Towards Healthy Air in Dwellings in Europe

THADE Project

Report

SUMMARY OF OPPORTUNITIES TO IMPROVE INDOOR ENVIRONMENT IN EUROPEAN RESIDENCES TO ALLEVIATE THE SYMPTOMS OF ALLERGIC AND ASTHMATIC CHILDREN AND ADULTS

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This project received financial support from the European Commission.

ABBREVIATIONS

ach = air changes in hour; ventilation air flow divided by room volume [1/h]
CEN = European standardisation organisation
CIB = International council for building research and documentation
CO = carbon monoxide
CO_2 = carbon dioxide
COPD = chronic obstructive pulmonary disease
DALY = disability adjusted life years; sum of lost life due to mortality and lost disability due to illness
dp = decipol; a unit of perceived air quality
ETS = environmental tobacco smoke
IAQ = indoor air quality
$g/kg_{d.a.}$ = unit of absolute humidity = grams of water in kg of dry air
L/s = litres per second, unit of ventilation rate; 1 L/s = 3.6 m^3/h
MMMF = man made mineral fibre
MVOC = microbial volatile organic compound; product of metabolism of microbes
NO_x = nitrogen oxides: NO, NO_2 or NO_3
PAQ = perceived air quality
VOC = generic term of volatile organic compounds
WHO = World Health Organisation
μg = microgram = 10^{-6} g

SUMMARY

While allergic citizens and patients with other airways diseases used to be a minority in the past their health seem to be becoming a major concern in Western Europe. The measures, which are presented here will improve the indoor air quality, and alleviate the symptoms of allergic and asthmatic people, however, they do not necessarily prevent the asthma and allergies. The measures proposed in the report will enhance the quality of life of everybody, also those with chronic obstructive pulmonary diseases (COPD). The health determinants, which have causal relation with allergic diseases and are dealt with are: dust mites, mould, pollen, pets and cockroaches. Toxic or irritating health determinants dealt with are: environmental tobacco smoke, nitrogen oxides, formaldehyde, volatile organic compounds, man made mineral fibres, indoor generated particulate matter, and carbon monoxide. Carbon dioxide is included as an indicator of ventilation rates.

The proposed actions to control these health determinants are identified in four levels: international level like WHO, European Union level, national level, professional society level, and patient organisation level. The actions have been classified into five main categories:

- Improvement of ventilation
- Improvement of cleaning methods and housing hygiene
- Avoidance of wall to wall carpets
- Control of moisture in avoiding mould problems and
- Control the pollution sources such as tobacco smoking and emissions from building and consumer products.

Several methods to implement these actions are identified and discussed. The most important are:

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

Most of the recommended measures are independent on climate and cultural differences with the exception of those related to moisture control and ventilation. Even in those areas the common European guidelines should be developed.

More research is needed on the effects and costs of various measures. When developing common guidelines for remedial actions technical information on building stock should be available. This information should include also data on heating and ventilation systems, cooking appliances, ventilation rates, and moisture conditions. For the future analysis it would be useful to have more information on the prevalence of health determinants and number of people sensitive to each specific health determinants. However, the actions towards better indoor environment in Europe must continue without any delay with the present knowledge.

INTRODUCTION

The number of asthmatic and allergic citizens in Europe is close to 100 million. The table 1 summarises the numbers of those having asthma or allergic rhinitis as reported in the white paper of allergy (1). Some sources report higher percentages of allergic people (2). The discrepancy may be due to the different definition of asthma and allergy. Some sources, for example, define asthma patients with those who just have asthma-like symptoms, some with self-diagnosed asthma, and some only with those whose asthma is diagnosed with medical examination. The numbers do not include patients with chronic obstructive pulmonary diseases (COPD), which is becoming better-known and more common disease (NIH).

Table 1 Target population, estimated number of patients with asthma or allergic rhinitis (1, 2).

Country	**Population milj.**	**Allergic asthma %**	**Allergic asthma x1000 number**	**Allergic rhinitis x1000 number**	**Total number X1000**	**Prevalence of asthma symptoms** *(Stewart et al. 2001, ISAAC 1998)*
Austria	8	6	480	1040	1520	12
Belgium	10	6	600	1300	1900	12
Denmark	5.2	6	312	650	962	
Germany	81.4	6	4884	10582	15466	13-14
Finland	5	8	400	650	1050	13-18
France	48	8	3840	6240	10080	10-18
Great Britain	56	8	4480	7280	11760	20-37
Greece	7	6	420	910	1330	4
Ireland	3.5	6	210	45	255	25-32
Italy	57.2	6	3432	7410	10842	3-13
Luxembourg	0.6			78		
Netherlands	15.5	7.7	1200	2002	3202	
Norway	4.2	6	252	546	798	
Portugal	10	6	600	1300	1900	5-14
Spain	39	6	2340	5070	7410	5-15
Sweden	8.2	6	492	1066	1558	10-15
Switzerland	7	6	420	910	1330	
Western Europe	365.7	6.8	24362	47489	71851	

The prevalence of all allergic diseases has increased during last decades. The increase of the prevalence of asthma is well documented in some countries (e.g. 3). Increase in the prevalence allergic rhinitis had also been commonly observed (4). While allergic citizens and patients with other airways diseases used to be a minority in the past their health seem to be becoming a major concern in Western Europe. To alleviate the symptoms, and to improve the quality of life of this group of citizens indoor air quality should be improved (5). Minimising exposure to environmental allergens decreases the severity of asthma attacks and therefore also decreases the amount of medication required and the likelihood of side effects. The identification, avoidance and elimination of allergens should therefore play a central role in the management of any child with asthma. Studies in Asia and Europe have shown a positive correlation between indoor pollution and the prevalence of asthma (6). Everybody has right to healthy air (7).

At the same time the work for primary prevention of allergies should continue. The measures, which are presented here will improve the indoor air quality, and alleviate the symptoms of allergic and asthmatic people, however, they do not necessarily prevent the asthma and allergies. Some of the measures are focused on health determinants, which cause allergic diseases, some on those, which increase the allergic symptoms.

METHODS

An extensive literature survey was carried out dealing the indoor environment related health determinants, which cause the increase of prevalence or intensity of symptoms. The results of this literature survey are reported by other consultants. These health determinants are summarised in Table 2. They are supported also by previous summaries of health risks (e.g. 8, 9). The table also gives some information on the characteristics of the health determinants, control methods, and some examples of the actions, which could be taken to control these pollutants. These health determinants of indoor environment are briefly described. The health determinants, which have causal relation with allergic diseases, are;

- dust mites,
- mould
- pollen
- pets and
- cockroaches.

The common toxic or irritating health determinants dealt with are:

- environmental tobacco smoke
- nitrogen oxides
- formaldehyde
- volatile organic compounds
- man made mineral fibres
- suspended particulate matter
- carbon monoxide

In addition to these health determinants carbon dioxide is discussed as an indicator of ventilation.

HEALTH DETERMINANTS

Environmental tobacco smoke (ETS)

The avoidance of environmental tobacco smoke indoors is the most cost effective method to improve indoor air quality. WHO has estimated that that the smoking itself is number one cause of premature deaths in the world killing about 5 million people annually (10), and the number is increasing. Scientific evidence has also shown the adverse health effects of passive smoking (e.g. 11). Many European countries, but not all, have already prohibited smoking in public buildings, working places, and even restaurants. The favorable effects of the control of environmental tobacco smoke include also the positive influence on heart diseases, and reduction of energy consumption due to lower requirements of ventilation. These effects are independent of country and climate. Good examples of the effect of legislation and information campaigns can be seen from the experience gained in a number of European countries. ETS is a mixture of gases and particles. Many of the thousand compounds in the smoke are carcinogenic (12). The size of the particles of the smoke is relative small (Table 7), which makes the cleaning difficult.

Dust mites

Fragments and feaces of dust mites (including the families *Dermatophagoides, Pyroglyphidae, Tarsonemoidae and Acaridae*) are the most common and best-known indoor originating allergens in Europe. Dust mites are common all over Europe, but more in moderate climate in Middle Europe. The reasons of growth and control are also known. The generally accepted method of controlling the growth of dust mites is to limit the relative humidity indoors below 45 %. The control measures are primarily focused on the control of relative humidity indoors by controlling moisture sources, ventilation, heating or dehumidification. (13, 14, 15, 16). In the houses infected by dust mites it is important also to remove the fragments of dead mites and their feaces from carpets, furniture and textiles (17, 16). The size of mite allergens is relative large mainly between 2 – 11 µm (Table 7).

Mould

The term *mould* covers usually moisture-related microbial growth in buildings including fungi and some bacteria. Even though all mechanisms of the health effects of mould growth or damp buildings are not yet known, the scientific evidence shows that moisture-damage in buildings is a health risk. The mechanism of health effects include: IgE-mediated allergies (5 % of patients), cell mediated hypersensitivity, irritation of mucous membranes (MVOC), toxic effects (microbial toxins) and inflammation of airways (18).

The control of mould growth is, in principle, very simple: keep the building dry. The limit value of the microbial growth varies between 65 –95 % relative humidity depending on the species, Table 6 (19). The control methods are the same as those for dust mites, but, in addition, the building structures should be kept dry and ventilated properly. Mould problems are common in Northern and Middle Europe. Methods to control moisture in new buildings are described in Table 3, and in existing buildings in Table 4.

Pollen

Pollen is the most common allergen. Main exposure to pollen allergens occurs outdoors during the pollen season, but there are also detectable concentrations of birch and grass pollen allergens in indoor air (20). The sources of pollen differ by country (21). In northern Europe the most common source is birch trees. More than 50 % of children may be allergic to pollen from birch. The diameter of the pollen is relative large, i.e. 15-25 µm (Table 7), which makes it easy to filter from indoor air. However, the allergens are also in small fragments of pollen, and in the products of germination. Small particles can be carried by wind for long distances. Control of pollen indoors requires an airtight building envelope, mechanical ventilation and air cleaning or portable air cleaners. Source control of pollen can be effective to certain extent. The highly allergenic trees, and other plants should be avoided in residential areas. Well known allergic plants should of course be avoided indoors.

Nitrogen oxides

Scientific evidence shows the negative health effects of exposure to nitrogen oxides (11). The source of nitrogen oxides is combustion; the main outdoor source is traffic and energy generation. Indoor sources are related to open flame combustion either in kitchen or in heating appliances. The most feasible control method is to avoid unvented combustion indoors. Most dangerous is the use of solid fuels for cooking indoors without proper furnace with chimney. In the global basis the smoke from fuels indoors causes 1.6 million deaths annually in the world, and is number ten of all reasons causing lost disability adjusted life years (DALYs) in the world (10). Nitrogen oxides may be a problem in some new member countries. In many European countries natural gas or propane is used for cooking. Open flames are sources of nitrogen oxides. Kitchen range hoods and effective ventilation reduce concentration originating from indoor sources. Protection against outdoor sources is more difficult. Incoming outdoor air can be cleaned but the long-term performance of cleaning systems is not know.

Pets

It is widely recognised that dander and other particles from pets are allergens (e.g. 11, 22), (cats, dogs, guinea pigs etc.). What is not yet completely understood and documented is the possible protecting effect against allergy with the exposure to pets in the age of 0-6 years. Pets also have many positive effects on the quality life. The restriction of the pets in homes should be considered carefully, and limited only to most serious cases. However, the exposure to pet allergens in schools and other public places should be limited. These include public transportation, classrooms etc. where pet allergens may be carried even with clothing. The cat allergens are in the particle size range of 1 – 10 µm (Table 7).

Cockroaches

Cockroaches are sources of allergens, and common in low income housing areas, particularly in high rise apartment buildings in the USA (23). Cockroaches may be a problem also in the some new member countries of EU. The control of cockroaches should focus on the improvement of the housing hygiene: cleaning, control of moisture, storage of food, dish washing, and handling of laundry etc. Information campaigns and improvement of living standard are the methods of control. Size of cockroach allergens is large, > 10 µm.

Formaldehyde

Formaldehyde is an irritant and carcinogen (11). Its primary source used to be particle boards, a commonly used construction material in buildings and furniture (24). The emission control and labelling systems for particle boards have significantly reduced the formaldehyde concentrations indoors. However, other sources have become significant. These include textiles used for interior decoration, furniture, tobacco smoke, and household chemicals. These sources can be controlled through testing and labelling programs. The labelling programs of building materials used in some countries also include the limit values of formaldehyde emissions.

Volatile organic compounds (VOC)
Several studies have found the association between allergic symptoms and indoor concentration of some volatile organic compounds (8,11). Some guideline values for organic compounds have been published but they are focused mainly on outdoor air quality (25). Recent research indicates that VOCs may react in the indoor air with other substances like ozone (O_3), and generate compounds more harmful than those participating in the reaction. Sources of volatile organic compounds exist everywhere in buildings, however, the main sources are the building materials and household products. Labelling programs have been effective and resulted in a dramatic reduction of emissions of volatile organic compounds from building materials (26).

Man made mineral fibres
Man-made vitreous mineral fibres are made from glass, rock and other mineral materials. Typically the fibre diameter is 2-5 μm while its length is over 20 μm. The weight of the fibres causes them to fall, and attach mainly on the horizontal surfaces, from where they may end to the air ways and eyes through activities in the room. Mineral wools are used commonly in buildings for acoustical purposes and also for thermal insulation. Mineral fibres are irritants. Their carcinogenic effect has been also suspected but not proven. If the mineral wool is uncoated, the fibres may be released into the air, deposited on surfaces, and get to the respiratory track and eyes causing irritation. The fibre release can be prevented by coating, or otherwise treating materials properly.

Suspended particulate matter
Indoor concentrations of particulate matter may exceed the limit values for outdoor air, particularly in spaces with high occupant density and large amount of fleecy surfaces. The outdoor levels of particulate matter vary widely depending on country and micro climatic conditions. The health effects of the dust in the air depend on the composition of the dust, but, in general, high dust concentrations are related to higher prevalence of allergic symptoms. Airborne particles may carry allergens, bacteria and viruses. Some volatile organic compounds are also bound to particles. The particle concentration may affect the concentration of VOCs and microbial contamination in the air. The primary method of controlling dust concentration is to control the source. Wall-to-wall carpets should be avoided, particularly in public buildings and working places. Proper cleaning is an effective method to reduce dust concentration in the air as well. Cleaning during occupancy should be avoided to reduce the exposure to dust generated by cleaning itself.

Carbon monoxide (CO)
Carbon monoxide is extremely poisonous and odourless. The only way to control the exposure is the control of source, and proper use of appliances where the generation of CO is possible (11). Sources of carbon monoxide are incomplete combustion in cooking, fireplaces, ovens and other heating appliances, and tobacco smoking. Control of CO-emission involves the control of combustion and limiting smoking.

Carbon dioxide (CO_2)
Indoor source of carbon dioxide is the metabolism of building occupants and pets. Outdoor concentration of CO_2 is fairly constant but varies depending on the location and the time of the day. Typical outdoor air concentrations are 350 –450 ppm (parts per million ie. cm^3/m^3). Indoor air concentration is dependent on ventilation, and indoor sources (number of occupants). The typical indoor air concentrations of CO_2 are between 500 – 1500 ppm. CO_2 in those concentrations is not harmful, however, it is an indicator of other pollutants in the air and ventilations rate. The CO_2-concentration depends on number of occupants, and duration of occupancy, ventilation rate, and room volume. As the occupancy (the generation of CO_2) varies the concentration of CO_2 is seldom constant in a building, and should be evaluated accordingly. Control of CO_2 is the same as to control ventilation (27).

Table 2 Health determinants in indoor environment, their characterisation and control (28)

Health determinant in indoor environment	Source characterisation	Control methods	Examples of the actions which could be taken on EU or national level
1. Environmental tobacco smoke	Secondary smoke is in particle and gaseous form. Small particle size. Sorption on surfaces, Difficult to remove from air and surfaces.	Limit smoking indoors, especially in homes. Provide smoking rooms. Provide better ventilation Use air cleaning as a last measure	Limit smoking in public buildings and working places Campaign against smoking at homes Improve ventilation to reduce the exposure of non smokers Provide smoking rooms
2. Dust mites	Fragments of mites, but more import are the fecal pellets Requires high relative humidity indoors. Fragments mites and feaces stored in carpets and textiles etc.	Reduce indoor relative humidity: - increase ventilation. - control of indoor moisture generation. - use dehumidification	Better building codes for the new construction* Improved indoor moisture control in existing building stock** Use special mite resistant bedding materials
3.Mould (fragments, mouldy material, spores, MVOC)	Moisture controls the mould growth Moisture damages are common: wet structures, water leakages, condensation, high indoor humidity.	Prevent and repair moisture damages and leakages immediately. Improve ventilation. Control of pressure differences over structures. Control indoor moisture sources	Better building codes for the new construction* Improved indoor environment in existing building stock**
4. Pollen	Relative large particle size, but small fragments may carry also allergens: birch, alder, linden, oak, beech, hays, olive tree, mugwort etc.	Tight building envelope and filtration of incoming outdoor air. Indoor air cleaners.	Present tested methods to protect against pollen. Develop testing and Labelling procedures for air cleaners

Health determinant in indoor environment	Source characterisation	Control methods	Examples of the actions which could be taken on EU or national level
5. Nitrogen oxides (NO_x)	Side product in combustion. Indoor sources: - gas fires - cooking and heating appliances - smoking	Avoid open flame fires indoors. Remove the flue gases where produced. Use chimneys. Use effective ventilation.	- Encourage the use of electrical kitchen appliances. - Do not use unvented heating appliances. - Use central heating. - Improve ventilation - Use range hoods in kitchens
6. Formaldehyde	Common emission from building materials. Other sources that particle boards are relevant such as household chemicals, ETS, and carpets other textiles for interior decoration	Limit the emission from sources Use of labelled particle boards Limit smoking indoors	Product control and labelling systems for building products and household chemicals.
7. Chemicals, volatile organic compounds (VOCs)	All manufactured building materials emit some VOCs, especially as they are new also cleaning products etc.	Limit the use of high emitting products. Ventilate new buildings and furniture before used. Provide adequate ventilation.	Labelling systems for building materials, furniture and household products
8. Indoor generated particulate matter and dust	Carpets, textiles, food (especially protein in dust), occupants Also a problem in schools and other buildings and spaces with high density of occupants	Avoid excess use of 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 the cleaning after or before the operation hours of the schools and offices
9. Man made mineral fibres (MMMF)	MMMF are used in insulation materials, and acoustic linings. Fibres are irritants	Limit the use of uncoated of mineral wools indoors, or in ventilation systems.	Limit the release of fibres by coating. Stop using uncoated mineral wool indoors. Develop testing methods
10. 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
11. Pets	Skin and hair fragments, dander from cat, dog etc. All furred animals are a risk factor at homes and have high allergy potential. Small particle size. Difficult to get rid with cleaning.	Avoid furred pets in homes of families with seriously allergenic members. Better cleaning. Air cleaners	Inform the public on the risks and benefits of furred pets at homes. Limit the entrance of pet in public transportation. Use easy to clean furniture in public spaces. Restrict the pet exhibitions in public places (schools etc) Do not take the outdoor clothing in classrooms.

Health determinant in indoor environment	Source characterisation	Control methods	Examples of the actions which could be taken on EU or national level
12. Carbon monoxide (CO)	Sources of carbon monoxide are incomplete combustion in fireplaces, ovens and other heating appliances, and tobacco smoking.	Control of CO-emission is the same as the control of combustion: supply enough combustion air, use chimneys to remove flue gases, control the pressure differences to avoid back draft. And limit the smoking indoors.	- Inspection and control of small heating appliances. - Proper design guidelines and building codes.
13. Carbon dioxide (CO_2)	Indoor source of carbon dioxide is the metabolism of building occupants and pets. Typical outdoor air concentrations are 350 – 450 ppm (parts per million eg. cm^3/m^3). Typical indoor air concentrations of CO_2 are between 500 – 1500 ppm Indoor air concentration is dependent on ventilation, and occupancy. CO_2 concentration as such in those concentrations is not harmful, however, CO_2-concentration is a indicator of ventilations rates.	Control of CO_2 concentrations is the same as to control ventilation. The concentration depend on number, and duration of occupants, ventilation rate, and room volume. As the occupancy (and the generation of CO_2) varies the concentration of CO_2 is seldom constant in a building, and should be evaluated accordingly.	Ventilation standards should give also levels of CO_2 – concentration. Methods of CO_2 measurements for indicator of ventilation should be developed.

* see details in the Table 3
** see details in the Table 4

Table 3 Methods to control moisture (control of the dust mites and microbial growth) in new buildings with better building codes (28).

Method	Effect on construction cost	Effect on energy consumption
Building construction		
Improve thermal properties of windows	Increases	Decreases
Design the structures to stand moisture loads of local climate and typical use of buildings (use vapour barriers etc)	Negligible	No effect or small decrease
Ventilate walls and other building components to prevent condensation	Negligible	No effect or small decrease

Method	**Effect on construction cost**	**Effect on energy consumption**
Improve thermal insulation of building envelope to increase indoor surface temperatures to prevent condensation in cold and moderate climate	Increases	Decreases
Prevent moisture migration from the ground – draing the surface waters	Negligible	No effect or small decrease
Improve protection against rain, roofing, walls, windows	Negligible	No effect or small decrease
Design and install for minimum leakage of plumbing		
Ventilation		
Provide openable windows in all living rooms and kitchen	Slight increase	May increase or decrease
Provide adequate, controllable average ventilation for the residence	Slight increase	May increase or decrease
Ventilate all rooms –eg. use the ventilation where needed	Slight increase	May increase or decrease
Provide effective kitchen range hood	Slight increase	May increase or decrease
Provide possibility to control ventilation by demand	Slight increase	Decreases
Use mechanical exhaust ventilation in warm and moderate climate – tighten the building envelope to prevent excess ventilation	Slight increase	Decreases due to reduced air leakage
Use mechanical supply and exhaust ventilation with heat recovery to reduce relative humidity indoors	Slight increase	Decreases
Heating		
Use central heating in cold and moderate climates	Slight increase	Slight increase
Do not use open flame unvented heaters	No effect	No effect
Control heating by indoor temperature with thermostats	Slight increase	Decrease
Encourage the use of district heating	Negligible	Decreases the use of primary energy

Require chimneys for all heating boilers and furnaces	Slight increase	Better efficiency – decrease in primary energy
Improve the control of fire places with dampers, shutters etc. – improve the thermal efficiency of fireplaces	Slight increase	Decrease

Table 4 Methods to control moisture in existing buildings (28).

Method	**Effect on construction cost**	**Effect on energy consumption**
Consumer behaviour and operation		
Limit the use of humidifiers	No effect	Decreases
Do not dry the laundry in living area	No effect	Decreases
Use the kitchen range hoods and ventilation during cooking	No effect	May increase or decrease
Use ventilation and airing to prevent high indoor humidity and condensation	No effect	May increase or decrease
Increase indoor temperature to decrease relative humidity	No effect	Increases
Refurbishment		
Improve the performance of ventilation (natural or mechanical)	Minor effect	May increase or decrease
Install mechanical ventilation system to improve ventilation (with or without heat recovery)	Medium	Decrease
Install second pane in windows to prevent condensation	Medium	Decrease
Improve roofing to prevent water leakages when applicable	Medium	Decrease
Ventilate crawl spaces to prevent moisture migration from ground when applicable	Small	No effect
Install range hoods in kitchen	Small	May increase or decrease
Replace unvented open flame heaters and appliances with vented ones	Small	Improves efficiency and reduces primary energy use

Sensitive and exposed population

The number of population sensitive and exposed to each health determinant varies between countries. Table 5 presents the estimated numbers in Finland. The estimated target population is those with allergic asthma or allergic rhinitis. Percentage of target population sensitive to the specific pollutant is derived from various sources by the Finnish Asthma and Allergy Federation. The percentage of the sensitive people exposed to the specific health determinant is also estimated in the table. Unfortunately consistent data is not available from Europe.

As an example up to 37,6 % of allergic people in Finland are sensitive to environmental tobacco smoke, and 20 % of those are still exposed to the tobacco smoke. This means that health of 112 000 (1500000 x 0.376 x 0.20) allergic patients in Finland is still deteriorated due to passive smoking. Even though the smoking indoors in Finland is limited by legislation.

Table 5 Estimation of allergic or asthmatic patients (target population) in Finland (total population of Finland is app. 5.2 million), and percentage of population sensitive to specific health determinant and exposed to it (28). According to the numbers in the table the health of 112 000 (1500000 x 0.376 x 0.20) patients is still deteriorated due to environmental tobacco smoke.

Indoor pollutant	**Number allergic or asthmatic patients (target population)**	**% of target population sensitive to the pollutant**	**% of target population exposed to the pollutant**
1. ETS	1 500 000*	27,6 – 37,6*	20*
2. Dust mites	1 500 000	6,5*	58*
3. Mould	1 500 000	35 – 44*	27*
4. Pollen	1 500 000	22 – 26*	~100
5. NO_x	1 500 000	NA	NA (low indoors)
6. Pets	1 500 000	25,3 – 26,2*	NA
7. Cockroaches	1 500 000	NA	<1
8. Formaldehyde	1 500 000	NA	~100
9. VOCs	1 500 000	NA	~100
10. MMMF	1 500 000	NA	<20
11. PM	1 500 000	NA	~100
12. CO	1 500 000	NA	<1

*Estimated by Finnish Asthma and Allergy Federation based on Finnish statistics
**NA = not available

CONTROL OF THE HEALTH DETERMINANTS INDOORS

The control methods of health determinants, which were summarised in Table 2, are discussed in more detailed in this chapter.

Environmental tobacco smoke

The most effective method of controlling exposure to tobacco smoke is the control of smoking. It is almost impossible to control exposure to safe levels with other means in a room where smoking takes place. For example the control with ventilation by dilluting requires very high ventilation rates. Typical ventilation rates are 4-10 L/s per person in residences and 10-25 L/s in offices (27, 29, 30). If the tobacco smoke is diluted to acceptable level from health standpoint it would require ventilation rate of 555 L/s per a smoked cigarette in an hour (nicotine concentration of 1 $\mu g/m^3$ and 2 mg of nicotine per cigarette). Ventilation rates like that are impossible in practice.

Even though the restrictions of smoking cannot cover the homes the limitations of smoking in public places and working places may also reduce the smoking at homes.

Information about the health risks of smoking may also be effective. Typically in the countries with higher public awareness on the risks of smoking the rate of smoking is also lower. Smoking amongst lung physicians is extremely low. The proportion of smokers in the population is decreasing in industrialised countries and increasing in non-industrialised countries, particularly in the Far East.
If smoking is allowed the specific smoking rooms with high ventilation rates and effective air distribution should be provided. The smoking rooms should be designed and operated with under pressure so that the smoke does not escape from the rooms.

An important WHO agreement against smoking was accepted by 192 countries in May 2003. The parties agreed to take more specific actions against smoking including the exposure to environmental tobacco smoke. The member countries of EU should implement the proposed actions as soon as possible, and also consider the actions how to limit the exposure to environmental tobacco smoke at homes.

Mould and mites

Moisture accumulation into building structures or materials may lead to microbial growth, and subsequently to microbial contamination and other emissions in buildings. In epidemiological studies, moisture damage and microbial growth in buildings have been associated with a number of health effects including respiratory symptoms and diseases and other symptoms (31, 18). The health effects associated with moisture damage and microbial growth seem to be consistent in different climates and geographical regions (19).

It has been shown with relatively good certainty that building-related moisture and microbial growth increases the risk of respiratory symptoms, respiratory infections, allergy and asthma. The underlying mechanisms are irritation of mucous membranes, allergic sensitisation and non-specific inflammation. Also toxic mechanisms may be involved, especially in connection with toxin producing fungi and bacteria. Certain building materials seem to support the growth of potentially toxic microbes, and even induce toxin production more readily other materials (18).

Preventive measures against mould can be taken even though all mechanisms between microbial growth and health effects are not yet known. The primary controlling factor of the mould growth is moisture, specially the relative humidity indoors and in the structures. The limit values of relative humidity of some species of mould are presented in Table 6. In addition to relative humidity the mould growth depends also on the surface properties, nutrition, temperature and time. Criteria of mouldy unhealthy home should be developed as soon as possible. WHO has a working group working in this issue. The remedial measured should be introduced and implemented.

Table 6 Moisture levels required for growth of selected microorganism from construction, finishing or furnishing materials (19); a_w = water activity, ERH= equilibrium relative humidity.

Moisture level	Category of micro-organism
High (a_w >0.90, ERH >90 %)	Tertiary colonizers (hydrophilic) *Mucor plumbeus* *Aleternaria alternata* *Stachyrobotrys atra* *Ulocladium consortiale* Yests, e.g. *Rhodotorula, sporobolomyces* Actinomyces
Intermediate (a_w 0.80 - 0.90, ERH 80 - 90 %)	Secondary colonisers *Cladosporium cladosporioides* *C. sphaerosperum* *Aspergillus flavus* *A. versicolor**
Low (a_w >0.80 - 0.90, ERH < 0.80 - 90 %)	Primary clonizers (xerophilic) *A. versicolor*** *A. glaucus group* *A. penicillioides* *Penicillium brevicompactum* *P. chrysogenum* *Alemia sebi*

* at 12 °C **at 25 °C

Relation between absolute and relative humidity

The relative humidity is affected by temperature and absolute humidity (water contents in the air g/kg dry air or g/m^3 air). That means that relative humidity indoors can be controlled either by temperature or by water contents of the air. Water contents of the indoor air can be reduced by decreasing the release of water into air (cooking, dish washing, drying of laundry etc.). In most cases also the ventilation reduces the moisture contents indoors (most of the time in most European countries the indoor absolute humidity is higher indoors than outdoors). The relation between moisture contents of the air, temperature and relative humidity is shown in Figure 1. It shows the relative humidity (value on the curves) of air with selected combinations of temperature (in vertical axis) and moisture contents (absolute humidity) in horizontal axis. It illustrates that when the outdoor air in temperature of –8 °C with 100 % RH (relative humidity of outdoor air is usually very in the winter) (point A in the figure) is brought to indoor temperature of 20 °C its relative humidity has deceased to 15 %. This shows that cold outdoor air is effective in carrying moisture from indoor. Drying capacity of warmer outdoor air is smaller, and higher ventilation rates may be needed in moderate than in cold climate in respect of moisture control.

The effect of heating on relative humidity can be demonstrated in with the following example: relative humidity of the air in the temperature of 15 °C with absolute humidity of 5.5 g of water in 1 kg of dry air is 50 %, just above the limit value of dust mites.

When air is heated to the temperature of 18 ^{o}C its relative humidity is decreased to 40 %, just below the limit value of dust mites.

Third example shows that when the air in the temperature of 20 ^{o}C and relative humidity of 58 % (point B in the figure), just below the limit value of mould growth, is cooled down its relative humidity increases to 75 % when the temperature is decreased to 15 ^{o}C, and reaches 100 % RH when the temperature is 12 ^{o}C. Water will condensate on the surfaces in this temperature or below (window pane, unheated section of the house, poorly insulated walls etc.). These examples illustrate how the relative humidity is affected by temperature. Relative humidity may thus rise above the limit values of microbial growth if the temperature in home decreases locally.

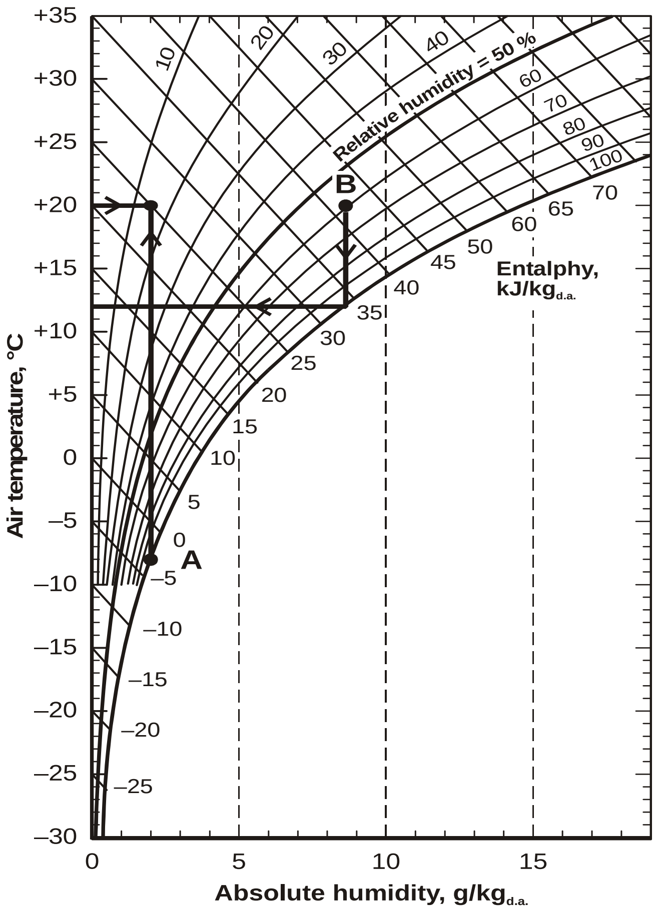

Figure 1 Relation between air temperature, absolute humidity (water in grams in kg of dry air) and relative humidity in the air. When air in temperature of –8 ^{o}C with 100 % relative humidity (point A in the figure) is brought to indoor temperature of 20 ^{o}C its relative humidity has decreased to 15 %. When the air in the temperature of 20 ^{o}C and relative humidity of 58 % (point B in the figure) is cooled down its relative humidity increases and it reaches 100 % RH when the temperature is 12 ^{o}C. Figure also shows that relative humidity of the air in the temperature of 15 ^{o}C with absolute humidity of 5.5 g/kg$_{d.a.}$ is 50 %, just above the limit value of dust mites. When air is heated to the temperature of 18 ^{o}C its relative humidity is decreased to 40 %, just below the limit value of dust mites.

Measures against moisture damages

The measures against moisture damages described in Table 3 are grouped into three categories. The first group deals with building constructions. The structures should be designed, constructed and maintained so that they stand the indoor humidity without harmful condensation of water vapour migrating to the structure.

The second group deals with ventilation. Its effect is two fold. Ventilation can remove indoor generated moisture directly, and dilute the moisture to a lower level. In some climatic conditions (summer in some costal areas) the outdoor moisture contents may be high. In those conditions the ventilation is not effective. However, those conditions do not last very long.

Several studies have been performed on the effect of improved ventilation with or with out humidification on the population of dust mites in residences (11, 13, 16, 32, 33, 34). Most of them have reported a reduction in the mite population but not improvement in symptoms or allergen levels. Some researchers (17) have pointed out the shortages in these studies. It is natural that the effect of ventilation and dehumidification is not seen in symptoms, and other human outcomes if the indoor environment is not cleaned from the accumulated allergens at the same time. The mite population generates many times more fragments of dead mites and fecal pellets that the mass of the living population. If these allergens are not removed at the same time it is obvious that the symptoms are not alleviated.

Third group of measures in Table 3 deals with heating. Effective central heating, preferably with co-generated district heating decreases indoor relative humidity and decreases the moisture and pollutant generation from combustion.

Some additional measures can also be taken to reduce moisture problems. Indoor relative humidity can depend on the air circulation in the room. Soft furniture, book selves close to exterior walls and carpets may increase locally the relative humidity indoors and cause mould growth. It has been estimated that the relative humidity in the carpets may be 10 % higher than in the room air. Textile surfaces and carpets are good reservoirs for the microbiological contamination, and very difficult to clean when contaminated. Heavy wall to wall carpets are a risk factor in a humid climate.

Indoor air dehumidification can also be used. With these devices air is circulated through a cooling coil where water is condensed and drained. After cooling and dehumidification the air can be heated with the same device back to the room temperature if necessary. These devices are particularly applicable for temporary use. From the standpoint of the energy use it is important that air is not dehumidified too much, not much lower that the limit value of the growth of mites 45 % RH.

Exposure to mites in the contaminated bedding can be decreased by using specific impermeable, mite-tight, pillow cases and sheets. This is, however, only a temporary solution.

Pollen

Pollen is extremely common allergen outdoors and indoors, as the pollen is carried inside with clothing and ventilation air. Exposure to allergenic pollen can be reduced by trying to avoid and get rid of the most common allergens in the residential areas and in homes. The species vary highly by the country. Pollen particles are large and can be removed from incoming air easily. Even in buildings with exhaust ventilation the filters can be installed in the air inlets. The control is easiest in the buildings with mechanical exhaust and supply ventilation, commonly used in Nordic countries. Germination of pollen begins in humid conditions. Germination of pollen result in small allergenic particles which are more difficult to remove from the air than pollen itself. Room air cleaner remove effectively particles from the air. Their effect on the total dose depend on their total cleaning effect. Effective cleaning air flow of those devices is the removal efficiency multiplied by the air flow through the device. The effective air flow divided by the air volume of the space to be cleaned should be more than one before the cleaning is effective. Removal efficiency of air cleaners is dependent on particle size, typical size distribution of common indoor particles is shown in Table 7. Small particles are more difficult to clean that large ones. Electrical air cleaners remove also the small particles from the air, their draw back is the potential ozone generation which may be harmful. The performance of these devices varies, and is not always clearly presented to consumers. Harmonised test procedures of air cleaning devices are needed, as well as controlled studies on the actual effect of air cleaning on symptoms.

Nitrogen oxides

Sources of nitrogen oxides are all kind of combustion ranging from internal combustion engines to gas cooking and heating appliances. Scientific evidence shows more adverse health effects of indoor climate in the residences with open flame cooking with gas or solid fuel. It is thus obvious that all open flame cooking or heating without proper chimneys or flue gas pipes should be avoided.

The use of range hoods will help some as they can capture part of the flue gases, but their typical capture efficiency is only 60 %, and the effectiveness is highly dependent on their proper use and cooking practice. All cooking, space heating, and water heating that can be done with proper control of combustion and removal of flue gases, will improve the air quality. In most cases this technology is also more cost effective than many others.

In the long run electrical ranges should be favoured and non-polluting gas appliances developed.

Formaldehyde and other volatile organic compounds

Material emissions have been recognized to have an influence on the total pollution load of buildings. The research and development activities in the area of material emissions started with formaldehyde emissions from particle boards about thirty years ago. The labelling schemes and quality control have solved the problem with particle boards manufactured in Europe but not with those imported from some other countries. During the last decade, research has shown that almost all materials emit chemical pollutants. Focus has been on paints, varnishes, and flooring materials. Unfortunately the harmful emissions are not limited to the finishing materials, but include also furniture, partitions etc. In some cases, also sealants and injection putties have created problems due to high VOC emissions.

The problems related to the control of material emissions are not limited in the health effects and air chemistry. For the user of the materials the system of emission control should be easy to understand. This is achieved, for example, with a labelling or classification system. These kinds of programs exist for some material groups and in some countries (35, 36, 37, 38). Best known in Europe may be the Danish (39) and Finnish labelling programs (26).

The Finnish classification and labelling system of materials (37), was developed by the Finnish Society of Indoor Air Quality and Climate in 1995 and revised in 2001. The Classification system has three classes, category M1 being the best and category M3 containing materials with highest emission levels.
The best category M1 is designated to the materials which fulfil the following requirements:

1. The emission of total volatile organic compounds (TVOC) is below 0.2 mg/m^2h;
2. The emission of formaldehyde is below 0.05 mg/m^2h;
3. The emission of ammonia is below 0.03 mg/m^2h;
4. The emission of carcinogenic compounds (IARC) is below 0.005 mg/m^2h;
5. The material is not odorous (dissatisfaction with the odour is below 15 %).

By summer 2003, about six hundred materials have been granted the best, category M1, label. The material manufacturers use the classification certificates and labels in their own marketing. The labelling system has reduced significantly emissions from building materials (Figure 2).

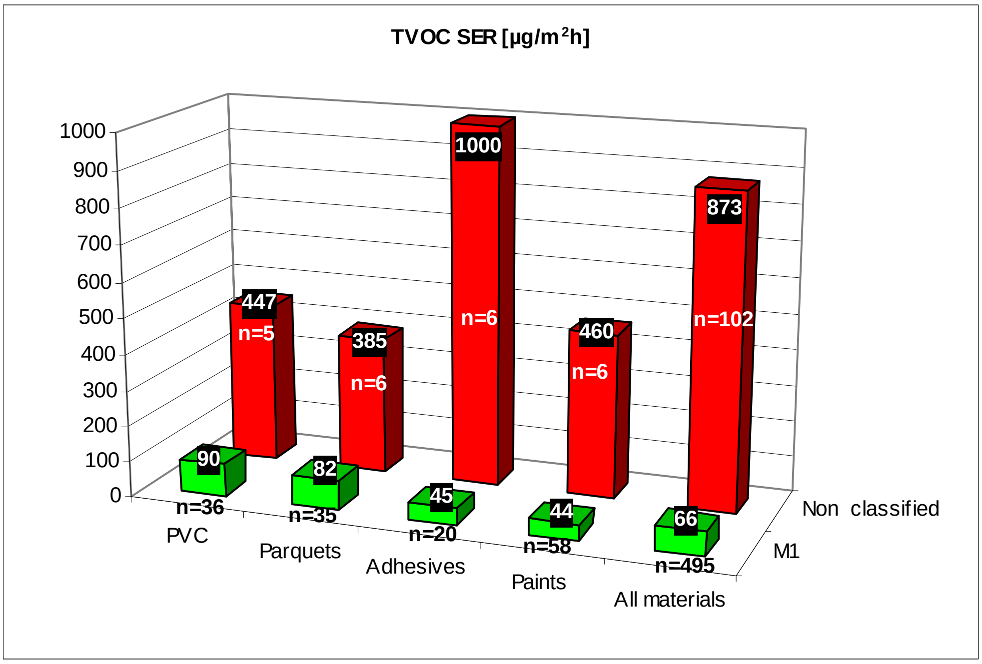

Figure 2. The effect of the Finnish material labelling system on emissions (SER) of some building material groups. Those labelled with M1 are those that have met the criteria (26).

The work dealing with the measurement methods and chemical analysis of material emissions is going on in several European level working groups and some standards have been published (40, 41) or under preparation (42). This work should be supported, and also used to develop common criteria for material emissions and labelling systems in Europe. This is very important as the building material will be imported from various countries which may not yet have recognised the harmful effects of the chemical emissions.

Indoor generated particulate matter

Health effects of the particulate matter depend on the particle size and its composition. The particles with diameter smaller than 5 μm do not settle by gravity (settling velocity about 0.15 mm/s) but stay air borne with air currents. The most harmful in general are those with small diameter (<0.3 μm). They penetrate deep in the lungs, and are most difficult to remove from the air. Inert particles may carry also bacteria and virus and allergens. Typical size for the particles carrying bacteria is 1-2 μm, particles with fungal spores are larger in the range of 2-3 μm. Cat allergens are in the wide size range (Table 7). As the particle size varies much between harmful particles the efficiency of various removal measures varies as well. The size of some harmful particles are shown in the Table 7.

Table 7. Reported size distributions of particles associated with asthma (43).

Type of Particle	Reported Size Ranges	References
Environmental Tobacco Smoke (ETS)	For emitted particles, the mass median diameter is 0.22 μm. Virtually all particle mass is within 0.09 to 1.0 μm size particles	(44)
Plant pollens	15 – 25 μm; fragments may be much smaller	(45)
Dust mite allergens	30% to 90% of allergen is in particles < 11 μm; Only a few % of allergen is in particles < 2 μm	(46) (47)
Common fungal spores	2 – 10 μm	(45)
Cockroach antigen	~ 80% of allergen > 10 μm	(48)
Cat antigen	From < 1 μm to > 10 μm, Based on Custovic et al. (1997), 45% is > 9 μm, 23% is < 4.7 μm. Based on Luczynska et al (1990), 75% > 5 μm and 25% (range 10 to 62%) < 2.5 μm.	(49) (50) (51)

The dust concentration in the air is affected also by the dust accumulated on the room surfaces from where they get air borne through the activities and air currents in the room. An effective method against exposure to dust is to keep surfaces clean and dustless (22). That means frequent dusting or cleaning the surfaces with effective vacuum cleaners. As the finest particles easily penetrate the dust collection reservoir of vacuum cleaner and pollutes the room air, it is important that cleaner filters the fine particles from the air returned back to the room, or exhaust that air outdoors as is done in central vacuum cleaning systems. It would be beneficial to develop testing and labelling systems for the vacuum cleaners. As the cleaning itself increases temporarily the dust concentration in the air the cleaning should be done during the unoccupied period of the space. Also adequate ventilation should be provided during the cleaning.

Sources of dust are numerous. Not all of them can be avoided but most harmful can, and should be avoided such as wall-to-wall carpets.

Man made mineral fibres

Uncoated mineral wool may be a source of fibres indoors. Mineral wool is used to modify the acoustic properties of spaces, and for thermal insulation in buildings. In some cases the mineral wool is uncoated and may release the fibres into air. It is important that all surfaces of mineral wool are treated so that fibres do not get released, including the edges of the material. Potential source of the fibres are the air handling systems where acoustical lining is used to control noise of fans. In some countries air ducts are made totally from mineral wool. This should be discouraged. The Finnish labelling criteria for clean air handling components include also the criteria for fibre release (Table 8).

Table 8 The requirements of the cleanliness classification for ducts and accessories at factory (37)

Pollutant	*Limit value*
Surface density of oil in ducts [1)]	0.05 g/m^2
Surface density of oil in accessories, terminal units, and air and fire dampers[1)]	
• Parts manufactured by cutting, bending or jointing	0.05 g/m^2
• Parts manufactured from deep-drawn sheet metal, processes requiring oil	0.3 g/m^2
Mineral fibres released into air flow (MMMF) [2)]	10^4 fibres/m^3
Amount of surface dust	<0.5 g/m^2

Cockroaches

The eradication of cockroaches should be done in the whole building, as in the apartment building they may migrate from flat to flat through the conduits for water and sewage pipes, ventilation ducts and electrical wires. The eradication should include improvement of housing hygiene. Better cleaning, storage of food etc. are important elements in the campaigns for better housing hygiene (52, 53, 54).

Pets

Control of exposure to allergens from pets is in principle very simple as soon as the specific allergen is identified. However, in practice, it may be complicated. Allergens stay a long time in the homes and furniture, and may be impossible to remove from carpets and upholstered furniture. This may create a problem when changing the apartment. Pet allergens should be avoided in places where the exposure is not expected like schools, public transportation etc. Pets should be kept out from these places.

Carbon monoxide

The source of carbon monoxide is incomplete combustion in which CO is generated instead of CO_2. The adequate supply of air for the combustion is the method to control the generation of carbon monoxide. The most potential sources of CO are the room heaters with gas, oil or solid fuel. Use of these should be avoided. Central heating with better possibility to control combustion should be recommended. In the Nordic countries were central heating or electrical heating of residences is common, the carbon monoxide poisonings are rare.

Carbon dioxide and ventilation

The source of carbon dioxide indoor is metabolism of people and pets. Typical concentrations indoors range from 500 ppm to 1500 ppm. Carbon dioxide is not yet harmful in these concentrations but is an indicator of ventilation rates. The control of CO_2 concentration is in many cases the same as the control of ventilation.

European draft standard for ventilation in non-residential buildings (55) has presented ventilation rates and differences of carbon dioxide concentrations between indoor air and outdoor air (Table 9) for four indoor air categories based on the technical report published earlier (56). This is an example how CO_2-concentration is used as a surrogate of ventilation. The use of CO_2 as a metric of ventilation rate can be done best in steady state conditions, which are more common in residences than in non-residential buildings. In residential building with constant occupancy to reach the steady state concentration of CO_2 takes about six hours when the ventilation rate is 0.5 ach.

Table 9 Air quality and ventilation rates (outdoor air) in European draft standard (55) for non-residential buildings with non- or low-polluting building materials.(IAQ= indoor air quality, PAQ = perceived air quality, dp = decipol)

Category	IAQ	ΔCO_2	PAQ/ dp	L/s per person No smoking	L/s per person Smoking allow
IDA 1	High	≤400	1.0	>15	>30
IDA 2	Medium	400-600	1-1.4	10-15	20-30
IDA 3	Acceptable	600-1000	1.4-2.5	6-10	12-20
IDA 4	Low	>1000	>2.5	<6	<12

Reviews (27, 29) on the association of ventilation rates and human responses show that ventilation rates below 10 L/s per person are associated with negative health effects in non-residential buildings. Available studies further show that increases in ventilation rates above 10 L/s per person, up to approximately 20 – 25 L/s per person, are associated with a significant decrease in the prevalence of SBS symptoms, or with improvements in perceived air quality.

The reviews of ventilation rates and human responses (27, 29,) summarize the results of four studies available at that time on the health effects of ventilation rates. All of them reported a significant association between low ventilation rates and an increase in health problems: pneumonia, upper respiratory illnesses, influenza and short-term sick-leave. The consistent findings are a strong indication of the association of ventilation rates with health effects. The strong evidence was provided in a study (58) where the association with sick-leave was analysed for 3720 employees in 40 buildings using 115 independently ventilated ventilation areas. Among office workers, the relative risk of short-term sick-leave was 1.53, with the estimated ventilation of 12 L/s per person compared to a ventilation rate of 24 L/s per person.

Less information is available on health effects of ventilation rates in residential buildings, however, the EUROVEN group[1] (29) concluded that the ventilation rates below 0.5 ach are a health risk in Nordic residential buildings. This is a quite low value, and the minimum ventilation rates may be much higher in moderate climate where the outdoor air humidity is higher and more ventilation is needed to carry away the indoor generated moisture. In residential building the ventilation rates depend on air tightness of the building envelope and the ventilation system. In Nordic countries most new residential buildings use balanced ventilation with mechanical supply and exhaust of the air with heat recovery from the ventilation air. With mechanical ventilation the required ventilation rates are easily provided to each room. The drawbacks have been poor technical implementation of these systems.

Natural ventilation is used more commonly in moderate climates. In these systems the ventilation depends on natural forces (wind, and temperature difference between outdoor and indoor) and the openings in the building envelope. The ventilation rates vary depending on climatic conditions, and may be very low if the building envelope is air tight and the opening for ventilation are closed. Performance of various ventilation systems is discussed in the recent European report (9), and a review (30). These summaries do not give a clear solution to the problem related to ventilation, however, it stresses the importance of adequate ventilation, and recommends further actions in the area of ventilation including the following:

1. Encourage and support European engineering organisations such as REHVA[2] (Federation of European Heating and Air Conditioning Associations) to develop guidelines for best practice of ventilation design, commissioning, operation and maintenance.
2. National bodies should collect statistical information of air flow rates and energy use of ventilation in buildings as available for Scandinavian countries.
3. Ventilation and IAQ criteria should be developed as an essential part of the criteria of sustainable buildings.
4. Procedures for regular inspections of ventilation systems should be developed as an essential part of the energy or IAQ audits or inspection of air conditioning systems.

An essential part of good indoor air quality and climate is the proper operation and maintenance of buildings (59). Some national guidelines have already published in this area focusing on hygiene of ventilation systems and the training of operation personnel (60).

Ventilation and energy

Ventilation rates have an important role on efficiency of buildings. Residential and service buildings use about 42 % (61) of primary energy. Its breakdown by end use in the residential sector of EU countries is: space heating 57 %, water heating 25 %, cooking 7 % and electrical appliances 11 %. In the service buildings 52 % is for space heating, 9 % for water heating, 14 % for lighting, 5 % for cooking, 4 % for cooling and

[1] Euroven expert group was established based on the needs of DG Sanco to review the scientific literature on ventilation and health

[2] REHVA is the Federation of European Heating and Air Conditioning Associations. Its member societies from 29 European countries represent more than 100 000 engineers and experts on indoor environmental technology.

16 % for other use. The proportion of the heated ventilation air derived from the energy delivered for space conditioning of residential and service buildings is roughly 33 %. About 10 % of all primary energy is used for ventilation. A recent European Directive on Energy Performance of Buildings (62) requires the member countries to implement several measures to reduce the energy efficiency of buildings. When these measures are implemented it is important that the indoor quality is not deteriorated, as happened after the first energy crisis in the early 70´s. Fortunately the directive also emphasises good indoor climate.

However, there is still is a danger that without proper design and engineering the saving of energy is done by reducing ventilation which may degrade indoor air quality (24). The expense of deteriorated indoor climate is not recognised as easily as wasteful energy consumption, but it may be equal to or more than the cost of heating and cooling the same buildings. Poor indoor air quality incurs costs to the economy through increased illnesses and sick leave, decreased productivity, and heavy medical care expenses. Calculations (63, 64), have shown that the order of magnitude of energy costs for space conditioning and for inferior indoor climate is the same. Thus, from an economic point of view, energy and health aspects are equally important, **and energy ought not be saved if indoor air deteriorates at the same time, and quality indoor air quality and climate should be integrated in the definition of energy performance and efficiency.**

The requirements for good indoor air quality and energy efficiency have often been seen to conflict with each other, yet buildings with low energy consumption may also show a lower rate of building related symptoms if the ventilation system is properly designed, constructed and operated. Many technologies are available which meet both of the goals: good energy efficiency and indoor quality (9, 59, 65).

CLIMATIC AND GEOGRAPHIC ASPECTS

The effectiveness of a measure to control health determinants indoors may vary by climate, existing building construction, heating, ventilation and air conditioning systems. But only those related to ventilation and moisture control are affected by these factors. These are summarised also in table 11. Moisture control is the primary method to control mould and mites. The reasons for the mould and mites are the same all over the Europe but the methods of control may differ.

It is interesting to note that most of the measures to control health determinants indoors presented are independent on the climate, existing building construction, and heating, ventilation and air conditioning systems. These include environmental tobacco smoke, nitrogen oxides, formaldehyde and other chemical organic compounds, man made mineral fibres, pets and carbon monoxide. Uniform international guidelines and instruction can be developed in respect of these health determinants.

Control of moisture

While microbial growth and health outcomes are consequences, the common nominators for them are different forms of undesired moisture behaviour. Water intrusion, dampness and moisture and related phenomena are not only harmful for the occupants' health but also a serious risk to the condition of the building structures. All these may decrease indoor air quality of the building. In addition to risks of rot to wooden structures, building materials may also be deteriorated by chemical processes induced by moisture.

The technical causes of water damage, dampness or moisture control failure are often closely connected to the climate. The prevailing temperature, humidity, rain and wind conditions regulate much of the principles and practices of construction, e.g., foundation, insulation, structure of the building envelope and ventilation system. Indoor humidity is also physically connected to the outdoor climatic conditions. Therefore, the whole issue and problematics of building moisture and dampness, microbial contamination, repair and control practices varies strongly according to the climatic zone. However, regardless of the climate, the prevention and control of moisture problems, and subsequent effects, should be addressed in early phases of building construction practices, and in sustained maintenance of building. Some methods of controlling moisture in new buildings are described in Tables 3 and 4 and illustrated in the figure 3.

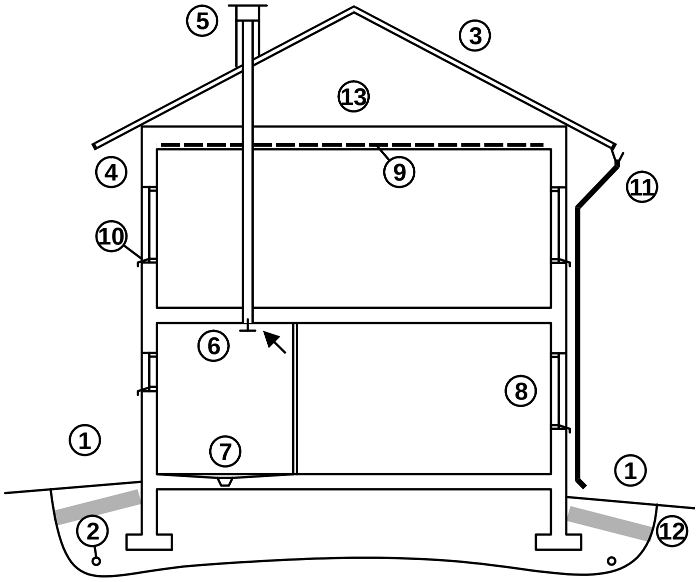

Figure 3 Important points to control moisture during the building design and construction
1) Drain the rain and surface waters from the proximity of building, 2) Drain the foundations with under ground pipes 3) Use tilted roof instead of flat roof in wet climate 4) Have the eaves to protect walls from rain 5) Have water tight piping penetration of the roof 6) Have good ventilation especially in bathrooms, laundry rooms, and kitchen 7) Have watertight sloping floors in the rooms with drains 8) Prevent condensation on walls and windows 9) Have vapour barriers in walls 10) Have good water tight window construction including the window sills 11) Drain the rainwater from the roof 12) Protect against frost when applicable 13) Ventilate attic and crawl space when applicable

Effectiveness of control actions against moisture depend on if they are focus on new or existing buildings. Wider variety of control method can be applied in new constructions (Table 3) than in existing buildings (Table 4).

The measures to control moisture may increase or decrease the construction or operation cost of a building. The effect of the measure is indicated in Tables 4 and 5. In new constructions most of the proposed measures reduce the operating cost due to lower energy consumption, but have a slight increase in construction cost. It is particularly important to have in buildings adequate ventilation rate when the thermal performance and air tightness is improved to meet the energy performance criteria.

In existing buildings the major focus to control moisture is on consumer behaviour and improvement of ventilation. The measures dealing with building envelope are expensive, and not so cost effective as those with ventilation.

ANALYSIS OF THE MEASURES

Types of remedial measures

Based on the analysis above the most important measures are summarised in Table 10. Improvement of ventilation, better cleaning and housing hygiene, removal of carpets, control of moisture and control of the source of the pollutant. Relative significance of each type in controlling of each health determinant is indicated with (+)-signs in the table.

- control of the source is the most effective in respect: ETS, NO, formaldehyde, VOC, MMMF and CO
- dust mites and mould are controlled primarily by controlling moisture
- ventilation has an influence on ten out of thirteen health determinants
- removal of carpets and better cleaning and housing hygiene affect half of the measures

Ways to implement the measures

The measures can be implemented wiyh various types of actions. These include mandatory and voluntary actions on international or national level. They can be characterised and classified into three groups as follows:

Control of building products

As health is already one of the essential requirements in European Construction Product Directive adopted in 1988, it is natural that procedures to control harmful effect of construction products continues on the European and national level. The health determinants controlled with product control include:

formaldehyde, VOC, MMMF, CO, NO_x

Building codes and standards

As the buildings represent the largest share of property values in Europe it is natural that the quality of buildings are controlled with European and national building codes and standards. For the construction industry the common European standards would be beneficial. Of course the climatic and cultural differences should be considered in the standards and guidelines. Prenormative work (65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76) done by research institutes, construction companies and professional organisations is important in this area. Building codes and standards are needed specially:

- *to improve ventilation and*
- *to control moisture in buildings.*

Consumer information

Third way to implement the measures is based on voluntary actions with education and information campaigns. The patient associations like the member societies of European Federation of Allergy and Airways Diseases Patients´ Association have an important role in implementing this type of campaigns, however, the campaigns should be implemented in co-operation with professional organisations and with government support. Good experience of this type of successful campaigns is the Finnish Asthma Programme (77). The programme has been effective. Mortality and days of hospitalisation have decreased even though percentage of asthmatic persons has increased to four fold during the last twenty years (3). Shorter campaigns like Swedish Indoor Climate Year 1999 and Finnish Indoor Climate Information and Education Year 2002 (78) have also been effective. Some efforts have also been done on the international level (79, 80). The campaigns should focus, but not limit to the following actions:

- *to limit the exposure to environmental tobacco smoke*
- *to improving cleaning and housing hygiene*

- *to avoid the use of carpets and other harmful materials*

Table 10 The effectiveness of most important measures (28)
+++ = primary control method
++ = important secondary measure
+ = secondary effect
A blank space in the table denotes that the control method is not significant.

Health determinant in indoor environment	**Improvement of ventilation**	**Better cleaning and housing hygiene**	**Avoid carpets**	**Control of moisture**	**Control of the source**
1. Environmental tobacco smoke	++		+		+++
2. Dust mites	++	++	++	+++	
3.Mould (fragments, mouldy material, MVOC)	++			+++	
4. Pollen	+	+	+		+
5. Nitrogen oxides	++				+++
6. Formaldehyde	+		+		+++
7. Chemicals, volatile organic compounds (VOCs)	++		+		+++
8. Indoor generated particulate matter and dust	+	+++	+++		
9. Man made mineral fibres (MMMF)		++			+++
10. Cockroaches		+++			
11. Pets		++	+		++
12. Carbon monoxide	+				+++
13. Carbon dioxide	+++				

Bodies to implement the measures
Various bodies and methods can implement different measures. After an analysis of each measure bodies, which are important in the implementation of each measure were indentified Table 11). The following levels were used.

1. International level (WHO, CIB, ISO etc.)
2. EU-level including new directives or European standards (CEN)
3. National level (national building codes and standards etc)
4. Professional organisation level (engineering and architecture, building owners, facility managers etc.)
5. Patient organisation level (respiratory illnesses etc.)

The action items against health determinants presented in Table 11 are in the following listed by the level at which the measure could be taken:

International level

- Develop criteria for healthy homes including the limit values for indoor pollutants
- Develop a criteria for homes and building with microbial harmful growth and moisture damages

- Campaigns against tobacco smoking and exposure to the environmental tobacco smoke
- Campaigns against the unvented heating and cooking combustion indoors

EU-level

- Actions to avoid smoking in public buildings and working places
- Campaign against smoking at homes
- Better building codes for the new constructions specially for ventilation and moisture control
- Measures to improve indoor environment in existing building stock
- Develop testing and labelling procedures for air cleaners
- Restrict the pet exhibitions in public places (schools etc)
- Develop product control and labelling systems for building materials, furniture and household products in respect of harmful emissions including:
    - Develop performance criteria for vacuum cleaners
    - Develop testing methods for fibre release from mineral wools
    - Develop inspection methods and control of small heating appliances

National level

- Campaign against smoking at homes
- Improvement of ventilation to reduce the exposure of non-smokers in the building where smoking still is possible
- Provide smoking rooms
- Better building codes for the new constructions specially for ventilation and moisture control
- Measures to improve indoor environment in existing building stock
- Encourage the use of electrical 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
- Campaigns for better housing hygiene
- Limit the entrance of pet into public transportation
- Restrict the pet exhibitions in public places (schools etc)
- Discourage the outdoor clothing in classrooms
- Avoid unvented combustion indoors
- Use in ventilation standards also CO_2 – concentration as an indicator of ventilation

Professional society level

- Improve ventilation to reduce the exposure of non smokers
- Campaign against smoking at homes
- Provide smoking rooms
- Present tested methods for protection against pollen
- Develop testing and labelling procedures for air cleaners

- Encourage the use of electrical kitchen appliances and discourage the use of gas fired appliances
- Discourage the use of unvented heating appliances
- Encourage 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 the cleaning after or before the operation hours of the schools and offices
- 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 and give also levels of CO_2 – concentration.
- Develop further the methods of CO_2 measurements to control ventilation

Patient association level and health care personnel

- Campaign against smoking at homes
- Encourage the use of effective cleaning methods
- Encourage the use of electrical kitchen appliances and
- Discourage the use of unvented heating appliances and discourage the use of gas fires appliances
- Implement information and education campaigns for better ventilation
- Encourage the use range hoods in kitchens
- Encourage the use of vacuum cleaners
- Encourage the use of central vacuum cleaning systems
- Encourage the cleaning after or before the operation hours of the schools and offices
- Implement campaigns for better housing hygiene
- Inform public on the risks and benefits of furred pets at homes
- Restrict the pet exhibitions in public places (schools etc)
- Discourage the outdoor clothing in classrooms
- Discourage the use of unvented combustion indoors
- Encourage the use of dust proof bedding materials when applicable

Table 11 Evaluation the effectiveness of the control of health determinants related to indoor environment (28)

Health determinant in indoor environment	**Examples of the actions which could be taken on EU or national level**	*The body which could take the responsibility of the proposed action* EU=European level N=national level S=patient or P=professional organisation	**The effectiveness of the measure is affected by** Climate = C Building construction=B Heating and ventilation system=HVAC
1. Environmental tobacco smoke	a. Limit smoking in public buildings and working places b. Campaign against smoking at homes c. Improve ventilation to reduce the exposure of non smokers d. Provide smoking rooms	EU (Health) N, S N, P N, P	HVAC
2. Dust mites	a. Better building codes for the new construction* b. Improved indoor environment in existing building stock** c. Dust proof bedding materials d. Encourage effective cleaning methods	EU,N EU,N S S	C, B, HVAC C, B, HVAC
3.Mould (fragments, mouldy material, MVOC)	a. Better building codes for the new construction* b. Improved indoor environment in existing building stock**	EU,N EU,N	C, B, HVAC C, B, HVAC
4. Pollen	a. Present tested methods to protect against pollen. b. Develop testing and labelling procedures for air cleaners	P EU, P	B, HVAC
5. Nitrogen oxides	a. Encourage the use of electrical kitchen appliances b. Do not use unvented heating appliances. c. Use central heating. d. Improve ventilation e. Use range hoods in kitchens	N, P, S EU, N, P, S P P,S N, P,S	
6. Formaldehyde	a. Product control and labelling systems for building materials, furniture and household products	EU, N, P	

Health determinant in indoor environment	**Examples of the actions which could be taken on EU or national level**	*The body which could take the responsibility of the proposed action* EU=European level N=national level S=patient or P=professional organisation	The effectiveness of the measure is affected by Climate = C Building construction=B Heating and ventilation system=HVAC
7. Chemicals, volatile organic compounds (VOCs)	a. Product control and labelling systems for building materials, furniture and household products	EU, N, P	
8. Indoor generated particulate matter and dust	a. Encourage the use of vacuum cleaners b. Develop performance criteria for vacuum cleaners c. Encourage the use of central vacuum cleaning systems d. Encourage the cleaning after or before the operation hours of the schools and offices	S EU, P P, S P,S	
9. Man made mineral fibres (MMMF)	a. Limit the release of fibres. b. Develop testing methods	N, P EU	
10. Cockroaches	a. Campaigns for better housing hygiene	N, S	
11. Pets	a. Information on the risks and benefits of furred pets at homes. b. Limit the entrance of pet in public transportation. c. Use of easy to clean furniture in public spaces. d. Restrict the pet exhibitions in public places (schools etc) e. Do not carry the outdoor clothing in classrooms.	S N P N, S N, S	
12. Carbon monoxide	a. Avoid unvented combustion indoors b. Inspection and control of small heating appliances c. Limit smoking indoors	N, P, S EU S	
13. Carbon dioxide	a. Ventilation standards should give also levels of CO_2 – concentration. b. Methods of CO_2 measurements should be developed further	EU, N, P P	B, C, HVAC

RECOMMENDED ACTIONS TOWARDS HEALTHY AIR IN DWELLINGS

Based on the analysis of the health determinants indoors, existing building technology and guidelines serious gaps in the technology and practices in respect of the healthy living was identified. The following action items with specific objectives were formulated based on this information. Participation of several bodies is needed to implement effectively the proposed measures.

1. Environmental tobacco smoke
Implement the policy and campaigns to avoid smoking indoors and smoking in general. This requires co-operation in all levels. International agreements are good support, but implementation requires European directive, national legislation, information campaigns by patient associations and health care personnel, and technology to control exposure to ETS in building were smoking is still possible.

2. Ventilation
Develop technical standards and guidelines for ventilation in residential and non-residential buildings from the health standpoint (control of pollutants generated indoors). This requires also co-operation on several levels. International work like done ISO committee 205 is good support, but implementation requires European directive, changes in national legislation and building codes, and guidelines by professional societies, including training of professionals.

3. Control of moisture indoors
Develop technical standards and guidelines to control moisture in residential and non-residential building from the health standpoint (dust mites, mould and other harmful effects of excess moisture). This requires also co-operation in several levels. International co-operation and work done in WHO and CIB gives a good support, but implementation requires European directive, changes in national building codes, and guidelines by professional societies, including training of professionals.

4. Criteria of healthy buildings and target values of indoor climate
Clear criteria for healthy buildings is needed. These criteria should include but not be limited to limit values of indoor air pollutants. Work done in WHO, ISO, CIB should be utilised but developed further to be integrated in national legislation and building codes. Implementation requires European directive, changes in national building codes, and guidelines by professional societies, including training of professionals.

5. 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 including the criteria for low polluting materials and products, and labelling system. This would be the implementation of construction product directive, where health is one of the essential requirements of building products.

6. Heating
Proper heating to avoid harmful side effects should be promoted through building codes and standards. It is important to improve the thermal control of building to avoid moisture problems, and use in heating methods which minimum generation of pollutants. Central heating and district heating should be promoted.

7. Indoor air quality in existing building
Building audits are common in respect of energy performance. The necessary European Directive and national legislation should be developed so that the audits in respect of indoor air quality and climate would become possible. The professional societies should develop procedures for such audits.

8. Performance testing of IAQ affecting equipment
Many equipment affect on indoor air quality. Often these are complicated and consumers do not understand all consequences of the equipment. Standards and labelling systems should be developed for these products. These include but are not limited to: ventilation equipment, vacuum cleaners, range hoods, air cleaners, portable heaters, water heaters.

9. Gas heaters and cocking
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.

10. Hygiene and cleaning
Better household hygiene and cleaning would have positive effect on several health determinants. Campaigns for better hygiene and cleaning should be implemented in co-operation with patient organisations and national authorities. These campaigns should also educate tenants towards healthier living. Example of the contents of such campaign is described in the following chapter "Criteria for healthy home environment".

11. Operation and maintenance
Good operation and maintenance of buildings is often neglected even though it is a key element in respect of good indoor air quality and climate. Typically the building codes are limited to the construction phase of building, and no legislation based maintenance is required. A European directive and national legislation with emphasis on maintenance of buildings in respect of health and life cycle cost would improve the situation. Technical guidelines, education and training would be a task of professional societies.

12. Pets
As allergens will stay in space and are difficult to remove with cleaning the access of pets to schools and other public building and spaces should be limited. International and national guidelines should be developed in co-operation with patient associations.

CRITERIA OF HEALTHY HOME ENVIRONMENT

1. Think the health of your fellow citizens – do not smoke indoors.
2. Correct temperature is most important indoor factor, in the wintertime 18 – 22 ^{o}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 more 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 the windows when necessary to increase ventilation rates. Demand that the ventilation is operated and balanced properly.

4. Ventilation of bedrooms is improved during the night when the interior doors between rooms are open. Ventilation of bathroom is inadequate if the condensation from the mirror does not disappear in a couple of minutes after a shower or bath.
5. Kitchen rage hood with ventilator is needed in all kitchens particularly in those with gas cooking. The grease filter of the range hood should be cleaned or change within intervals of 2-3 months.
6. Cross ventilation is the best way to increase ventilation temporarily. In the winter much heating energy will be lost through the open windows if the windows are open for long periods.
7. A strange, new smell at home is often a sign of health hazard. Find out where the smell is coming from and remove the source with necessary refurbishment or remodelling.
8. Keep the surfaces at home clean from dust with regular cleaning. Use cleaning methods that do not pollute the air. Avoid the surfaces which accumulate dust easily.
9. Be sure that your vacuum cleaner has a proper filter. Ventilate properly after the vacuuming to get rid of air borne small particles.
10. Typically room air cleaners (filtering device) have a capacity to clean only the air of one room, not the whole home. Be sure that room air cleaner has been maintained properly.
11. Many factors such as high temperature, dust and formaldehyde in the air make it feel dry. Humidification of air is needed only during coldest winter period. Do not humidify to higher than 35 % of relative humidity. Keep the humidifiers clean. The steam humidifier with elevated water temperature is safest in respect of microbial growth.
12. Indoor relative humidity should not be over 60 % for long periods to prevent growth of mould and over 45 % to control dust mites. Indoor humidity should not in any circumstances condense on the windows or exterior walls.
13. Monitor the condition and quality of the interior surfaces. Report the changes to building owner or care-taker. Materials and structures damaged with moisture shall be dried thoroughly or replaced immediately.
14. Use low emission building materials and consumer products. Avoid materials and products with strong smell or odour.
15. Avoid living in an apartment or a house during remodelling.
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.

FUTURE RESEARCH NEEDS

During the study on the preventive measures against adverse health determinant the shortage of scientific information was faced. For the future analysis it would be important to know the number of people sensitive to each specific health determinants to focus the actions better. In developing common guidelines for remedial actions technical data on building stock should be available. This information should include, not only the general information, but also detailed information on heating and ventilation systems, cooking appliances, ventilation rates, and moisture conditions. More research is also needed on the effects and costs of various measures. However, the incomplete information must not delay the actions towards better indoor environment in Europe. Actions presented here are based on the scientific evidence and the reasoning that by avoiding the adverse health determinants the health is improved.

Future research should provide information for more accurate analysis of the effects remedial measures including the following:

1. More studies on the number of population allergic or sensitised to a specific agent or pollutant including characterisation of pollution sources in buildings, and technologies to control the sources and their effects on health and well-being. Housing statistics in general does not give information on technical details on the residential buildings (e.g. 81).
2. More detailed analysis on the technical quality of the housing stock in the Europe.
3. Studies on the effectiveness of the remedial measures.
4. Research on the actual ventilation rates and energy use in different type of existing buildings and simultaneous effects on indoor air quality and climate, health, and well-being.
5. Focused research on the linkage between properties of air handling systems and human responses (mechanical vs. natural ventilation).
6. Measured performance of good naturally ventilated buildings and their properties including human responses.
7. 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 measurement of air flows within the system.
8. Research and new technology for cleaning the indoor air and the outdoor air for ventilation.
9. Research and development of design tools for ventilation and calculations of indoor air quality.

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