European Federation of Allergy and Airways Diseases Patients Associations

Towards Healthy Air in Dwellings in Europe.

The THADE Report

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The data reviewed and the recommendations made within the THADE project are condensed in this volume. The full reports compiled by the expert consultants can be accessed on the EFA website (**www.efanet.org**). See inside back cover for the CD containing the pollution mapping programme.

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PREFACE

Asthma and allergies are the most common chronic illnesses in children, and are among the most frequent chronic diseases overall in industrialised countries. Strikingly, cases of asthma and allergy have practically doubled over the past 15 years. The indoor environment has been implicated in this increase, and is known to be a major factor in asthma exacerbation. Indoor air pollution is a problem shared by most countries. We all live in houses and most of us work indoors, and spend more than 90% of our time in a building of one sort or another.

One of EFA's major concerns is to identify measures that can help to halt or slow down the increasing trend in allergy and asthma. It was in this light that EFA welcomed the opportunity afforded by the European Parliament and Council's programme of Community Action on Pollution-related Diseases to investigate indoor air pollution.

Following in the wake of the very successful 'Indoor Air Pollution in Schools' (2000) study, in 2002 EFA was awarded a grant by the European Commission (DG SANCO) for a project entitled 'Towards Healthy Air in Dwellings in Europe – THADE'. The aim of this far-reaching project was to compile an overview of evidence-based data about exposure to indoor air pollution and its health effects, particularly as regards allergies, asthma and other respiratory diseases such as chronic obstructive pulmonary disease (COPD); review cost-effective measures and technology to improve indoor air quality; review legislation and guidelines on indoor air pollution; and recommend an integrated strategy that defines appropriate indoor air quality policies for implementation in Europe.

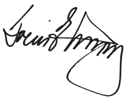
This volume contains the information about air quality in dwellings and indoor environment-related diseases that has been collected by expert consultants within the framework of THADE and terminates with recommendations for actions that will improve indoor air quality. The full report of each expert consultant can be accessed from the EFA website: www.efanet.org

The data come from a wide variety of sources: EUROSTAT, national statistics agencies, and scientific societies such as the European Academy of Allergy and Clinical Immunology (EAACI), the European Respiratory Society (ERS), the European Federation of Heating and Air-conditioning Associations (REHVA), the Global Initiative for Asthma (GINA) and the International Society of Indoor Air Quality and Climate (ISIAQ). A questionnaire, completed predominantly by EFA member associations, was used to collect data on national legislation and policies. Various experts met at a Multidisciplinary Workshop in June 2003 to discuss and analyse the data collected. The recommendations for a healthy dwelling environment arising from the Workshop are included in this volume.

The results of the THADE project confirm that air pollution in dwellings is a real health problem. It is a complex issue that must be approached at European and international level, and involves the medical profession, scientific societies, patients' organisations, lawmakers, architects, builders and the building industry as a whole, ventilation experts, etc.

The THADE project arose from an idea generated by Mariadelaide Franchi (EFA Honorary Member). Not only was she the co-ordinator of the project, she was the driving force throughout all the various phases. We are deeply indebted to Ms Franchi, without whom this project would not have been realized.

We hope that the THADE report will serve as a tool for all those at international, national, governmental and local level who are striving for healthy dwellings for European citizens.



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Thanks go to Dr Marzia Simoni, Dr Antonio Scognamiglio and Mrs Patrizia Silvi for their assistance in collecting and collating statistical and epidemiological data about air pollution in dwellings and its related health effects. We acknowledge the contributions of Dr Ludovicus G.H. Koren and Dr Cor E.E. Pernot to the work on air quality in homes and mapping pollutants in dwellings. Thanks are due also to Dr Giuliana Pensa, Ms Daniela Finizio, Ms Susanna Palkonen, Ms Elisabetta Rea and Ms Florence Crovato for their help and expertise. Lastly, we are deeply indebted to Dr Marc Seguinot of the European Commission, formerly responsible for development of the health and environment policies of DG-SANCO, for his enthusiastic support and advice during the THADE project.

EXECUTIVE SUMMARY

Indoor air pollution may cause or aggravate illnesses, increase mortality, and have a major economic and social impact. Millions of Europeans spend more than 90% of their time indoors: at home, in the office, factory, school, restaurants, theatres, etc. What is the impact of poor air quality at home on health and what measures can be taken to improve it?

The THADE project was designed to address these two issues, and was funded by the European Commission within the Pollution-related Diseases programme. It was endorsed by the major scientific societies in this field: the European Academy of Allergology and Clinical Immunology (EAACI), European Respiratory Society (ERS), European Federation of Heating and Air-conditioning Associations (REHVA), Global Initiative on Asthma (GINA), International Society of Indoor Air Quality and Climate (ISIAQ). Twenty-one associations affiliated to the EFA network took part in the project. Expert consultants examined the various aspects of health determinants related to indoor air quality in dwellings. Their findings are condensed in this volume. Their full-length reports can be accessed from the EFA website: www.efanet.org

The right to breathe healthy air in dwellings was recognised as a fundamental right by the World Health Organisation in 2000 consequent to scientific evidence of the health risks related to poor air quality. Unfortunately, this right and the adverse effects of indoor air pollution are largely ignored. The public and authorities need to be made aware that each day we are all exposed to potentially harmful substances in our homes. Although people with allergy, asthma or chronic obstructive pulmonary disease (COPD), children and the elderly are particularly susceptible to indoor air pollution and are aware of the hazards, everyone should be concerned about poor air in their homes.

The THADE expert consultants identified the main health determinants in dwellings: tobacco smoke, indoor-generated particulate matter, carbon monoxide, carbon dioxide, formaldehyde, dust mites, pet allergens, cockroaches, mould, pollen, nitrogen oxide, volatile organic compounds (VOCs), man-made mineral fibres, and radon. These determinants can affect the respiratory system in various ways; they can cause or exacerbate chronic bronchitis, asthma, and acute respiratory diseases. They can also cause a decline in respiratory functions and sensitisation to common aeroallergens. Some pollutants, like radon, environmental tobacco smoke and VOCs pose a significant cancer risk.

Methods and actions to prevent, reduce or eliminate the adverse effects of poor air quality have been identified for each of the above determinants. The measures suggested will improve indoor air quality, and alleviate the symptoms of allergy, asthma and COPD, but they will not necessarily prevent these conditions. The measures proposed in this report will enhance the quality of life of everyone – the sick and the healthy alike.

Guidelines, actions and programmes related to indoor air quality in dwellings are already in place in many European countries. However, these actions are usually targeted to a specific topic or issue rather than aiming for an overall European and/or a national strategy.

It is clear that the reduction of indoor pollution requires the intervention of all parties involved: institutions, scientific societies, professional organisations, patients' organisations and the public. The actions proposed to control the indicated health determinants must be co-ordinated at various levels: international level (WHO), European Union level, national level, professional society level, and patient organisation level.

The actions identified have been classified into the following main categories:

- Improve ventilation.
- Improve cleaning methods and housing hygiene.
- Avoid wall-to-wall carpeting.
- Moisture control to prevent microbial growth.
- Control the sources of pollution, e.g. tobacco smoke and emissions from building and consumer products.

The measures recommended to implement these actions are:

- Avoidance of smoking indoors.
- Labelling systems to control emissions from building and consumer products.
- Better building codes and guidelines for ventilation and moisture control.
- Education and information campaigns.

Most of these measures are independent of cultural and climate differences. The exceptions are measures related to moisture control and ventilation, and even in these cases, European guidelines should be developed.

More research is needed about the effects and costs of prevention and remedial measures related to indoor air quality. Technical information about the building stock should be taken into consideration when developing guidelines for remedial action. This information should include data on heating and ventilation systems, cooking appliances, ventilation rates and moisture conditions. In addition, we need to know more about the prevalence of health determinants and the number of people sensitive to each specific determinant.

Although there is a large body of scientific information on healthy buildings, very little has been translated into practice. Unless policies are developed and put to work nationally and internationally, advances made in the indoor air sciences will not be exploited in real life and will have a limited impact on the community.

There is clearly an urgent need for a strategy to improve the quality of air in dwellings in Europe, and this can be developed on the data now available.

1 DESCRIPTION OF THE PROJECT

1.1 BACKGROUND

European Federation of Asthma and Airways Diseases Patients' Associations
The European Federation of Asthma and Airways Diseases Patients Associations (EFA) was founded in Sweden on November 1991 consequent to the initiative of eight European countries (Finland, Iceland, Ireland, The Netherlands, Norway, Poland, Sweden and United Kingdom) with the aim of improving the health conditions and quality of life of people with asthma and allergy throughout Europe. The rationale was that a strong international organisation would be the most effective means to serve the needs and safeguard the rights of patients and their families.

Today, EFA is an important patients' network representing 400,000 individuals who are members of 42 associations in 23 European countries (Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Norway, Portugal, Serbia and Montenegro, Slovenia, Spain, Sweden, Switzerland, The Netherlands, United Kingdom).

EFA's Approach to Air Quality
During the first EFA conference held in Lunteren (The Netherlands) in 1993, the General Assembly adopted a resolution that drew the attention of European institutions and authorities to the increase in the prevalence of asthma and allergy and to the need for a European Community action in this field. Upon the request of the European Commission, in May 1994 EFA presented the first document giving the patient's point of view about the effect of air pollution on asthma and allergy conditions (EFA Position Paper on Air Pollution).

EFA project: Asthma in Europe. Report on Asthma Prevalence, Policy and Action in the European Union (1995)
In 1995 the European Commission funded an EFA project designed to collect data about the prevalence of asthma and allergy in Europe, and about the actions taken in European Union countries to prevent these conditions and to improve the lot of patients. The findings of this study were collected in the volume 'Asthma in Europe. Report on Asthma Prevalence, Policy and Action in the European Union' and presented at EFA's 1997 conference entitled '21st Century: Towards an Asthma and Allergy Prevention Policy in Europe'. Asthma was shown to affect between 3% and 8% of the adult population in Europe, and the prevalence was even higher in children. Despite this high prevalence and the cost in social and human terms, the development of prevention policies was found to

be insufficient. The report recommended measures to improve information about asthma, particularly regarding the collection of statistics. It stressed that prevention policies depend much on the spread of information about asthma and allergy, and suggested means to improve the flow of information. The results of this project prompted EFA to strive for a greater accessibility of information on asthma- and allergy-related topics.

It was clear that further studies were required to improve knowledge about the impact of environmental factors on the health conditions of people with asthma and allergy. Consequently, EFA welcomed the decision adopted in June 1998 by the European Council and the European Parliament for a three-year Programme of Community Action on pollution-related diseases.

Air pollution-related diseases were discussed at the 1998 and 1999 EFA conferences, 'Air Pollution: Asthma and Allergy', and 'Indoor Air, Allergy and Asthma', respectively.

EFA project: Indoor Air Pollution in Schools

More than 1 in 4 children in Europe has asthma or allergy. These diseases are the major causes of days lost from school and their socio-economic costs are very high. Poor air quality in schools has been shown to interfere with learning activities and can cause discomfort, irritation, and various short- and long-term health problems in students, teachers, and staff. Indoor pollutants can be particularly harmful for students already affected by allergies or asthma.

In 2000 EFA received support from the European Commission (DG SANCO) to examine the issue of 'Indoor Air Pollution in Schools'. The study showed that the issue of air quality in schools is greatly underestimated in many countries. One of the recommendations of that study was to alert people working in schools to the problem of indoor air pollution, and to implement a multidisciplinary European programme on indoor air quality focusing on schools.

1.2 TOWARDS HEALTHY AIR IN DWELLINGS IN EUROPE – THADE

Increases in allergies and respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD) parallel increases in air pollution. European Union policy requires that all citizens be effectively protected from risk to health from air pollution. Whereas there is an abundance of data about outdoor airborne pollutants, little is known about the public health risks of poor indoor air, particularly in dwellings. The THADE project was designed to learn more about the health effects of air pollution in the home, and to identify measures to counteract it.

1.3 AIMS

The aims of the THADE project were to:

1. Review the data and evidence-based information related to exposure and to the health effects of air pollution in dwellings particularly as regards allergies, asthma and other respiratory diseases.

2. Review cost-effective measures and technology to improve air quality in dwellings.
3. Review legislation and guidelines on air pollution and air quality in dwellings.
4. Produce maps of pollutants in dwellings.
5. Recommend an integrated strategy that defines appropriate indoor air quality policies for implementation in Europe, and identify appropriate technology.

1.4 METHODS

1.4.1 Phases of the project

On 18 March 2002, the THADE Scientific Committee and expert consultants met in Brussels to fine-tune the working schedule, coordinate data collection, review data sources and examine recent and emerging evidence/events in the field of indoor air quality in dwellings. Between March and October 2002, a THADE network was set-up to circulate and obtain information about and for the project in relation to project partners, EFA member associations and other interested bodies. A questionnaire ('National Data Collection for the Project Towards Healthy Air in Dwellings in Europe') was distributed to project partners, EFA associations and other interested bodies.

The expert consultants presented their interim reports at a multidisciplinary workshop held in Rome on 25 October 2002 to the THADE Scientific Committee, and representatives of EFA member associations.

The contents and structure of draft reports were discussed at a technical meeting held at the Euroforum Building in Luxembourg on 13 March 2003. Updated reports were presented at a European Conference held in Lisbon (26-29 June 2003), attended by EFA Board members, THADE project partners, the THADE Scientific Committee and experts in medicine, biology, chemistry, and in building management.

A core-working group subsequently discussed the actions required to achieve healthy dwelling environments. A general consensus on recommendations and practical initiatives in relation to indoor air pollution in dwellings was defined. The EFA board, the project Scientific Committee and the EFA project partners approved the final document.

1.4.2 Data collection

The consulting experts surveyed the evidence-based literature, authoritative publications and internet sources to identify the main health determinants indoors, their effects on allergies and the respiratory system, possible control methods, legislation and guidelines, and actions aimed at preventing or attenuating the adverse effects of indoor air pollution.

Air pollution in dwellings and related health effects

Data about the health effects of particulate matter (PM), nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), formaldehyde, damp/mould and dust mites in European dwellings were collected from the Medline database (January 1991-September 2003), and the Proceedings of the 9th International Conference of Indoor Air (Monterey, CA, USA, 2002). For each study, the authors' names, source, year of data collection (range: 1983–2001), geographical area, type of sample, and main results were recorded.

Monitoring in Dwellings. Pollutants were reported as follows: mean of 24 or 48 hours monitoring, in µg/m^3; NO_2, mean of different sampling periods, in µg/m^3 (if transformed, 1 ppb=1.88 µg/m^3); CO and CO_2, levels in mg/m^3 (if transformed, 1 ppm=1.25 mg/m^3 for CO; 1 ppm=1.83 mg/m^3 for CO_2); VOC and formaldehyde, levels in µg/m^3; mite allergens, concentration in µg/g of dust; and dampness and mould, positive response to a questionnaire.

The *Po Delta and Pisa indoor studies*[1,2] were conducted between 1991 and 1994 on subsamples of random samples, stratified for socioeconomic status, age group and area of residence, of the general Italian population, previously enrolled in two cross-sectional epidemiological surveys.[3,4] Data on PM with an aerodynamic diameter <2.5 µm ($PM_{2.5}$) and NO_2 were collected during one week, in winter and summer, in 139 houses in the Po Delta rural area, and in 282 houses in the Pisa urban area, and reported as 48 h mean ($PM_{2.5}$) and weekly mean (NO_2). The levels of NO_2 in the immediate vicinity of the home were also measured ('micro-outdoor'). Information about the type of house and the family's habits were collected by questionnaire.

Health effects. Papers were included in this review if they contained data about relative risk for symptoms/diseases. The population attributable risk (PAR) % was computed (where possible) to estimate the amount of disease or condition abatable by eliminating the exposure or risk factor: PAR=100*p(RR-1)/p(RR-1)+1, where p= proportion of total population exposed and RR= relative risk for exposed versus non exposed.[5] In the Po Delta and Pisa indoor studies, information about daily activity pattern and presence of acute respiratory illness/symptoms during the monitored weeks was collected by questionnaire. Each subject performed peak expiratory flow measurements four times daily using a mini-Wright peak flow meter. NO_2 and $PM_{2.5}$ exposure indices as a product of pollutant concentration and exposure time were computed.[6]

Legislation and guidelines

Data on legislation and guidelines on air pollution and air quality in dwellings in Europe and outside Europe was obtained from various sources. The proceedings of the most authoritative indoor air quality congresses (the *Indoor Air and Healthy Buildings* series) were consulted. The Internet was scanned for relevant documents, policies and actions aimed at providing healthy indoor air in dwellings. A questionnaire was designed to collect information from reports, research programmes and policies on indoor air quality in dwellings, and distributed to European countries through the EFA network.

Control methods and recommendations

For each health determinant, an extensive literature survey was conducted to identify methods to eliminate or reduce the harm caused by poor air quality. The recommendations to improve indoor air in dwellings in Europe are based on information collected from numerous sources, including experts of European scientific societies and representatives of patients' associations.

1.5 PROJECT PARTNERS

The project co-ordinator was Mariadelaide Franchi, supported by the EFA Board. The associations affiliated to the EFA network collaborated on the project.

The THADE Scientific Committee assessed the work throughout the various stages of the project.

The following experts were directly involved in the project: Paolo Carrer, Department of Occupational Health, University of Milan, Italy; Dimitris Kotzias, Commission of the European Union/Institute for Health and Consumer Protection, Ispra, Italy; Edith M.A.L. Rameckers, EFA Advisor/ER Health Consultancy, Slenaken, The Netherlands; Olli Seppänen, European Federation of Heating and Air-conditioning Associations (REHVA)/Helsinki University of Technology, Finland; Giovanni Viegi, Pulmonary Environmental Epidemiology Unit, CNR Institute of Clinical Physiology, Pisa, Italy; Johanna E.M.H. van Bronswijk, Technische Universiteit Eindhoven, The Netherlands.

The following scientific societies and institutes gave their enthusiastic backing to the project and collaborated in all the various phases: European Academy of Allergology and Clinical Immunology (EAACI), European Respiratory Society (ERS), Global Initiative for Asthma (GINA), International Society of Indoor Air Quality and Climate (ISIAQ) and Eindhoven University of Technology (TU/e).

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2 INDOOR AIR QUALITY

People living in urban areas spend most of their time indoors, where concentrations of many air-borne pollutants are higher than outdoors.[1] Concentrations of air pollutants in homes, offices, shopping malls and schools are often 2-5 times those found outdoors, and can occasionally reach 100 times outdoor levels.

Indoor environments changed enormously with the introduction of soft furnishings, fitted carpets and mechanical air ventilation systems. The rate at which indoor air is exchanged for fresh air is now 10 times lower than it was 30 years ago, with a consequent increase in humidity and in levels of indoor pollutants and airborne allergens.

Many factors affect indoor air quality. Outdoor pollutants (e.g. pollen, and traffic and industrial emissions) enter buildings through open windows, ventilation system air intakes, and building leaks. These pollutants, together with pollutants that arise inside the building (mould spores and chemical emissions from carpeting, wallpaper, furnishings and cleaning products) concentrate in tightly sealed, inadequately ventilated buildings. Ventilation systems meant to bring in clean or filtered outdoor air and to flush out 'used' indoor air, do not always function properly, because of poor design or poor maintenance.

2.1 SOURCES OF INDOOR AIR POLLUTANTS

The indoor environment in any kind of building, including dwellings, is a result of the interaction between building system (original design and subsequent modifications in the structure and mechanical systems), construction techniques, contaminant sources (building materials and furnishings, moisture, processes and activities within the building), building occupants and outdoor sources. The most important sources of indoor pollutants are:[2]

- Tobacco smoking indoors.
- Water and moisture damage.
- Emissions from building materials and furnishings.
- Household activities (cooking, cleaning chemicals and procedures, use of deodorisers and fragrances, sweeping, and vacuuming).
- Heating, ventilation and air conditioning (HVAC), dust or dirt in ductwork or other components, microbiological growth in drip pans, humidifiers, ductwork and coils, improper use of biocides, sealants and/or cleaning products.
- Contaminated outdoor air (pollen, dust, fungal spores, industrial pollutants, and general vehicle exhaust).
- Soil gas (radon, contaminants from previous uses of the site, and pesticides).
- Redecorating/remodelling/repair activities (paint, caulk, adhesives, and other products).

- Pest control.
- Unsanitary conditions.
- Supplies (solvents, toners, ammonia).
- Individuals (body odour, and cosmetic odours).
- Accidental events.

2.2 HEALTH EFFECTS RELATED TO INDOOR AIR QUALITY

2.2.1 Building-related illnesses

Building-related illnesses (BRI) are illnesses (e.g. certain allergies or infections) that can be directly attributed to environmental agents present in the air of a building. Legionnaire's disease and hypersensitivity pneumonitis are examples of BRI that can have serious, even life-threatening consequences.

2.2.2 Allergic diseases associated with indoor air pollution

Indoor allergens have been linked with the following allergic manifestations:[3]

- Rhinitis with 'hay fever' symptoms: nasal congestion, runny nose, sneezing, conjunctivitis and lachrymation.
- Asthma with wheezing, tightness of the chest and shortness of breath.
- Extrinsic allergic alveolitis (hypersensitivity pneumonitis), with acute pneumonia-like bouts of fever, cough, tightness of the chest and lung infiltration, or chronic development of cough, shortness of breath and infiltration of lungs.
- Humidifier fever with fever, chills, muscle ache and malaise, but no obvious respiratory effects.

2.2.3 Sick building syndrome

The term 'sick building syndrome' (SBS) refers to buildings in which the majority of the building occupants experience acute health and comfort effects that seem to be linked to the time they spend in the building, but in which no specific illness or cause can be identified.[3] The complaints may occur in a particular zone, or may occur throughout the building. Respiratory complaints, irritation and fatigue are associated with SBS. Symptoms generally attributed to poor indoor air quality are: headache, fatigue, shortness of breath, sinus congestion, cough, sneezing, eye, nose and throat irritation, skin irritation, dizziness, and nausea. Odours are often associated with a perception of poor air quality, whether or not they cause symptoms.

2.2.4 Multiple chemical sensitivity syndrome

A small percentage of the population may be sensitive to chemicals (even at very low concentrations) in indoor air. This condition, known as 'multiple chemical sensitivity' (MCS), is a matter of controversy. It is not recognised by the major medical organisations, but medical opinion is divided, and further research is needed.

2.2.5 Individuals susceptible to indoor air pollution

Subjects that may be particularly susceptible to indoor air contaminants include, but are not limited to, people with allergy or asthma, people with respiratory disease, people with a suppressed immune system, and contact lens wearers.

Other subjects may be particularly vulnerable to certain pollutants or pollutant mixtures. For example, people with heart disease may be more affected by exposure to lower levels of carbon monoxide than healthy individuals. Children exposed to environmental tobacco smoke are at a higher risk of respiratory illnesses, and those exposed to nitrogen dioxide are at a higher risk of respiratory infections.

Symptoms can be limited to a few people when the pollutant is confined to their area. In other cases, complaints may be widespread. Reactions can differ in degree and type in different people.

2.3 HEALTH DETERMINANTS RELATED TO INDOOR AIR QUALITY

The main indoor air pollutants are:

Inorganic pollutants
Carbon monoxide
Nitrogen dioxides (NO_2 and NO)
Particulate matter
Man-made mineral fibres
Carbon dioxide (indicator of ventilation rate)

Organic pollutants
Volatile organic compounds
Formaldehyde

Environmental Tobacco Smoke

Pesticides

Biocontaminants
Viruses
Bacteria

Allergens
Mould/fungi
Dust mites
Dander from furred animals
Cockroaches
Green plants (*Ficus benjamina* or weeping fig, *Spathiphyllum floribundum* or spathe flower)
Outdoor allergens (pollens and moulds)

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3 IMPORTANCE OF AIR QUALITY IN HOMES

Breathing is a prerequisite of life. We cannot stop breathing for more than a few minutes without loosing life. And during life, effective breathing with sufficient carbon dioxide removed from the body, and oxygen entering the bloodstream, determines a person's capacity for independence, vitality and productivity, in short his or her capacity for a good quality of life and a high number of vital years in the human life span.

Depending on regional culture and outdoor climate, Europeans spend most or almost all of their time in indoor environments. Something between 8-16 hours/day is regularly spent in dwellings. To breathe healthy indoor air is therefore considered a fundamental right by the World Health Organisation.[1] Apparently this fundamental right is regularly breached. Assessing the actual impact of poor air-quality at home is one of the central research questions in the THADE project.

3.1 POLLUTION, PEOPLE AND DWELLINGS

Everything we breathe, apart from acceptable concentrations of oxygen, nitrogen and carbon dioxide gasses, may be considered a pollutant. But not all of those accidentally inhaled gasses or dust particles are considered of health relevance. Disease or unhealthy conditions resulting from noxious exposures include different building (services)-related diseases, allergic afflictions, the sick building syndrome, the multiple chemical sensitivity syndrome, and effects only seen by persons with an increased susceptibility to indoor air pollution (Chapter 2).

In some cases the causal relation between pollutant and disease is immediately evident, due to a short incubation time of the disease. Think of building-related infectious disease caused by the *Legionella* bacterium in potable and warm water systems (veteran's disease) or the SARS Coronavirus in ventilation and sewer systems of dwellings. In those cases awareness is generally high and measures to contain the disease are taken by policy makers, at least for the major part of the population.

Unfortunately more susceptible sections of society, the so-called YOPI: the Young, the Old, the Pregnant and the Immuno-suppressed, are catagorized as 'persons with special needs', together with people who have a chronic condition, such as asthma or chronic obstructive pulmonary disease (COPD), instead of considering them as a part of the natural variation in society. This discrimination of susceptible persons is even stronger in case of chronic (partially) building-related afflictions, such as house-dust mite allergy.

In case the incubation time of a disease or condition is increased or health effects are caused by prolonged exposure, such as occurs for asthma and COPD, the long-term effects leading to these conditions tend to be ignored by policy makers and the general public. These conditions tend to be classified as ‘normal in our region’, or ‘intrinsically age-related’, etc. The fact that the majority of European regions have too high a level of dust mites (Fig. 3.1, left panel) is considered just climatic variation, although in all the ‘A’ and ‘B’ areas, building interventions may decrease mite populations to below hygienic levels for sensitization and symptom development, thus greatly improving current poor indoor air.

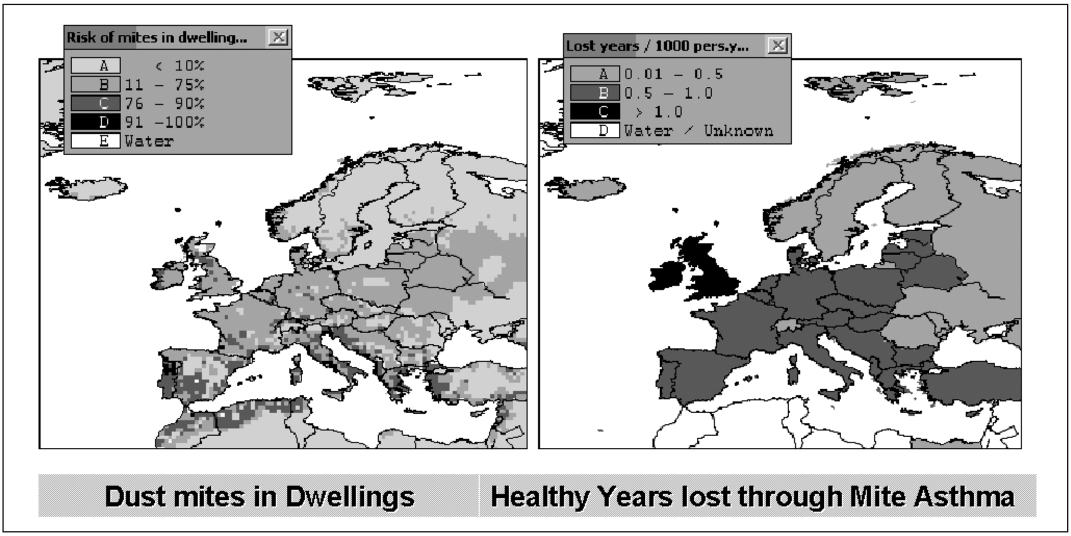

Figure 3.1. Infiltration of dwellings with dust mite populations and resulting loss of healthy years in a life span (DALY) as mapped in the mapping programme (see Chapter 5). The United Kingdom and Ireland appear to be the worst countries for house-dust mite asthma in Europe. Because of the limited resolution of available disease prevalence figures, the health outcome (right panel) could only be mapped by country, not by 10’ latitude and longitude as was possible with house-dust mite exposure (left panel). (Images are in colour in the mapping programme; see CD on inside back cover).

3.2 CONCENTRATION, EXPOSURE, DISEASE

To understand the importance of poor indoor air in homes and its health consequences, we need to combine the effects of a large number of phenomena. This includes the time spent at home, the different sources of pollutants arising from persons, pets, household activities, indoor conditions suitable for mites, fungal and insect growth, and infiltrations from the outdoors through air or holes (rodent pests), as well as the efficiency of the removal of pollutants with ventilation and infiltration of air.

These data are used to assess actual concentrations of air pollutants in dwellings as well as intensity and length of noxious exposures. Subsequently, these short-term or long-term exposures may lead to disease.

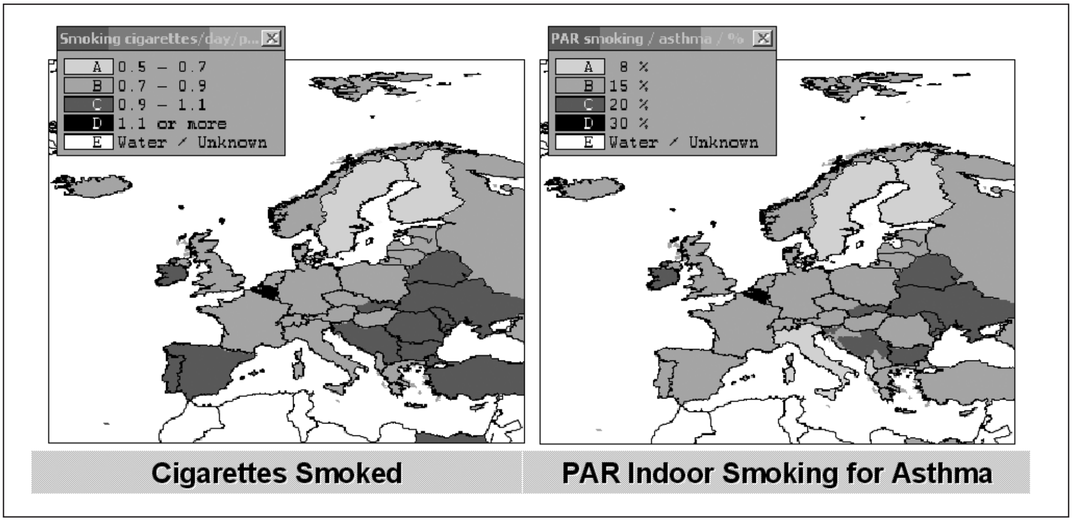

Figure 3.2. Exposure to cigarette smoke in dwellings and the population attributable risk (PAR) of this exposure for asthma. Belgium is the country were the most health can be gained by stopping indoor smoking. In this case, the prevalence figures of smoking and of asthma were only available by country. (Images are in colour in the mapping programme; see CD on inside back cover).

3.3 HEALTH OUTCOMES OF EXPOSURE AND PREVENTION

Health effects of pollutant exposure may be assessed from two different angles: (1) a disease load on the population (DALY), and (2) the amount of disease or condition abatable by eliminating a specific exposure, population attributable risk or 'PAR' (Fig. 3.2). By mapping these health outcomes, high priority regions are shown at a glance within the European sphere.

Using information on the prevalence of asthma symptoms in 12 European countries, interpolation (taking into account the mapped risk of exposure to dust mites, fungi and pollen) and additional data, disability adjusted life years (DALYs) and PARs related to asthma were mapped by country (Figs 3.1 and 3.2). A comparable procedure was performed for COPD, taking into account the mapped data on smoking and time spent indoors.

The PAR (= attributable risk x prevalence of exposure to a certain risk factor in the population) was calculated from European-wide exposure and prevalence figures. Due to missing data and to the level of integrity of available data, this calculation is only reliable for the combinations 'cigarette smoke and COPD', and 'house-dust mites and asthma' (Fig. 3.2).

What can prevention do? Let's take the case of asthma (Figs 3.3 and 3.4). A 'simple' measure such as pet removal, shows a straightforward result (Fig. 3.3), since the act of pet removal always diminishes pet allergen concentration after some time. The effect of improved ventilation on asthma disease load is more complex (Fig. 3.4). In all

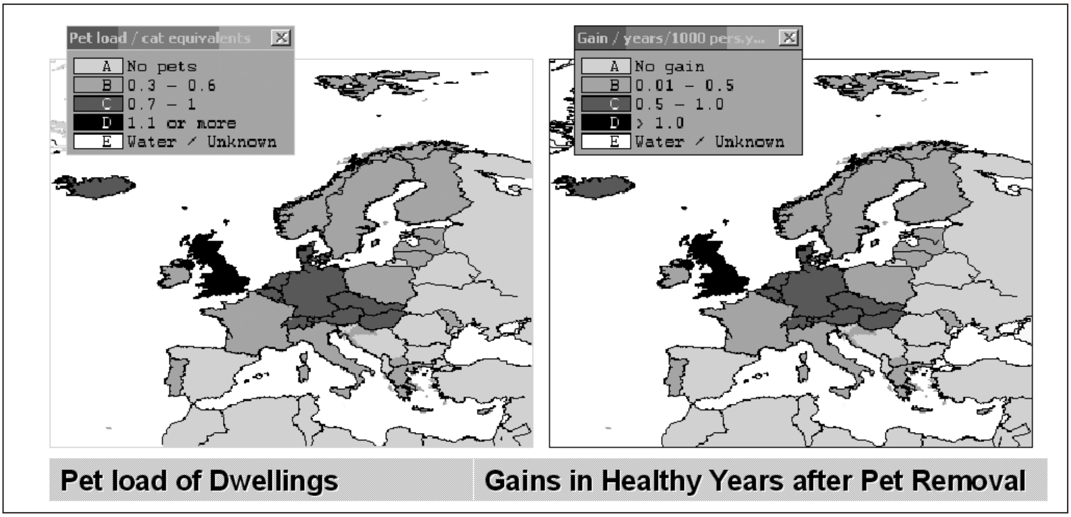

Figure 3.3. The result of pet-removal on gains in healthy years as related to asthma can be dramatic, especially in the United Kingdom that shows the highest pet prevalence in Europe. Here the exposure map and the health outcome map show the same picture since removal of pets always decreases pet allergen concentration after some time. Considerable health gains are only possible, of course, in regions that have a high incidence of pets in dwellings. (Images are in colour in the mapping programme; see CD on inside back cover).

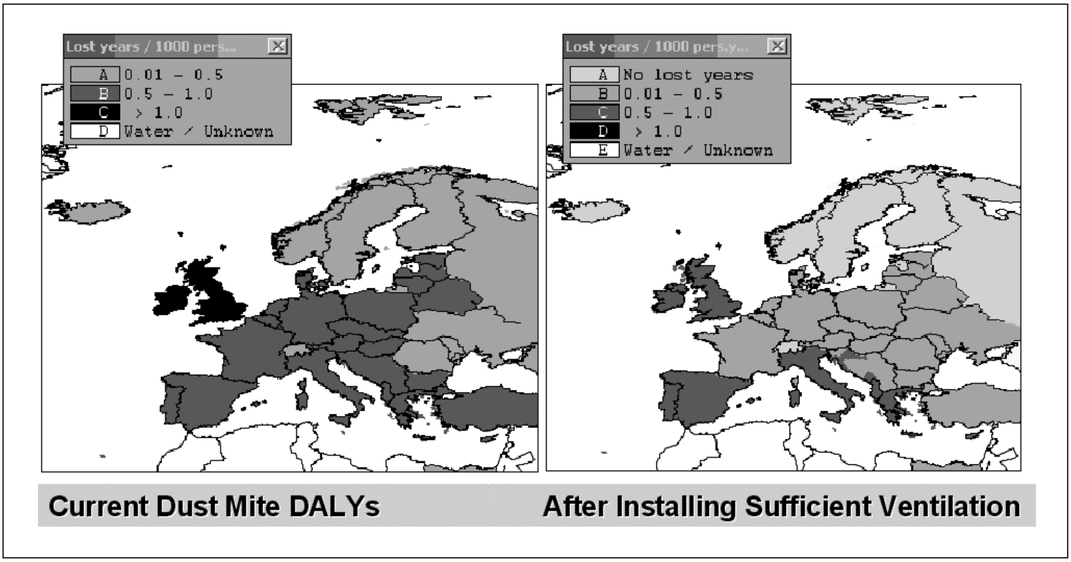

Figure 3.4. Prevention of house-dust mite asthma through optimizing ventilation of dwellings. This is most effective in regions with cold winters due to the low humidity associated with ventilation air in winter, and the increased ventilation efficiency when the indoor-outdoor temperature difference increases. Fully air-conditioned dwellings are not taken into account. (Images are in colour in the mapping programme; see CD on inside back cover).

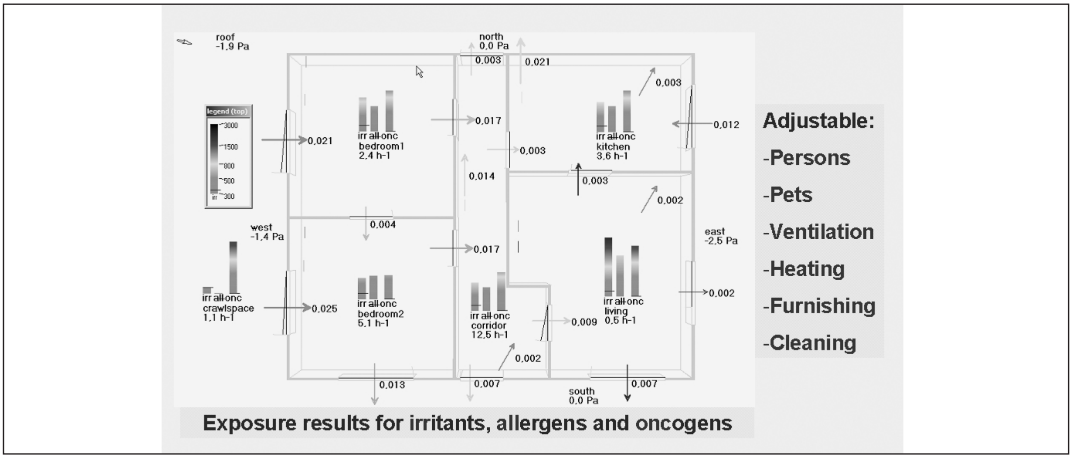

Figure 3.5. Assessment of a single-home situation. In an interactive process the user adapts the standard dwelling, virtually executes preventive measures and observes the short-term and long-term effects on exposure. Shown is an apartment with a kitchen, living room, two bedrooms and a corridor. The different shades of grey indicate pollutant load, also of air streams (denoted with arrows). Values above 800 are harmful to the health of susceptible persons. Outdoor arrow in the upper left corner indicates wind direction and wind pressure. (Images are in colour in the mapping programme; see CD on inside back cover).

regions increased ventilation will lead to a higher degree of removal of mite allergen from indoor air. Since, however, most of the mite allergen in dwellings is stored in soiled textiles used in furniture and furnishing, the 'loss' of airborne allergen is quickly replenished. Depending on the conditions of outdoor air and ventilation efficiency, ventilation can have a second effect on dust mite concentrations: hampering or stimulating mite growth and indoor allergen production. The moisture content of indoor air is especially important. Therefore, optimizing ventilation will have (almost) no effect on disease load in sub-tropic European countries and a net reduction in other regions.

By mapping exposures and health outcomes on a geo-spatial European scale, we are able to identify the epidemiological priorities and effects. What about more localized or even personal prevention? To assess those conditions the mapping procedure uses a simulated dwelling (Fig. 3.5). Depending on local cultural, personal and climatic conditions, the most effective measures to ease disease load vary from removal of pets (especially in pet-loving regions), optimizing ventilation and furnishing (regions with extensive heating in winter), and improved cleaning routines (mainly sub-tropical regions).

It is interesting to note that no single preventive measure is significantly effective in any European region. This makes it difficult to formulate a European agenda on specific long-term (aimed at children) and short-term (aimed at both children and adults) preventive measures, given the diversity of the member states and their inhabitants. A broader perspective, aiming at understanding the mechanisms leading to poor indoor air, should be taken into account. This should also lead to a united call for further research and the creation of network structures to regularly update the content of the mapping tool.

3.4 GAPS IN KNOWLEDGE AND RECOMMENDATIONS

The gap in knowledge on the importance of air quality in homes is primarily a gap of translation and communication. Data have been collected on almost all noxious exposures and resulting health problems. Part of them are managed in databases of primary research results, such as in the EC-funded project EUROHEIS, and were analysed for certain regions and specific noxious agents.

In the THADE project, a long list of problems was encountered when we tried to tap data from existing primary databases to translate the result into European-wide, comparative concentrations, exposures and health outcomes to guide consumers and policy makers.

The much needed translation and communication of required knowledge to practice and policy making would be greatly enhanced when financial barriers to data availability are demolished.

In addition, the distinction between primary research databases and knowledge databases for practice and policy making, should be made more clear in both the scientific and policy-making world. Primary research databases need more detail as to sources and methodology of individual data in order to re-analyse the body of data under future new hypotheses. Database tools for European-wide practice and policy making, such as the mapping programme produced within the THADE project, require a higher level of aggregation and more extensive interpolation of figures to show European variation, trends and relationships. Of course this is something of a cultural 'revolution' among building researchers and epidemiology scientists, who have to accept a lower level of reliability of individual data used by consumers and policy makers. By constructing software links between the primary research databases and our mapping programme, this practice and policy mapping tool could regularly be updated with the newest scientific findings, thereby overcoming part of the resistance that may be encountered in the scientific world.

Within the European Research Area a Network of Excellence has recently been formed under the name of GA^{2}LEN (Global Allergy and Asthma European Network).[2] It consists of 25 leading European institutions and two organisations, the European Academy of Allergology and Clinical Immunology (EAACI), and EFA. One of the objectives of GA^{2}LEN is to enhance the quality and relevance of research, to address all aspects of allergy and asthma, and to eventually decrease the burden of these diseases throughout Europe. We think that the GA^{2}LEN network is well suited to take up the continuous task of collecting and assessing primary scientific knowledge to be included in the mapping programme for use by consumers and policy makers.

And last but not least, the category of 'people with special needs' should be discarded and the Young, the Old, the Pregnant, the Immuno-suppressed (YOPI) as well as Europeans suffering from chronic afflictions, such as asthma or COPD, should be included in the natural variation of human populations. Legislature pertaining to built environments can subsequently also take into account the needs and capabilities of all sections of society. By advocating Universal Design[3] the European Union has already expressed this view, but this Universal Design approach should be implemented more fully in the different disciplines of policy making in Europe.

3.5 BUILDING DIRECTIVE

The European Union possesses a splendid tool for improving indoor air conditions that has not yet been used to its fullest power. The allowable health risk of a building is treated in EU Council Directive 89/106/EEC,[4] which says that 'The construction work must be designed and built in such a way that it will not be a threat to the hygiene and health of the occupants and neighbours.' It also states that this condition should be satisfied for both existing and new dwellings. Since a sizeable part of the European population is currently experiencing dwelling-related health-diminishing effects, Member States should be requested to show to which level of 'hygiene and health' national building legislation guarantees. Subsequently a discussion may start about the required level in the Union, and national legislature can be adapted to prevent mite and fungal growth, and to more efficiently eliminate other pollutants in indoor air. This way the long-term effects of poor indoor air can be reduced and the societal burden of disease diminished.

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4 HEALTH DETERMINANTS OF INDOOR AIR QUALITY

For each pollutant, we list the source(s), and the evidence-based information related to exposure and to the health effects of air pollution in dwellings, particularly as regards allergies, asthma and other respiratory diseases.

Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless and tasteless gas. It is a product of the incomplete combustion of carbon-containing materials, and is also produced by some industrial and biological processes. Carbon monoxide is widely generated indoors by unvented combustion appliances, particularly if they are operated in poorly ventilated rooms. Tobacco smoking is an important source of indoor CO pollution.

A review of indoor concentrations of CO is provided in Table 4.1. High CO levels are mainly caused by wood burning for cooking/heating, especially in developing countries. In England[1] CO levels are 0.43 mg/m^3 (geometric mean). In other European countries (Expolis Study),[4] the mean is 1.39 mg/m^3 in houses and workplaces, similar to Costa Rica,[2] Canada[3] and Korea.[5] The standard US Environmental Protection Agency (EPA) value is 10 mg/m,[3,9] whereas The Finnish Society of Indoor Air Quality (FSIAQ) suggests 2, 3 and 8 mg/m^3 for 'very good', 'good' and 'satisfactory' indoor air quality, respectively.[10]

Like oxygen, CO binds to haemoglobin so forming carboxyhaemoglobin (COHb). However, CO is about 200 times as effective as oxygen in binding with haemoglobin. Thus, in the presence of CO, haemoglobin will be less available to transport oxygen to tissues. The health effects of CO exposure are generally discussed in terms of the per cent of COHb in the blood. The level of COHb is directly related to the air-borne CO concentration, duration of exposure, and the individual's level of activity. As the CO concentration increases or decreases from this point, the COHb level will follow. Normally, metabolic processes in the body will result in a COHb level of 0.5% to 1.0%. Average COHb levels in non-smokers are 1.2%-1.5%. In cigarette smokers COHb levels are about 3%-4% on average, but can reach 10% in heavy smokers. Carbon monoxide can have detrimental effects on the heart and lungs, and on the central nervous system. COHb levels of 2.5% have been shown to aggravate symptoms in angina pectoris patients. At a level of 10%, the major effects are cardiovascular and neurobehavioural.

It has been noticed that for an increase of 10 ppm of CO (12.5 mg/m^3), an increased risk for wheezing attacks (O.R.=1.12, 95% CI 1.02-1.28) was found in Korean asthmatic children.[5] Moreover a Chinese study[7] reported harmful effects of CO level on pulmonary function.

Table 4.1. Indoor residential levels of CO/CO_2

Author – Source	Study Area	Survey year(s)	Methods	N° homes	Concentration Mean (mg/m^3)	Main results
Raw et al.[1]	UK (rural-urban-suburban-central urban)	1997-99	CO 2 weeks mean (2 weeks)	235 339 222 31 821	0.31 (rural) 0.46 (suburban) 0.52 (urban) 0.71(central urban) 0.43 (total indoor) (geom. mean)	Influencing factors were gas cooking, unflued heaters, smoking, outdoor.
Lee and Park[2]	Costa Rica (rural area)	1998	CO 24 h mean (24 h)	22	1.63 (wood-burning stoves)	Biomass combustion can release a considerable amount of CO.
Levesque et al.[3]	Canada (Quebec City)		CO 12 h mean (12 h)	37 24 9	not detected (n=28) 2.50 (n=9, with stoves /fireplace)	Measurements of CO only in homes with combustion appliances were detectable.
Maroni et al.[4]	Italy (Milan) Greece (Athens) Switzerland (Basel) Finland (Helsinki) Czech Rep (Prague) (Expolis Study)	1996-98	CO 48 h mean (48 h)	50	2.38 (home) 1.30* 2.02* 1.18* 0.59* 1.84* * home+workplace	In all the cities the highest CO exposures were found during commuting.
Kim et al.[5]	Korea (Seoul)	1999	CO CO_2	110	2.09 1031	Indoor CO_2 concentrations are correlated with home ventilation.
Frisk et al.[6]	Sweden (Örebro) Estonia (Tallinn)	1996	CO_2 1 week mean (1 week)	97 98	1556 1665	Airtight less frequent in Tallinn. Higher crowding index in Tallinn.
Pan et al.[7]	China (Anhui-rural)	1999	CO	189	2.00 (kitchen) 1.62 (bedroom) 3.00 (during cooking) 1.62 (during non cooking)	Values of CO were significantly higher during cooking time.
Naeher et al.[8]	Guatemala (7 villages)	-	CO (2-3 minutes per home per meal)	-	28.6 (open fire)	The highest concentrations of CO were measured in homes using open fire (maximum >31 mg/m^3).

Carbon dioxide

Carbon dioxide (CO_2) is a colourless, odourless gas. Solely by breathing, man continuously emits carbon dioxide and water vapour. Gas-, kerosene- or wood-fuelled appliances are generally the main sources of CO_2, depending on how combustion exhausts find their way into the indoor atmosphere. In the absence of combustion sources, the indoor CO_2 concentration is considered a useful ventilation indicator.

Only two studies, performed in Sweden and Latvia[6] and in Korea,[5] reported CO_2 levels at home; these were 1556–1665 and 1031 mg/m^3, respectively. Unvented heaters, gas cooking, tobacco smoke and outdoor environment were the major sources of indoor CO_2. The FSIAQ suggests 1300 for 'very good', 1650 for 'good', and 2200 mg/m^3 for 'satisfactory' indoor air quality.[10] At these concentrations, CO_2 is not harmful; however, it is an indicator of other airborne pollutants and ventilation rate.

No differences were found in CO_2 levels in the houses of asthmatic children versus non-asthmatic children.[6] Differently, in adults, nocturnal breathlessness was significantly correlated with the indoor concentration of CO_2 (O.R.=20.0; 95% CI 2.7-146.0) for an increase of 1000 ppm (1830 mg/m^3).[11]

Nitrogen dioxide

Nitrogen dioxide (NO_2) is a gas that has a pungent, acrid smell. Generally, NO_2 results from sources of indoor combustion: tobacco smoke, gas appliances, kerosene heaters, woodstoves and fireplaces. Outdoor air is also a source of indoor NO_2 pollution.

Nitrogen dioxide levels in European homes are reported in Table 4.2 I and II, and Figure 4.1. Levels were lowest in Scandinavia (range: 10-15 µg/m^3)[23,24] and highest in Poland (65 µg/m^3).[23] Levels of 8–35 µg/m^3 were reported in Switzerland[22] and Germany,[17] and 20-40 µg/m^3 in Italy, France, England, Germany and Croatia.[12-16,18,23] Nitrogen dioxide levels were higher in Asia (43-81 µg/m^3),[19,21,23] New Mexico (USA)[25] and Mexico,[23] whereas in North America they were similar to European levels.[23] The Air Quality Guidelines in Europe[26] suggest a daily maximum NO_2 concentration of 200 µg/m^3 (1 h), whereas the World Health Organization recommends an annual average limit of 40 µg/m^3.[27]

Nitrogen oxide is an oxidising agent that is highly irritating to mucous membranes, and causes a wide variety of health effects. Table 4.3 shows the effects of NO_2 and major sources of NO_2 on respiratory health in people of all ages and both sexes. In a Polish study on elderly women, asthma and dyspnea were related to high exposure to gas cooking.[31] In England, gas cooking was a risk for reduced lung function.[32]

Particulate matter

Airborne particulate matter (PM) is a composite of hundreds of different substances that exist as particles that are extraordinarily heterogeneous in terms of chemistry and size with a high degree of spatial and temporal variability.

Studies on PM levels are reported in Table 4.4 and Figure 4.2. The lowest level (9.5 µg/m^3) was measured in Finland[33] and the highest in Italy (mean about 50 µg/m^3).[4,12] In other European countries, PM levels in dwellings were below 40 µg/m^3,[15,16,33,35] sim-

Table 4.2 part I. Indoor residential levels of NO_2

Author – Source	Study Area	Survey year(s)	Methods (duration)	N° homes	Concentration Mean (µg/m^3)	Main results
Simoni et al.[12]	Italy-1 (Pisa) Italy-2 (Po Delta)	1991-94	1 week mean (2 weeks)	282 139	26.3 34.8	Slightly higher levels of NO_2 in the rural than in the urban area. Importance of assessing exposure from outdoor concentrations and indoor sources separately in epidemiological studies.
Gallelli et al.[13]	Italy-3 (Genoa)	2000	- (2 months)	89	47.0 (kitchen) 24.8 (bedroom)	NO_2 was affected by (a) the presence of a chimney equipped with an active aspiration device in the kitchen and (b) the heating system.
Coward et al.[14]	UK-1	1997-99	2 weeks mean (2 weeks)	812	21.8 (kitchen) 11.9 (bedroom) (geometric mean)	Indoor concentration was positively related to gas appliances, ETS and outdoor concentrations.
Gee et al.[15]	UK-2 (Manchester)	2000-01	5 days mean (5 days)	69	27.2 (living room) 20.3 (bedroom)	Presence of smoking did not seem to affect NO_2 levels.
Zmirou et al.[16]	France-1 (Paris, Nice, Toulouse, Clermont-Ferrant, Grenoble)	1998-2000	48 h mean (48 h)	109	36.1	In addition to penetration of outdoor pollutants, indoor sources contribute significantly to indoor concentrations at home.
Cyrys et al.[17]	West Germany (Hamburg) East Germany (Erfurt)	1995-96	1 week mean	201 204	17 (median) 15 (median)	Gas for cooking was the major indoor source of NO_2. This variable caused an increase in the NO_2 level of 43% in Erfurt and of 47% in Hamburg.
Saintot et al.[18]	France-2 (South France)	1998	1 h mean (2 x 5 dd)	-	41	The site of the dwelling with regard to high traffic street and the presence of a gas stove influenced NO_2 indoor concentration. Mechanical air extraction decreased NO_2 level.
Shima et al.[19]	Japan (Chiba Prefecture)	1993	24 h mean (2 x 24 h)	842	47.8	NO_2 concentration was higher in homes with unvented heaters.
Garrett et al.[20]	Australia (Victoria)	1994-95	4 days mean	80	11.6 (median)	Major indoor NO_2 sources were: gas stoves, vented gas heaters and smoking. Some 67% of variation in NO_2 levels could be explained by the presence of major sources, house age, and outdoor levels.

Table 4.2 part II. Indoor residential levels of NO_2

Author – Source	Study Area	Survey year(s)	Methods (duration)	N° homes	Concentration Mean (µg/m³)	Main results
Leung et al.[21]	China (Hong Kong)	-	1 week mean (1 week)	40	91.6 (kitchen) 61 (bedroom /lounge room)	NO_2 is present in varying quantities in residential homes.
Monn et al.[22]	Switzerland-2 (4 urban +2 rural +2 alpine areas)	1993-94	1 week mean (1 week)	about 140	21	Gas-cooking and smoking were important factors for elevated indoor NO_2 levels.
Levy et al.[23]	Finland (Kuopio)	1996	48 h mean (48 h)	30	10.34	Large variation of NO_2 across the world. Gas appliances and presence of smokers increase indoor levels.
	Norway (Kjeller)			30	14.66	
	Switzerland-1 (Geneve)			33	15.60	
	Germany-1 (Erfurt)			29	16.97	
	Canada (Ottawa)			29	20.12	
	Germany-2 (Berlin)			31	23.12	
	Croatia (Zagreb)			15	31.58	
	USA (Boston)			20	36.10	
	UK-3 (London)			117	40.42	
	Japan-2 (Sapporo)			59	43.43	
	Manila (Philippines)			14	45.12	
	China (Beijing)			44	47.75	
	Poland (Sosnowiec)			15	64.67	
	Korea-1 (Taejon)			40	72.76	
	India (Bombay)			20	76.70	
	Japan-3 (Tokushima)			30	78.77	
	Korea-2 (Seoul)			31	81.22	
	Mexico (Mexico City)			30	117.88	
Hagenbjork-Gustafsson et al.[24]	Sweden (Umea, suburban control)	1994	24 h mean (2 x 24h)	23 20	11 (urban area) 6 (control area)	There was a lower level of penetration of outdoor air into the houses in the urban area, possibly due to the differences in air-exchange rates. No presence of gas-appliances in the homes.
Lambert et al.[25]	New Mexico (Albuquerque)	1988-91	2 weeks mean	1205	63.9 (kitchen) 54.5 (living room) 39.5 (bedroom)	The mean NO_2 concentration was higher in the homes with gas cooking stoves than in those with electric cooking stoves.

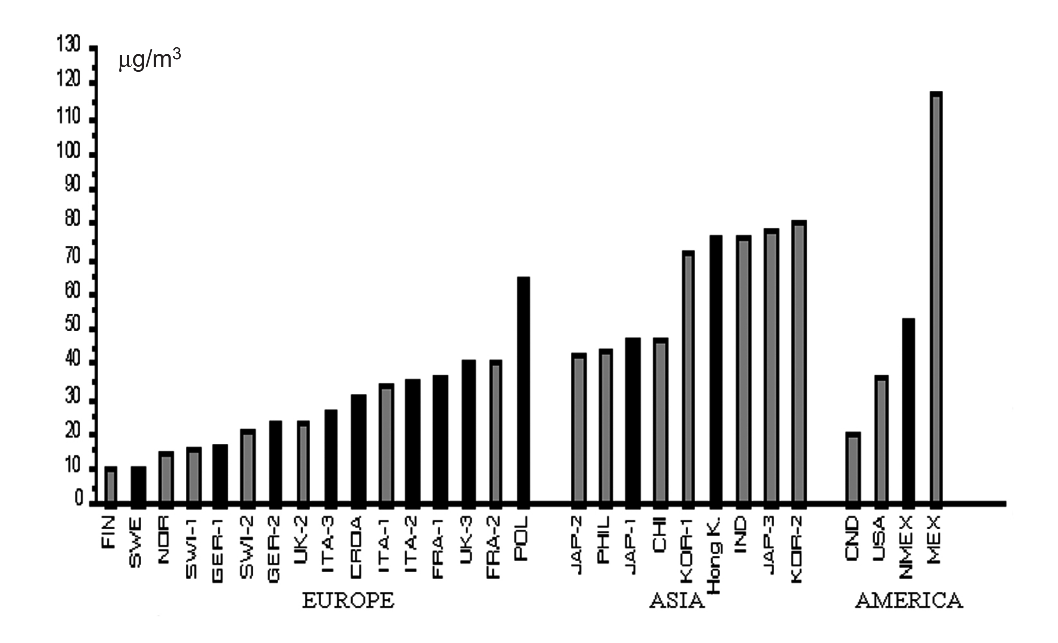

Figure 4.1. Residential mean NO_2 concentrations in different countries

ilar to concentrations reported for USA[38] and Mexico.[34] The EPA air quality guideline is 65 µg/m^3 (48-hour mean),[9] whilst the FSIAQ sets maximum values of 20, 40, 50 µg/m^3 for a 'very good', 'good' and 'satisfactory' indoor air quality, respectively.[10] The outdoor environment, tobacco smoking and combustion of fuel for heating or cooking are the main determinants of elevated PM levels. Outdoor combustion particles arise from industrial smokestack emissions, vehicle exhaust (from diesel and gasoline), heating exhaust (from coal or wood), forest fires and other open fires or incineration (e.g. yard waste and trash burning). The extent to which these outdoor-source particles affect a building's indoor air depends on the building's location, its proximity to pollution sources, type of ventilation system, the proportion of outdoor air in the indoor air mixture, and the location of air intakes. Indoor combustion particulate sources are heating appliances, dry-process photocopying machines, cooking appliances and tobacco smoke.

The studies conducted on the health effects of PM and major sources of PM are shown in Table 4.5. Respiratory symptoms/diseases were significantly related to environmental tobacco smoke (ETS) exposure in adults in Poland[31] and in Switzerland[41]. The population attributable risk (PAR) % values, especially for wheezes, and shortness of breath with wheezes ranged from 22% to 52%.

Epidemiological studies suggest that PM pollution, at levels found in many urban and industrial areas, contributes to human morbidity and mortality for cardiorespiratory diseases.[43] The main health effects associated with PM exposure are premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure,

Table 4.3. Effects of NO_2 levels/gas appliances on respiratory health

Author – Source	Country/Survey yr (sample)	Risk factor [% of exposed]	Disease/condition	O.R.	95% C.I.	PAR (%)
Shima et al.[19]	Japan/1992 (Children-females)	NO_2 (10 ppb increasing)	Bronchitis Wheeze Asthma	1.42 1.90 1.63	1.06-1.90 1.30-2.83 1.06-2.54	- - -
Garrett et al.[28]	Australia/1994-95 (Children)	gas stove (yes vs. no)	Respiratory Symptoms	2.32	1.04-5.18	-
Neas et al.[29]	USA/1983-86 (Children)	NO_2 (15 ppb increasing)	Respiratory Symptoms	1.2 (boys) 1.7 (girls)	0.9-1.5 1.3-2.2	- -
Simoni et al.[12]	Italy/1991-94 (Adults)	NO_2 (over median value vs. under median value of exposure index: level x exposure time) [49.9%]	Acute Respiratory Illness	1.50	0.96-2.33	**20.0**
Pilotto et al.[30]	Australia/1995 (Adult males)	gas heaters (yes vs. no)	Asthma	3.27	1.40-7.64	-
Jedrychowski et al.[31]	Poland/- (Women 65+ yr)	gas cooking exposure (highest exposure vs. other categories)	Asthma (never smokers) Asthma (ex-curr. smokers) Dyspnea (never smokers) Dyspnea (ex-curr. smokers)	2.81 2.36 7.16 3.05	1.73-4.57 1.00-5.59 5.02-10.2 1.50-6.20	- - - -
Moran et al.[32]	UK (all ages)	fuel for cooking (gas vs. electricity)	Lung function: decrement in FEV_1: -70mL decrement in FVC: -35mL			

Table 4.4. Indoor residential levels of particulate matter

Author – Source	Study Area	Survey year(s)	Methods (duration)	N° homes	Concentration Mean (µg/m^3)	Main results
Simoni et al.[12]	Italy-2 (Pisa) Italy-3 (Po Delta-rural)	1991-94	$PM_{2.5}$ 48 h mean (2 weeks)	282 139	57 63	Slightly higher levels of PM in rural than in urban area. Presence of smoking significantly increased PM levels.
Gotschi et al.[33]	Greece (Athens) Switzerland (Basel) Finland-1 (Helsinki) Czech Rep (Prague)	1996-98	$PM_{2.5}$ 48 h mean (48 h)	43 41 82 20	35.6 21.0 9.5 34.4	Main predictors for PM, beside centers, were outdoor concentrations, number of smoked cigarettes/day and use of gas appliances.
Maroni et al.[4]	Italy-1 (Milan)	1996-98	$PM_{2.5}$ 48 h mean (48 h)	39	42.7	Presence of smoking significantly increased PM levels.
Gee et al.[15]	UK (Manchester)	2000-01	$PM_{2.5}$ 5 days mean (5 days)	69	28.4 (living room) 19.0 (bedroom)	Presence of smoking significantly increased PM levels.
Zmirou et al.[16]	France (Paris, Nice, Grenoble)	1998-2000	$PM_{2.5}$ 48 h mean (48 h)	44	22.5	In addition to penetration of outdoor pollutants, indoor sources contribute significantly to indoor concentrations.
Cortez-Lugo et al.[34]	Mexico (Mexico City)	-	$PM_{2.5}$ PM_{10} 24 h mean (6 weeks)	39 30	29 44	Indoor sources of PM affect personal exposure.
Pan et al.[7]	China (Anhui-rural)	1999	PM_{10} 2 real time/d (2 weeks)	189	518 (kitchen) 340 (bedroom)	Main cause of the indoor pollution in rural areas comes from the combustion of fuel in cooking and warming.
Janssen et al.[35]	Holland (Amsterdam) Finland-2 (Helsinki)	1983-88	$PM_{2.5}$ 24 h mean (beweekly x 6mm)	36 46	28.6 11.0	High correlation between personal, indoor and outdoor concentrations.
Caceres et al.[36]	Chile (La Pintana-Santiago)	-	PM_{10} 24 h mean (24 h)	24	250 (coal heat) 489 (wood heat)	Accumulation of highly toxic pollutants, caused by a lack of ventilation.
Evans et al.[37]	USA (Fresno-Ca) Residential retirement	1999	$PM_{2.5}$ 24 h mean (28 days)	60	8.9	Very low concentration, due to the lack of indoor sources in these residences (no smoking, minimal cooking...).
Neas et al.[38]	USA (six Cities Study)	1983-88	$PM_{2.5}$ 24 h mean (4 weeks)	1237	30.5	Presence of smoking significantly increased PM levels.

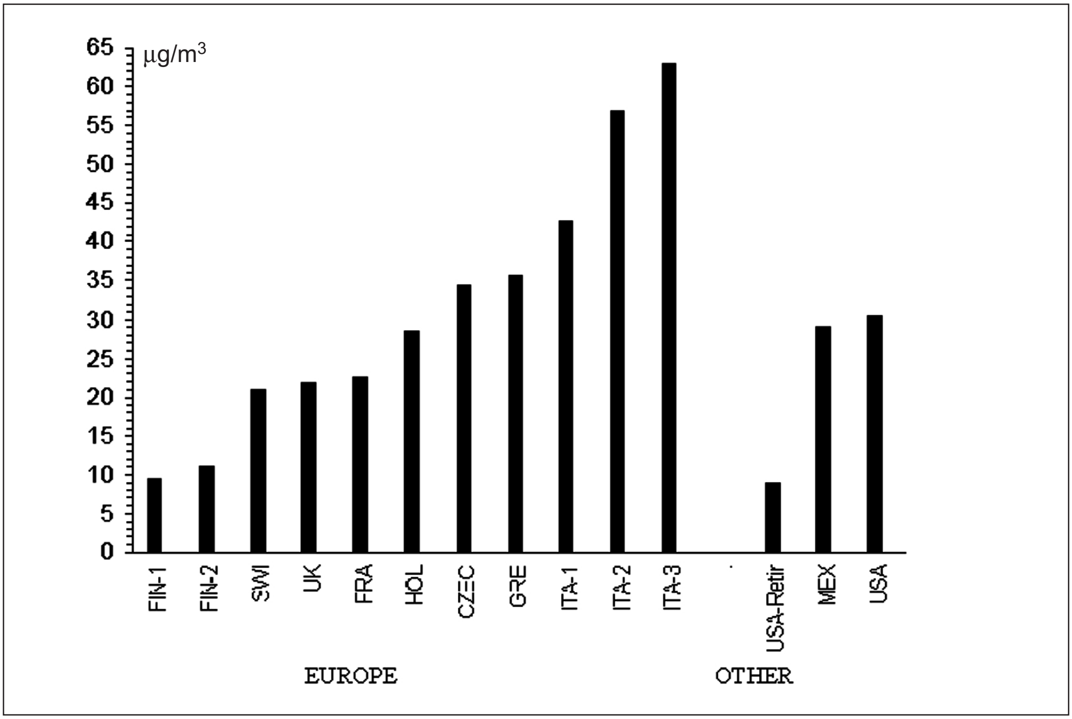

Figure 4.2. Residential mean $PM_{2.5}$ concentrations in different countries

and altered respiratory defence mechanisms. Short-term exposure to PM has been linked to hospital admissions for respiratory symptoms, respiratory diseases (e.g. asthmatic attack, chronic obstructive pulmonary disease and pneumonia) and cardiac diseases. Decreased lung function and increased respiratory symptoms have been associated with increased PM concentrations in community epidemiological studies and controlled laboratory exposure studies of laboratory animals and humans. Particularly noteworthy is the observation of these PM-associated effects in children.

Volatile organic compounds

Volatile organic compounds (VOCs) are defined by a boiling-point range with a lower limit between 50°C and 100°C and an upper limit between 240°C and 260°C. They are ubiquitous in the indoor environment. The number of VOCs detected in indoor air is usually higher than in outdoor air and has been increasing over the past decade. Over 900 VOCs have been identified thus far.[44]

Various materials commonly found in homes emit VOCs. Furniture made from pressed-wood can produce VOCs and the emissions are mainly from resins, adhesives and glues. Emissions from furniture are usually highest in the first few months after manufacture and installation, after which they rapidly subside. Indoor concentrations may fluctuate widely with temperature, humidity, occupant activities and ventilation changes. Interior treatments, paints, polyurethane, coatings, sealants, polishes and

Table 4.5. Effects of indoor PM level/ETS/coal smoke on respiratory health

Author – Source	Country/Survey yr (sample)	Risk factor [% of exposed]	Disease/condition	O.R.	95% C.I.	PAR (%)
Simoni et al.[12]	Italy/1991-94 (Adults)	$PM_{2.5}$ (over median value vs. under median value of exposure index: level x exposure time) [49.4%]	Acute resp. illness:			
			- with fever	1.70	1.10-2.65	25.5
			- without fever	1.31	1.10-1.55	13.2
Qian et al.[39]	China/1993-96 (Children)	heating coal smoke:	Bronchitis			
		lightly vs. no [10.6%]		1.61	1.35-1.92	6.3
		moderately vs. no [10.4%]		1.73	1.42-2.12	6.8
		heavily vs. no [11.5%]		2.20	1.81-2.68	12.6
Wang et al.[40]	Taiwan/1995-96 (Adolescent)	ETS (yes vs. no)	Asthma	1.08	1.05-1.12	-
Jedrychowski et al.[31]	Poland/- (Elderly women-never smoker)	ETS (yes vs. no)	Dyspnea	2.23	1.45-3.44	-
Leuenberger et al.[41]	Switzerland/1991-93 (Adults)	ETS (yes vs. no) [30.0%]	Wheeze	1.94	1.39-2.70	22.0
			Asthma	1.39	1.04-1.86	10.5
			Dyspnea	1.45	1.20-1.76	11.9
			Chronic bronchitis	1.65	1.28-2.16	16.3
Neas et al.[38]	USA/1983-86 (Children)	$PM_{2.5}$ (30 µg/m^3 increasing)	Resp. Symptoms	1.13	0.99-1.30	-
Xu et al.[42]	USA/1986 (never smokers)	use of coal stove:				
		either cooking or heating vs. no [22.6%]	Wheeze with SOB	2.9	1.4-5.9	30.4
		both cooking and heating vs. no	Wheeze with SOB	3.3	1.7-6.3	51.9
		both cooking and heating vs. no	Cough	1.8	1.0-3.3	27.3
		both cooking and heating vs. no [47.2%]	Phlegm	2.0	1.2-3.4	32.0

cleaners can also emit VOCs. Dry-cleaned fabrics can emit harmful concentrations of tetrachloroethylene (also known as perchloroethylene or PERC). Floor covering adhesives can emit significant levels of VOCs, particularly because they are often spread over large areas. Emissions from adhesives are highest during application and for some time thereafter. The main emissions from hardwood floors are from urea-formaldehyde and polyurethane coatings applied to the surface. Adhesives used to attach parquet to the sub-floor also add to the level of VOCs in indoor air.

Regular building maintenance can help prevent indoor air contamination, but cleaning may itself add pollutants to the air. Most cleaning materials, air fresheners and pesticides emit VOCs and other contaminants, which can be harmful to building occupants and maintenance and janitorial workers. Emissions from cleaning products can linger for a long time, and can affect occupants in areas served by the same ventilation system.

In all buildings, there is exchange between outdoor and indoor air. Therefore, outdoor air can contaminate indoor air. This is especially important during pollination seasons. In mechanically ventilated buildings, polluted outdoor air may contribute to indoor air pollution because of malfunctioning of the ventilation system or because the air inlet is near a source of pollution (e.g. a parking lot, van loading bays etc.).

Studies on VOC concentrations are listed in Table 4.6, part I. Detected levels of toluene,[10] the most studied compound within this group,[45,47,48] ranged from 15.1 in England[45] to 37.3 $\mu g/m^3$ in Germany,[47] similar to those measured in Italy.[48]

Table 4.7 lists the studies conducted on the health effects of VOCs. A German study showed a significant association of VOC exposure with irritation symptoms of the upper respiratory tract.[49] In Sweden, asthma was related to newly painted surfaces (OR 1.5; 95% CI 1.0–2.4).[57]

Volatile organic compounds can cause irritation of the eyes and respiratory tract and sensitisation reactions that involve the eyes, skin and the respiratory tract. Symptoms of VOC exposure include fatigue, headache, drowsiness, dizziness, weakness, blurred vision, skin irritation, irritation of the eyes and respiratory tract; there is some evidence that VOCs can provoke some of the symptoms typical of sick building syndrome. At higher concentrations, many VOCs are potent narcotics and cause depression of the central nervous system, and liver and kidney damage. Benzene is a human carcinogen, and carbon tetrachloride, chloroform, trichloroethylene, tetrachloroethylene and p-dichlorobenzene are animal carcinogens. 1,1,1-trichloroethane, styrene and pinene are mutagens and possible carcinogens. Although the health risks of indoor VOC pollution have yet to be studied, these chemicals appear to pose a significant cancer risk.[44]

Formaldehyde

Formaldehyde is the simplest and most common aldehyde found in the environment. It is perhaps the most important single indoor air pollutant because of its wide occurrence and its strong irritation potential.

The major sources of formaldehyde affecting human beings are in the indoor environment. They include cigarette smoke and other combustion sources, and urea-

Table 4.6 part I. Indoor concentrations of organic volatile compounds – General

Author – Source	Study Area Years	Methods	Concentration	Main results
Brown et al.[45]	UK	VOCs were monitored in 876 homes for a single period of 4 weeks.	Geometric mean: Benzene: 3.0 µg/m^3 Toluene: 15.1 µg/m^3	Main factors influencing VOCs levels were: dwelling age, season, location (urban/rural), vehicle fuel, smoking, use of painting and decorating.
Cox et al.[46]	USA	Particles were collected on sorbent tubes and analyzed by gas chromatography/mass spectrometry.	VOCs levels ranged from 5.10 µg/g of vinyl flooring to 130 µg/g of vinyl flooring	Vinyl flooring releases high concentrations of VOCs.
Schneider et al.[47]	East-Germany (Erfurt) West-Germany (Hamburg) 1995-1996	VOCs measurements in 204 households in Erfurt and 201 in Hamburg, were performed during one week in summer and winter, using passive sampler.	Toluene: 37.29 µg/m^3 (Erfurt) 20.46 µg/m^3 (Hamburg) Benzene: 2.17 µg/m^3 (Erfurt) 1.48 µg/m^3 (Hamburg)	Winter VOCs concentrations exceeded the summer values. Indoor concentrations were higher than the outdoor concentrations.
Carrer et al.[48]	Italy (Milan) 1995-1996	Personal air monitoring (on 100 adults) at home, in the office, and during commuting. Blood benzene and toluene measurements were performed.	Geometric means of the total 24h personal exposure were: Total VOCs: 514 µg/m^3 benzene: 21.2 µg/m^3 toluene: 35.2 µg/m^3	Daily exposure to VOCs was almost totally determined by indoor exposure at home and in the office.
Pitten et al.[49]	Germany	VOCs were monitored in completely redeveloped buildings.	Total VOCs: 2000-3000 µg/m^3 2 months after moving into the building. Total VOCs after 10 months: 900-1300 µg/m^3	VOCs concentrations may reach very high levels in completely redeveloped buildings.

Table 4.6 part II. Indoor concentrations of formaldehyde

Author – Source	Country Years	Methods	Concentration	Main results
Minami et al.[50]	Japan 1997-1998	Indoor formaldehyde concentrations were measured 17 times, for 28 days, in 42 homes (48 hours sampling for each measurement).	Formaldehyde concentrations ranged between 0.07 ppm (91.25 $\mu g/m^3$) and 0.23 ppm (290.00 $\mu g/m^3$).	Formaldehyde concentrations exceeded the Japanese Government's guideline value of 0.08 ppm (100.00 $\mu g/m^3$) in 34 homes (81%).
Brown et al.[51]	UK	Measurements were performed over three consecutive days in 876 homes (in bedrooms).	Geometric mean: 22.2 $\mu g/m^3$. The highest levels were found in new homes, and in autumn (26.1 $\mu g/m^3$). The lowest levels were measured in winter (19.5 $\mu g/m^3$).	The levels of pollutant were higher in the homes with particleboard floors.
Garrett et al.[52]	Australia Latrobe Valley, Victoria 1994-1995	Formaldehyde levels were measured in 80 dwellings on four occasions with passive sampler.	The median indoor formaldehyde level was 15.8 $\mu g/m^3$ with a maximum of 139 $\mu g/m^3$.	Formaldehyde levels may reach peak concentrations in Australian dwellings.
Lemus et al.[53]	USA Southern Louisiana	Gas chromatography analyses were performed from air samples collected in 53 homes.	Indoor formaldehyde concentrations ranged from non-detectable values to 6.60 $\mu g/m^3$.	Indoor formaldehyde concentrations generally exceeded the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommended levels.
Liu et al.[54]	USA	Indoor formaldehyde concentrations were measured in mobile homes using passive monitors. Formaldehyde concentrations were measured for 1 week in summer and 1 week in winter.	Indoor formaldehyde concentrations ranged from non-detectable values (0.01 ppm) (12.50 $\mu g/m^3$) to 0.46 ppm (575 $\mu g/m^3$).	Formaldehyde concentrations may be very high in mobile homes.

formaldehyde resins that are used in large quantities as glues in the manufacturing of wood products such as particleboard and plywood. Formaldehyde may also be used in urea formaldehyde foam insulation. Formaldehyde can be released over long periods of time, even years, at a slowly decreasing rate. Indoor concentrations are influenced by temperature, humidity, ventilation rate, age of the building, product usage, presence of combustion sources, and the smoking habits of occupants.

Formaldehyde indoor concentrations are listed in Table 4.6, part II. Indoor levels vary substantially among countries and are generally very high compared with the FSIAQ standard values.[10] For example, in the United States formaldehyde levels ranged between barely detectable (12.5 $\mu g/m^3$) to very high (575 $\mu g/m^3$).[54] Levels were high also in Japan.[50] In the UK the geometric level was 22.2 $\mu g/m^3$.[51]

Studies on the health effects of formaldehyde are reported in Table 4.7. Formaldehyde has a pungent odour and has irritating properties causing discomfort. The symptoms displayed after short-term exposure to formaldehyde are: irritation of eyes, nose and throat, together with exposure-dependent discomfort, lachrymation, sneezing, coughing, nausea and dyspnoea. Children have been reported to be more sensitive. Several reports show that formaldehyde gas exposure causes direct irritation of the respiratory tract. Because of absorption in the upper respiratory tract, higher concentrations of formaldehyde are required to stimulate bronchial receptors than those needed to cause sensory irritation. A number of studies indicated that formaldehyde could predispose certain groups, particularly children, to respiratory tract infections.

There is no scientific evidence demonstrating that formaldehyde gas *per se* can cause respiratory tract allergy. There are clinical reports that challenge tests with formaldehyde gas elicited allergic respiratory reactions, but the issue remains open. There may be susceptible groups or genetic differences in the population. Formaldehyde was shown to be an irritant for the respiratory tract, and could cause sensitisation in exposed children (OR 1.40; 95% CI 0.98-2.00).[52] An Australian survey indicated that each 10 $\mu g/m^3$ increase in formaldehyde concentrations was associated with an enhanced risk of having asthma (OR 1.003; 95% CI 1.002-1.004).[55] Occupational studies indicate that 1-2% of the population exposed to high concentrations of formaldehyde may develop asthma.

Environmental tobacco smoke

Environmental tobacco smoke (ETS) is the single largest contributor to indoor particulate concentrations in office buildings, residences and other public buildings where tobacco smoking occurs. In some cases, the particulates attributable to ETS account for 50%-90% of the total particulate concentration. Inhaling ETS is sometimes referred to as ‘passive smoking’. Environmental tobacco smoke consists of:

- Mainstream smoke (inhaled and exhaled by the smoker).
- Sidestream smoke (from the end of the cigarette between puffs).
- Vapour-phase components (diffused through the cigarette paper).

Table 4.7. Health Effects of indoor organic volatile compounds and formaldehyde

Author – Source	Country Years	Methods	Risk factor	Health effects	Relative risk
Rumchev et al.[55]	Australia (Perth) 1997-1999	Young children (6 month-3 years) in a population-based control study (88 cases and 104 controls) were studied using respiratory questionnaires.	Formaldehyde (every 10 $\mu g/m^3$ increase)	Asthma	OR 1.003; 95% CI 1.002-1.004
Diez et al.[56]	Germany (Leipzig)	VOC were measured in the infant bedrooms using passive sampling for 4 weeks after birth. A medical examination was performed at the age of six weeks and 1 year.	Styrene Benzene	Pulmonary infections during the first six weeks of life	(Styrene) OR 2.10; 95% CI 1.10-4.20 (Benzene) OR 2.40; 95% CI 1.28-4.48
Pitten et al.[49]	Germany	Fifty-eight subjects were studied. VOC levels were measured in completely redevelop buildings. Health information were collected by questionnaire.	VOC exposure	Soreness of throat Irritation of mucous membranes	OR 10.72; 95% CI 1.46-465.20 OR 10.45; 95% CI 1.43-453.80
Garrett et al.[52]	Australia-Latrobe Valley, Victoria 1994-1995	A total of 148 children, aged 7-14 years, were included in the study. A respiratory questionnaire was filled in and skin prick tests were performed.	Formaldehyde exposure	Formaldehyde sensitization	OR 1.40; 95% CI 0.98-2.00
Wieslander et al.[57]	Sweden	The participants (562 adult subjects) filled in a self-administered questionnaire about respiratory symptoms and indoor exposure. A methacholine provocation test was performed.	Exposure to: Newly painted surfaces (a) Newly painted wood details (b) Kitchen painting (c)	Asthma (combination of bronchial hyper-responsiveness and asthma-related symptoms)	(a) OR 1.5; 95% CI 1.0-2.4 (b) OR 2.3; 95% CI 1.2-4.5 (c) OR 2.2; 95% CI 1.1-4.5

Burning cigarettes emit particulates in sidestream smoke and exhaled mainstream smoke. About 85% of passive smoke exposure comes from sidestream smoke and 15% from mainstream smoke. Sidestream and mainstream smoke components are similar in number, but vary in composition. Some ETS components are more prevalent in sidestream smoke. For example, carbon monoxide is 2.5 times higher in sidestream smoke than in mainstream smoke. Overall, PM is up to three times more concentrated in sidestream smoke. Therefore, many toxic and carcinogenic compounds are at higher levels in sidestream smoke, though dilution by room air significantly reduces the concentrations inhaled by non-smokers compared with those inhaled by smokers.

The health effects caused by inhaling these particles and other ETS constituents have been reviewed by the USA Environmental Protection Agency[58] and Jaakkola.[59] Widespread exposure to ETS has a serious, substantial health impact. In children there is evidence that exposure to ETS is:

- Causally associated with an increased risk of lower respiratory tract infections such as bronchitis and pneumonia.
- Causally associated with additional episodes and increased severity of symptoms in children with asthma.
- A risk factor for new cases of asthma in children who have not previously displayed symptoms.
- Causally associated with an increased prevalence of fluid in the middle ear, symptoms of upper respiratory tract irritation, and a small but significant reduction in lung function.

Several studies support the conclusion that ETS causes lung cancer.[58,59] Childhood ETS exposure may influence the development of lung cancer in adult life, since childhood may represent a more susceptible age period, and because childhood exposure adds to the total cumulative exposure.

Many people do not tolerate tobacco smoke. Non smokers exposed to smoke often complain of intolerance to its odour, eye irritation, nasal symptoms, cough and headache.

Man-made mineral fibres

The man-made mineral fibres (MMMF) discussed in this document are restricted to a subset known as man-made vitreous fibres (MMVF), which are fibres manufactured from glass, natural rock or other minerals. They are classified according to their source material. Slag wool, rock wool and glass wool or filaments are produced from slag, natural rock and glass, respectively. While naturally occurring fibres are crystalline in structure, most MMMF are amorphous silicates. MMMF are widely used as asbestos substitutes. Fibrous glass accounts for about 80% of MMMF and is mainly used in acoustic and thermal insulation. Textile grades (5-10% of fibrous glass production) are used mainly to reinforce resinous materials and in textiles, such as draperies. Less than 1% of the production of glass fibre is in the form of fine fibres used for such speciality applications as high efficiency filter paper and insulation for aircrafts. Mineral wool (rock wool/slag wool), which accounts for about 10-15% of MMMF production in the USA, is used mainly in acoustic and thermal insulation. In Europe, glass wool and rock wool are produced in practically equal volumes and are also used for thermal and acoustic insulation.

It seems likely that the main source of emissions of MMMF (mainly glass fibres) in indoor air is insulation in public buildings or homes. Although quantitative data are not available, emissions are probably highest shortly after installation or after disturbance of the insulation.

Mineral fibres are irritants. Fibrous glass and rock wool fibres (mainly those greater than 4.5-5 μm in diameter) cause mechanical irritation of the skin characterised by a fine, punctuate, itching erythema, which often disappears with continued exposure. If the mineral wool is uncoated, the fibres may be released into the air, deposited on surfaces, and enter the respiratory track and eyes causing irritation. While carcinogenic effects have been suspected in cases of high occupational exposure to mineral fibres, no such studies have been conducted under non-occupational circumstances.

Pesticides

Pesticides are an indoor source of pollution. The substances that make the pesticides fatal to rats, mice, insects and other pests are also toxic to humans. Exposure to chemical pesticides can have serious health effects, ranging from mucous membrane irritation to systemic toxic effects, depending on the exposure concentration. The ‘active’ components constitute only about 0.5%-5% of the volume of ingredients in pesticide solutions. The ‘inert’ ingredients, such as xylene, n-decane, 1,1,1-trichloroethane, mesitylene, methyl ethyl benzene, cumene and kerosene, dissolve the active ingredients and allow for better dispersion on application. However, ‘inert’ ingredients can also be toxic.

Biocontaminants

Biological agents are natural, ubiquitous components of the earth’s ecosystems. In recent decades levels of biocontaminants and their by-products have increased in many indoor environments. Biocontaminants that can contribute to indoor air quality problems are bacteria, fungi and fungal spores, viruses, algae, parasites (free-living amoebae), pet dander allergen, dust mite allergens, plant pollen and insect pest allergens. Microbial growth and other biocontaminants in indoor environments have been associated with human health effects, including allergic and irritant responses, infectious diseases, respiratory problems and hypersensitivity reactions. Factors affecting indoor biocontaminant proliferation include:

- Sources of micro-organisms: outdoor air, air handling systems, humidification systems, building materials and furnishings, occupants, pets and houseplants.
- Water sources: roof and plumbing leaks, water migration, condensation, houseplants, humidifiers, human occupants and aquariums.

- Nutrient (or food) sources*:* dust, dirt, food, water, houseplants, detritus (dead plant tissue), building materials and furnishing surfaces.
- Temperature*:* indoor ambient and surface temperatures in the range most favourable to the growth of many micro-organisms.

The growing significance of biocontaminants in indoor environments over the last few decades is due to various factors:

- Building envelopes have become tighter.
- Less outdoor air is used in heating, ventilation and air conditioning (HVAC) systems.
- Micro-organisms shed indoors by humans are not readily diluted by mixing with outdoor air.
- Energy conservation measures have contributed to the build-up of moisture in indoor environments, which facilitates the growth of micro-organisms.
- Poor maintenance has contributed to the build-up of dirt and debris (potential nutrients for micro-organisms) in HVAC systems.

The four major categories of biological particles that affect indoor air quality are viruses, bacteria including actinomycetes, fungi, including moulds and yeast, mites and their faeces, and dander from pets and other furred animals.

Viruses

Such viral illnesses as the common cold and measles can be transmitted via indoor air, e.g. measles in schools, and the rates of viral infection in buildings equipped with recirculating-air HVAC systems may be higher than in naturally ventilated buildings. However, it is generally held that person-to-person transmission is the main cause of outbreaks of most viral diseases, e.g. mumps.

Bacteria

The main sources of bacterial aerosols in indoor air are usually humans and animals. Disturbing settled dust can also create bacterial aerosols. Humidifiers and drainage fans in HVAC systems are potential sources of airborne bacteria.

Together with fungi, bacteria (including their antigens and endotoxins) in humidifiers are implicated in humidifier fever, a disease with both toxic and allergic manifestations. Infrequently, bacteria in buildings may cause extrinsic allergic alveolitis in occupants. *Bacillus subtilis*, *Pseudomonas aeroginosa* and thermophilic actinomycetes in the air of dwellings and offices have been reported to cause extrinsic allergic alveolitis in occupants.

Occasionally, bacteria that cause important infectious diseases and that are present in droplet nuclei from individuals shedding pathogenic agents, e.g. *Mycobacterium tuberculosis*, can be rapidly dispersed throughout an enclosed environment via a recirculation system. Another example is *Legionella*. This Gram-negative bacterium causes two types of disease, Legionnaires' disease and Pontiac fever.

Legionnaires' disease is a severe type of pneumonia that takes its name from a serious outbreak at a meeting of the American Legion. The disease has a considerable mortality rate and appears mostly as sporadic or hyperendemic cases. Epidemics are rare. The frequency of sporadic cases is estimated to be 2% of all hospitalised pneumonias in the UK, and 10% of community-acquired pneumonias in France and Germany.[60] Less than 5% of people exposed appear to develop the illness; in 10-15% of these the illness is fatal.

Pontiac fever, named after an outbreak in 1968 in Pontiac, USA, is caused by a number of the *Legionella* species, is milder and appears as a non-pneumonic fever. The illness resolves spontaneously in 2-5 days. No fatal cases have been reported in relation to Pontiac fever. This disease mainly appears as epidemics, and 95% of those exposed to aerosols will become ill. However, the incidence of Pontiac fever in the general population is unknown and sporadic cases are unlikely to be reported even if they are recognised.[60]

Moulds/Fungi

The term 'mould' refers to moisture-related microbial growth (including fungi and some bacteria). Mould growth in any building is in itself undesirable and uncontrollable, but in addition to being a potential health hazard it is an indicator that conditions of relative humidity may also be favourable for yeast and bacteria. The most common species found in buildings belong to the genera *Cladosporium*, *Penicillium*, *Alternaria* and *Aspergillus*.

Data on the presence of damp and mould in homes are reported in Table 4.8. Visible damp and mould were present inside 15% of Finnish homes,[61] 25% of Dutch homes,[64] and 35% of Italian dwellings.[62]

The health effects of damp and mould are reported in Table 4.9. In a large Finnish survey exposure to visible mould was associated with a risk of asthma (OR 2.21; 95% CI 1.48-3.28), and PAR was estimated at about 15%.[61] Swedish subjects exposed to damp inside their homes had a higher risk of asthma (OR 1.8; 95% CI 1.1-3.0) with a PAR estimated at 16%.[65] Exposure to damp was a risk factor for bronchial hyperresponsiveness (OR 5.77; 95% CI 1.17-28.44), with a PAR estimated at 38% in Germany.[66] In The Netherlands, exposure to damp/mould was associated with an augmented risk of lower respiratory symptoms in males (OR 1.70; 95% CI 1.38-2.09) and females (OR 1.55; 95% CI 1.27-1.89). Considering the whole sample, the PAR was 9.5%.[64]

Mycotoxins are produced by a wide range of moulds. It is well established that ingested mycotoxins can cause illness and death in humans and animals. Inhalation of high concentrations of mould spores containing these toxins may deleteriously affect respiratory health. Mycotoxin-induced effects on the immune system could reduce resistance to other micro-organisms perhaps resulting in chronic health problems.

Lastly, fungi produce a complex mixture of volatiles that are frequently evident as 'mouldy smells'. The volatiles are mixtures of alcohols, esters, aldehyde, various hydrocarbons and aromatics, which can cause nausea and make some subjects quite ill.

Table 4.8. Data on the presence of home dampness/mould

Author – Source	Country Years	Methods	Main results
Kilpelainen et al.[61]	Finland 1995-1996	The survey studied 10,667 Finnish students, aged 18-25 years. Presence of visible mould or water damage was collected by questionnaire.	Visible mould or water damage were reported by 15% of the respondents.
Leung et al.[21]	Hong Kong	Forty homes were visited.	Visible dampness and mould were present in 27.5% of homes.
Simoni et al.[62]	Italy (Po Delta area, North Italy) 1991-1992	Presence of mould in the kitchen was assessed by questionnaire in 140 homes.	Visible mould was present in 35% of dwellings.
Naftstad et al.[63]	Norway	A matched case-control study was carried out in 251 cases of bronchial obstruction and their paired controls. Information on dampness signs were collected by questionnaire.	Dampness problems were present in the homes of 27% of the cases and 14% of the controls.
Brunekreef[64]	The Netherlands (Helmond)	Information on dampness problems were collected by questionnaire returned by the parents of 3,344 children.	Dampness signs and mould growth were present in 23.6% and 15.0% of homes, respectively.

Table 4.9. Health effects of home dampness/mould

Author – Source	Country Years	Methods	Risk factor	Health effects	Relative risk	PAR (%)
Kilpelainen et al.[61]	Finland 1995-1996	The survey studied 10,667 Finnish students aged 18-25 years by questionnaire about respiratory symptoms/illnesses and presence of dampness.	Exposure to visible mould	Asthma	OR 2.21; 95% CI 1.48-3.28	15.0
Norback et al.[65]	Sweden Uppsala 1991-1992	A nested case-control study with 98 prevalent cases of asthma and 357 controls was performed within a stratified random population sample (aged 20-44 years). Data about respiratory symptoms and presence of home dampness were collected by questionnaire.	Signs of dampness inside home	Asthma symptoms	OR 1.8; 95% CI 1.1-3.0	16.0
Nicolai et al.[66]	Germany (Munich) 1989-1990	A total of 155 school-children were investigated with bronchial provocation. Information on presence of dampness were collected by self-administered parental questionnaire.	Exposure to home dampness	Bronchial hyper-reactivity	OR 5.77; 95% CI 1.17-28.44	38.0
Nafstad et al.[63]	Norway (Oslo) 1992-1993	A case-control study was carried out in 251 cases with symptoms or signs of bronchial obstruction and their 251 paired controls. Information on dampness problems were collected by questionnaire.	Exposure to home dampness	Bronchial obstruction	OR 3.8; 95% CI 2.0-7.2	20.0
Brunekreef[64]	The Netherlands (Helmond)	Information on dampness/mould signs and lower respiratory symptoms were collected by questionnaire returned by 2685 subjects.	Exposure to dampness/mould	Lower respiratory symptoms	Males OR 1.70; 95% CI 1.38-2.09 Females OR 1.55; 95% CI 1.27-1.89	9.5 (Males + females)

Dust mites

Dermatophagoides pteronyssinus and *D. farinae* are the most widespread mite species. The major mite allergens are now well characterised and purified, in particular Der p I for the *D. pteronyssinus* and Der f I for the *D. farinae*; they are faecal allergens. House-dust mites feed mainly on skin scales shed by humans.[67]

Dust mites proliferate in warm, humid environments. Data on house-dust mite levels are shown in Table 4.10. These allergens are normally found in homes: high allergen values are found in mattresses, and significantly higher allergen values were found in carpeted living rooms and bedrooms than in uncarpeted living rooms and bedrooms. European studies identified mites in more than 50% of the observed dwellings.[69,71,72] Mite allergen concentrations were generally about 2 µg/g of dust and could sensitise exposed subjects.[69,70] The highest levels were found in Sweden.[71] Mite allergen levels in house dust do not correlate well with mite numbers in house dust; dead or degraded mite bodies retain their allergenic properties. Dust mite allergens may become airborne during indoor activity. It is important to note that dust mite allergens can be found also in such other environments as offices and schools.

Mite-induced health effects are reported in Table 4.11. In Germany[66] and Australia[74] exposure to high mite allergen levels was associated with bronchial hyper-responsiveness (OR 2.30; 95% CI 1.03-5.12) and current asthma (OR 21.3; 95% CI 10.5-43.2), respectively.

Dander from furred animals

Domestic pets animals (cats, dogs and rodents) may cause allergic asthma and rhinoconjunctivitis. The allergens derived from pets are mostly associated with dander, hair, saliva and/or urine. The prevalence of cat allergy and dog allergy was estimated at about 20% and 4-15%, respectively.

Dander is the most important source of cat allergens; the major allergen released by the cat, named Fel d I, has been isolated, characterised and standardised.[75] Fel d I is released in indoor environments with dander and shed hair.[76] The allergen becomes airborne, presumably after it dries and flakes off the fur, on particles from 1 to 10 µm in diameter, mostly on 5 µm particles. The fact that airborne Fel d I is associated with small particles that remain airborne for long periods may explain the distinctive rapid onset of asthma or rhinitis in patients allergic to cats entering a house where there is a cat.[77] In houses where at least one cat is present, allergen concentrations ranged from 250 to 1,140 ng/m^3 air. The Fel d I concentration in dust from houses without cats goes from below the detection limit to 100,000 ng/g dust. In houses where cats were present the concentrations ranged from usually more than 8 ng Fel d I/g dust to around 300,000 ng/g.[76-78]

The major dog allergen, Can f I, has also been isolated, characterised and standardised.[79] The concentrations of dog allergens in house dust vary widely. Concentrations of 110-82,500 IU/g were found in dust from houses without dogs versus 1,100-585,000 IU/g in houses with dogs.[78] Dog allergens have also been detected in mattress dust. In houses where dogs are present, dust samples generally contain more than 10 ng Can f I/g dust.

Table 4.10. Data on the presence of house dust mites

Author – Source	Country Years	Methods	Concentration	Main results
Solarz[68]	Poland 1989-2000	Dust samples were collected in 335 dwellings located in 27 different localities.	Total mean number of mites/g of dust was 204.1.	Mites were found in 158 of the examined samples (47.2%).
Oppermann et al.[69]	Germany 1991	Dust samples were collected in 218 dwellings in East and West Germany.	In 86% of the specimens were found > 2 µg mite allergen/g of dust.	Dust mites infestation ranged from 55.3% to 86% of dwellings.
Hirsch et al.[70]	East Germany 1992-1996	Dust mites allergen concentrations were determined in 634 dwellings.	House dust mites allergen in mattresses: 2.07 µg/g of dust (geometric mean) House dust mites allergen in carpets: 0.48 µg/g of dust (geometric mean)	High relative humidity and temperature were associated with increased levels of dust mites allergens (especially Der p I).
Munir et al.[71]	Sweden 1989	Dust samples were collected in 130 homes.	Der p I levels generally ranged between 16 ng and 50 µg/g of dust. Der f I levels generally ranged between 16 ng and 73 µg/g of dust.	Mites allergens (Der p I, Der f I, or both) were detected in 62% of the homes.
Harving et al.[72]	Denmark 1984-1986	Dust samples were collected in 96 houses during the winter period.	House dust mite concentration was generally above the Danish proposed limit of 10 mites/0.1 g of dust.	Mites allergens were detected in 76% of the homes of persons allergic to mites.

Table 4.11. Health effects of house dust mites

Author – Source	Country Years	Methods	Risk factor	Health effects	Relative risk
Huss et al.[73]	USA (8 cities throughout North America). 1993-1995	Target: 1041 children, aged 5 to 12 years, with mild to moderate asthma. Skin tests were performed.	Exposure to high mite antigen levels (> 10 µg/g dust)	Positive skin test	OR 9.0; 95% CI 5.4-15.1
Nicolai et al.[66]	Germany (Munich) 1989-1990	A total of 155 school-children were investigated with bronchial provocation. Mites antigen levels were measured in dwellings.	Exposure to high mite antigen levels	Bronchial hyper-reactivity	OR 2.30; 95% CI 1.03-5.12
Peat et al.[74]	Australia Lismore (hot, humid region 40 km from the coast). Moree/Narrabri (hot, dry inland region)	A total of 1575 children (aged 8-11 years) were studied. Respiratory symptoms were collected by questionnaire. Histamine inhalation test, skin-prick tests and dust samples were performed.	Sensitization to house dust mites	Current asthma (combination of wheezes and bronchial hyper-reactivity)	Lismore OR 21.3; 95% CI 10.5-43.2 Moree/Narrabri OR 2.7; 95% CI 1.3-5.4

The level of pet-derived allergenic material in homes where pets are kept is also determined by the thoroughness of cleaning, in particular the removal of allergenic material produced in the house. It is independent of such environmental factors as humidity, temperature and the quality of the building.

People can be exposed to pet-derived allergens in various places, particularly in places where people aggregate, because pet-owners carry allergens in their clothes to other environments.[80,81] Curtains, mattresses, upholstered furniture and soft toys are the most important reservoirs of dog and cat allergens.[82]

Microbial allergens

A wide range of micro-organisms (thermophilic actinomycetes, moulds, bacteria, amoebae and nematodes) are sources of allergens. Persistent damp areas, particularly bathrooms and basements, may support abundant mould growth indoors. Also water seepage in building material leading to damp ceilings, walls, carpeting and furniture create favourable conditions for the growth of moulds. Furthermore, draught-proofed ('tight') buildings may facilitate mould growth when indoor humidity is high and there is moisture condensation on cold areas, walls or windows.[83]

Contaminated humidifiers in homes, industrial and non-industrial buildings, and cars can generate aerosols loaded with micro-organisms and debris of micro-organisms, and have been associated with allergic asthma, humidifier fever and extrinsic allergic alveolitis.

It should be noted that non-immune specific inflammation is more important than allergic reactions in the respiratory health effects induced by inhaled microbial agents, but allergic reactions may be stronger and occur more frequently in atopics and asthmatics.

Insects

Shed skin scales, dried secretions and faecal particles from insects may cause allergic asthma and rhinoconjunctivitis. Cockroaches are sources of allergens, and are common in low income housing areas, particularly in high rise apartment buildings in the USA.[84] Cockroaches may be a problem also in some countries of the EU.

Green plants

Green plants indoors should be considered potential allergen sources and should be investigated with allergological tests; examples are *Ficus benjamina* (weeping fig) and *Spathiphyllum floribundum* (spathe flower).

Pollen

Exposure to pollen allergens is high outdoors during the pollen season, but birch and grass pollen allergens can be found in indoor air.[85] In northern Europe the most common source is birch trees. More than 50% of children may be allergic to pollen from birch.[86] Pollen grains are relatively large, i.e. 15-25 μm (Table 4.12), and can thus be trapped in filtering devices. However, allergens are also found on small fragments of pollen and on plant debris ('microparticles'), and these can enter the indoor environment. Wind-borne microparticles can be a problem in dwellings far from the original source.

Table 4.12. Size distributions of particles associated with asthma[87]

Type of Particle	Size
Environmental tobacco smoke[88]	The mass median diameter of emitted particles is 0.22 µm. Virtually all particle mass is constituted by particles measuring from 0.09 to 1.0 µm
Plant pollens[89]	15–25 µm; fragments may be much smaller
Dust mite allergens[90,91]	30% to 90% of allergens is in particles <11 µm; Only a low percent of allergens is in particles <2 µm
Common fungal spores[89]	2–10 µm
Cockroach antigen[92]	~ 80% of allergen >10 µm
Cat antigen[93]	From <1 µm to >10 µm, According to Custovic et al.,[93] 45% is >9 µm, 23% is <4.7 µm. According to Luczynska et al.,[77] 75% >5 µm and 25% (range: 10-62%) <2.5 µm.

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5 MAPS OF POLLUTANTS IN DWELLINGS

European dwellers live in a sub-optimal indoor environment. However, most people are not aware of the risks of their own living environment, and neither are policy makers. Graphic representations may be useful in increasing both awareness and understanding of risks and possible solutions. In one of the THADE meetings, to 'map' was taken to mean Make Available to People the knowledge needed to arrive at concrete actions for healthy indoor air. Taking into account European diversity as to nature and extent of pollutant exposure, the second core question of THADE, 'What measures can be taken to improve poor air quality at home?', may only be answered for different European regions when both consumers and policy makers have a clear view on their local situation.

Therefore mapping at a geo-spatial level of exposure, disease prevalence and effective preventive measures was performed as a means of communication between science and policy making. For communication with the consumer this mapping is combined with interactive intervention-simulations that, hopefully, will increase understanding of the mechanisms of noxious exposure and the benefits of household and building interventions. As far as health effects are concerned we will restrict ourselves to asthma, allergies and chronic obstructive pulmonary disease (COPD).

5.1 RESTRICTIONS AND FLOW DIAGRAM

Several restrictions are inherent to the chosen approach (Fig. 5.1).

5.1.1 Geographical distribution and resolution

Firstly, the geographic area to be included in the mapping had to be delimited. The best approach would probably have been to take the whole of geographic Europe. However, information from the regions east of Moscow were not readily available. This has forced us to include only the western and central part of the continent (Fig. 5.2).

Secondly, the geographic resolution in degrees latitude and longitude had to be chosen, taking into account the accuracy of our knowledge. It was found that overall this is currently no better than 10 x 10'. Only those pollutants for which a resolution of at least 1° x 1° could be reached were mapped geographically. In some cases mapping by country was still possible. In the course of the THADE project a tool has been constructed to use simple Excel sheets for inputting of geo-spatial data (programmed by E.J. Hansen, MSc, Denmark). It is hoped that the use of this tool will improve the possibilities of interfacing with databases of primary research results, such as EUROHEIS,[1] to increase resolution, validity and scope of our programme as a tool for consumers, professionals and policy makers. When such an interface becomes available, the mapping programme on the EFA website will be updated.

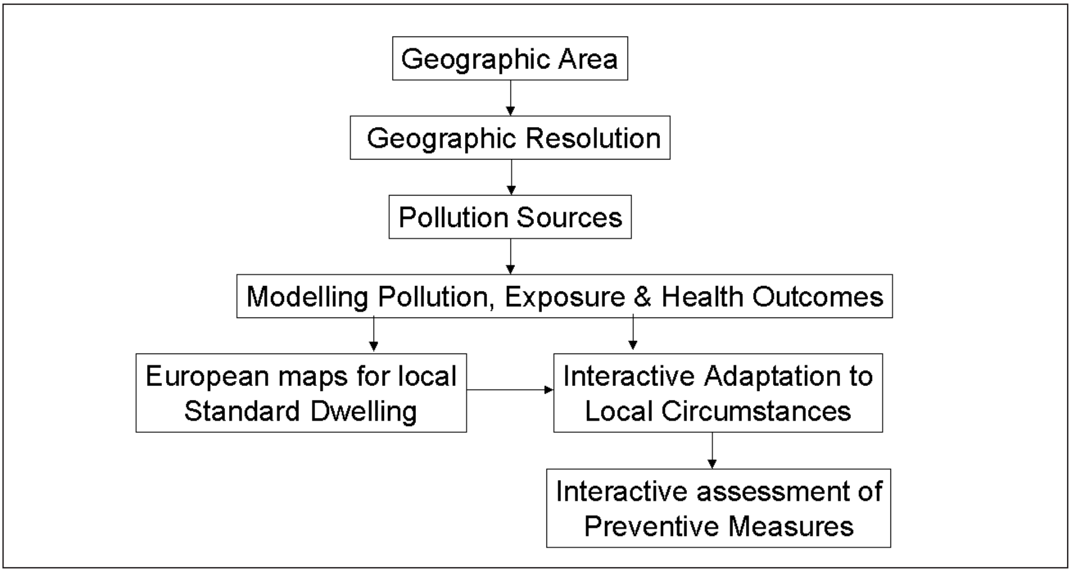

Figure 5.1. Flow diagram of the mapping operation

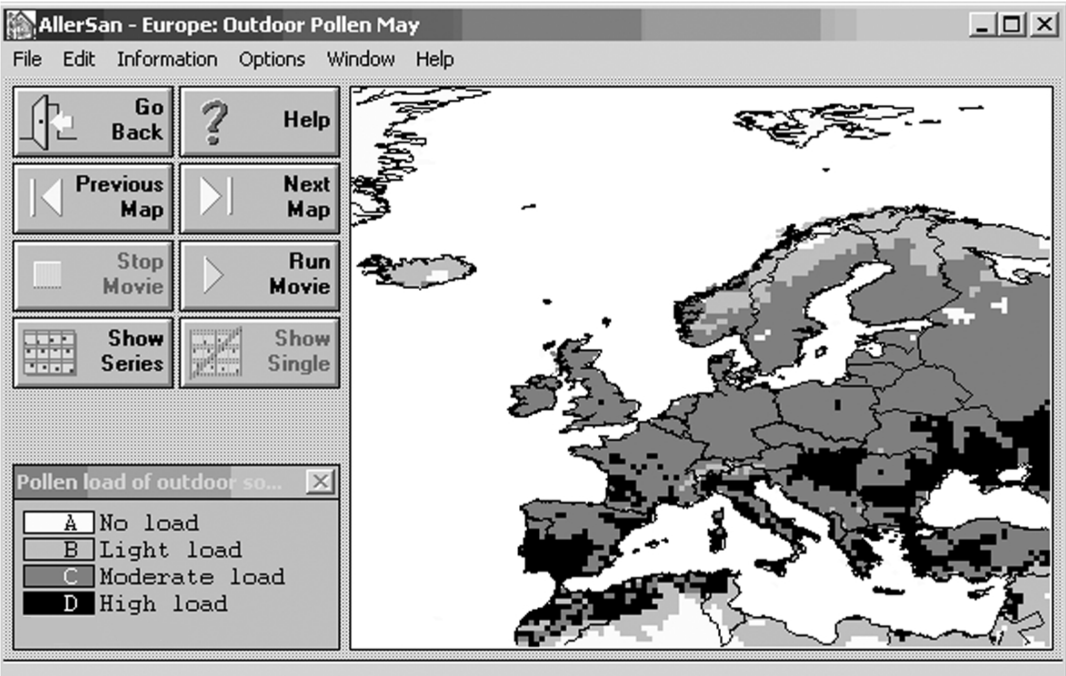

Figure 5.2. Geographic area mapped in the THADE project. It shows an outdoor pollutant (pollen) in the month of May that was used in calculations of outdoor contributions to indoor allergen levels. (Images are in colour in the mapping programme; see CD on inside back cover).

5.1.2 Pollution sources included

The next step in the mapping process was to select the pollution sources to be included. Only those pollutants that adhered to the following conditions were mapped, i.e.:

- Those of common occurrence in at least some regions of Europe.
- Those of known relevance to health-relevant indoor air quality.
- When concentrations have been reported under a number of different circumstances so as to make it possible to model exposure on a European scale.

The resulting list of pollutants consists of irritants, allergens and oncogens (i.e., oncogenic agents) arising from body odours, furnishings, smoking, cooking, damp, pets, cockroach, soil and outdoor air. Since servicing dwellings with potable water and sewer systems was not included in the mapping, we could not take into account relevant infectious agents, such as *Legionella*, causing veteran's disease (related to handling potable and hot water) or the SARS Coronavirus (related to ventilation and sewer systems and their use). Some pollutants have been left out because of too incomplete data on a geo-spatial level of the indoors. These include carbon monoxide, man-made fibres, some specific volatile organic compounds and species of indoor plants.

To increase the effectiveness of communication with the user in the interactive module (local circumstances in dwellings) pollutants were aggregated in three classes: irritants, allergens and oncogens, and a color code was devised to show the health potency of the situation and its changes.

5.1.3 Modelling of concentrations and exposure

The next step of the mapping process included the modelling on a European and a seasonal scale of concentrations and exposure indoors. To this end pollutants were distributed over three classes depending on the nature of their relationship with the built environment:

1. Pollutants that enter the dwelling from the outside (from soil or air) and do not show seasonal presence (e.g. radon gas from the soil); their values may be derived from published literature with interpolation and extrapolation when needed.
2. Pollutants that enter the dwelling from the outside but have strong seasonal fluctuations; in these cases we reduced seasonal fluctuations to monthly fluctuations and mapped the pollutants for each month.
3. Pollutants that arise within the dwelling, such as body odours or house-dust mites; in these cases the main determinants were identified and mapped (see Fig. 5.3 for an example).

Simulation tools were adapted from published models in the building physics discipline.
To go from concentrations to actual exposure other factors had to be taken into account, as are included in published epidemiological models. Overall algorithms to assess exposure include: indoor production of pollutant (may be nil for some pollutants), infiltration of pollutant from outside (may be nil for some pollutants), ventila-

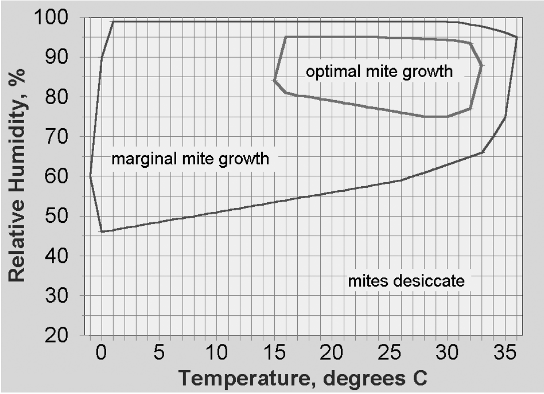

Figure 5.3. Relationships between survival and growth of house-dust mites and temperature and moisture conditions, as has been used to calculate indoor mite concentrations.

tion and infiltration in m^3/hour (also in relation to prevailing wind direction and pressure), room space/person, and length of stay indoor. Epidemiology literature was taken to calculate health outcomes, such as loss of healthy years in a life span (disability adjusted life years, DALY) and population attributable risk (PAR) (Chapter 3).

5.1.4 The Standard Dwelling

After modelling of concentrations and exposure, the flow diagram splits. One way is towards showing geo-spatial maps applied to a standard dwelling. The standard dwelling has been defined as having a total volume of 350 m^3, three inhabitants, a floor surface of 100 m^2 with 50 m^2 of carpet and 50 m^2 of PVC covering, 2 bedrooms, 1 kitchen, and 1 living room, with ceilings, walls and room partitions plastered or painted. The living room is furnished with one three-seated couch, two padded arm chairs, one table and four non-padded chairs. The bedrooms contain a total of three beds and the kitchen has one cooking place.

5.1.5 Local conditions in interactive mode

A second road in the flow diagram goes towards the interactive updating and changing of the local indoor situation, although most users of the mapping programme will enter the interactive module by clicking on their home pixel on a geo-spatial map. The first and automatic simulation takes the parameters of that day (i.e., the date on the personal computer) and the geographic conditions of the chosen pixel. The user may change all local circumstances except for longitude and latitude. To perform the simulations for another geographic locality the user must first return to one of the geo-spatial maps and select other coordinates.

5.2 INTERFACING WITH PRIMARY DATABASES

The mapping approach we chose includes a certain amount of interpolation, extrapolation and guessing, since well-detailed geo-databases that cover most of Europe are non-existent or have a restrictive use. Since the mapping tool is meant to remain free of charge for consumers, the use of commercial databases to import data is hardly possible.

As mentioned before, the mapping programme now contains a subroutine for easy transport of data to graphic representation with the aid of an excel sheet. This not only eases data import for graphic representation and calculations in interactive mode, it also supports the algorithms that require a number of those sheets for calculations (e.g. assessing the level of ventilation with sheets of prevailing wind directions, wind pressure and outdoor temperatures).

One of the primary databases that we studied in more detail is the outdoor knowledge structure of the EU project group on EUROHEIS (a European Health and Environment Information System for Disease and Exposure Mapping and Risk Assessment). This group has built a database that is professional-oriented, and aims to improve the understanding of the links between environmental exposures, especially outdoor exposures, health outcomes and risk through the development of an integrated information system for the rapid assessment of relationships between environment and health.

Differences in resolution, data structure and programme architecture are extensive, but should not prevent data transport in the future. Including EUROHEIS data on outdoor air pollution and allergic or hyper-reactive disease could strongly increase the power of the mapping programme and its use on regional level, while still providing the European overview as a comparison. On the other hand, it will also mean a revision of the algorithms used to simulate individual indoor climates and their management, which is a major operation.

5.3 AWARENESS AND UNDERSTANDING

As stated above our mapping is meant to Make Available to People the knowledge needed to arrive at healthy indoor air. In this respect it intends to raise awareness among patients and policy makers alike through an interactive process. Not only may the user rapidly retrieve information of Europe at large or of a specific 1° x 1° latitude and longitude square, he or she may also simulate individual indoor spaces thereby researching the specific effects of lifestyle and technology changes.

It must be said that the programme user-interface could still be improved by graphically designing the interactive building part, and by introducing a higher level of user-adaptivity. Although these improvements are left to future projects, such an approach would clearly foster awareness among patients, patient organisations and policy makers.

5.4 GAPS IN KNOWLEDGE

We need a more in-depth analysis of the geo-spatial distribution of climatic, technological and life-style factors relevant to asthma, allergies and COPD. Currently environment-disease relationships found in one country or one region are quickly generalized to larger regions, sometimes even to a complete continent, without validation. Cultural and climatic diversity in Europe is an asset, but it could become a threat to health when it is not respected by advocating inflexible measures for the whole of Europe. Mapping our European diversity will help to select the best measures to improve indoor air for each region.

5.5 TOWARDS HEALTHY INDOOR AIR

By using our mapping approach to show geo-spatial diversity as well as variations within single dwellings due to lifestyle and technology, priorities for action on a European, national and regional level may be assessed.

Due to aging of the population and the resulting increase in the prevalence of chronic bronchitis and lung emphysema, the need for awareness and understanding of indoor air processes will also increase. We hope that our mapping approach will support solutions on both policy and practical levels.

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6 CONTROL OF HEALTH DETERMINANTS

Methods aimed at controlling indoor health determinants are summarised in Table 6.1, and their effectiveness is listed in Table 6.2. Greater details are posted on the EFA website www.efanet.it.

Environmental tobacco smoke

Smoking indoors and smoking in general should be discouraged. This requires co-operation at all levels. Anti-smoking implementation requires European directives, national legislation and information campaigns by patients' associations and healthcare professionals. Technology should be used to control exposure to environmental tobacco smoke (ETS) in buildings were smoking is still allowed. The only effective measure is to provide specific smoking rooms with high ventilation rates and effective air distribution, which is operated with under pressure so that smoke does not escape from the rooms.

Ventilation

Technical standards and guidelines for ventilation in residential and non-residential buildings from the health standpoint (control of pollutants generated indoors) should be developed. This requires co-operation on several levels. International work like that of the International Organisation for Standardisation (ISO) Technical Committee 205 "Building Environment Design – Indoor Air Quality" is useful, but implementation requires European directives and European standards from e.g. the European Committee for Standardisation (CEN), changes in national legislation and building codes, and guidelines devised by professional societies that include training of personnel.

Moisture-control indoors

Technical standards and guidelines to control moisture in residential and non-residential buildings from the health standpoint (dust mites, mould and other harmful effects of excess moisture) should be developed. This requires co-operation on several levels. Various working groups of the World Health Organisation and the International Council for Building Research Studies and Documentation (CIB) have done groundbreaking work, but their recommendations should be implemented through European directives and standards, changes in national building codes, and guidelines developed by professional societies that include training of professionals.

Criteria of healthy buildings and target values of indoor climate

Clear criteria for healthy buildings are needed. These criteria should include but not be restricted to limit values of indoor air pollutants. Work done by the WHO, ISO, CIB

Table 6.1. Health determinants in the indoor environment, their source and control methods

Health determinant	Source	Control methods	Potential actions at EU and national level
Carbon monoxide (CO)	Incomplete combustion in fireplaces, ovens and other heating appliances, and tobacco smoking.	Ensure sufficient combustion air, use chimneys to remove flue gases, and control pressure differences to avoid back draft. Limit smoking indoors.	Inspection and control of small heating appliances. Proper design guidelines and building codes.
Carbon dioxide (CO_2)	The metabolism of building occupants and pets.	CO_2 concentrations can only be controlled with ventilation rates. An increase of ventilation will decrease the indoor concentration of CO_2.	Include CO_2 limit values in ventilation standards. Develop methods of CO_2 measurements as an indicator of ventilation.
Nitrogen oxides (NO_x)	Side product of combustion. Indoor sources: gas fires, cooking and heating appliances, smoking	Avoid open-flame fires indoors. Remove flue gases. Use chimneys. Use effective ventilation.	Encourage the use of electrical kitchen appliances, central heating and kitchen range hoods. Discourage the use of unvented heating appliances. Devise ventilation guidelines.
Indoor-generated particulate matter and dust	Carpets, textiles, food, animal and plant proteins in dust, and occupants (especially in buildings with a high density of occupants).	Avoid dust generating materials. Avoid carpets especially in public spaces, day-care centres, schools etc. Improve cleaning and ventilation and airing.	Encourage the use of vacuum cleaners. Develop performance criteria for vacuum cleaners. Encourage the use of central vacuum cleaning systems. Encourage cleaning outside school and office hours.
Chemicals, volatile organic compounds (VOCs)	All man-made building materials emit VOCs, especially when new. Cleaning products.	Limit the use of high emitting products. Air new buildings and furniture before use. Provide adequate ventilation.	Devise labelling systems for building materials, furniture and household products.
Formaldehyde	Building materials, particle boards, household chemicals, ETS, and carpets and other household textiles.	Limit the emission from sources by developing and using low-emitting products. Use only particle boards labelled for low emission. Limit smoking indoors.	Devise product control and labelling systems for building products and household chemicals.
Environmental tobacco smoke	Secondary smoke is in particle and gaseous form. Small particle size. Absorption to and desorption from surfaces. Difficult to remove from air and surfaces.	Abolish smoking indoors, no smoking in homes. Provide smoking rooms where smoking is still allowed.	Prohibit smoking in public buildings and in the workplace. Campaign against smoking at homes. Provide smoking rooms where smoking is still allowed.

Table 6.1. continued

Health determinant	Source	Control methods	Potential actions at EU and national level
Man made mineral fibres (MMMF)	MMMF are used in insulation materials, and acoustic linings. Fibres are irritants.	Limit the use of uncoated mineral wools indoors, and in ventilation systems.	Limit the release of fibres by coating. Stop using uncoated mineral wool indoors. Develop testing methods.
Mould (fragments, mouldy material, spores. microbial VOC)	Mould growth depends on moisture: wet structures, water leakages, condensation, high indoor humidity.	Prevent and repair moisture damages and leakages. Improve ventilation. Control pressure differences between the exterior and interior surfaces of structures. Control indoor moisture sources.	Better building codes for new constructions. Improved indoor environment in the existing building stock.
Dust mites	Fragments of mites and the fecal pellets. Fragments mites and faeces stored in carpets and textiles etc. Dust mites require high relative humidity indoors.	Reduce indoor relative humidity: - increase ventilation. - reduce indoor moisture. - use dehumidification.	Better building codes for new constructions. Improved indoor moisture control in the existing building stock. Use mite-resistant bedding materials.
Pets	Skin and hair fragments, dander from cat, dog etc. All furred animals are risk factors in homes and have high allergy potential. Small particle size. Can be transported on the clothing of pet owners. Difficult to eliminate with cleaning.	Avoid furred pets in homes where there are seriously allergenic people. Thorough cleaning. Air cleaners.	Inform the public about the risks and benefits of furred pets at homes. Limit pets on public transport. Use easy to clean furniture in public spaces. Restrict pet exhibitions in public places (schools etc). Do not take outdoor clothing into classrooms.
Cockroaches	Related to low housing hygiene	Improve housing hygiene: cleaning, ventilation, moisture control	Public campaigns for better housing hygiene. Improve the quality of low-income housing.
Pollen	Relatively large particle size, but small fragments of plants may carry allergens: birch, alder, linden, oak, beech, olive, grasses, mugwort etc.	Tight building envelope and filtration of incoming outdoor air. Indoor air cleaners.	Develop and apply tested methods to protect against pollen. Develop testing and labelling procedures for air cleaners.

Table 6.2. The effectiveness of the main control and remedial measures

Health determinant	Improvement of ventilation	Better cleaning and house hygiene	Avoid carpets	Control of moisture	Control of the source
Carbon monoxide	+				+++
Carbon dioxide	+++				
Nitrogen oxide	++				+++
Indoor-generated particulate matter and dust	+	+++	+++		
Formaldehyde	+		+		+++
Chemicals and volatile organic compounds	++		+		+++
Environmental tobacco smoke					+++
Man made mineral fibres		++			+++
Mould (fragments, mouldy material, microbial volatile organic compounds)	++			+++	
Dust mites	++	++	++	+++	
Cockroaches		+++			
Pets		++	+		++
Pollen	+	+	+		+

+++, primary control method; ++ important secondary method; + method has some but not adequate effects. A blank space denotes that the method does not have an effect on the health determinant or has only indirect effects.

should be utilised but developed further to be integrated in national legislation and building codes. Implementation requires European directives and standards, changes in national building codes, and guidelines by professional societies that include training of professionals. Health experts should also participate more in working groups for technical standards such as the CEN Technical Committee 156 on Ventilation.

Control of harmful emissions from building materials and consumer products

European action should be taken to develop guidelines and procedures to measure emissions from building materials and consumer products. Guidelines should include the criteria for low polluting materials and products, and a labelling system. The Construction Products Directive 'Hygiene, health and the environment' (89/195/EEC; *Official Journal of the European Commission* 11 February 1989) states that 'The construction work must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours.' The control of harmful emissions from building materials would be a step towards implementation of the principles of the directive. Indeed, as regards this health aspect, the directive is generally not well implemented.

Heating

Heating systems that do not induce adverse effects should be promoted through building codes and standards. It is important to improve the thermal control of buildings to avoid moisture problems, and to use heating methods that have a low pollutant level. Central and district heating should be promoted.

Indoor air quality in existing buildings

Building inspections are commonly undertaken in many European countries to save energy and improve the energy efficiency of buildings. Improvement of energy efficiency is the focus of the Energy Performance of Buildings Directive 2002/91/EC (16 December 2002; *Official Journal of the European Commission*, 4 January 2003). The inspections required by the directive should include the proper measures to ensure a healthy indoor environment in buildings. European directives and national legislation should be developed so that building inspections and audits include indoor air quality and climate inspections. Professional societies and standardisation organisations should develop procedures for such inspections.

Performance testing of equipment that affect indoor air quality

Many types of equipment affect indoor air quality. The equipment is often complicated and consumers do not understand all consequences of their use. Standards and labelling systems should be developed for these products, e.g. ventilation equipment, vacuum cleaners, range hoods, air cleaners, portable heaters, water heaters.

Gas heaters and cooking

Open-flame unvented combustion indoors is a health risk, and should be avoided. Policy and technology to promote the use of non-polluting appliances and energy sources should be developed.

Hygiene and cleaning

Better household hygiene and cleaning would have a positive effect on several health determinants. Campaigns for better hygiene and cleaning should be implemented in co-operation with patients' organisations and national authorities. These campaigns should also educate tenants towards healthier living. Criteria for a healthy home environment are reported in the Annex.

Operation and maintenance

Good operation and maintenance of buildings, which are key elements for good indoor air quality and climate, are often neglected. Typically, building codes are limited to the construction phase of building, and no legislation-based maintenance is required. A European directive and national legislation about maintenance of buildings with respect to health and life-cycle cost would improve the situation. Technical guidelines, education and training should be provided by professional societies.

Pets

As allergens are difficult to remove with cleaning, the access of pets to schools and other public buildings and spaces should be limited. International and national guidelines should be developed in co-operation with patient associations.

7 GUIDELINES AND STANDARDS REGARDING INDOOR AIR QUALITY IN DWELLINGS

Guidelines, actions and programmes related to indoor air quality in dwellings are already in place in many European countries (Table 7.1). The main implementation strategies are legislation, codes and norms, research projects and general public information. However, these actions are usually targeted to a specific topic or issue rather than aiming for an overall national strategy. The priorities most frequently addressed are: environmental tobacco smoke (ETS), ventilation guidelines, and specific regulation in the consumer protection area (toxic materials, asbestos, biocides, etc.).

The WHO Office for Europe has encouraged states to have a comprehensive, meaningful indoor air quality programme.[1] Suggestions for comprehensive international and national plans are reported by ISIAQ-CIB Task Group TG 42 ('Performance criteria of buildings for health and comfort')[2] and by NATO/CCMS ('Pilot study on indoor air quality - Erice statement on indoor air quality for a sustainable indoor environment').[3] Examples of comprehensive national guidelines in Europe are those from the Scandinavian countries. In Finland 'The Classification of Indoor Climate, Construction, and Finishing Materials' includes target values for indoor air quality and climate, instructions for design and construction, and requirements for building products. These guidelines are intended to be used in the design and construction of buildings and their mechanical systems and also to encourage manufacturers of equipment and materials to produce low-emitting building products.[4] Indoor air quality guidelines have been produced for Norway ('Recommended guidelines for indoor air quality')[5] and Sweden. In Italy a 'National prevention plan for health protection and promotion in the indoor environments' has been prepared by the Health Ministry.[6]

Guidelines for air pollutant values have been developed by the WHO.[7] Guidelines for indoor air pollutant values have been proposed in Finland[4] and Germany.[8] Outside Europe, guidelines for indoor pollutants have been adopted in Canada[9] and China.[10]

The EU has sponsored various projects regarding indoor air quality (see Table 7.2). The INDEX project is aimed at creating a network of European leading scientists in the area of indoor air pollution and the associated health impacts, in order to identify priorities and assess the need for a Community strategy and action plan. The key points of the project are:

- The setting-up of a list of priority substances to be regulated in indoor environments on the basis of health impact criteria.
- To provide suggestion and recommendations on potential exposure limits for these substances.
- To provide information on links with existing knowledge, ongoing studies, legislation etc. at world scale.

Table 7.1. Guidelines and actions regarding indoor air quality in dwellings in European countries

European Countries	Laws/Guidelines			Actions
	General	Specific	Target Values	
Austria	*	*		*
Belgium	*			
Bulgaria	*			*
Czech Republic	*			*
Denmark	*			*
Estonia		*		
Finland	*	*	*	*
France	*			*
Germany	*		*	*
Italy	*	*		*
The Netherlands	*			*
Norway	*	*	*	*
Poland		*		
Portugal	*			*
Spain				*
Sweden	*	*	*	*
United Kingdom	*			*

Protocols to measure the health and energy efficiency status have been developed within the European IAQ-Audit[11] and the TOBUS and EPIQR projects.[12] The goal of the ongoing HOPE project is to provide the means to increase the number of buildings that are both energy-efficient and healthy. The technical aims are to define a set of qualitative and quantitative performance criteria for healthy and energy-efficient buildings for Europe and to determine a protocol for testing performance criteria for healthy and energy-efficient buildings.[13]

There are two European thematic networks concerning indoor air quality: PeBBu-Performance Based Buildings, which aims at improving the implementation of research information, practical tools and guidance available for the purpose of achieving a more sustainable built environment; and EUROVEN designed to create a multi-disciplinary forum between different disciplines as regards associations between ventilation and health.[14]

Information programmes have been developed in many countries. In Sweden the 'Healthy Building Research Programme' that supports Swedish and Nordic scientists in

Table 7.2. EU-sponsored studies on air quality in buildings

Project no.	Title	Status
EN4-CT96-0202	EXPOLIS: Air pollution exposure distributions of adult urban populations in Europe	Completed 1998
JOU2-CT92-002	European audit to optimise indoor air quality and energy consumption in office buildings	Completed 1996
JOR3-CT96-0044	EPIQR: A cost predictive European retrofitting evaluation method for improving the energy performance and the indoor environment of existing apartment buildings	Completed 1998
JOR3-CT97-0076	Development and test of modern control techniques applied to solar energy buildings	Completed 1999
JOR3-CT98-0235	TOBUS: A decision making tool for selecting office building upgrading solutions	Completed 2000
JOR3-CT97-0171	AIRLESS: Design operation and maintenance criteria for air handling systems and components for better indoor air quality and lower energy consumption. Pre-normative research	Final reporting
JOR3-CT97-0194	MATHIS: Materials for healthy indoor spaces and more energy efficient buildings	Final reporting
EN4-CT96-0202	EXPOLIS: Air pollution exposure distributions of adult urban populations in Europe	Completed 1998
DG SANCO N. S12.130758 (99CVF2-602)	MaNaPI: Managing Natural Pollutants Indoors	Completed 2001
EVK4-CT99-20002	SURERUO: Sustainable refurbishment in Europe	On-going
EVK4-CT99-20008	CRISP: Construction and city-related sustainability indicators	On-going
IEA Annex 36	Retrofitting in educational buildings. New annex dealing with the development and demonstration of energy-efficient techniques applicable in the refurbishment of educational buildings.	On-going
DG SANCO N. SI2.291168 (2000CVG2-604)	EUROVEN: European multidisciplinary scientific network on indoor environment and health concerning associations between ventilation and health	On-going
ENK6-CT-2001-00505	HOPE: Health optimisation protocol for energy-efficient buildings. Pre-normative and socio-economic research to create healthy and energy-efficient buildings (2001-2004)	On-going
DG SANCO	INDEX: Critical appraisal of the setting and implementation of indoor exposure limits in the EU	On-going

resolving key issues of the indoor environment and health is ongoing; 'The Healthy Building' key action is aimed at increasing the knowledge of occupants about building-related adverse effects as well as about the indoor environment itself, and at diminishing the risk of mismanagement of building facilities that may affect the health of occupants.[15] In Denmark the research programme *Moulds in buildings aims* at combating mould growth in existing buildings and at preventing growth in future buildings.[16] The Finnish 'Nationwide campaign year 2002 for good indoor air quality and climate' includes such actions as information campaigns on indoor air quality for the general public using diverse media, i.e. magazines, television, radio and courses for key target groups of the construction, real estate and heating, ventilation and air conditioning (HVAC) branches for better indoor air quality.[17] The Municipal Health Service of Rotterdam (The Netherlands) has started a programme entitled 'Public health and prevention in asthma and allergy: low allergen housing' with the purpose of creating an allergen-poor/free indoor environment especially suitable for people with severe atopic asthma.[18]

In the US, the Environmental Protection Agency (EPA) has made booklets available on the Internet to help people decide whether to take actions to reduce the level of indoor air pollution in their own home, namely 'The inside story – a guide to indoor air quality'[19], and has provided information for building owners and facility managers[20].

A WHO working group has agreed a set of statements on 'The right to healthy indoor air'; the statements are based on nine principles and the first is that everyone has the right to breathe healthy indoor air.[21] The working group made several recommendations, in particular, promotion of the indoor air quality issue at national government level; stimulation of (inter)national collaboration; promotion of educational and informational programmes; cooperation between energy, building, and environmental sectors; and policy promotion.

Policies and programmes must be established and implemented in order to improve indoor air quality in dwellings. There is a large body of scientific information on healthy buildings, but very little has been translated into practice. Unless policies are developed and put to work nationally and internationally, advances made in the indoor air sciences will not be exploited in real life and will have a limited impact on the community.

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8 RECOMMENDATIONS FOR A EUROPEAN PROGRAMME ON INDOOR AIR QUALITY IN DWELLINGS

The importance of indoor air quality in dwellings

Pollutant levels in dwellings differ widely across Europe. Indoor exposure to pollution can include peak levels and be more prolonged than outdoor exposure. Although indoor air pollutants have been linked to health effects, studies have tended to focus on the sources of pollution rather than pollution concentrations.

Asthma and allergies are the most common chronic illnesses among children, and some of the most common chronic diseases overall in the developed regions of the world. There has been a rapid increase in such illnesses; often a doubling in the past 15 years. The indoor environment has been implicated in the incidence of such illnesses, and is known to play a major role in asthma exacerbation.

Indoor factors act at three levels:

1. By activating the immune system to react unfavourably to a factor in the environment (initial sensitisation).
2. By triggering symptoms (exacerbation of asthma) in subjects already sensitised.
3. By maintaining a sustained inflammatory state in the mucous of the respiratory passages which results from a heightened sensitivity to allergens and other irritants or provocative conditions, such as oxidants or corrosive air pollutants, cold air or physical exertion.

Exacerbation of asthma and allergic illnesses is strongly linked to exposure to allergens such as house-dust mite, cat, dog, cockroach, fungi and mould, and to environmental tobacco smoke (ETS). Exposure to domestic birds, horses, cows, insects other than cockroaches, certain houseplants, endotoxins, pesticides, rodents, viruses and certain chemical compounds (e.g. formaldehyde, NO_2 and oxidants) could also be involved in asthma and allergy exacerbation. The concentration of these factors and, therefore, exposure levels can increase if ventilation is not sufficient. Dampness can also exacerbate asthma and allergy.

Recommended actions towards healthy air in dwellings

The actions recommended to ensure healthy air in dwellings fall into five main categories:

- Improve ventilation.
- Improve cleaning methods and housing hygiene.
- Avoid wall-to-wall carpeting.
- Moisture control to prevent accumulation of mould.
- Control the sources of pollution, e.g. tobacco smoke and emissions from building and consumer products.

The measures recommended to implement these actions are:

- Prohibition and avoidance of smoking indoors.
- Labelling systems to control emissions from building and consumer products.
- Better building codes and guidelines for ventilation and moisture control.
- Education and information campaigns.

Most of these measures are independent of cultural and climate differences. The exceptions are those related to moisture control and ventilation, and even in these cases, common European guidelines should be developed.

More research is needed about the effects and costs of prevention and remedial measures related to indoor air quality. Technical information about the building stock should be taken into consideration when developing common guidelines for remedial action. This information should include data on heating and ventilation systems, cooking appliances, ventilation rates and moisture conditions. In addition, we need to know more about the prevalence of health determinants and the number of people sensitive to each specific health determinant.

Guidelines, actions and programmes related to indoor air quality in dwellings are already in place in many European countries. However, these actions are usually targeted to a specific topic or issue rather than aiming for an overall European and/or a national strategy. There is an urgent need for a strategy to improve the indoor environment in dwellings in Europe, and this can be developed on the data available at present.

Actions at European level

Various bodies must be involved in implementing the proposed measures, each according to specific competence. The following levels have been identified:

1. International level (WHO, CIB, ISO etc.).
2. EU-level for new directives and European standards (from, e.g. the European Committee for Standardisation, CEN).
3. National level (national building codes and standards etc.).
4. Professional organisations (engineers and architectures, building owners, facility managers etc.).
5. Patients' organisations (respiratory illnesses etc.).

The measures (included new directives and European standards) that could be taken at EU-level are:

- Actions to prohibit smoking in public buildings and the workplace.
- Campaign against smoking at homes.
- Better building codes for the new constructions especially as regards ventilation and moisture control.
- Measures to improve the indoor environment in the existing building stock.

- Develop testing and labelling procedures for air cleaners.
- Restrict pet exhibitions in public places (schools etc.).
- Develop product control and labelling systems for building materials, furniture and household products as regards harmful emissions:
  - Develop performance criteria for vacuum cleaners.
  - Develop testing methods for fibre release from mineral wools.
  - Develop inspection methods and control of small heating appliances.
- Promote research on indoor air quality in dwellings health effects and prevention.

Actions at international and national level

International level

- Develop a platform for websites on the topic of indoor air in dwellings so that all the different disciplines involved in this topic can 'talk' to each other.
- Develop criteria for healthy homes including limit values for indoor pollutants.
- Develop criteria for homes and buildings in regard to harmful microbial growth and moisture damage.
- Campaigns against tobacco smoking and exposure to ETS.
- Campaigns against unvented heating and cooking combustion indoors.

National level

- Campaigns against smoking at homes.
- Prohibit smoking in public buildings and the workplace and enforce implementation.
- Provide smoking rooms where smoking is still allowed.
- Better building codes for new constructions especially for ventilation and moisture control.
- Measures to improve the indoor environment in the existing building stock.
- Encourage the use of electric kitchen appliances and discourage the use of gas-fired appliances.
- Discourage the use of unvented heating appliances.
- Encourage the use of range hoods in kitchens.
- Develop product control and labelling systems for building materials, furniture and household products.
- Take actions to limit the release of fibres.
- Campaign for better housing hygiene.
- Limit pets on public transport.
- Restrict pet exhibitions in public places (schools etc.).
- Discourage outdoor clothing in classrooms.
- Avoid unvented combustion indoors.
- Include CO_2-concentration as an indicator of ventilation in ventilation standards.

Professional society level

- Campaign for a ban on smoking in public buildings and the workplace.
- Campaign against smoking in homes.
- Provide smoking rooms in offices and public places where smoking is still allowed.
- Develop effective, reliable methods for protection against pollens.
- Develop testing and labelling procedures for air cleaners.
- Encourage the use of electric kitchen appliances and discourage the use of gas-fired appliances.
- Discourage the use of unvented heating appliances.
- Encourage the use of central heating.
- Improve ventilation in existing buildings.
- Encourage the use of range hoods in kitchens.
- Develop product control and labelling systems for building materials, furniture and household products.
- Develop performance criteria for vacuum cleaners.
- Encourage the use of central vacuum cleaning systems.
- Encourage cleaning outside school and office hours.
- Limit the release of fibres.
- Encourage the use of easy-to-clean furniture in public spaces.
- Discourage the use of unvented combustion indoors.
- Develop ventilation standards and guidelines that include CO_2 levels.
- Develop further the methods of CO_2 measurement to control ventilation.

Patients' association level and healthcare professionals

- Campaign for a ban on smoking in public buildings and the workplace.
- Campaign against smoking at homes.
- Encourage the use of effective cleaning methods.
- Encourage the use of electric kitchen appliances.
- Discourage the use of unvented heating appliances and of gas fire appliances.
- Implement information and education campaigns for better ventilation.
- Encourage the use of range hoods in kitchens.
- Encourage the use of vacuum cleaners to decrease dust concentration indoors.
- Encourage the use of central vacuum cleaning systems.
- Encourage cleaning outside school and office hours.
- Implement campaigns for better housing hygiene.
- Inform the public about the risks and benefits of furred pets at homes.
- Restrict pet exhibitions in public places (schools etc.).
- Discourage outdoor clothing in classrooms.
- Discourage the use of unvented combustion indoors.
- Encourage the use of dust-proof bedding materials where appropriate.

Future research

It clearly emerged from this investigation that there is a shortage of evidence-based information about health indoor determinants and measures to prevent/counteract adverse health determinants. For instance, for future analyses, it is important to know the number of people sensitive to each specific health determinant in order to better focus actions.

From the evidence-based data at present available it is not possible to establish safe limit values for indoor exposure guidelines; this is particularly true in the case of dwellings. Furthermore, there is an urgent need to assess the effects of short- and long-term exposure in the home. Studies should be performed in general population samples on the relationship between health and measured indoor levels, taking into account exposure time and exposure variability (e.g. the exposure peak). The European Union should assign research funds to address these issues. Research institutions and patients' organisations of member countries should collaborate to conduct updated epidemiological surveys.

Guidelines for remedial actions should take account of technical data on the building stock. Therefore, we need more data about the effects of heating and ventilation systems, cooking appliances, ventilation rates and moisture conditions. Similarly, more research is required to determine the effects and costs of preventive and remedial measures.

Below are listed the areas in which more data are required in order to make an accurate analysis of the effects of preventive/remedial measures:

1. More studies on the number of individuals allergic or sensitised to a specific agent or pollutant. These should include characterisation of pollution sources in buildings and technologies to control the sources and their effects on health and well-being. Housing statistics do not usually include technical details information on technical details on residential buildings (e.g. Housing Statistics in the European Union 2001. OTB Research Institute for Housing, Urban and Morbidity Studies, Delft University of Technology, 2002).
2. More detailed analyses of the technical quality of the housing stock in the Europe.
3. Studies on the effectiveness of remedial measures.
4. Research on ventilation rates and energy use in different types of existing buildings and effects on indoor air quality and climate, health and well-being.
5. Focused research on the link between the properties of air handling systems and human responses (mechanical versus natural ventilation).
6. Performance measurements of good naturally ventilated buildings and their properties including human responses.
7. Studies to develop and evaluate improved strategies and systems to control ventilation rates, including demand-controlled systems using pollutant sensors for indoor and outdoor air quality and more accurate measurements of air flows within the system.
8. Research and new technology to clean the indoor air and the outdoor air used for ventilation.

9. Research and development of design tools for ventilation and calculations of indoor air quality.

Despite gaps in the body of knowledge, there must be no delay in taking action to improve the indoor environment in European dwellings. The actions proposed in this report are based on scientific evidence and the reasoning that, by counteracting adverse health determinants, health is improved.

9 CONCLUSIONS

Actions and programmes on indoor air quality in dwellings are in place in many countries. The main implementation strategies are legislation, codes and norms, research projects and information for the general public. However, these actions are usually targeted to a specific topic or issue rather than an overall national strategy. The difficulty in establishing global policies and programmes on indoor air quality stems from the partition of jurisdiction of indoor air problems among governing bodies. In fact, comprehensive national programmes must necessarily involve many different governmental departments and integrate various levels of political and technical responsibility. Particularly in large countries, actions and programmes are planned and managed also at region/country/municipal level and are subjected to regional and national control. Therefore, national and international bodies active in this area should be encouraged to use their experiences to produce comprehensive national plans.

The core messages of the THADE project can be summarised as follows:

1. Everyone has the right to breathe healthy indoor air.
This important statement was endorsed by the WHO in June 2000, subsequent to a body of scientific data that revealed the risks related to poor indoor air quality (IAQ) and the technical means to counteract it.

2. IAQ is not taken in due consideration by either the public-at-large or policy decision makers. Thus far, only allergy and asthma patients have experienced the consequences of bad IAQ (at home, in school, in hotels, etc.). Therefore, poor IAQ is mistakenly believed to be a problem that concerns only a limited number of people. However, IAQ is an important problem for everyone, including 'healthy' people.

3. The public-at-large is unaware of the negative effects of poor IAQ. The public-at-large is more conscious of the negative effects of bad outdoor air quality, particularly as regards traffic pollution. The impact of IAQ is very high because we spend almost all our time indoors (dwellings, workplaces, schools, means of transportation, etc.). Moreover, the public is not aware that various substances found in homes (cleaning products, furniture components, paint etc.) and in material used to build their houses are dangerous, 'hidden' sources of pollution.

4. Air quality, mainly outdoor air quality, has received great attention in recent decades, whereas IAQ has been largely ignored. It is important to understand the effect of pollutants originating outdoors and indoors on IAQ and control both of them.

5. Health determinants of the indoor environment have been identified. The most relevant are: environmental tobacco smoke, dust mites, mould, pollen, nitrogen oxide, formaldehyde, volatile organic compounds, suspended particulate matter, man-made mineral fibres, cockroaches, allergens from pets, carbon monoxide and carbon dioxide.

6. Reduction of indoor air pollution requires a combination of public health policy and protective measures taken by the individual. This is particularly true for IAQ in dwellings. The actions that can be taken at political and industrial level are: abolish tobacco smoking; elimination of sources of pollution, and substitute materials and equipment that are sources of pollution, with more environmental-friendly materials. On the other hand, families can avoid smoking at home, they can use cleaning products that do not emit polluting substances, and ensure adequate ventilation, etc.

7. Indoor air pollution may cause or aggravate health effects, particularly in more susceptible people (i.e. people with allergies, asthma and COPD, the very young and the elderly).

8. National and international bodies, together with all parties concerned should draw-up comprehensive national/international plans to improve IAQ based on recent advances in this field and should encourage industry to produce building products that emit low levels of pollution. These plans should include actions to avoid smoking indoors, information campaigns for the public on how to maintain a healthy indoor environment.

9. Guidelines for a healthier indoor environment should be developed on European and national level with the help of professional societies. These guidelines should include but not be limited to:

- How to control moisture in buildings so as to avoid problems related to mould and dust mites.
- Ventilation guidelines for residential and non-residential buildings to control pollutants generated indoors.
- Guidelines and procedures to measure emissions from building materials and consumer products including criteria for low polluting materials and products, and labelling systems.
- Criteria for buildings to ensure a healthy indoor environment, including the limit values of known pollutants.
- Guidelines for the public on how to check and control the indoor environment of their home to ensure it is 'healthy'.
- Guidelines for the operation and maintenance of buildings as regards health.
- Guidelines for heating and cooking to avoid indoor pollution and moisture problems.

From the data collected and reviewed in this report, we have identified a series of highly feasible actions that will undoubtedly lead to healthy indoor air in dwellings in Europe.

GLOSSARY

Air cleaning. An indoor air quality control strategy to remove various airborne particulates and/or gases from the air. The three types of air cleaning most commonly used are particulate filtration, electrostatic precipitation, and gas sorption.

Air exchange rate. Used in two ways: 1) the number of times that the outdoor air replaces the volume of air in a building per unit time, typically expressed as air changes per hour; 2) the number of times that the ventilation system replaces the air within a room or area within the building.

Antimicrobial. An agent that kills microbial growth.

Biological contaminants. Living organisms (e.g. viruses, bacteria, fungi, and mammal and bird antigens) and derivatives that can be inhaled and can cause allergic reactions, respiratory disorders, hypersensitivity diseases, and infectious diseases. Also referred to as 'microbiologicals' or 'microbials.'

Building-related illness (BRI). Diagnosable illness whose symptoms can be identified and whose cause can be directly attributed to airborne building pollutants (e.g. Legionnaire's disease, hypersensitivity pneumonitis).

Confidence intervals (CI). A confidence interval is a range of values that has a high probability of containing the parameter being estimated. The 95% confidence interval is constructed in such a way that 95% of such intervals will contain the parameter.

Exhaust ventilation. Mechanical removal of air from a portion of a building (e.g. piece of equipment, room, or general area).

Fungi. The unicellular or multicellular eukaryotic organisms embracing a large group of microflora including moulds, mildews, yeasts. Few fungi actually cause infectious diseases; most health effects are associated with allergic responses to antigenic material or toxic effects from mycotoxins.

Indoor air quality (IAQ). The characteristics of the indoor climate of a building, including the gaseous composition, temperature, relative humidity and airborne contaminant levels.

Indicator compounds. Chemical compounds, such as carbon dioxide, whose presence at certain concentrations may be used to estimate certain building conditions (e.g. airflow, presence of sources).

Mould. A fungal infection that causes disintegration of substance.

Natural ventilation. The supply of outdoor air through passive flow from windows, chimneys, doors, and other infiltration.

Particulate matter (PM). Small airborne particles (x = dimension of the aerodynamic diameter).

Passive smoking. The inhalation of environmental tobacco smoke.

Sick building syndrome (SBS). Term sometimes used to describe situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified. The complaints may be localised in a particular room or zone, or may be spread throughout the building.

Ventilation air. Defined as the total air, which is a combination of the air brought into the system from outdoors and the air that is being recirculated within the building. Sometimes, however, used in reference only to the air brought into the system from the outdoors.

Volatile organic compounds (VOCs). Compounds that evaporate from the many housekeeping, maintenance, and building products made with organic chemicals. These compounds are released from products that are being used and that are in storage. In sufficient quantities, VOCs can cause eye, nose, and throat irritations, headaches, dizziness, visual disorders, memory impairment; some are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans. At present, not much is known about what health effects occur at the levels of VOCs typically found in public and commercial buildings.

ANNEX

CRITERIA FOR A HEALTHY HOME ENVIRONMENT

1. Think of the health of your fellow citizens – do not smoke indoors.
2. Correct temperature is one of the most important indoor factors. In winter it should be 18–22° C. Control and demand a correct temperature for you and your family.
3. Ventilation of residential buildings should be continuous, not only during cooking and other polluting activities. Mechanical ventilation should be running all the time. Ventilation should not cause noise or draft. Natural ventilation should be assisted with airing by opening windows when necessary. Demand that the ventilation system is operated and correctly balanced.
4. Opening doors between rooms improves the ventilation of bedrooms during the night. Bathroom ventilation is inadequate if the condensation on the mirror does not disappear in a couple of minutes after a shower or bath.
5. A kitchen range hood with ventilator should be fitted in all kitchens particularly those with gas cooking. The grease filter of the hood should be cleaned or changed every 2-3 months.
6. Cross ventilation is the best way to increase ventilation temporarily. Heating energy will be lost if windows are open for long periods.
7. A strange, new smell at home is often a sign of a health hazard. Find out where the smell is coming from, remove the source and do refurbishment or remodelling, if necessary.
8. Regularly clean surfaces at home to keep them free of dust. Use cleaning methods that do not pollute the air. Avoid surfaces that accumulate dust easily.
9. Ensure that your vacuum cleaner has a proper filter. Ventilate properly after vacuuming to eliminate small airborne particles.
10. Typically room air cleaners (filtering devices) have the capacity to clean the air of only one room, not the whole home. Be sure that the room air cleaner has been properly maintained.
11. A high temperature, dust and formaldehyde in the air make the air feel dry. Indoor air need be humidified only during prolonged periods of freezing outdoor temperatures. Do not humidify to higher than 35% of relative humidity. Keep humidifiers

clean. Steam-humidifiers that have a high water temperature are better in preventing microbial growth.

12. Indoor relative humidity should not exceed 60% for long periods so as not to favour the growth of mould, and should be below 45% to control dust mites. Indoor humidity should not in any circumstances condense on windows or outside walls.
13. Monitor the condition and quality of interior surfaces. Report changes to the building owner or care taker. Materials and structures damaged by moisture should be thoroughly dried or immediately replaced.
14. Use low-emission building materials and consumer products. Avoid strong smelling materials and products.
15. Avoid living in an apartment or a house that is being remodelled so as to avoid exposure to pollutants from fresh paints and other building materials.
16. Have the radon concentration measured in your home if you live in a house or in a ground floor flat in a building located in radon area.
17. Remember that pets may cause serious allergic reactions.

EFA MEMBER ASSOCIATIONS

AFPRAL – Association Française pour la Prévention des Allergies, France
www.prevention-allergies.asso.fr

aha! – Schweizerisches Zentrum für Allergie, Haut und Asthma, Switzerland
www.ahaswiss.ch

Allergia-ja Astmaliitto, Finland
www.allergia.com

Allergie preventie vzw, Belgium
www.astma-en-allergiekoepel.be

ANIKSI, Greece
www.allergyped.gr

APA - Associação Portuguesa de Asmáticos, Portugal
www.apa.org.pt

ASGA - Asociación Gallega de Asmáticos y Alérgicos, Spain
www.accesible.org/asga

Association of Allergic Children Clubs, Lithuania

Association of Asthma Patients' Clubs of Lithuania – Lietuvos astmos klubu asociacija, Lithuania

Association of Bulgarians with Bronchial Asthma (ABBA), Bulgaria
www.asthma-bg.com

Association of Patients with Bronchial Asthma (APBA), Bulgaria

Associazione Italiana Pazienti BPCO, Italy
www.pazientibpco.it

Asthma Society of Ireland, Ireland
www.asthmasociety.ie

Asthma UK, UK
www.asthma.org.uk

Astma-Allergi Forbundet, Denmark
www.astma-allergi.dk

Astmafonds vzw, Belgium
www.astma-en-allergiekoepel.be

Astma Patiënten Vereniging VbbA/LCP, The Netherlands
www.astmapatientenvereniging.nl

Astmastichting België vzw, Belgium
www.astma-en-allergiekoepel.be

Astma- och Allergiförbundet, Sweden
www.astmaoallergiforbundet.se

British Allergy Foundation BAF - Allergy UK, UK
www.allergyuk.org

British Lung Foundation, UK
www.britishlungfoundation.org

Czech Initiative for Asthma, Czech Republic
www.cipa.cz

Deutscher Allergie- und Asthmabund e.V. (DAAB), Germany
www.daab.de

FARES - Fondation contre les Affections Respiratoires et pour l'Education à la Santé, Belgium
www.fares.be

FEDERASMA, Italy
www.federasma.org

FFAAIR - Fédération Française des Associations et Amicales d´Insuffisants Respiratoires, France
www.ffaair.org

Fondation pour la Prévention des Allergies (ASBL), Belgium
www.oasis-allergies.org

Hungarian Society of Allergology and Clinical Immunology (MAKIT), Hungary
www.makit.hu

JUDAH - Yugoslav Association for Asthma and COPD, Serbia and Montenegro
www.yudah.org.yu

LHL - Landsföreningen for Hjerte- og Lungesyke, Norway
www.lhl.no

Lungeliga Schweiz, Switzerland
www.lung.ch

National Eczema Society (NES), UK
www.eczema.org

National Society of Asthmatic and Allergic Patients in Hungary (ABOSZ), Hungary

Nederlands Anafylaxis Netwerk, The Netherlands
www.anafylaxis.net

Nederlands Astma Fonds (AF), The Netherlands
www.astmafonds.nl

Norges Astma- og Allergiforbund (NAAF), Norway
www.naaf.no

Österreichische Lungen-Union (ÖLU), Austria
www.lungenunion.at

Pulmonary Patients' Association of Slovenia (DPBS), Slovenia
www.astma-info.com

Stichting VoedselAllergie, The Netherlands
www.stichtingvoedselallergie.nl

Vereniging Nederland-Davos, The Netherlands
www.nederland-davos.nl

Vereniging voor Mensen met Constitutioneel Eczeem (VMCE), The Netherlands
www.vmce.nl

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