cold	public	2006 or after	small	46.9	20	43
S_RUR2_A2	Rural	Primary school	classroom	warm	public	2006 or after	small	46.9	21	45
S_RUR2_B1	Rural	Primary school	classroom	cold	public	2006 or after	small	46.9	27	58
S_RUR2_B2	Rural	Primary school	classroom	warm	public	2006 or after	small	46.9	26	55
S_RUR2_LR1	Rural	Primary school	canteen	cold	public	2006 or after	small	NA	160	NA
S_RUR2_LR2	Rural	Primary school	canteen	warm	public	2006 or after	small	NA	160	NA
S_RUR3_A1	Rural	Primary school	classroom	cold	public	Before 2006	small	48.7	10	21
S_RUR3_A2	Rural	Primary school	classroom	warm	public	Before 2006	small	48.7	11	23

B2 – Detailed characteristics of all the studied microenvironments (n = 101): floor, ventilation, heating, signs of dampness, flooring material, chalkboard, cleaning frequency, cleaning schedule and dust cleaning method

ID	Floor	Ventilation	Heating	Signs of dampness	Flooring material	Chalkboard	Cleaning frequency	Cleaning schedule	Dust cleaning method
I_URB1_A1	ground floor	DAC	Gas or oil	Yes	Laminate	No	Daily	During	Sweep
I_URB1_A2	ground floor	DAC	None	Yes	Laminate	No	Daily	After	Wash
I_URB1_B1	ground floor	DAC	None	Yes	Laminate	No	Daily	During	Sweep
I_URB1_B2	ground floor	DAC	None	Yes	Laminate	No	Daily	After	Wash
I_URB2_A2	ground floor	DNV	None	No	Laminate	No	Twice a day	After	Wash
I_URB2_A1	ground floor	DNV	Electric	No	Laminate	No	Twice a day	After	Vacuum
I_URB2_B2	ground floor	DNV	None	No	Laminate	No	Twice a day	After	Wash
I_URB2_B1	ground floor	DNV	Electric	No	Laminate	No	Twice a day	After	Vacuum
I_URB3_A2	1st	DNV	Electric	No	Hardwood	No	Daily	After	Vacuum
I_URB3_A1	1st	DNV	Electric	No	Hardwood	No	Daily	After	Vacuum
I_URB3_B2	1st	DNV	Electric	No	Hardwood	No	Daily	After	Vacuum
I_URB3_B1	1st	DNV	Electric	No	Hardwood	No	Daily	During	Vacuum
I_URB3_C1	1st	DNV	Electric	No	Ceramic tile	No	Daily	After	Vacuum
I_URB3_DA2	1st	DNV	Electric	No	Hardwood	No	Twice a day	After	Vacuum
I_URB3_DA1	1st	DNV	Electric	No	Hardwood	No	> Daily	After	Vacuum
I_URB3_DB1	1st	DNV	Electric	No	Ceramic tile	No	> Daily	After	Vacuum
P_URB1_A1	1st	DNV	Electric	No	Laminate	No	Daily	After	Sweep
P_URB1_B1	2nd	DNV	Gas or oil	Yes	Laminate	No	Daily	After	Sweep
P_URB1_B2	2nd	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB1_LR1	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash

B2 (*cont.*) - Detailed characteristics of all the studied microenvironments (n = 101): floor, ventilation, heating, signs of dampness, flooring material, chalkboard, cleaning frequency, cleaning schedule and dust cleaning method

ID	**Floor**	**Ventilation**	**Heating**	**Signs of dampness**	**Flooring material**	**Chalkboard**	**Cleaning frequency**	**Cleaning schedule**	**Dust cleaning method**
P_URB1_LR2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB2_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB2_A1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Vacuum
P_URB2_LR2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB2_LR1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Vacuum
P_URB3_A2	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_URB3_B2	1st	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_URB3_LR2	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_URB4_A1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Sweep
P_URB4_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB4_B1	ground floor	DNV	None	No	Laminate	Yes	Daily	After	Sweep
P_URB4_B2	ground floor	DNV	None	No	Laminate	Yes	Daily	After	Wash
P_URB4_LR1	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_URB4_LR2	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Wash
P_URB5_A2	ground floor	DNV	None	No	Laminate	No	Daily	Before	Wash
P_URB5_B2	ground floor	DNV	None	No	Laminate	No	Daily	Before	Wash
P_URB5_LR2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB6_A2	1st	DNV	Electric	No	Hardwood	No	Daily	After	Vacuum
P_URB6_B2	1st	DNV	Electric	No	Hardwood	No	Daily	After	Vacuum
P_URB6_C2	1st	DNV	Electric	No	Hardwood	No	Daily	After	Vacuum

B2 (*cont.*) – Detailed characteristics of all the studied microenvironments (n = 101): floor, ventilation, heating, signs of dampness, flooring material, chalkboard, cleaning frequency, cleaning schedule and dust cleaning method

ID	Floor	Ventilation	Heating	Signs of dampness	Flooring material	Chalkboard	Cleaning frequency	Cleaning schedule	Dust cleaning method
P_URB6_LRA2	1st	DNV	Electric	No	Ceramic tile	No	Daily	After	Wash
P_URB6_LRA1	1st	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_URB6_LRB2	1st	DNV	Electric	No	Ceramic tile	No	Daily	After	Wash
P_URB7_A1	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_URB7_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB1_A2	2nd	DNV	None	No	Laminate	No	Daily	After	Sweep
S_URB1_A1	2nd	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB1_B2	2nd	DNV	None	No	Laminate	No	Daily	After	Sweep
S_URB1_B1	2nd	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB1_C2	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_URB1_C1	1st	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB1_D1	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB2_A2	1st	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB2_A1	1st	DNV	Electric	No	Laminate	No	Daily	After	Vacuum
S_URB2_B1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Vacuum
S_URB3_A1	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB3_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB3_B1	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB3_B2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB4_A1	1st	DNV	None	No	Hardwood	Yes	Daily	After	Sweep

B2 (*cont.*) – Detailed characteristics of all the studied microenvironments (n = 101): floor, ventilation, heating, signs of dampness, flooring material, chalkboard, cleaning frequency, cleaning schedule and dust cleaning method

ID	**Floor**	**Ventilation**	**Heating**	**Signs of dampness**	**Flooring material**	**Chalkboard**	**Cleaning frequency**	**Cleaning schedule**	**Dust cleaning method**
S_URB4_B1	ground floor	DNV	None	No	Hardwood	Yes	Daily	After	Sweep
S_URB5_A1	ground floor	DNV	None	Yes	Laminate	Yes	Daily	After	Wash
S_URB5_A2	ground floor	DNV	None	Yes	Laminate	Yes	Daily	After	Wash
S_URB5_B1	ground floor	DNV	None	Yes	Laminate	No	Daily	After	Wash
S_URB5_B2	ground floor	DNV	None	Yes	Laminate	No	Daily	After	Wash
S_URB5_C1	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_URB5_C2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
I_RUR1_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
I_RUR1_B2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
I_RUR1_LR2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
I_RUR2_A1	ground floor	DAC	Electric	No	Laminate	No	Twice a day	After	Wash
I_RUR2_A2	ground floor	DAC	None	No	Laminate	No	Twice a day	After	Wash
I_RUR2_B1	ground floor	DAC	Electric	No	Laminate	No	Twice a day	After	Wash
I_RUR2_B2	ground floor	DAC	None	No	Laminate	No	Twice a day	After	Wash
P_RUR1_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Sweep
P_RUR1_B2	ground floor	DNV	None	No	Laminate	No	Daily	After	Sweep
P_RUR1_LR2	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Wash
P_RUR2_A2	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_RUR2_LR2	ground floor	DNV	None	No	Ceramic tile	No	Daily	After	Sweep
P_RUR3_A1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Sweep

B2 (*cont.*) – Detailed characteristics of all the studied microenvironments (n = 101): floor, ventilation, heating, signs of dampness, flooring material, chalkboard, cleaning frequency, cleaning schedule and dust cleaning method

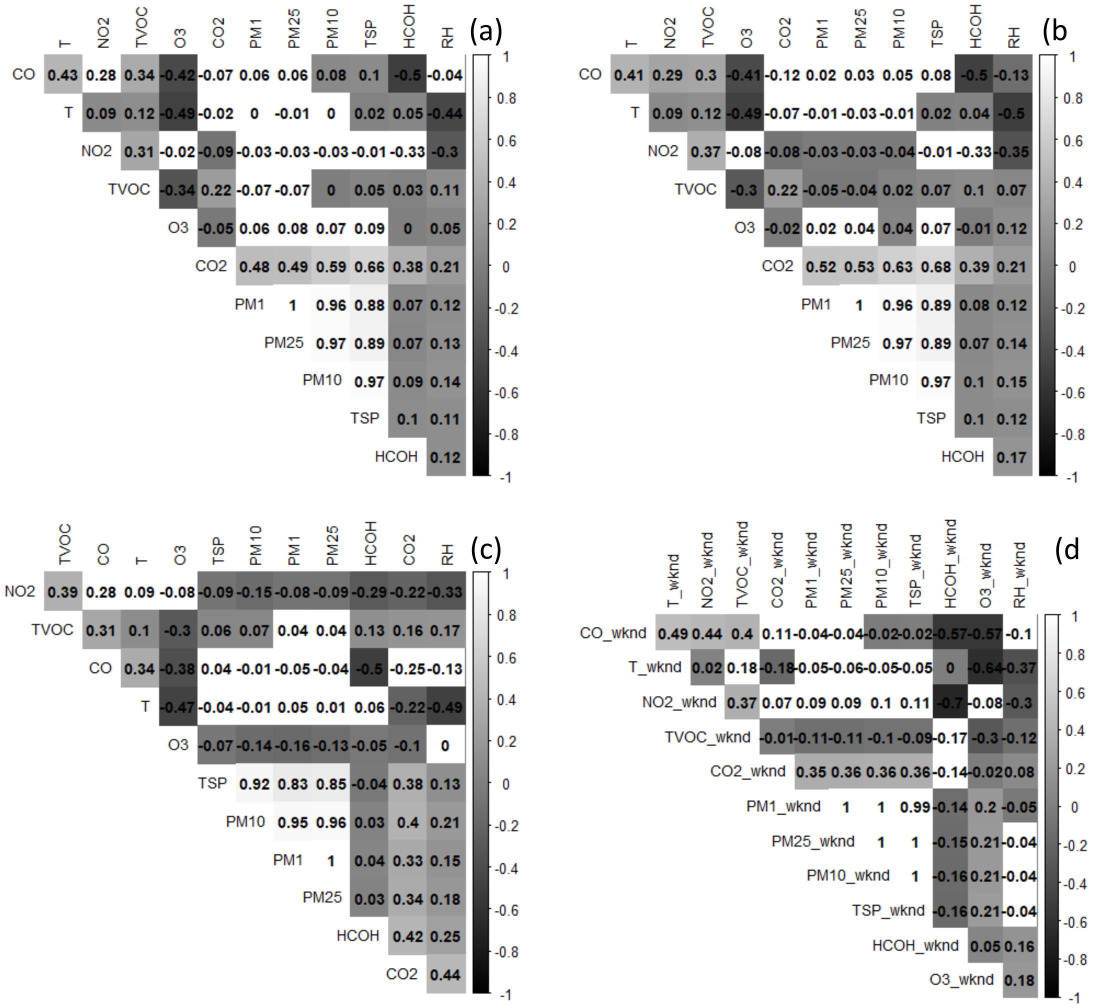
ID	Floor	Ventilation	Heating	Signs of dampness	Flooring material	Chalkboard	Cleaning frequency	Cleaning schedule	Dust cleaning method
P_RUR3_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Sweep
P_RUR4_A1	ground floor	DNV	Gas or oil	No	Laminate	No	Daily	After	Wash
P_RUR4_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_RUR4_B1	ground floor	DNV	Gas or oil	No	Laminate	No	Daily	After	Wash
P_RUR4_B2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
P_RUR5_A1	ground floor	DNV	None	No	Hardwood	No	Daily	During	Sweep
P_RUR5_A2	ground floor	DNV	None	No	Hardwood	No	Daily	During	Sweep
S_RUR1_A1	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR1_A2	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR1_B1	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR1_B2	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR1_C1	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR1_C2	1st	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR2_A1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Sweep
S_RUR2_A2	ground floor	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR2_B1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Sweep
S_RUR2_B2	ground floor	DNV	None	No	Laminate	No	Daily	After	Sweep
S_RUR2_LR1	ground floor	DNV	Electric	No	Laminate	No	Daily	After	Wash
S_RUR2_LR2	ground floor	DNV	None	No	Laminate	No	Daily	After	Wash
S_RUR3_A1	ground floor	DNV	None	Yes	Hardwood	Yes	Daily	After	Sweep
S_RUR3_A2	ground floor	DNV	None	Yes	Hardwood	Yes	Daily	After	Sweep

B3- Descriptive statistics of indoor air pollutants' concentrations and comfort parameters levels, on weekdays, during occupancy periods and on weekend

All rooms		**CO_2 (mg m^{-3})**	**CO (g m^{-3})**	**CH_2O (µg m^{-3})**	**NO_2 (µg m^{-3})**	**O_3 (µg m^{-3})**	**TVOC (µg m^{-3})**	**PM_1 (µg m^{-3})**	**$PM_{2.5}$ (µg m^{-3})**	**PM_{10} (µg m^{-3})**	**TSP (µg m^{-3})**	**T (°C)**	**RH (%)**
Weekdays	**Median**	970.7	1635.8	5.0	0.0	8.1	0.0	25.5	26.4	31.5	36.4	21.0	56.7
	IQR	995.9	3196.7	59.2	44.5	17.1	93.9	25.0	25.4	40.0	72.2	3.9	17.5
Weekend	**Median**	711.2	1279.4	0.0	0.0	7.2	0.0	16.0	16.4	17.0	17.4	20.5	54.4
	IQR	112.6	2572.8	49.7	38.0	16.6	0.0	15.1	15.6	16.0	16.1	4.0	16.1
Occupancy periods	**Median**	2114.7	2086.1	16.7	0.0	7.9	10.2	36.8	38.0	59.5	116.2	21.9	57.3
	IQR	1551.0	3316.7	69.6	49.7	13.8	163.4	26.5	26.3	42.7	92.9	3.6	17.6
Classrooms													
Weekdays	**Median**	1060.2	1799.9	7.9	0.0	7.8	0.0	25.5	26.5	31.6	36.1	21.0	57.9
	IQR	1182.6	3332.6	63.1	38.7	15.0	108.1	23.5	24.5	41.7	80.3	4.2	19.0
Weekend	**Median**	711.2	1279.4	0.0	0.0	7.2	0.0	16.4	16.6	17.4	17.5	20.5	54.4
	IQR	112.6	2572.8	49.7	38.0	16.6	0.0	15.8	15.9	16.4	16.6	4.0	16.1
Occupancy periods	**Median**	2190.5	2101.8	18.9	0.0	7.6	11.1	36.4	37.6	59.3	118.5	21.9	57.7
	IQR	1571.9	3355.3	69.4	47.4	13.2	167.1	25.6	25.8	42.5	94.3	3.6	18.2
Canteens													
Weekdays	**Median**	798.7	1394.0	0.0	15.2	12.4	0.0	25.8	26.0	33.8	42.4	20.3	55.0
	IQR	286.7	2806.8	22.6	85.6	22.4	39.1	28.6	29.2	34.7	61.4	3.0	10.9
Occupancy periods	**Median**	1339.7	1961.8	2.9	22.9	11.5	10.6	44.4	45.6	65.5	104.7	20.9	54.2
	IQR	560.2	2628.5	42.9	110.4	19.3	82.5	28.5	28.6	41.9	69.2	2.7	11.1

IQR - interquartile range; TVOC - total volatile organic compounds; TSP - Total Suspended Particles; T - temperature; RH - relative humidity

B4 – Correlograms with Spearman's rank correlation coefficients between indoor air pollutants and comfort parameters in: (a) weekdays on all rooms; and (b) weekdays on classrooms, (c) occupancy periods on classrooms, and (d) weekend on classrooms.



(a)

	T	NO2	TVOC	O3	CO2	PM1	PM25	PM10	TSP	HCOH	RH
CO	0.43	0.28	0.34	-0.42	-0.07	0.06	0.06	0.08	0.1	-0.5	-0.04
T		0.09	0.12	-0.49	-0.02	0	-0.01	0	0.02	0.05	-0.44
NO2			0.31	-0.02	-0.09	-0.03	-0.03	-0.03	-0.01	-0.33	-0.3
TVOC				-0.34	0.22	-0.07	-0.07	0	0.05	0.03	0.11
O3					-0.05	0.06	0.08	0.07	0.09	0	0.05
CO2						0.48	0.49	0.59	0.66	0.38	0.21
PM1							1	0.96	0.88	0.07	0.12
PM25								0.97	0.89	0.07	0.13
PM10									0.97	0.09	0.14
TSP										0.1	0.11
HCOH											0.12

(b

	T	NO2	TVOC	O3	CO2	PM1	PM25	PM10	TSP	HCOH	RH
CO	0.41	0.29	0.3	-0.41	-0.12	0.02	0.03	0.05	0.08	-0.5	-0.13
T		0.09	0.12	-0.49	-0.07	-0.01	-0.03	-0.01	0.02	0.04	-0.5
NO2			0.37	-0.08	-0.08	-0.03	-0.03	-0.04	-0.01	-0.33	-0.35
TVOC				-0.3	0.22	-0.05	-0.04	0.02	0.07	0.1	0.07
O3					-0.02	0.02	0.04	0.04	0.07	-0.01	0.12
CO2						0.52	0.53	0.63	0.68	0.39	0.21
PM1							1	0.96	0.89	0.08	0.12
PM25								0.97	0.89	0.07	0.14
PM10									0.97	0.1	0.15
TSP										0.1	0.12
HCOH											0.17

(c)

	TVOC	CO	T	O3	TSP	PM10	PM1	PM25	HCOH	CO2	RH
NO2	0.39	0.28	0.09	-0.08	-0.09	-0.15	-0.08	-0.09	-0.29	-0.22	-0.33
TVOC		0.31	0.1	-0.3	0.06	0.07	0.04	0.04	0.13	0.16	0.17
CO			0.34	-0.38	0.04	-0.01	-0.05	-0.04	-0.5	-0.25	-0.13
T				-0.47	-0.04	-0.01	0.05	0.01	0.06	-0.22	-0.49
O3					-0.07	-0.14	-0.16	-0.13	-0.05	-0.1	0
TSP						0.92	0.83	0.85	-0.04	0.38	0.13
PM10							0.95	0.96	0.03	0.4	0.21
PM1								1	0.04	0.33	0.15
PM25									0.03	0.34	0.18
HCOH										0.42	0.25
CO2											0.44

(d

	T_wknd	NO2_wknd	TVOC_wknd	CO2_wknd	PM1_wknd	PM25_wknd	PM10_wknd	TSP_wknd	HCOH_wknd	O3_wknd	RH_wknd
CO_wknd	0.49	0.44	0.4	0.11	-0.04	-0.04	-0.02	-0.02	-0.57	-0.57	-0.1
T_wknd		0.02	0.18	-0.18	-0.05	-0.06	-0.05	-0.05	0	-0.64	-0.37
NO2_wknd			0.37	0.07	0.09	0.09	0.1	0.11	-0.7	-0.08	-0.3
TVOC_wknd				-0.01	-0.11	-0.11	-0.1	-0.09	-0.17	-0.3	-0.12
CO2_wknd					0.35	0.36	0.36	0.36	-0.14	-0.02	0.08
PM1_wknd						1	1	0.99	-0.14	0.2	-0.05
PM25_wknd							1	1	-0.15	0.21	-0.04
PM10_wknd								1	-0.16	0.21	-0.04
TSP_wknd									-0.16	0.21	-0.04
HCOH_wknd										0.05	0.16
O3_wknd											0.18

B5– Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of CO_2 in non-occupancy periods

	Coefficient (ß)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	3.311	3.096, 3.526	0.108	30.692	**< 0.01***
Season of sampling					
warm (*ref*. cold)	-0.039	-0.100, 0.021	0.030	-1.295	0.20
Type of management					
public (*ref*. private)	0.065	-0.002, 0.133	0.034	1.935	0.06
T *(continuous variable)*	-0.017	-0.028, -0.007	0.005	-3.254	**< 0.01***
Cleaning schedule					
during classes (*ref*. after classes)	0.156	0.034, 0.278	0.06	2.543	**0.01***
before classes (*ref*. after classes)	-0.056	-0.236, 0.125	0.09	-0.617	0.54
Date of construction					
2006 or after (*ref*. before 2006)	0.081	0.011, 0.151	0.03	2.308	**0.02***
Cleaning frequency					
twice a day (*ref*. daily)	-0.079	-0.190, 0.031	0.05	-1.428	0.16

T – temperature; CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B6 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of CO_2 in occupancy periods

	Coefficient (β)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	1.172	0.602, 1.742	0.286	4.103	**< 0.01***
CO_2 in non-occupancy *(continuous variable)*	0.639	0.448, 0.830	0.096	6.682	**< 0.01***
Season of sampling					
warm (*ref*. cold)	-0.025	-0.086, 0.037	0.031	-0.799	0.43
RH *(continuous variable)*	0.005	0.003, 0.008	0.001	4.452	**< 0.01***
Flooring					
Ceramic tile (*ref*. laminate)	-0.074	-0.215, 0.067	0.070	-1.045	0.30
Hardwood (*ref*. laminate)	-0.124	-0.197, -0.051	0.036	-3.392	**< 0.01***
Age of children					
Pre-schoolers (*ref*. infants)	-0.072	-0.143, -0.001	0.036	-2.014	**0.05***
Schoolers (*ref*. infants)	-0.012	-0.085, 0.062	0.037	-0.317	0.75
Heating					
Electric (*ref*. none)	-0.027	-0.102, 0.048	0.038	-0.715	0.48
Gas or oil (*ref*. none)	0.116	-0.015, 0.248	0.066	1.768	0.08

RH – relative humidity; CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B7 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of $PM_{2.5}$ in non-occupancy periods

	Coefficient (ß)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	0.033	-0.997, 1.063	0.516	0.064	**< 0.01***
Season of sampling					
warm (*ref*. cold)	-0.157	-0.260, -0.054	0.051	-3.04	**< 0.01***
CO_2 in non-occupancy *(continuous variable)*	0.487	0.150, 0.823	0.168	2.889	**< 0.01***
Site location					
Rural (*ref*. urban)	-0.105	-0.206, -0.004	0.050	-2.077	**0.04***

CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B8 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of $PM_{2.5}$ in occupancy periods

	Coefficient (β)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	0.682	0.430, 0.933	0.126	5.424	**< 0.01***
$PM_{2.5}$ in non-occupancy *(continuous variable)*	0.635	0.468, 0.802	0.083	7.606	**< 0.01***
Season of sampling					
warm (*ref*. cold)	0.020	-0.060, 0.100	0.040	0.504	0.62
Flooring					
Ceramic tile (*ref*. laminate)	-0.235	-0.411, -0.058	0.088	-2.659	**0.01***
Hardwood (*ref*. laminate)	0.083	-0.008, 0.173	0.045	1.816	0.07
Type of management					
public (*ref*. private)	0.091	0.020, 0.162	0.036	2.551	**0.01***

CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B9 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of PM_{10} in non-occupancy periods

	Coefficient (β)	**95%CI**	**SE**	***t* value**	***p*-value**
Intercept	-0.226	-1.233, 0.781	0.504	-0.449	0.66
Season of sampling					
warm (*ref*. cold)	-0.115	-0.214, -0.016	0.050	-2.325	**0.02***
CO_2 in non-occupancy *(continuous variable)*	0.593	0.265, 0.922	0.164	3.613	**< 0.01***
Site location					
Rural (*ref*. urban)	-0.104	-0.201, -0.007	0.049	-2.147	**0.04***
Cleaning frequency					
twice a day (*ref*. daily)	-0.126	-0.283, 0.030	0.078	-1.615	0.11

CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B10 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of PM_{10} in occupancy periods

	Coefficient (β)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	0.894	0.597, 1.190	0.148	6.025	**< 0.01***
PM_{10} in non-occupancy *(continuous variable)*	0.588	0.396, 0.781	0.096	6.106	**< 0.01***
Season of sampling					
warm (*ref*. cold)	0.022	-0.068, 0.112	0.045	0.488	0.63
Type of management					
public (*ref*. private)	0.108	0.024, 0.191	0.042	2.580	**0.01***
Flooring					
Ceramic tile (*ref*. laminate)	-0.266	-0.471, -0.062	0.102	-2.600	**0.01***
Hardwood (*ref*. laminate)	0.054	-0.051, 0.160	0.053	1.033	0.31

CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B11 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of PM_{10} in non-occupancy periods (considering $PM_{2.5}$ influence)

	Coefficient (ß)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	-0.349	-0.573, -0.125	0.112	-3.119	**< 0.01***
Season of sampling					
warm (*ref*. cold)	0.040	0.017, 0.064	0.012	3.394	**< 0.01***
$PM_{2.5}$ in non-occupancy *(continuous variable)*	0.933	0.881, 0.985	0.026	35.975	**< 0.01***
CO_2 in non-occupancy *(continuous variable)*	0.149	0.071, 0.227	0.039	3.835	**< 0.01***
Age of children					
Pre-schoolers (*ref*. infants)	0.035	0.007, 0.063	0.014	2.464	**0.02***
Schoolers (*ref*. infants)	0.055	0.027, 0.083	0.014	3.894	**< 0.01***
Signs of dampness, yes (*ref*. no)	0.050	0.019, 0.080	0.015	3.249	**< 0.01***

CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

B12 – Results of final multivariate linear regression model of school and classrooms' characteristics as predictors of PM_{10} in occupancy periods (considering $PM_{2.5}$ influence)

	Coefficient (β)	**95% CI**	**SE**	***t* value**	***p*-value**
Intercept	-0.227	-0.495, 0.041	0.134	-1.691	0.10
Season of sampling					
warm (*ref.* cold)	0.033	0.003, 0.063	0.015	2.233	**0.03***
$PM_{2.5}$ in occupancy *(continuous variable)*	1.066	0.980, 1.151	0.043	24.877	**< 0.01***
Age of children					
Pre-schoolers (*ref.* infants)	0.062	0.026, 0.098	0.018	3.470	**< 0.01***
Schoolers (*ref.* infants)	0.081	0.043, 0.118	0.019	4.336	**< 0.01***
CO_2 in occupancy *(continuous variable)*	0.124	0.045, 0.203	0.040	3.134	**< 0.01***
PM_{10} in non-occupancy *(continuous variable)*	-0.118	-0.206, -0.031	0.044	-2.719	**0.01***

CI – confidence interval; SE – standard error; * statistically significant ($p < 0.05$)

APPENDIX C – ISAAC-derived questionnaire to collect health data

QUESTIONÁRIO

Este **questionário** deve ser **respondido pelos Encarregados de Educação** que autorizaram os seus educandos a participar no estudo **"INAIRCHILD - Poluição do Ar Interior em Infantários e Escolas Primárias - Impacte na Asma Infantil".**

Por favor, responda apenas nos espaços disponíveis para o efeito.

Caso se engane, explicite com clareza o que pretende responder.

OBRIGADO PELA SUA COLABORAÇÃO!

DATA_____/_____/_________

DADOS RELATIVOS À CRIANÇA

ESCOLA ____

ANO __________________________ TURMA ______________________________

REFERÊNCIA ____________________________

DATA DE NASCIMENTO _____/_____/__________

SEXO

☐ FEMININO ☐ MASCULINO

PESO ALTURA

☐ KILOGRAMAS ☐ METROS

PROFISSÃO DA MÃE ____

PROFISSÃO DO PAI ____

DISTÂNCIA APROXIMADA DA HABITAÇÃO À ESCOLA__________________________________

1

1. **Quantos irmãos mais velhos tem o seu educando?**

   ☐ irmãos e irmãs.

2. **Quantos irmãos mais novos tem o seu educando?**

   ☐ irmãos e irmãs.

3. **O seu educando nasceu em Portugal?**

   ☐ Sim
   ☐ Não

4. **Há quantos anos vive o seu educando em Portugal?**

   ☐ Anos.

5. **Quais são as habilitações literárias da mãe da criança?**

   ☐ 1º, 2º ou 3º ciclo do ensino básico (5º ao 9º ano de escolaridade)
   ☐ Ensino secundário (10º ao 12º ano de escolaridade)
   ☐ Ensino universitário

6. **O seu educando vive com algum fumador?**

   ☐ Sim
   ☐ Não

7. **Quantas pessoas do agregado familiar do seu educando fumam?**

   ☐ pessoas.

8. **A mãe da criança ou o seu encarregado de educação do sexo feminino fuma?**

   ☐ Sim, ☐ cigarros por dia.
   ☐ Não

9. **O pai da criança ou o seu encarregado de educação do sexo masculino fuma?**

   ☐ Sim, ☐ cigarros por dia.
   ☐ Não

10. **A mãe da criança ou o seu encarregado de educação do sexo feminino fumou durante o primeiro ano de vida do seu educando?**

    ☐ Sim
    ☐ Não

11. A mãe ou pai da criança tem ou teve asma?

☐ Sim

☐ Não

12. O seu educando teve ou tem asma?

☐ Sim

☐ Não

13. O seu educando alguma vez teve pieira (assobios) no peito?

☐ Sim

☐ Não

SE RESPONDEU “NÃO” POR FAVOR PASSE À QUESTÃO 19

14. Nos últimos 12 meses o seu educando teve pieira?

☐ Sim

☐ Não

SE RESPONDEU “NÃO” POR FAVOR PASSE À QUESTÃO 19

15. Nos últimos 12 meses quantos ataques de pieira o seu educando teve?

☐ Nenhum

☐ 1 a 3

☐ 4 a 12

☐ Mais de 12

16. Nos últimos 12 meses, em média, quantas vezes o seu educando acordou devido à pieira?

☐ Nunca acordou com pieira

☐ Menos de uma noite por semana

☐ Uma ou mais noites por semana

17. Nos últimos 12 meses a pieira foi suficientemente forte para limitar a conversa do seu educando a apenas uma ou duas palavras entre respirações?

☐ Sim

☐ Não

18. Nos últimos 12 meses o seu educando alguma vez sentiu pieira durante ou depois de fazer exercício?

☐ Sim

☐ Não

19. O seu educando alguma vez sentiu falta de ar?

☐ Sim

☐ Não

SE RESPONDEU "NÃO" POR FAVOR PASSE À QUESTÃO 22

20. Nos últimos 12 meses, quantas vezes o seu educando sentiu falta de ar?

☐ Nenhuma

☐ 1 a 3

☐ 4 a 12

☐ Mais de 12

21. Nos últimos 12 meses, em média, quantas vezes o seu educando acordou devido à falta de ar?

☐ Nunca acordou com falta de ar

☐ Menos de uma noite por semana

☐ Uma ou mais noites por semana

22. Nos últimos 12 meses o seu educando alguma vez teve tosse seca à noite sem estar constipado ou com infeção respiratória?

☐ Sim

☐ Não

23. O seu educando pratica algum desporto?

☐ Sim - Por favor especifique qual ____________________________________.

☐ Não

SE RESPONDEU "NÃO" POR FAVOR PASSE À QUESTÃO 25

24. Quantas vezes por semana o seu educando pratica desporto?

☐ vezes por semana.

25. Quantas vezes por semana o seu educando faz exercícios físicos suficientemente longos que o façam respirar com dificuldade?

☐ Nunca ou ocasionalmente
☐ 1 a 2 vezes por semana
☐ 3 ou mais vezes por semana

26. Numa semana normal, quantas horas por dia (em 24h) passa, em média, o seu educado em espaços ao ar livre?

☐ Horas.

27. Numa semana normal, quantas horas por dia (em 24h) o seu educando vê televisão?

☐ Menos de 1 hora
☐ de 1 a 3 horas
☐ de 3 a 5 horas
☐ 5 ou mais horas

28. Em sua casa qual é a fonte de energia utilizada para cozinhar?

☐ Eletricidade
☐ Gás
☐ Brasas (fogueira aberta)
☐ Outro - Por favor especifique: ____________________________________.

29. Em sua casa qual é a fonte de energia utilizada para aquecimento?

☐ Eletricidade
☐ Gás, querosene, parafina
☐ Madeira, Carvão, Óleo
☐ Outro - Por favor especifique: ____________________________________.

30. Em sua casa o chão é alcatifado?

☐ Sim
☐ Não

31. Em sua casa possui carpetes/tapetes no quarto do seu educando?

☐ Sim
☐ Não

32. Qual a frequência de passagem de automóveis em dias úteis na rua onde vive?

☐ Nunca
☐ Raramente
☐ Frequentemente durante o dia
☐ Quase todo o dia

33. Qual a frequência de passagem de automóveis ao fim de semana na rua onde vive?

☐ Nunca
☐ Raramente
☐ Frequentemente durante o dia
☐ Quase todo o dia

34. Qual foi o peso com o qual o seu educando nasceu?

☐ Kilogramas

35. O seu educando foi alimentado com leite materno?

☐ Sim, durante ☐ meses.
☐ Não

36. Nos primeiros 12 meses de vida do seu educando, era usual dar-lhe paracetamol (ex: benuron) para a febre?

☐ Sim
☐ Não

37. Nos últimos 12 meses quantas vezes, em média, deu ao seu educando paracetamol (ex: benuron)?

☐ Nunca
☐ Pelo menos 1 vez no ano
☐ Pelo menos 1 vez por mês

38. **Nos primeiros 12 meses de vida, o seu educando tomou antibióticos?**

☐ Sim

☐ Não

39. **Nos últimos 12 meses, quantas vezes, em média, o seu educando comeu ou bebeu os seguintes alimentos?** (por favor deixe em branco se desconhece os alimentos)

	Nunca ou ocasionalmente	1 ou 2 vezes por semana	3 ou mais vezes por semana
Carne (ex: vaca, frango, porco)	☐	☐	☐
Peixe e Marisco	☐	☐	☐
Fruta	☐	☐	☐
Vegetais	☐	☐	☐
Leguminosas (ex: ervilhas, feijão)	☐	☐	☐
Cereais (incluindo pão)	☐	☐	☐
Massas	☐	☐	☐
Arroz	☐	☐	☐
Manteiga	☐	☐	☐
Margarina	☐	☐	☐
Nozes	☐	☐	☐
Batatas	☐	☐	☐
Leite	☐	☐	☐
Ovos	☐	☐	☐
Hambúrgueres/*Fast food*	☐	☐	☐

40. **Teve algum gato em casa durante o primeiro ano de vida do seu educando?**

☐ Sim, sem raça.

☐ Sim, de raça ____.

☐ Não

41. **Durante os últimos 12 meses teve algum gato em sua casa?**

☐ Sim, sem raça.

☐ Sim, de raça ____.

☐ Não

42. **Teve algum cão em casa durante o primeiro ano de vida do seu educando?**

☐ Sim, sem raça.

☐ Sim, de raça ____.

☐ Não

43. **Durante os últimos 12 meses teve algum cão em sua casa?**

☐ Sim, sem raça.

☐ Sim, de raça ____.

☐ Não

44. **No primeiro ano de vida, o seu educando teve contacto regular (pelo menos 1 vez por semana) com animais em quintas (ex: porcos, vacas, cabras, ovelhas, galinhas)?**

☐ Sim

☐ Não

45. **A mãe da criança teve contacto regular (pelo menos 1 vez por semana) com animais em quintas enquanto esteve grávida desta criança?**

☐ Sim

☐ Não

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
Lepabe Laboratory for Process Engineering, Environment, Biotechnology and Energy
U.PORTO FMUP FACULDADE DE MEDICINA UNIVERSIDADE DO PORTO
SÃO JOÃO HOSPITAL
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA
COMPETE QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL UNIÃO EUROPEIA

APPENDIX D – Informed consent

DECLARAÇÃO DE CONSENTIMENTO

para participantes privados do exercício de autonomia

Considerando a "Declaração de Helsínquia" da Associação Médica Mundial
(Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996 e Edimburgo 2000)

Designação do Estudo

INAIRCHILD: Poluição do Ar Interior em Infantários e Escolas Primárias - Impacte na Asma Infantil

Eu, abaixo-assinado, (nome completo) --**responsável pelo participante (nome completo)** --, **REFERÊNCIA:** ---------------, compreendi a explicação que me foi fornecida, por escrito e verbalmente, acerca da investigação que se tenciona realizar, para qual é pedida a sua participação. Foi-me dada oportunidade de fazer as perguntas que julguei necessárias, e para todas obtive resposta satisfatória.

Tomei conhecimento de que, de acordo com as recomendações da Declaração de Helsínquia, a informação que me foi prestada versou os objetivos, os métodos, os benefícios previstos, os riscos potenciais e o eventual desconforto. Além disso, foi-me afirmado que tenho o direito de decidir livremente aceitar ou recusar a todo o tempo a sua participação no estudo. Sei que se recusar não haverá qualquer prejuízo na assistência que lhe é prestada.

Foi-me dado todo o tempo de que necessitei para refletir sobre esta proposta de participação.

Nestas circunstâncias, decido livremente aceitar que participe neste projeto de investigação, tal como me foi apresentado pelo investigador(a).

Data: _____ / ___________________ / 20_____

Assinatura do responsável pelo participante:

____

O(A) Investigador(a) responsável:
Nome: Sofia Isabel Vieira de Sousa
Assinatura: Sofia Isabel Vieira de Sousa

APPENDIX E – Supplementary material from Chapter 9

E1 – Potential host and environmental risk factors for childhood asthma

Factors	Description
Host factors	
Sex	Sex of the child: male or female
Age group	Age group: pre-schooler or primary school children (schooler)
BMI classification	Body Mass Index (BMI) classification[a]: underweight (< 5th percentile), normal (5th – 85th percentile), overweight (85th – 95th percentile), obese (≥ 95th percentile)
Birthweight	Birthweight (in grams), considering “low” if < 2500g according to WHO and UNICEF[b]
Older brothers	Number of older brothers
Younger brothers	Number of younger brothers
Born in Portugal	Was the child born in Portugal?
Parental history of asthma	Mother or father of the child has or had asthma
Environmental factors	
Location	Site location according to the outdoor environment: urban or rural
SES classification	Family socioeconomic status (SES) classification in 6 classes[c] based on father and mother jobs and education
Maternal education	Based on the completed mother’s level of education: low (basic education, ≤ 9 years), medium (secondary school, 9-12 years), high (university, > 12 years)
Living with a smoker	Does the child usually live with a smoker?
Smokers in family	How many smokers are in the household?
Smoking during pregnancy	Did the child’s mother smoke during pregnancy?
Sports practice	Does the child practice any sport?
Sports location	The environment where child practice sport: indoor, outdoor or swimming pool
Breath limiting physical activities	How many times per week does the child practice physical activities long enough to limit breathing?
Energy source for cooking	What is the main source of energy used for cooking at child’s home?
Energy source for heating	What is the main source of energy used for heating at child’s home?
Carpet floor in house	Is home’s floor carpeted?
Carpet in child’s bedroom	Is child’s bedroom floor carpeted?

E1 (*cont.*) – Potential host and environmental risk factors for childhood asthma

Factors	**Description**
Environmental factors (cont.)	
Traffic near home during week	Traffic frequency on the street where the child lives during weekdays
Traffic near home during weekend	Traffic frequency on the street where the child lives during weekend
Paracetamol administration in child's 1st year of life	Did your child was usually given paracetamol during his/her first of life?
Paracetamol administration in previous year	How often was your child given paracetamol in the last 12 months?
Antibiotics administration in child's 1st year of life	Did your child was given antibiotics during his/her first of life?
Meat intake	In the last 12 months, how often did your child eat meat per week?
Fish intake	In the last 12 months, how often did your child eat fish per week?
Fruit intake	In the last 12 months, how often did your child eat fruits per week?
Vegetables intake	In the last 12 months, how often did your child eat vegetables per week?
Legumes intake	In the last 12 months, how often did your child eat legumes per week?
Cereals intake	In the last 12 months, how often did your child eat cereals (including bread) per week?
Pasta intake	In the last 12 months, how often did your child eat pasta per week?
Rice intake	In the last 12 months, how often did your child eat rice per week?
Butter intake	In the last 12 months, how often did your child eat butter per week?
Margarine intake	In the last 12 months, how often did your child eat margarine per week?
Nuts intake	In the last 12 months, how often did your child eat nuts per week?
Potatoes intake	In the last 12 months, how often did your child eat potatoes per week?
Milk intake	In the last 12 months, how often did your child drink milk per week?
Eggs intake	In the last 12 months, how often did your child eat eggs per week?
Fast food intake	In the last 12 months, how often did your child eat fast food per week?
Cat at home in child's 1st year of life	During the first year of life, was there a cat at the child's household?
Cat at home in previous year	In the last 12 months, was there a cat at the child's household?
Dog at home in child's 1st year of life	During the first year of life, was there a dog at the child's household?

E1 (*cont.*) – Potential host and environmental risk factors for childhood asthma

Factors	**Description**
Environmental factors (cont.)	
Dog at home in previous year	In the last 12 months, was there a dog at the child's household?
Regular contact with farm animals in child's 1st year of life	During the first year of life, was the child in regular contact (at least once a week) with farm animals?
Regular contact with farm animals during pregnancy	During pregnancy, was the child's mother in regular contact (at least once a week) with farm animals?
Breastfeeding time	Duration of breastfeeding: ≥ 4 months, < 4 months, or no breastfeeding
Daily time watching TV	In a typical week, how many hours per day does your child watch television?

[a] According to *Nihiser, A.J., et al., Body mass index measurement in schools. J Sch Health, 2007. 77(10): p. 651-71; quiz 722-4.*

[b] *World Health Organization and UNICEF, Low birthweight: country, regional and global estimates. Geneva, 2004.*

[c] Adapted from Graffar's scale, with class 1 representing the highest SES, class 5 the lowest and class 6 for those not classified (unemployed, professions not known): *Graffar, M and Corbier, J, Contribution to the study of the influence of socioeconomic conditions in growth and development of children, Rev Chil Pediatr 1966; 37: 801-2.*

E2 – Summary of bivariate analysis (crude odds ratio, 95% confidence intervals and *p*-values) for all the studied factors

Factors	**OR (95%CI)**	***p*-value**[a]	***p*-value**[b]
Campaign			
C2 vs C1	1.00 (0.59-1.70)	0.991	0.991
Host factors			
Sex			
Male vs Female	1.84 (1.11-3.05)	**0.017***	**0.015***
Age			
Schooler	Reference		0.183
Pre-schooler	0.71 (0.42-1.18)	0.189	
BMI classification			
Normal	Reference		0.996
Underweight	1.06 (0.36-3.10)	0.921	
Overweight	0.96 (0.43-2.15)	0.929	
Obese	1.07 (0.51-2.24)	0.851	
Birthweight			
Low vs Normal	1.71 (0.85-3.44)	0.135	0.156
Older brothers			
0	Reference		0.700
1	0.83 (0.48-1.42)	0.493	
2 or more	0.75 (0.31-1.82)	0.530	
Younger brothers			
0	Reference		0.295
1	0.76 (0.40-1.41)	0.381	
2 or more	2.29 (0.66-7.95)	0.191	
Born in Portugal			
No vs Yes	0.62 (0.15-2.61)	0.519	0.489
Parental history of asthma			
Yes vs No	4.21 (2.49-7.11)	**< 0.001***	**< 0.001***
Environmental factors			
Location			
Rural vs Urban	0.78 (0.48-1.29)	0.340	0.337
SES classification			
1	Reference		0.196
2	0.41 (0.15-1.12)	0.082	
3	0.88 (0.38-2.03)	0.768	
4	1.07 (0.56-2.01)	0.846	
5	0.56 (0.22-1.46)	0.236	
6	1.46 (0.55-3.84)	0.448	
Maternal education			
Medium (9-12 years)	Reference		0.698
Low (≤ 9 years)	1.18 (0.64-2.18)	0.586	
High (> 12 years)	0.92 (0.51-1.65)	0.777	
Living with a smoker			
Yes vs No	1.23 (0.75-2.00)	0.410	0.412

E2 (*cont.*) – Summary of bivariate analysis (crude odds ratio, 95% confidence intervals and *p*-values) for all the studied factors

Factors	**OR (95%CI)**	***p*-value**[a]	***p*-value**[b]
Smokers in family			
0	Reference		0.598
1	0.96 (0.54-1.71)	0.903	
2	0.99 (0.45-2.18)	0.984	
>=3	2.25 (0.75-6.73)	0.147	
Smoking during pregnancy			
Yes vs No	1.03 (0.52-2.06)	0.933	0.933
Sports practice			
Yes vs No	1.07 (0.65-1.74)	0.797	0.797
Sports location			
indoor	Reference		0.386
outdoor	1.96 (0.68-5.71)	0.215	
pool	1.58 (0.70-3.59)	0.273	
Breath limiting physical activities			
Never or ocasionally	Reference		0.939
1 or more times a week	1.02 (0.60-1.74)	0.939	
Energy source for cooking			
Gas or other vs Electricity	1.04 (0.63-1.70)	0.889	0.889
Energy source for heating			
Electricity	Reference		0.344
Gas- kerosene- paraffin	0.58 (0.27-1.24)	0.161	
Wood- coal- oil	0.72 (0.42-1.23)	0.227	
None	1.56 (0.35-7.02)	0.561	
Carpet floor in house			
Yes vs No	-	-	-
Carpet in child's bedroom			
Yes vs No	0.48 (0.29-0.78)	**0.003***	**0.004***
Traffic near home during week			
Almost all day	Reference		0.300
Often during the day	0.64 (0.37-1.12)	0.119	
Rarely or never	0.77 (0.41-1.45)	0.420	
Traffic near home during weekend			
Almost all day	Reference		0.337
Often during the day	0.75 (0.41-1.35)	0.335	
Rarely or never	0.60 (0.31-1.18)	0.141	
Paracetamol administration in child's 1st year of life			
Yes vs No	1.82 (1.08-3.07)	**0.025***	**0.021***
Paracetamol administration in previous year			
Less than once a month	Reference		**< 0.001***
At least once a month	3.95 (2.40-6.49)	**< 0.001***	
Antibiotics administration in child's 1st year of life			
Yes vs No	2.72 (1.59-4.66)	**< 0.001***	**< 0.001***

E2 (*cont.*) – Summary of bivariate analysis (crude odds ratio, 95% confidence intervals and *p*-values) for all the studied factors

Factors	**OR (95%CI)**	***p*-value[a]**	***p*-value[b]**
Meat intake			
< 3 times/week vs ≥ 3 times/week	1.07 (0.62-1.82)	0.816	0.817
Fish intake			
< 3 times/week vs ≥ 3 times/week	1.13 (0.67-1.90)	0.646	0.644
Fruit intake			
< 3 times/week vs ≥ 3 times/week	0.80 (0.36-1.78)	0.579	0.568
Vegetables intake			
< 3 times/week vs ≥ 3 times/week	1.26 (0.74-2.14)	0.391	0.396
Legumes intake			
< 3 times/week vs ≥ 3 times/week	0.72 (0.44-1.18)	0.191	0.192
Cereals intake			
< 3 times/week vs ≥ 3 times/week	0.70 (0.30-1.64)	0.406	0.385
Pasta intake			
< 3 times/week vs ≥ 3 times/week	0.78 (0.47-1.28)	0.319	0.316
Rice intake			
< 3 times/week vs ≥ 3 times/week	0.85 (0.50-1.42)	0.527	0.524
Butter intake			
≥ 3 times/week	Reference		0.089
1 or 2 times/week	0.65 (0.37-1.13)	0.129	
Never or ocasionally	0.49 (0.24-0.99)	**0.048***	
Margarine intake			
< 3 times/week vs ≥ 3 times/week	0.89 (0.49-1.63)	0.716	0.713
Nuts intake			
≥ 1 time/week vs Never or ocasionally	1.34 (0.75-2.40)	0.326	0.337
Potatoes intake			
< 3 times/week vs ≥ 3 times/week	1.10 (0.67-1.79)	0.716	0.716
Milk intake			
< 3 times/week vs ≥ 3 times/week	1.27 (0.57-2.85)	0.562	0.573
Eggs intake			
≥ 3 times/week	Reference		0.577
1 or 2 times/week	1.07 (0.54-2.13)	0.836	
Never or ocasionally	1.43 (0.75-2.71)	0.280	
Fast food intake			
≥ 1 time/week vs Never or ocasionally	1.55 (0.83-2.91)	0.171	0.188
Cat at home in child's 1st year of life			
Yes vs No	1.98 (1.05-3.72)	**0.035***	**0.047***
Cat at home in previous year			
Yes vs No	1.75 (1.03-2.96)	**0.037***	**0.043***
Dog at home in child's 1st year of life			
Yes vs No	1.78 (1.05-3.02)	**0.031***	**0.038***
Dog at home in previous year			
Yes vs No	1.17 (0.70-1.98)	0.546	0.550
Regular contact with farm animals in child's 1st year of life			
Yes vs No	0.62 (0.31-1.23)	0.174	0.154

E2 (*cont.*) – Summary of bivariate analysis (crude odds ratio, 95% confidence intervals and *p*-values) for all the studied factors

Factors	**OR (95%CI)**	***p*-value**[a]	***p*-value**[b]
Regular contact with farm animals during pregnancy			
Yes vs No	0.72 (0.36-1.43)	0.353	0.336
Breastfeeding time			
≥ 4 months	Reference		0.795
< 4 months	1.01 (0.56-1.85)	0.964	
No	1.25 (0.65-2.40)	0.499	
Daily time watching TV			
< 1h	Reference		0.283
1-3h	0.74 (0.44-1.24)	0.256	
> 3h	0.50 (0.19-1.34)	0.167	

a – Wald's test; b – Likelihood-ratio test; OR – odds ratio; CI – confidence interval; BMI – Body Mass Index; SES – Socioeconomic status; *statistically significant (*p*-value < 0.05)

E3 – Missing data in the studied variables, imputation decision and method

Variable	Missing data (%)	To impute?	Method of imputation
Campaign	0.00	No	NA
Location	0.00	No	NA
Sex	0.00	No	NA
Age group	0.00	No	NA
BMI classification	31.24	Yes	polyreg
SES classification	0.41	Yes	polyreg
Older brothers	8.03	Yes	polyreg
Younger brothers	8.79	Yes	polyreg
Born in Portugal	0.59	Yes	logreg
Maternal education	1.99	Yes	polyreg
Living with a smoker	0.41	Yes	logreg
Smokers in family	6.80	Yes	polyreg
Smoking during pregnancy	0.82	Yes	logreg
Parental history of asthma	0.59	Yes	logreg
Sports practice	0.47	Yes	logreg
Sports location	**56.39**	No	NA
Breath limiting physical activities	4.51	Yes	logreg
Energy source for cooking	0.12	Yes	polyreg
Energy source for heating	1.99	Yes	polyreg
Carpet floor in house	0.35	Yes	logreg
Carpet in child’s bedroom	0.35	Yes	logreg
Traffic near home during week	0.59	Yes	polyreg
Traffic near home during weekend	0.70	Yes	polyreg
Paracetamol administration in child’s 1st year of life	0.94	Yes	logreg
Paracetamol administration in previous year	1.58	Yes	logreg
Antibiotics administration in child’s 1st year of life	2.29	Yes	logreg
Meat intake	1.93	Yes	logreg
Fish intake	2.70	Yes	logreg
Fruit intake	1.76	Yes	logreg
Vegetables intake	3.58	Yes	logreg
Legumes intake	2.87	Yes	logreg
Cereals intake	2.29	Yes	logreg
Pasta intake	1.99	Yes	logreg
Rice intake	2.34	Yes	logreg
Butter intake	4.28	Yes	polyreg
Margarine intake	9.67	Yes	logreg
Nuts intake	5.16	Yes	logreg
Potatoes intake	2.29	Yes	logreg
Milk intake	2.17	Yes	logreg

E3 (*cont.*) – Missing data in the studied outcomes and variables, imputation decision and method

Variable	**Missing data (%)**	**To impute?**	**Method of imputation**
Eggs intake	3.11	Yes	polyreg
Fast food intake	3.05	Yes	logreg
Cat at home in child's 1st year of life	0.47	Yes	logreg
Cat at home in previous year	0.41	Yes	logreg
Dog at home in child's 1st year of life	0.76	Yes	logreg
Dog at home in previous year	0.53	Yes	logreg
Regular contact with farm animals in child's 1st year of life	0.59	Yes	logreg
Regular contact with farm animals during pregnancy	0.76	Yes	logreg
Breastfeeding time	2.99	Yes	polyreg
Daily time watching TV	4.40	Yes	logreg
Birthweight	4.40	Yes	logreg

NA – not applicable; polyreg – polytomous regression; logreg – logistic regression

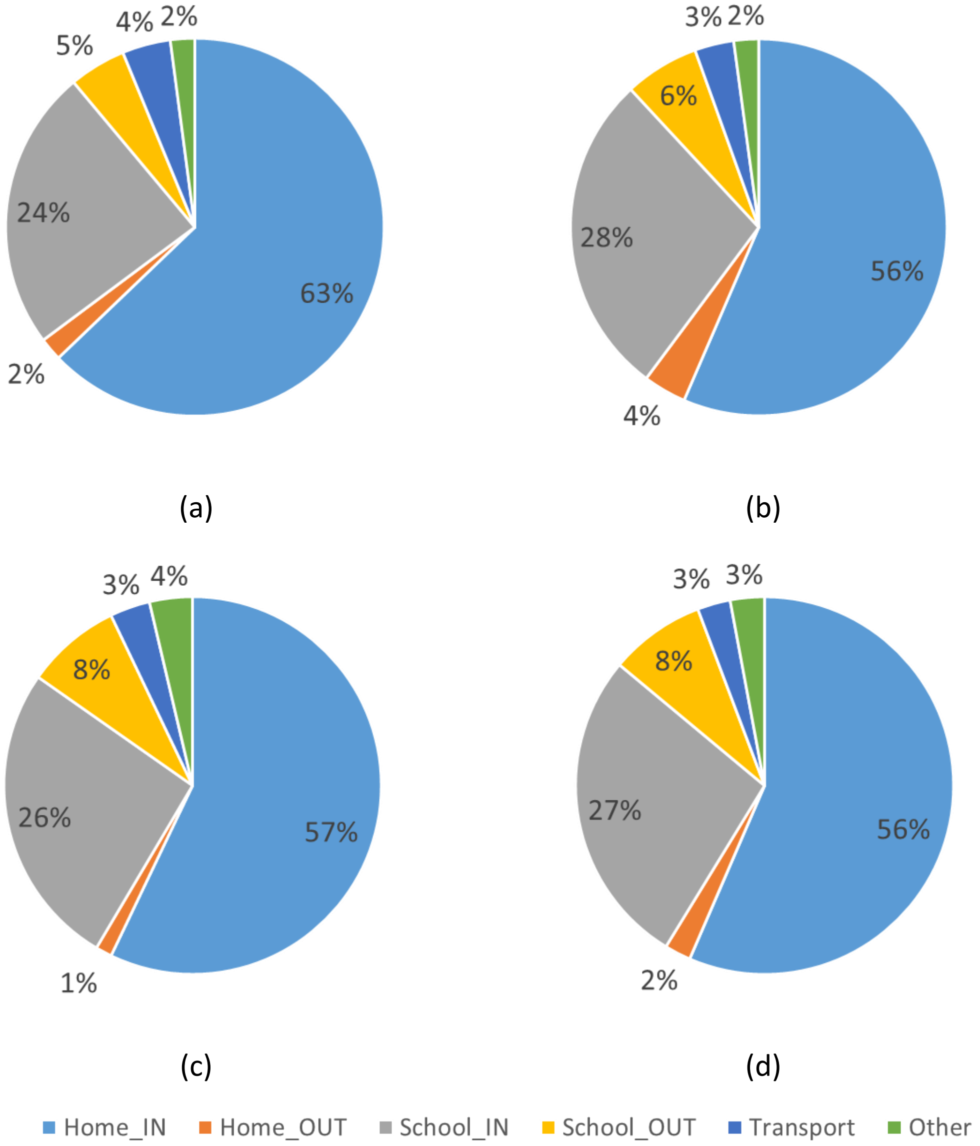
APPENDIX F – Supplementary material from chapter 10

F1- Aeroallergen sensitization in the subpopulation which reported asthma and/or asthmatic symptoms (n = 341)

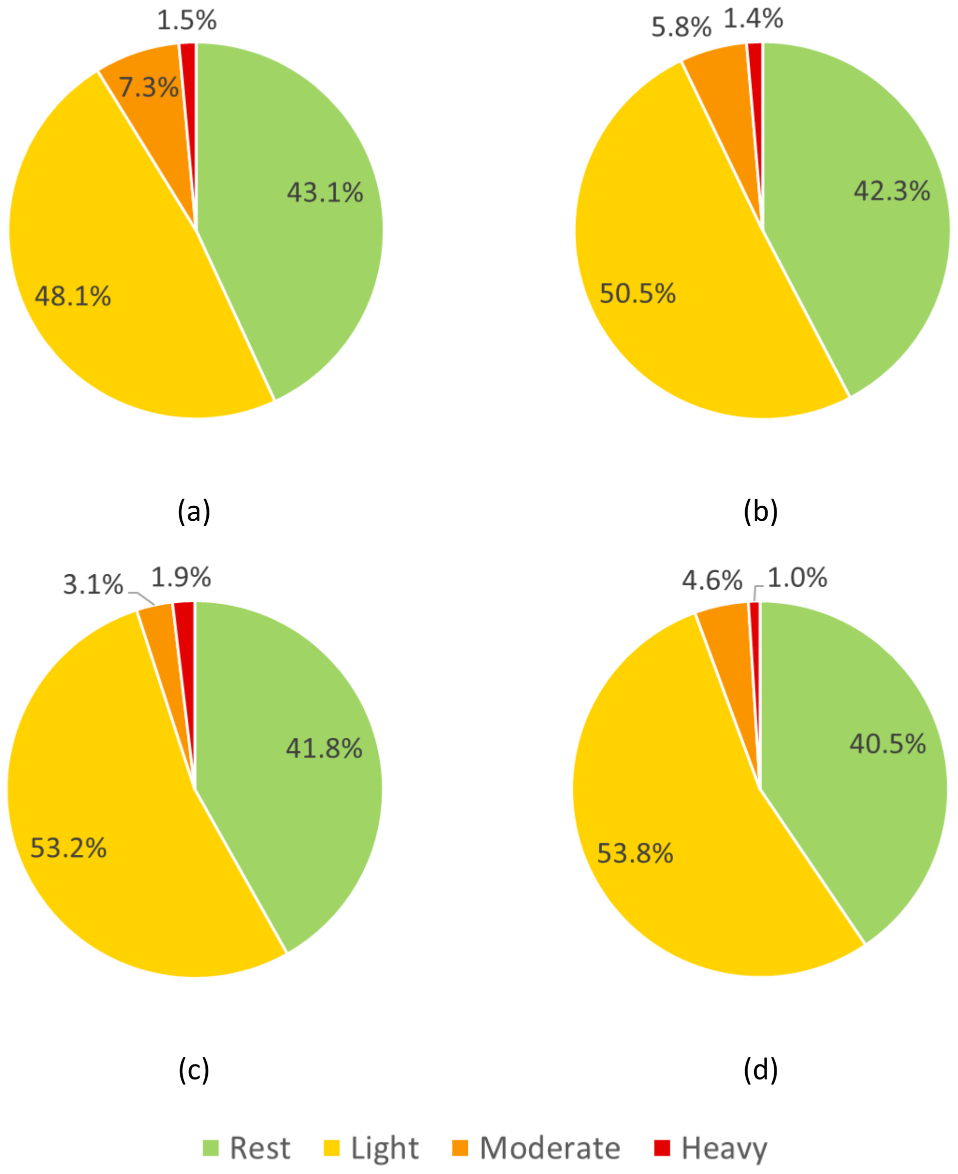
Allergen	**Subpopulation (n=341)**		**Pre-schoolers (n=117)**		**Primary school children (n=224)**		***p*-value**	**Urban (n=196)**		**Rural (n=145)**		***p*-value**
	n	**%**	**n**	**%**	**n**	**%**		**n**	**%**	**n**	**%**	
Dust mites	85	25	19	16	66	29	**0.01***	62	32	23	16	**< 0.01***
Pollens	37	11	20	17	17	8	0.37	42	21	27	19	0.62
Animal dander	50	15	17	15	33	15	1.00	26	13	24	17	0.49
Sensitization												
Monosensitised	58	17	12	10	46	21	**0.02***	42	21	16	11	**0.02***
Polysensitised	62	18	18	15	44	20	0.41	37	19	25	17	0.81

* statistically significant (*p*-value < 0.05)

F2 –Proportion (%) of time of a typical weekday (24-hour) spent in each major microenvironment by: (a) Pre-schoolers from urban sites; (b) Pre-schoolers from rural sites; (c) Primary school children from urban sites; and (d) Primary school children from rural sites.


(a)
(b)
(c)
(d)

F3 –Proportion (%) of time of a typical weekday (24-hour) spent in each type of activity by: (a) Pre-schoolers from urban sites; (b) Pre-schoolers from rural sites; (c) Primary school children from urban sites; and (d) Primary school children from rural sites.



F4 - Calculated hourly mean inhalation rates used to estimate daily inhaled doses

Hour	**Pre-schoolers**		**Primary school children**	
	Urban	**Rural**	**Urban**	**Rural**
0	0.273	0.272	0.288	0.288
1	0.273	0.272	0.288	0.288
2	0.273	0.272	0.288	0.288
3	0.273	0.272	0.288	0.288
4	0.273	0.272	0.288	0.288
5	0.273	0.272	0.288	0.288
6	0.279	0.274	0.289	0.296
7	0.363	0.375	0.382	0.455
8	0.628	0.638	0.633	0.652
9	0.657	0.670	0.662	0.661
10	0.660	0.673	0.659	0.790
11	0.671	0.665	0.660	0.661
12	0.660	0.657	0.668	0.675
13	0.638	0.690	0.671	0.814
14	0.707	0.654	0.668	0.663
15	0.700	0.665	0.678	0.673
16	0.867	0.677	0.698	0.811
17	0.981	0.767	0.801	0.670
18	1.082	1.095	1.022	0.859
19	0.884	1.049	1.095	0.922
20	0.798	0.844	0.825	0.782
21	0.661	0.628	0.670	0.677
22	0.290	0.292	0.307	0.299
23	0.286	0.286	0.297	0.294

F5 - Summary results of each unipollutant multivariate exposure model, considering exposure factorized by median as cutoff: adjusted odds ratio (aOR), its 95% confidence interval, and significance (p-value)

	Active wheezing		**Reported asthma**		**Diagnosed asthma**		**Obstructive disorder**		**Dysfunction**	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
CO_2	0.80 (0.54,1.17)	0.248	0.56 (0.31,1.02)	0.056*	0.90 (0.49,1.65)	0.725	0.81 (0.51,1.29)	0.373	1.06 (0.61,1.84)	0.827
CO	0.69 (0.46,1.04)	0.073*	0.84 (0.44,1.58)	0.582	0.51 (0.26,1.01)	0.051*	0.48 (0.28,0.79)	**0.004*** **	0.56 (0.31,0.99)	**0.047** **
CH_2O	0.80 (0.51,1.24)	0.307	0.47 (0.23,0.95)	**0.030** **	1.19 (0.60,2.39)	0.621	1.87 (1.07,3.26)	**0.028** **	1.43 (0.75,2.73)	0.283
NO_2	1.62 (1.09,2.43)	**0.017** **	0.90 (0.49,1.67)	0.748	0.89 (0.47,1.69)	0.729	1.48 (0.88,2.48)	0.135	1.36 (0.69,2.70)	0.371
O_3	1.24 (0.83,1.84)	0.297	1.24 (0.67,2.31)	0.494	1.14 (0.59,2.19)	0.694	1.36 (0.84,2.21)	0.210	2.70 (1.45,5.01)	**0.001*** **
TVOC	0.94 (0.64,1.37)	0.739	0.46 (0.25,0.85)	**0.011** **	0.65 (0.34,1.21)	0.169	1.04 (0.65,1.67)	0.868	0.87 (0.50,1.53)	0.638
$PM_{2.5}$	0.77 (0.51,1.17)	0.225	1.07 (0.55,2.09)	0.837	0.94 (0.46,1.89)	0.857	1.14 (0.67,1.92)	0.627	2.43 (1.29,4.61)	**0.005*** **
PM_{10}	0.74 (0.49,1.12)	0.148	1.25 (0.64,2.45)	0.515	0.80 (0.40,1.61)	0.531	1.11 (0.65,1.89)	0.708	3.54 (1.82,6.88)	**< 0.001*** **

aOR - odds ratio; CI - Confidence interval; * significant at p-value < 0.10; ** significant at p-value < 0.05; *** significant at p-value < 0.01

F6 – Summary results of each unipollutant multivariate inhaled dose model, considering inhaled factorized by median as cutoff: adjusted odds ratio (aOR), its 95% confidence interval, and significance (*p*-value)

	Active wheezing		**Reported asthma**		**Diagnosed asthma**		**Obstructive disorder**		**Dysfunction**	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
CO_2	0.81 (0.55,1.20)	0.285	0.58 (0.32,1.07)	0.079*	1.01 (0.54,1.89)	0.974	0.74 (0.46,1.18)	0.201	0.64 (0.36,1.13)	0.123
CO	0.71 (0.47,1.06)	0.094*	0.98 (0.52,1.84)	0.947	0.60 (0.31,1.17)	0.132	0.58 (0.35,0.97)	**0.035****	0.78 (0.44,1.39)	0.403
CH_2O	0.84 (0.54,1.29)	0.414	0.55 (0.28,1.10)	0.085*	1.32 (0.67,2.60)	0.423	1.62 (0.95,2.75)	0.075*	1.50 (0.82,2.75)	0.194
NO_2	1.57 (1.05,2.35)	**0.028****	0.99 (0.53,1.84)	0.976	1.08 (0.57,2.06)	0.805	1.70 (1.01,2.87)	**0.043****	1.03 (0.53,2.01)	0.932
O_3	1.19 (0.80,1.76)	0.399	0.99 (0.54,1.83)	0.984	0.78 (0.41,1.47)	0.437	1.55 (0.95,2.51)	0.075*	2.61 (1.42,4.82)	**0.002*****
TVOC	0.95 (0.65,1.39)	0.777	0.54 (0.30,0.97)	**0.039****	0.66 (0.36,1.24)	0.196	0.65 (0.40,1.04)	0.074*	0.50 (0.28,0.89)	**0.017****
$PM_{2.5}$	0.99 (0.62,1.59)	0.982	1.04 (0.51,2.13)	0.909	1.14 (0.54,2.39)	0.736	1.15 (0.69,1.93)	0.595	1.72 (0.95,3.11)	0.069*
PM_{10}	0.95 (0.60,1.51)	0.842	1.48 (0.72,3.07)	0.286	1.49 (0.71,3.15)	0.289	1.14 (0.68,1.91)	0.626	2.39 (1.30,4.41)	**0.005*****

aOR – adjusted odds ratio; CI – Confidence interval; * significant at p-value < 0.10; ** significant at p-value < 0.05; *** significant at p-value < 0.01

F7 **-** Summary results of each unipollutant multivariate exposure model, considering exposure factorized by threshold as cutoff: adjusted odds ratio (aOR), its 95% confidence interval, and significance (*p*-value)

	Active wheezing		**Reported asthma**		**Diagnosed asthma**		**Obstructive disorder**		**Dysfunction**	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
CO_2	0.80 (0.54,1.17)	0.253	0.64 (0.35,1.16)	0.139	1.09 (0.59,1.99)	0.785	0.90 (0.57,1.42)	0.649	1.08 (0.62,1.88)	0.786
CO	-	-	-	-	-	-	-	-	-	-
CH_2O	0.43 (0.18,1.01)	**0.037****	0.22 (0.03,1.79)	0.086*	0.29 (0.04,2.26)	0.159	0.72 (0.22,2.38)	0.581	1.34 (0.31,5.84)	0.704
NO_2	-	-	-	-	-	-	-	-	-	-
O_3	-	-	-	-	-	-	-	-	-	-
TVOC	2.82 (0.77,10.36)	0.139	a	a	2.18 (0.24,20.09)	0.524	2.93 (0.55,15.45)	0.218	2.06 (0.19,22.78)	0.575
$PM_{2.5}$	3.00 (0.70,12.94)	0.088*	0.95 (0.19,4.64)	0.951	0.99 (0.20,4.81)	0.991	1.22 (0.39,3.76)	0.729	1.63 (0.42,6.35)	0.466
PM_{10}	1.24 (0.74,2.08)	0.409	1.31 (0.56,3.10)	0.522	1.01 (0.44,2.30)	0.990	1.29 (0.70,2.36)	0.411	2.73 (1.21,6.12)	**0.010****

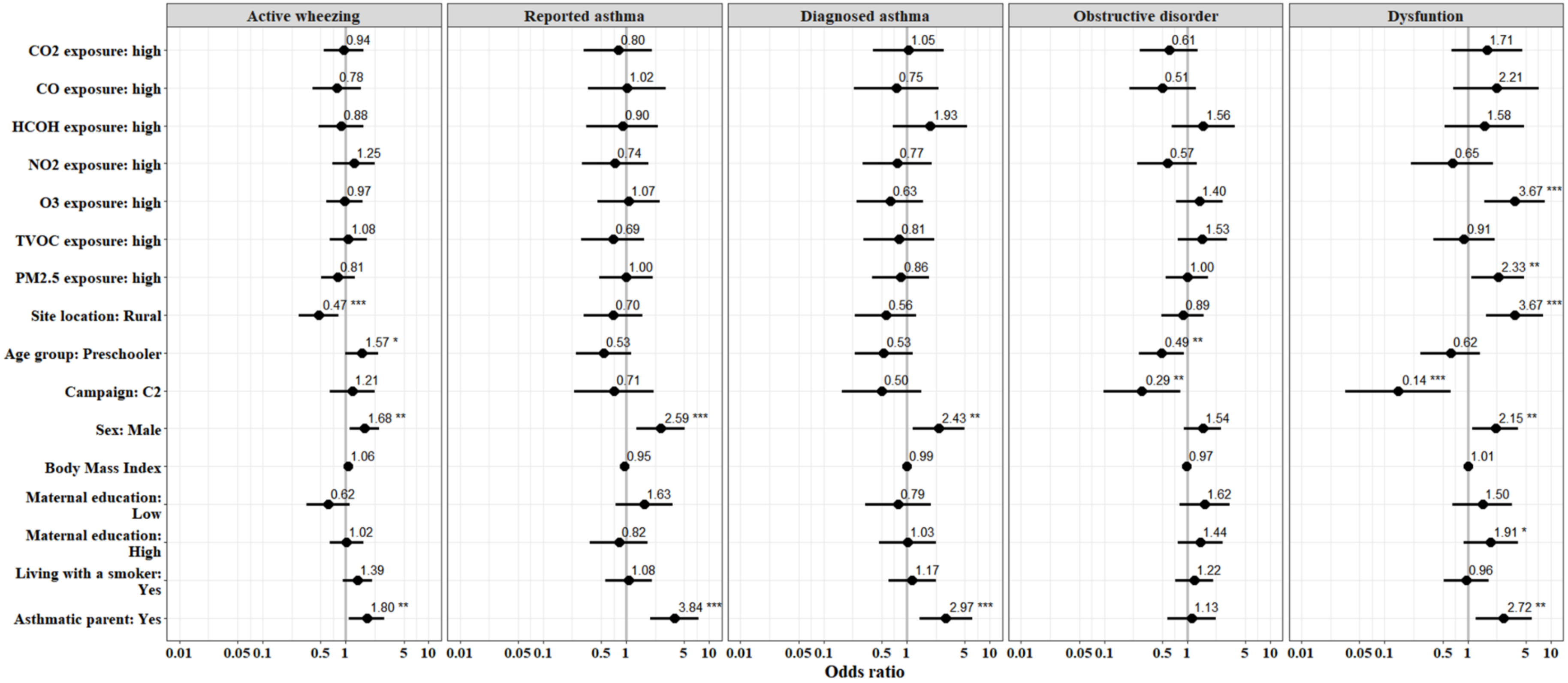
aOR - adjusted odds ratio; CI - Confidence interval; a - no cases of reported asthma when exposure exceeded TVOC threshold; * significant at p-value < 0.10; ** significant at p-value < 0.05; *** significant at p-value < 0.01

F8 –Summary results of each unipollutant multivariate exposure model, considering exposure factorized into those exposed to levels above (exposed at risk) or below the threshold (not exposed at risk): adjusted odds ratio (aOR), its 95% confidence interval, and significance (*p*-value)

	Active wheezing		**Reported asthma**		**Diagnosed asthma**		**Obstructive disorder**		**Dysfunction**	
	aOR (95% CI)	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**	**aOR (95% CI)**	***p*-value**
CO_2	0.72 (0.49,1.07)	0.102	0.58 (0.32,1.05)	0.068*	0.96 (0.52,1.75)	0.883	0.68 (0.42,1.09)	0.106	0.87 (0.50,1.51)	0.614
CO	-	-	-	-	-	-	-	-	-	-
CH_2O	0.58 (0.34,0.98)	**0.034****	0.42 (0.17,1.03)	**0.040****	0.59 (0.25,1.39)	0.205	0.42 (0.20,0.88)	**0.016****	1.09 (0.48,2.50)	0.832
NO_2	-	-	-	-	-	-	-	-	-	-
O_3	-	-	-	-	-	-	-	-	-	-
TVOC	0.79 (0.43,1.47)	0.454	0.42 (0.14,1.24)	0.086*	0.45 (0.13,1.51)	0.151	0.63 (0.23,1.73)	0.357	0.09 (0.01,0.78)	**0.004*****
$PM_{2.5}$	0.92 (0.60,1.41)	0.702	1.92 (0.86,4.30)	0.096*	1.27 (0.58,2.75)	0.545	1.13 (0.65,1.97)	0.662	2.08 (1.04,4.14)	**0.034*****
PM_{10}	0.74 (0.47,1.16)	0.187	0.78 (0.38,1.63)	0.510	0.82 (0.38,1.75)	0.595	1.08 (0.63,1.86)	0.778	3.19 (1.74,5.87)	**< 0.001*****

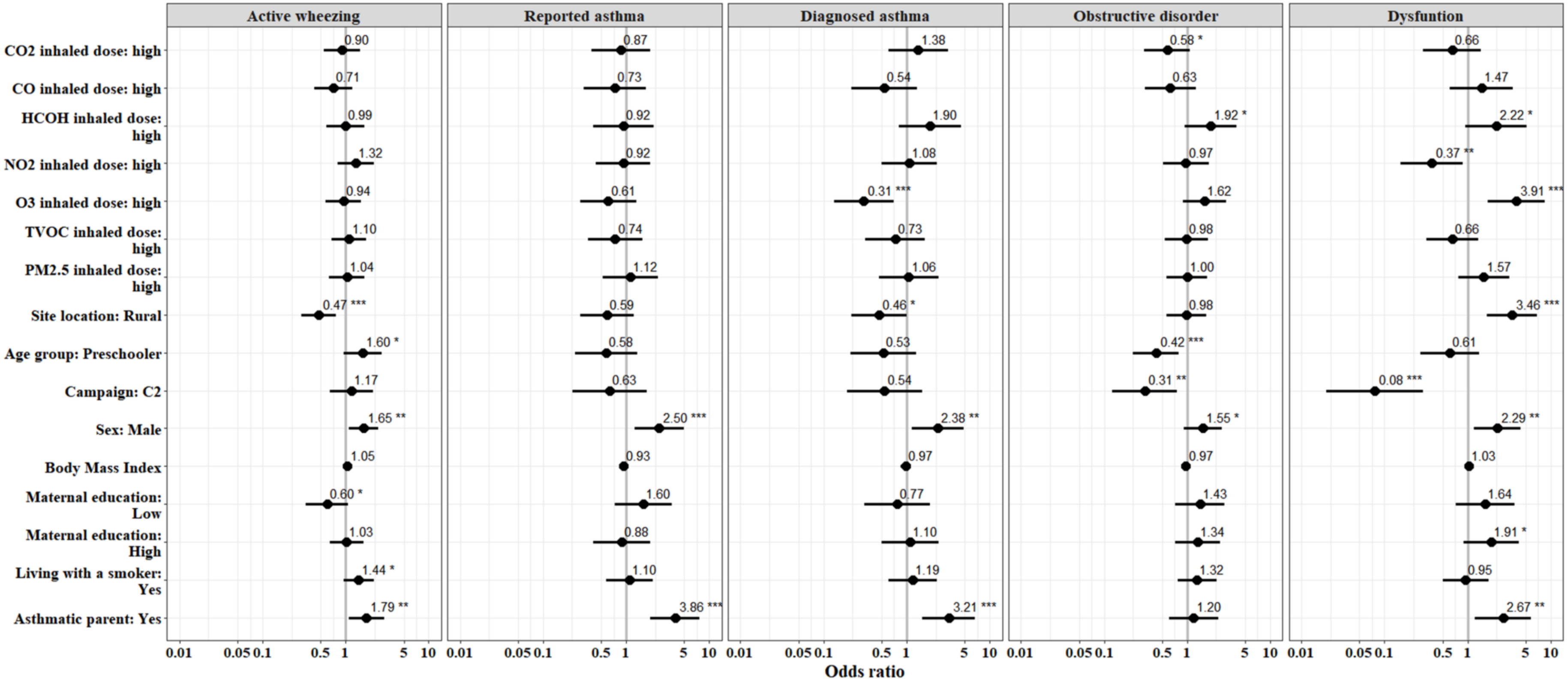
aOR – adjusted odds ratio; CI – Confidence interval; * significant at p-value < 0.10; ** significant at p-value < 0.05; *** significant at p-value < 0.01

F9 - Results from the multipollutant multivariate logistic regression models (adjusted odds ratio and 95% confidence intervals), when considering exposure to indoor air pollutants factorized by median as cutoff and all the studied respiratory health outcomes (active wheezing, reported asthma, diagnosed asthma, obstructive disorder and dysfunction).



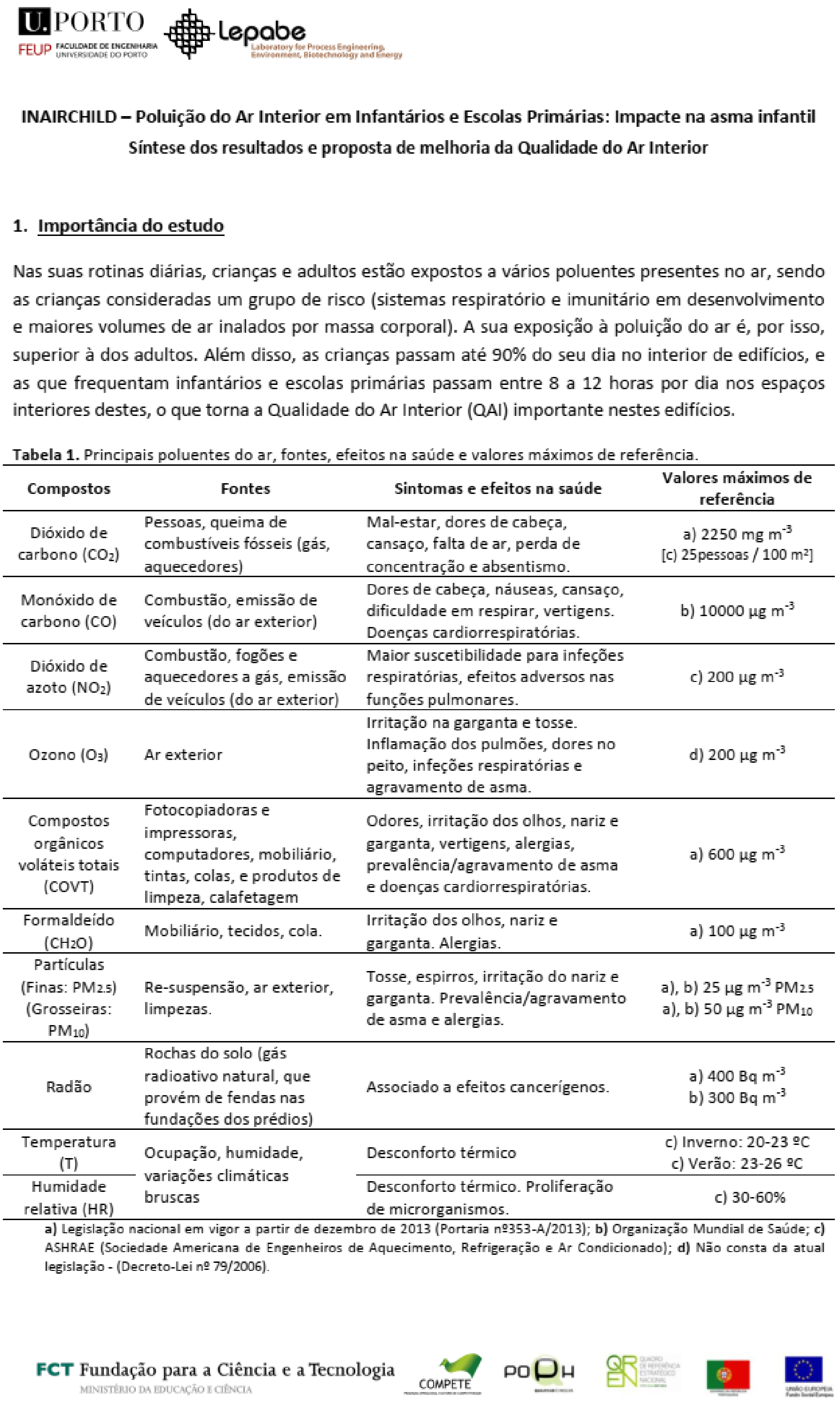
n.s. – not significant * *p*-value < 0.10; ** *p*-value < 0.05; *** *p*-value < 0.01

F10 - Results from the multipollutant multivariate logistic regression models (adjusted odds ratio and 95% confidence intervals), when considering inhaled dose of indoor air pollutants factorized by median as cutoff and all the studied respiratory health outcomes (active wheezing, reported asthma, diagnosed asthma, obstructive disorder and dysfunction).



n.s. – not significant * *p*-value < 0.10; ** *p*-value < 0.05; *** *p*-value < 0.01

APPENDIX G – Indoor air quality report



INAIRCHILD – Poluição do Ar Interior em Infantários e Escolas Primárias: Impacte na asma infantil
Síntese dos resultados e proposta de melhoria da Qualidade do Ar Interior

1. Importância do estudo

Nas suas rotinas diárias, crianças e adultos estão expostos a vários poluentes presentes no ar, sendo as crianças consideradas um grupo de risco (sistemas respiratório e imunitário em desenvolvimento e maiores volumes de ar inalados por massa corporal). A sua exposição à poluição do ar é, por isso, superior à dos adultos. Além disso, as crianças passam até 90% do seu dia no interior de edifícios, e as que frequentam infantários e escolas primárias passam entre 8 a 12 horas por dia nos espaços interiores destes, o que torna a Qualidade do Ar Interior (QAI) importante nestes edifícios.

Tabela 1. Principais poluentes do ar, fontes, efeitos na saúde e valores máximos de referência.

Compostos	Fontes	Sintomas e efeitos na saúde	Valores máximos de referência
Dióxido de carbono (CO_2)	Pessoas, queima de combustíveis fósseis (gás, aquecedores)	Mal-estar, dores de cabeça, cansaço, falta de ar, perda de concentração e absentismo.	a) 2250 mg m^{-3} [c) 25pessoas / 100 m^2]
Monóxido de carbono (CO)	Combustão, emissão de veículos (do ar exterior)	Dores de cabeça, náuseas, cansaço, dificuldade em respirar, vertigens. Doenças cardiorrespiratórias.	b) 10000 µg m^{-3}
Dióxido de azoto (NO_2)	Combustão, fogões e aquecedores a gás, emissão de veículos (do ar exterior)	Maior suscetibilidade para infeções respiratórias, efeitos adversos nas funções pulmonares.	c) 200 µg m^{-3}
Ozono (O_3)	Ar exterior	Irritação na garganta e tosse. Inflamação dos pulmões, dores no peito, infeções respiratórias e agravamento de asma.	d) 200 µg m^{-3}
Compostos orgânicos voláteis totais (COVT)	Fotocopiadoras e impressoras, computadores, mobiliário, tintas, colas, e produtos de limpeza, calafetagem	Odores, irritação dos olhos, nariz e garganta, vertigens, alergias, prevalência/agravamento de asma e doenças cardiorrespiratórias.	a) 600 µg m^{-3}
Formaldeído (CH_2O)	Mobiliário, tecidos, cola.	Irritação dos olhos, nariz e garganta. Alergias.	a) 100 µg m^{-3}
Partículas (Finas: $PM_{2.5}$) (Grosseiras: PM_{10})	Re-suspensão, ar exterior, limpezas.	Tosse, espirros, irritação do nariz e garganta. Prevalência/agravamento de asma e alergias.	a), b) 25 µg m^{-3} $PM_{2.5}$ a), b) 50 µg m^{-3} PM_{10}
Radão	Rochas do solo (gás radioativo natural, que provém de fendas nas fundações dos prédios)	Associado a efeitos cancerígenos.	a) 400 Bq m^{-3} b) 300 Bq m^{-3}
Temperatura (T)	Ocupação, humidade, variações climáticas bruscas	Desconforto térmico	c) Inverno: 20-23 ºC c) Verão: 23-26 ºC
Humidade relativa (HR)		Desconforto térmico. Proliferação de microrganismos.	c) 30-60%

a) Legislação nacional em vigor a partir de dezembro de 2013 (Portaria nº353-A/2013); **b)** Organização Mundial de Saúde; **c)** ASHRAE (Sociedade Americana de Engenheiros de Aquecimento, Refrigeração e Ar Condicionado); **d)** Não consta da atual legislação - (Decreto-Lei nº 79/2006).

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		Legislação Portuguesa [a]			OMS [b]			ASHRAE [c]		
		Semana		Fim Semana	Semana		Fim Semana	Semana		Fim Semana
Sala	Parâmetro	Com Ocupação	Sem Ocupação		Com Ocupação	Sem Ocupação		Com Ocupação	Sem Ocupação	
DOR[d] 2 Anos	CO_2	✓	☺	-	-	-	-	-	-	-
	CO	✓	☺	-	☺	☺	-	-	-	-
	NO_2	✓	☺	-	☺	☺	-	-	-	-
	O_3	✓	☺	-	-	-	-	-	-	-
	TVOC	✓	☺	-	-	-	-	-	-	-
	CH_2O	✓	☺	-	-	-	-	-	-	-
	Radão	✓	☺	-	☺	☺	-	-	-	-
	$PM_{2.5}$	✗	☺	-	☹		-	-	-	-
	PM_{10}	✓	☺	-	☹		-	-	-	-
	HR	-	-	-	-	-	-	☹	☹	-
	T	-	-	-	-	-	-	☹	☹	-
REF[e] 3-4 Anos	CO_2	✓	☺	-	-	-	-	-	-	-
	CO	✓	☺	-	☺	☺	-	-	-	-
	NO_2	✓	☺	-	☺	☺	-	-	-	-
	O_3	✓	☺	-	-	-	-	-	-	-
	TVOC	✓	☺	-	-	-	-	-	-	-
	CH_2O	✓	☺	-	-	-	-	-	-	-
	Radão	✓	☺	-	☺	☺	-	-	-	-
	$PM_{2.5}$	✗	☹	-	☹		-	-	-	-
	PM_{10}	✓	☺	-	☹		-	-	-	-
	HR	-	-	-	-	-	-	☹	☹	-
	T	-	-	-	-	-	-	☹	☺	-
REF 5 Anos	CO_2	✓	☺	-	-	-	-	-	-	-
	CO	✓	☺	-	☺	☺	-	-	-	-
	NO_2	✓	☺	-	☺	☺	-	-	-	-
	O_3	✓	☺	-	-	-	-	-	-	-
	TVOC	✓	☺	-	-	-	-	-	-	-
	CH_2O	✓	☺	-	-	-	-	-	-	-
	Radão	✓	☺	-	☺	☺	-	-	-	-
	$PM_{2.5}$	✓	☺	-	☹		-	-	-	-
	PM_{10}	✓	☺	-	☺		-	-	-	-
	HR	-	-	-	-	-	-	☺	☺	-
	T	-	-	-	-	-	-	☺	☺	-

a) Legislação nacional em vigor a partir de dezembro de 2013 (Portaria nº353-A/2013)
b) Organização Mundial de Saúde
c) ASHRAE (Sociedade Americana de Engenheiros de Aquecimento, Refrigeração e Ar Condicionado)
d) Dormitório
e) Refeitório
✓ - Em conformidade; ✗ - Não conformidade; ☺ - Favorável; ☹ - Desfavorável

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4. Medidas corretivas recomendadas

Tabela 4. Propostas de medidas corretivas recomendadas para melhorar a QAI no edifício, diminuindo assim a exposição de crianças e colaboradores a poluentes no ar interior.

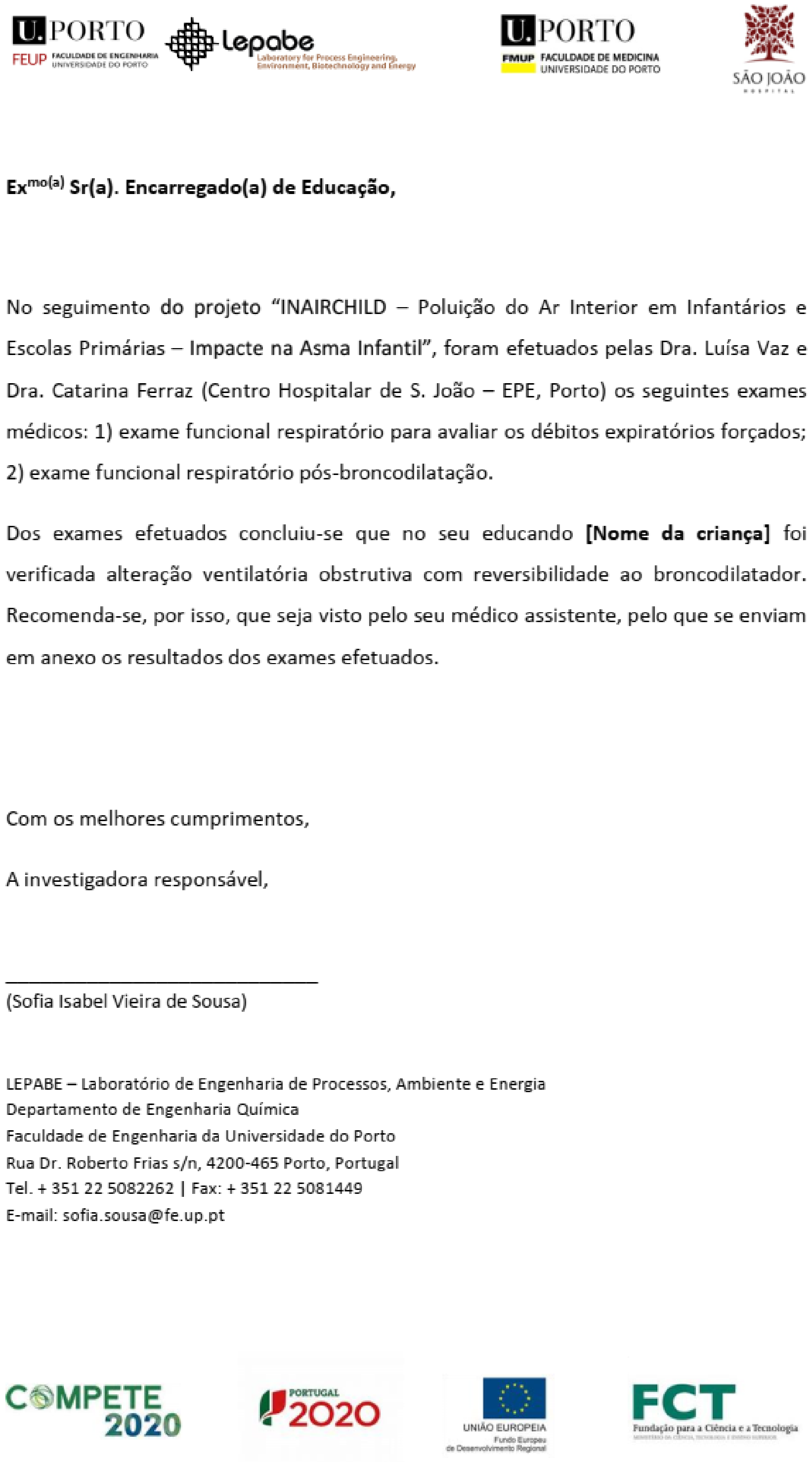
Tipo	Medida corretiva	Principais locais a aplicar
Ventilação	Aumentar o arejamento, sobretudo durante os períodos de ocupação, por exemplo através da abertura de janelas para o exterior sempre que as condições exteriores sejam favoráveis.	Sala 1 ano, Sala 3 anos, Dormitório 2 anos e Refeitório 3-4 anos.
Alteração de comportamentos	Melhorar as ações de limpeza a fim de reduzir a quantidade de partículas (em especial finas) presentes no ar, o que pode ser conseguido recorrendo por exemplo à aspiração e/ou à utilização de produtos e utensílios eletrostáticos para limpeza do chão e outras superfícies.	Sala 3 anos, Sala 4 anos, Refeitório 5 anos e especialmente na Sala 2 anos, Dormitório 2 anos e Refeitório 3-4 anos.
Tecnológica	Utilizar equipamentos que permitam reduzir a humidade (desumidificador).	Sala 2 anos, Dormitório 2 anos e Refeitório 3-4 anos.
	Utilizar equipamentos que permitam aumentar a temperatura até aos valores de conforto.	Sala 3 anos e Dormitório 2 anos.

De relevante importância é também a perceção das pessoas acerca da QAI. É muito importante que os responsáveis (professores e auxiliares) tomem atenção a sintomas como a sonolência, dificuldade de concentração, sensação de "ar pesado" ou de desconforto térmico (sensação de "calor" ou "frio"), para que assim possam rapidamente atuar no sentido de melhorar a QAI. Também é importante estarem visualmente atentos ao surgimento de zonas húmidas, infiltrações ou bolores nas paredes, que devem ser devidamente limpos pois podem conduzir à proliferação de fungos e bactérias. Todos estes sintomas podem indicar uma QAI deficiente e podem ser registados para serem comunicados à equipa de investigadores aquando de novas medições de QAI.

A equipa de investigadores do projeto INAIRCHILD mantém-se disponível para esclarecer qualquer dúvida e para ajudar a melhorar a QAI no v/ edifício.

Porto, 20 de maio de 2015.

APPENDIX H – Child’s individual allergy and asthma report



Ex$^{mo(a)}$ Sr(a). Encarregado(a) de Educação,

No seguimento do projeto “INAIRCHILD – Poluição do Ar Interior em Infantários e Escolas Primárias – Impacte na Asma Infantil”, foram efetuados pelas Dra. Luísa Vaz e Dra. Catarina Ferraz (Centro Hospitalar de S. João – EPE, Porto) os seguintes exames médicos: 1) exame funcional respiratório para avaliar os débitos expiratórios forçados; 2) exame funcional respiratório pós-broncodilatação.

Dos exames efetuados concluiu-se que no seu educando **[Nome da criança]** foi verificada alteração ventilatória obstrutiva com reversibilidade ao broncodilatador. Recomenda-se, por isso, que seja visto pelo seu médico assistente, pelo que se enviam em anexo os resultados dos exames efetuados.

Com os melhores cumprimentos,

A investigadora responsável,

____

(Sofia Isabel Vieira de Sousa)

LEPABE – Laboratório de Engenharia de Processos, Ambiente e Energia
Departamento de Engenharia Química
Faculdade de Engenharia da Universidade do Porto
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Vitalograph®

Relatório de função pulmonar

Informações do paciente

Apelido:	Flores	**ID:**	2362
Nome:	Victor	**ID alternativa:**	
Primeiro apelido:		**Grupo populacional:**	PORTUGUÊS
Data de nascimento:	24-01-2008	**Idade:**	7
Altura:	130 cm	**Sexo:**	Masculino
Peso:	30,3 kg	**IMC:**	17,9
Notas:	Testes negativos.		

Informações da sessão de testes

Data do teste:	13-02-2015 11:19	**Dispositivo:**	ALPHA Touch
Número de testes:	5	**Número de série:**	10312
Valores prev.:	ERS '93/Polgar	**Utilizador:**	<Nenhum utilizador>
Factor prev.:	100%	**Data da verificação de precisão:**	28-01-2015 10:04
Postura:	Sentado	**Grampo para nariz utilizado:**	Não

Valores em BTPS

Gráfico fluxo/volume

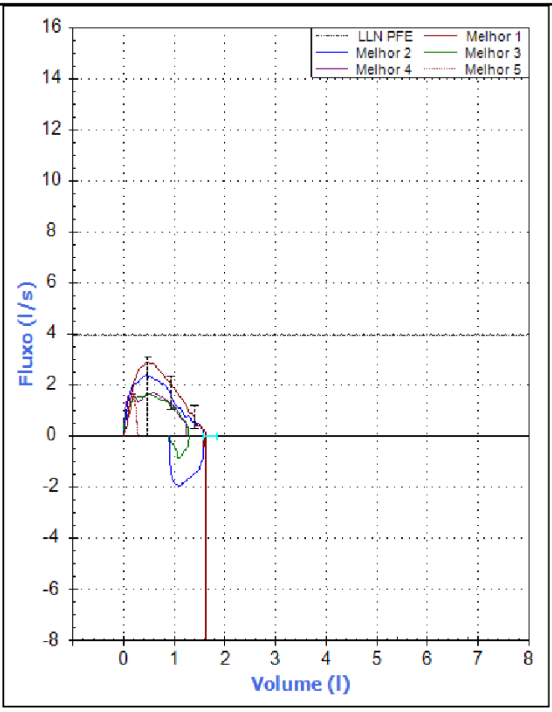
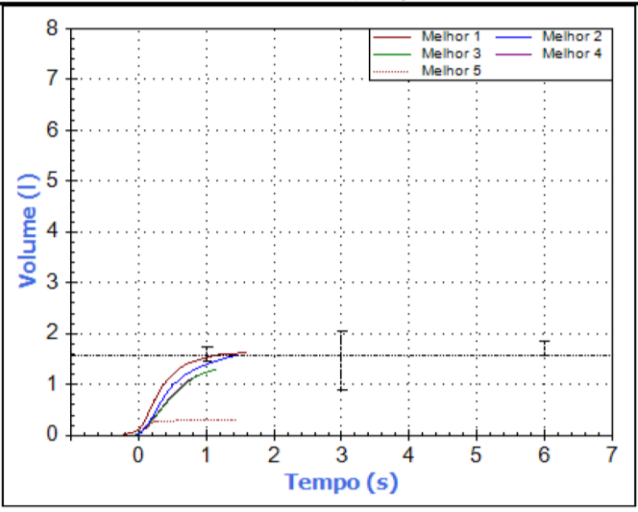


Gráfico volume/tempo



Resultados

Parâmetro	**Melhor ATS/ERS**	**Prev.**	**Prev. de %**	**Teste 4**	**Teste 5**	**Teste 3**	**Teste 2**	**Teste 1**	**Teste**	**Teste**	**Teste**
Hora (hh:mm:ss)				11:20:45	11:21:04	11:20:28	11:20:03	11:19:45			
CVF (l)	**1,62**	**1,85**	**88**	1,62	1,58	1,29*	1,24*	0,29*			
VEF0.5 (l)	**1,19**	**1,15**	**103**	1,19	1,04	0,80	0,83	0,29			
VEF0.75 (l)	**1,42**	**1,57**	**90**	1,42	1,27	1,09	1,11	0,29*			
VEF1 (l)	**1,52**	**1,74**	**87**	1,52	1,41*	1,25*	1,24*	0,29*			
Taxa de VEF1	**0,94**	**0,94**	**100**	0,94	0,89	0,97	1,00	1,00			
PFE (l/min)	**175***	**259**	**67**	175*	143*	100*	103*	101*			
FEF25-75 (l/s)	**2,11**	**2,23**	**95**	2,11	1,67*	1,45*	1,52*	1,14*			
FEF75-85 (l/s)	**0,95**	**1,19**	**80**	0,95	0,73	1,02	1,14	0,98			
Parâmetros de qualidade											
VExt/CFV	**0,06**			0,06	0,04	0,05	0,04	0,24			
Aceitabilidade de utilizador				Sim	Sim	Sim	Sim	Não			

*Abaixo do limite inferior de normalidade (LIN)

Qualidade de sessão e informações de repetibilidade

Classificação de sessão	**Rep. de CVF:**	**Rep. de VEF1:**	**Início de teste lento**	**Critérios de fim de teste não atingidos**	**Tosse detectada no 1.º segundo**
A	0,04 l	0,11 l	0 sopro(s)	4 sopro(s)	0 sopro(s)

Interpretação sugerida pelo computador

As interpretações de computador não podem servir de base ao diagnóstico.
Função ventilatória normal.

Assinatura: ________________________ **Data:** _______________