HealthVent

Health-Based Ventilation Guidelines for Europe

Deliverable 5

Summary of European ventilation standards, their implementation and ventilation systems used in European buildings

This publication arises from the project "Health-based ventilation guidelines for Europe, HealthVent" which has received funding from the European Union in the framework of the Health Programme.

REHVA

Federation of European Heating, Ventilation and Air-conditioning Associations

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HEALTHVENT

HEALTH-BASED VENTILATION GUIDELINES FOR EUROPE

WORK PACKAGE 5

EXISTING BUILDINGS, BUILDING CODES, VENTILATION STANDARDS AND VENTILATION IN EUROPE

THE FINAL REPORT

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List of abbreviations

Abbreviation	Meaning
AC	Air-conditioning
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CEN	European Committee for Standardization
CIBSE	The Chartered Institution of Building Services Engineers
CR	CEN Report
EC	European Commission
EFA	European Federation of Allergy and Airway Diseases Patients Associations
EFTA	European Free Trade Association
EN	European Standard
EPA	U.S. Environmental Protection Agency
EPBD	Energy Performance Buildings Directive
EUROVEN	European Multidisciplinary Scientific Network on Indoor Environment and Health
HVAC	Heating, ventilating and air-conditioning
IAQ	Indoor air quality
IOELV	Indicative occupational exposure limit values
ISO	International Organization for Standardization
ITG	Institute for Building Systems Engineering Dresden
MS	Member State of the European Union
OEL	Occupational exposure limit
REHVA	Federation of European Heating, Ventilation and Air-Conditioning Associations
SCOEL	Scientific Committee on Occupational Exposure Limits
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology
TC	Technical Committee
THL	Finnish National Institute for Health and Welfare
TLV	Threshold limit value
TR	Technical Report
USA	United States of America
WHO	World Health Organization
WP	Work Package

Preface

This report summarises the results of Work Package 5 of the HealthVent project. It provides the necessary background information for the work towards health based ventilation guidelines for Europe to be performed by other work packages of the project. The objective of this work package was to give an insight into the overall state of ventilation in Europe, comprising distribution of ventilation systems, building regulations, ventilation standards and compliance to regulations. The prescriptive ventilation guidelines based on the real world indoor air quality and ventilation problems were also developed although they were not proposed as original deliverables. They are considered being an important contribution on the way towards the general health based ventilation guidelines. They are not the part of the present report and will be included in the final report of HealthVent project.

Although numerous surveys on the state of ventilation in Europe have already been carried out, most of them have not been as extensive as the one presented here. The results provide a decent overview of the general situation regarding ventilation in Europe, describing the status in the 17 European Union and European Free Trade Association countries. The selection of countries participating in the present work has been made with respect to geographical spread, thus ensuring a good coverage of various cultural, climatic, political and economic regions, where the development of ventilation practice was not developing at the same pace and to the same extent throughout the history. Achieving such a good coverage would not be possible without the experts who provided information on national regulations and building practices by responding to the questionnaires for data collection and therewith also helped to overcome language and cultural barriers. The report can be used as a valuable source of information on ventilation.

The report reveals the lack of good information about the use of ventilation system in practice and their compliance to ventilation, suggesting thus what should be done to improve this situation.

The results of this report have shown that the motto of the European Union, “united in diversity”, is valid also for the ventilation systems. Considerable differences were found among the ventilation systems, regulations and compliance among the countries that were included in the research. However, given the right for breathing clean air as being the fundamental human right, this report shows that like so many times in the history, European countries must step together and take the necessary measures in the common goal for establishing healthy buildings with well performing ventilation systems.

The work was carried out in the REHVA office in Brussels under leadership of prof. Olli Seppänen. The project group consisted of Nejc Brelih from Slovenia, Andrei Lițiu from Romania, and Guillaume Goeders from Belgium. Other partners from HealthVent consortium also contributed to the present work.

Brussels, February 10, 2012

Olli Seppänen

Secretary general of REHVA

Executive summary

Ventilation systems in Europe

Ventilation systems are being used differently across the EU countries and this is of significant importance for equipment manufacturers, who have to adapt to the various local practices. One of the tasks of this project was to carry out a survey of existing ventilation systems throughout Europe, with the aim of providing a broader picture of the type of ventilation systems used. The data on ventilation were collected from the project partners and other national experts by means of a specific questionnaire. Each defined ventilation system was analyzed for five building groups: houses, apartments, schools, kindergartens, and office buildings. The responses were based either on national studies or national statistics and experts' own data. 11 European countries submitted data.

The analysis of the ventilation systems in the total building stock shows that most of the buildings are naturally ventilated; the degree of natural ventilation varies and is the highest in the southern European countries. It can also be noted that the share of naturally ventilated buildings is the highest among houses and apartments, and lowest among offices, schools and kindergartens. Data collected for Bulgaria, Finland, France, Germany, Greece and Italy for the current building stock show that in dwellings, natural ventilation systems are still dominating, ranging between 65% and 100%, except in Finland where the share of natural ventilation systems is only 28%. *Climate* is therefore an important determinant of the type of ventilation system installed.

Studying the time course of evolution of the types of ventilation systems installed in buildings shows that the number of mechanically ventilated systems is gradually increasing. A sharp increase of mechanical ventilation systems can be seen in certain countries after the building regulations have become more stringent, and cannot be fulfilled by natural or hybrid ventilation systems. Also within mechanical ventilation systems there has been a gradual shift from mechanical extract or supply ventilation to balanced mechanical supply and extract ventilation (with or without heat recovery) in almost all types of buildings. *Building codes* can thus influence the type of the system installed.

From the data, it is clear that the highest proportion of mechanical ventilation systems is in the Northern European countries where the climate is cold, and much lower in countries of the southern Europe. However, in countries with continental climate and relatively cold winters such as Romania, the share of mechanical ventilation systems is also low, which may suggest that the *economic situation* of a country also has an effect on the type ventilation systems.

The survey clearly shows that there is large difference in the amount of installed ventilation systems among European countries, even though the ventilation and building regulations have been recently updated. Moreover, natural ventilation systems are still widely used in some countries and in some building types where the regulations require mechanical ventilation. This may suggest, though is not verified, that the regulations are not being followed in practice and compliance with regulations is poor.

Effect of EPBD recast on ventilation regulation

The 2010 recast of the Directive on Energy Performance of Buildings (EPBD) requires that all new buildings in the EU are built as nearly zero energy by 2020. A very probable scenario is that in order to reduce overall building energy use, the ventilation rates will be reduced, as the simplest but not the recommended way of reducing energy usage.

Experts are very concerned that this will lead to deterioration of indoor air quality and related health problems. In order to get better picture of how the latest modifications of the EU legislation on energy use in buildings are expected to affect ventilation practice and indoor air quality (IAQ) in Europe, a questionnaire was sent to a group of ventilation experts in several European countries.

Experts form 17 countries returned the questionnaire. Analysis of answers produced the following conclusions:

- IAQ related problems are expected to increase due to the tighter building envelopes, and because requirements for the IAQ quality are not included in the EPBD. On the other hand, slightly less than half of the respondents think that IAQ will increase due to the revised ventilation regulation to tackle the IAQ problem.
- Building envelopes will almost certainly become tighter and IAQ will probably get more attention in the future.
- The majority thinks that IAQ will certainly or probably be included in future ventilation regulations with only 10% of the opinion that it will not be included.
- The opinion about the future enforcement of ventilation regulation is almost split in half, with one half foreseeing a reduction of the enforcement of the regulation and the other half an increase.
- The majority of the respondents expect ventilation regulation to be revised in the near future. The rest do not expect their regulation to change soon because it has just recently already been revised.
- According to the opinion of the majority, the future use of natural ventilation will decrease and the use of heat recovery will increase.
- Comparing several answers of the respondents indicates that countries, which do not intend to change the ventilation regulations and include IAQ requirements, may face IAQ related problems.
- Most of the countries do not allow for the possibility of reducing ventilation rates by using less polluting materials, and also do not allow for controlling ventilation rates based on the outdoor air quality.
- The majority of the countries in the survey believe that reduction of the ventilation rates can only be achieved if ventilation efficiency is improved or if effective cleaning of the room air is used in parallel.
- All the respondents think that demand controlled ventilation and heat recovery will be used in the future. The vast majority consider that any future adjustment of the ventilation rate will be based on the pollution loads and needs of the occupants.
- Two thirds of the respondents also think that reducing ventilation rates will be one of the future practices if ventilation efficiency is to be improved.
- Use of heat recovery in hot climate is not expected to increase.

Comparing the answers from different European countries does not show any relation between responses and climate, geographic location or construction practice. On the basis of answers provided by respondents we can conclude that the EPBD recast will have different effects in different European countries. The reason for that may be the fact that individual countries already have very different regulations, which will influence the countries response to the new EPBD in a different way.

European Standards and Technical Reports on ventilation

The European Standards on ventilation are published by the European Committee for Standardization (CEN). They are sets of voluntary technical and quality criteria for products, services and production processes, also called technical specification. Standards are formulated by consensus among stakeholders and are voluntary. Standards are often mistakenly described as regulations. It is again important to stress that the use of standards is voluntary, except if they refer to or are a part of the national legislation. In the latter case they are obligatory.

The ventilation related work of CEN is coordinated by the technical committee CEN TC 156 – Ventilation for buildings. A valid European Standard is indicated as EN with a number. After a standard passes weighted Formal Vote, each of the 30 National Standards Bodies publishes the new EN as an identical national standard, and withdraws any national standards that conflict with it. A standard under development is called a draft European Standard (prEN) and is not a European Standard. Besides standards, CEN also publishes Technical Reports (TR). A TR is a document that provides information on the technical content of standardization work.

EN standards are written by a group of experts from a specific field and describe the best available technology that reached consensus among the stakeholders. They are regularly revised and updated if necessary. Consensus makes EN standards applicable throughout the CEN Member States and they could be used more often as a basis for national and local regulations.

This project report provides two lists of standards on ventilation, which were collected by REHVA. The first list comprises indoor air quality related standards that directly address the functional properties, which influence indoor air quality. The second list is related to ventilation but does not specifically address measures that can influence indoor air quality. This list of IAQ related standards mostly includes ventilation standards that deal with functional properties of ventilation systems or equipment, whereas the second list of non IAQ related standards mostly includes ventilation standards that deal with mechanical properties and testing of ventilation system and equipment.

The review of standards on ventilation, which are listed in the group of IAQ related standards, has revealed that *none of them is health based*. Standards, which can be used for determination of ventilation rates (EN 15251 and EN 13779) use different categories of comfort, based on documents EN ISO 7730 and CR 1752. The general rule applied to these documents is that a better indoor air quality requires higher ventilation rates. Indoor air quality in EN standards is not well defined. The standards only give some general guidance on air quality and mention numeric values only for concentration of CO_2 and humidity. These two are mentioned in EN 15251, whereas there are no other generally accepted criteria and measuring methods for other pollutants.

Requirements for ventilation rates and indoor environment in some European countries

General remarks

Review of the European regulations on ventilation rates, indoor pollutants, and indoor environment criteria showed that the regulations are inconsistent and can provide different requirements (sometimes contradictory) depending on the country. Moreover, the majority of all regulated parameters are already defined in the European Standards, which were accepted by CEN voting process of the national bodies. Nevertheless, the values found in standards and those in regulations are not harmonized. Inconsistency on a national level between EN standards and regulations and on European level among countries causes problems to designers and industry, and increase the construction cost. These variations in current practice, contrast with the efforts towards unification and standardisation in the European common market

Clearly a common European guideline is needed, which would serve as a basis for uniform European regulations. A guideline should propose ventilation rates and technical properties and other parameters related to performance of ventilation.

Ventilation rates

A common factor of regulations of ventilation rates is the inconsistency in the ventilation rates, in the units in which they are given, and in their calculation procedures. Almost all countries use one of the following two units and their derivatives for ventilation rates: litres per second (l/s) or cubic metres per hour (m^3/h). Ventilation rates in classrooms, playrooms and offices are usually expressed as l/s or m^3/h per person, or a combination of both.

Countries have taken different approaches to define ventilation rates in dwellings, which require different boundary conditions to follow the calculation procedure. In order to be able to compare ventilation rates among different countries, in the project we developed test cases of rooms, for which the ventilation rates were calculated. Results show that a vast difference in ventilation rates exists between countries. The ratio between the lowest and highest ventilation rates in dwellings was found to be almost 1:6, or expressed as a ventilation rate per floor area 0.23 $l/s/m^2$ to 1.30 $l/s/m^2$. It was discovered that many countries lack a clear link between local exhaust rates and the ventilation rate of the whole dwelling that makes the design and balancing of the system difficult in practice. Very large differences in the rates were also found also for classrooms, playrooms, and offices. One group of countries has ventilation rates for the test cases of classroom and playroom around 250 l/s and the other group of countries around 100 l/s; this corresponds to 10 l/s per person and about 4 l/s per person, respectively. The group with higher ventilation rates consist predominantly of countries from the North and West of Europe. No countries from southern Europe are present in that group. Ventilation rates in offices cannot be grouped according to location because rates are much more scattered. Conclusions based on regional differences are therefore not possible in this case. Ventilation rates in offices are lower than 10 l/s per person in several countries.

Some countries still have no regulations on ventilation rates and only use voluntary values from standards. Although members of the EU accepted standards EN 15251 and EN 13779, which both define ventilation rates, the values prescribed in their regulations can be different. This is confusing for designers, and contrary to the European tendency towards common standards. This clearly suggests that Europe needs a common regulation on ventilation rates, which would harmonize calculation practice among countries and ensure that the required ventilation rates are among others not only comfort but also health based, which is not the case in many of the existing regulations.

Indoor pollutants

The EU has already adopted several directives on the quality of ambient air and occupational exposure limits of pollutants to protect the workers exposed to chemicals from industrial processes. These limits already existed in national regulations before the first EU directive, but EU Member States had to adopt them as common regulations. Research work on indoor air quality in non-industrial buildings, has however, lagged behind that on the ambient air quality and occupational exposures. Some guideline values protecting against negative health effects are available from WHO for few pollutants.

Some countries have included requirements on indoor air quality in their ventilation regulations for non-industrial buildings, either based on occupation limit values or national limit values. Limit values and number of pollutants included in the regulations vary greatly from country to country. This is most likely due to lack of a common guideline, which would be used as a basis. The rest of the European countries have adopted no regulations regarding pollutants in indoor air quality.

The differences are not only in the type of pollutants but also in the accepted levels of pollutants. PM_{10} values range from 0.05 to 0.15 mg/m^3, while the WHO recommended a value of 0.02 mg/m^3 in 2006. Formaldehyde levels range from 0.04 to 0.1 mg/m^3 in most countries. Bulgaria has exceptionally high limit value, namely 1 mg/m^3. The WHO recommended value is 0.1 mg/m^3 in the 2010 guidelines. Limit values for ammonium and amines were found in the range from 0.02 mg/m^3 in Finland to 350 mg/m^3 in Bulgaria. All the ranges of limit values are too wide, including the range for ammonia, which is exceptionally wide.

Findings show that there is a strong need for a common European regulation for indoor air quality. A new guideline should propose limit values of some pollutants, for which there is no minimum safety level in existing guidelines. Such levels should be adopted with a consensus among all countries in the EU. Requirements for indoor air quality should be included in the national regulations of all European countries. National regulations should include a minimum number of pollutants and limit levels. Current regulation on occupational exposure levels should be used only for industrial working places and not for non-industrial buildings.

Thermal and comfort requirements

Comparing values of all presented parameters shows that they are inconsistent among different countries. Some countries do not have any requirements on thermal comfort at all. Temperature limits for summer vary from 28 to 25°C and in winter from 18 to 21°C. Minimum air temperature limits are prescribed more commonly than maximum air temperature limits.

Maximum air velocities vary from 0.15 to 0.30 m/s. The majority of regulations only prescribe the maximum air velocity but not the air temperature and the velocity. Limits of air velocities are not prescribed as commonly as the temperature limits. Humidity levels are more consistent. Lower limits are at 30% RH while higher limits are 70% RH in all cases except one, where it is 75%.

Due to the inconsistency of values and lack of regulatory values in some countries, common European regulatory values are required for the minimum temperature during the heating season and the maximum temperature during the cooling season. Temperature requirements in future common regulations may need to be adjusted by the climatic conditions of the country. The same applies for maximum air velocities, which should be also based on the temperature of moving air.

Noise requirements

The noise level limits as defined in European regulations and standards are very inconsistent, similarly as in the requirements for the ventilation rates, temperature limits and air velocity limits. Inconsistency is present also in the use of units in which the values are given. Some countries provide noise levels as equivalent noise levels, while others do not. The third type of units for sound levels is noise-rating curves.

The minimum given equivalent level for bedrooms in dwellings is 28 dB(A) eq and the minimum given instantaneous level is 25 dB(A). The maximum levels are 35 dB(A) eq and 40 dB(A). The lower limit values for classrooms and playrooms are in a comparable range and also higher than in bedrooms. The range for equivalent levels (min – max) is 28 to 40 dB(A) eq, and for instantaneous levels 30 to 45 dB(A). The values in offices are for equivalent levels (min – max) 33 to 45 dB(A) eq and for instantaneous levels 35 to 50 dB(A). The differences minimum – maximum are large in both cases, equivalent and instantaneous. It seems that, on average, equivalent levels are usually 5 dB lower than instantaneous levels.

Many of the noise limit levels seem quite high, which is especially the case for bedrooms. A common European regulation is required. It should define noise levels in only one type of units to avoid confusion. To avoid inconsistency, new regulation should not prescribe tolerated limit sound levels as the range from minimum to maximum suggested value, as in practice in current EN standards, but as fixed levels to prevent countries from defining different limits on a national level.

Technical features of ventilation systems

It was investigated how European countries' national regulations regulate the technical features of ventilation systems. The task was performed by sending questionnaires comprising 18 questions set to a group of different European ventilation experts. The questions were specifically formed to investigate those parts of regulations concerning measures to prevent possible contamination of ventilation systems.

Sixteen responses were received from different European countries providing a good coverage of all European regions, climates and building practices. Analysis of the data produced the following conclusions:

- More than half of the countries do not have any requirements to prevent droplets from humidification to spread through system and to prevent condensation on the coils causing damage.
- Almost half the countries still do not have any requirements regarding the introduction of outdoor air pollutants into the indoor environment.
- Requirements for cleanliness of the system regarding dust, microbes and fibres from interior insulation are still not imposed in approximately one third of countries, while regulatory requirements for ozone and other chemicals are almost non-existent.
- More than a third of participating countries do not have any requirement for air filtering. Out of those that have requirements, more than half have no requirements for regular filter replacements.
- Approximately one third of countries still do not require operation instructions for the ventilation system.
- More than half of countries do not have requirements for cleaning the ventilation system during its lifetime.
- In more than half the cases, countries have no requirements on the qualifications of the operation and maintenance personnel of ventilation systems.
- Circulation of air is allowed in most countries but recommended only in one fifth.
- Countries use two different types of regulations for ventilation systems: prescriptive based and performance based. All types of mechanical ventilation can be used with prescriptive based regulations. Natural ventilation systems using windows are the exception. Countries with performance based regulations allow all types of ventilation systems as long as they are able to provide the required air change or air flow rates and fulfil energy regulation requirements.
- The vast majority of countries has no regulatory limitation regarding the location of ventilation systems in relation to outdoor pollution sources like heavily congested roads, industrial areas etc., which can all greatly influence the quality of the indoor air.
- Balancing of ventilation systems is required in 14 out of 16 countries but it is controlled in only 6 out of 14 countries.
- Three quarters of the countries have no requirements regarding the pressure differences between rooms and/or between rooms and outdoor air.
- Out of 16 countries, 11 have no requirements on follow-up measurements of ventilation rates, IAQ etc. during the lifetime of buildings.
- Again 11 of 16 countries have no requirements regarding the leakage of extract air to supply air in heat recovery exchangers.
- Contrary to the expectations, half of responding countries have requirements for regular inspections of ventilation systems.

By summing up the number of "yes" and "no" answers for each country it is possible to estimate how well the regulations of individual countries deal with the technical features of ventilation systems, which are related to health and comfort problems. Answers vary across a broad range among the responding countries, with number of "yes" answers ranging between 27 and 9 out of

32 possible "yes" answers. The number of answers is equally distributed among participating countries. The highest number of "yes" answers came from Finland where regulations deal with 27 out of 32 problematic technical features of the ventilation systems addressed in this questionnaire. Surprisingly, some Nordic countries such as Denmark and Norway are at the bottom of the scale, with regulations only dealing with 9 or 10 technical features, respectively. Results also suggest that there is no relation between the number of technical features dealt with by regulations and geographic location, climatic region or building practice in the area.

Compliance with regulations and problems related to ventilation

General remarks

Studies on ventilation rates, indoor air quality and the condition of ventilation systems in Europe, which are based on large number of buildings, are rare. Studies in some countries were performed on a sample of buildings, which represents the whole national building stock. Thus, results of these studies can be extended over the all buildings in that country.

The reviewed studies show that ventilation rates, indoor environmental parameters and noise do not comply with regulations. Deviations between measured and required values are considerable and actions need to be taken. A new European guideline is needed, which would serve as a base document for legislators in EU countries or in the European Commission. The guideline should provide guidance on suitable design, construction, maintenance and inspections of ventilation systems. For improved efficiency, the inspection of ventilation systems should be merged with the inspection of air-conditioning systems and energy auditing. More effort should be put into education of all parties involved in design, construction and operation of ventilation systems.

Dwellings

Dwellings in Europe are being retrofitted with new airtight windows, without assuring adequate ventilation. Resulting air change rates are almost always below the required values. Energy cost is still the main driving force for renovations, but at the same time, ventilation is being neglected. Mean ventilation rates in all studies on mechanically ventilated dwellings are lower than required and the standards deviate considerably. Results from countries where ventilation rates for dwellings are prescribed as air volume flow per floor area show that the ventilation rate for the whole dwelling may be sufficient, but at the same time ventilation rates in individual rooms may be too low. The definition of the air change rate for the whole dwelling may not be appropriate due to poor balancing of systems.

Ventilation rates in dwellings were reviewed in nine European studies. The mean air change rates and ventilation rates are quite low in all the studies. Where an air change rate of 0.5 is required, the mean measured air change rates are as low as 0.3 ach. Values are higher in dwellings equipped with balanced mechanical ventilation system but the mean never exceeds 0.45 ach, with up to 76% of buildings not achieving required rates. Old dwellings, retrofitted with new windows achieve a mean air change rate as low as 0.25 ach, with 50% of buildings having an air change rate below 0.18 when unoccupied. Equally poor results were observed in dwellings where ventilation rates were measured on air terminal devices. In France, only some 40% of local exhaust ventilation systems reached the required ventilation rates, with similar results in the Netherlands.

Noise in mechanical ventilation systems is a common problem. Even though systems are often able to provide the required ventilation rate, the occupants lower fan speed setting because of the noise disturbance. Too little attention is paid to noise during the design and construction phases. Surveys report that almost all regulated noise levels are too high in practice.

None of the average values of pollutants, based on the whole sample of participating buildings exceeded the recommended values. However, there were cases where average values were exceeded in individual dwellings. Surveys confirm that concentrations of VOCs are higher in in recently renovated and new buildings. Humidity was not reported to be a problem in any of the studies.

Indoor air temperatures in buildings were found to be consistent with minimum requirements or even higher in many cases. Air temperatures do not seem to be a problem in any part of the whole building stock. Results show that air supply temperatures depend on the type of ventilation system and on the course of the ductwork and were mostly found to be in the recommended range.

Studies report many of the shortcomings in the technical features of ventilation systems that were found to have a negative impact on the health of the building occupants. The most probable reason for these shortcomings is the lack of knowledge and experience among all parties involved in the design and construction of buildings. Technical shortcomings appear even in countries where mechanical ventilation systems have been standard practice for the last twenty years, therefore they are not due to the relative inexperience with such systems.

Schools and kindergartens

Natural ventilation cannot provide the required ventilation rates at all times of the year. Due to the fact that school buildings in Europe are mostly naturally ventilated, pupils are exposed, especially in wintertime, to unsatisfactory indoor air quality. Measured and estimated ventilation rates in existing schools are mostly insufficient when compared with the regulatory requirements. Studies show that ventilation rates in mechanically ventilated schools are higher than in naturally ventilated schools and that maximum levels of CO_2 are not exceeded.

All mean measured ventilation rates in schools were below the required values. Natural ventilation is not able to provide required ventilation rates, even as low as 3 l/s per person. The lowest recorded average rates in naturally ventilated classrooms were 0.5 l/s per person. In up to 87% of cases, ventilation rates in naturally ventilated classrooms were too low. Mechanical ventilation systems are able to provide the required ventilation rates. However in practice, some mechanical systems provide only one fifth of required ventilation rate.

The most commonly measured pollutant in schools is carbon dioxide. Results show that CO_2 levels are high in the majority of all schools, naturally or mechanically ventilated. However, studies providing results for each ventilation system conclude that mechanical ventilation systems generally reach lower CO_2 concentrations. When windows cannot be kept open all the time natural ventilation is unable to provide sufficient low levels of CO_2. On the other hand, this is possible to achieve with mechanical ventilation systems.

In none of the surveys formaldehyde levels in classrooms exceeded the maximum recommended values, despite relatively low ventilation rates in both cases. Average values from both studies were found to be in the same range for both studies. TVOC concentrations exceeded limit values in some individual cases. Exceeding the limits could have been prevented by higher ventilation rates, which were below 1 l/s per person.

Noise levels were found higher than the recommended levels, but only one study was available.

Observed relative humidity levels were mostly within the comfort range, i.e. between 40 – 70%. None of the countries where measurements were performed have any legal requirements regarding humidity levels. An excessive humidity was not reported to be a problem in any of the studies. In countries where legal requirements exist, temperature requirements were met for most of the time.

Only one study reported shortcomings in technical features. Identified shortcomings were found to have a negative impact on the health of the building occupants. The most probable reason for these shortcomings is lack of knowledge and experience among all parties involved in design and construction of buildings.

Offices

The available number of extensive studies in European offices, which include measurements of ventilation rates with one of the reliable tracer gas methods, is extremely limited. Ventilation rates of naturally ventilated office buildings were in the range of 4 l/s per person with a standard deviation of around 2 l/s per person. Ventilation rates in mechanically ventilated buildings were much higher, the mean values ranging from 9 to 25 l/s per person, often exceeding the minimum required rates. It has to be noted that reviews of the studies relating the ventilation rates and health effects showed that the prevalence of SBS symptoms was reduced with a ventilation rate of 20 l/s per person.

Studies reported wide ranges of measured ventilation rates, which is concurrent with the findings from the USA BASE study. The reason for that may be that ventilation rates for offices are most often determined based on the number of occupants, which can never be exactly determined during the design process. Also the arrangement of spaces and density of occupants often vary from the design conditions, resulting in high ventilation rates at low density and wide range of rates due to uneven occupant density.

Available reports indicate that shortcomings in the technical features of ventilation systems in offices are similar to those in schools. These shortcomings have a negative impact on health of the building occupants. The reason for the shortcomings is that they are overlooked by all parties involved in design, construction and maintenance of ventilation systems due to lack of experience and knowledge.

Indoor levels of CO_2 were in all cases below the recommended value of 1000 ppm. This is expected due to the fact that occupants, as the main source of CO_2, have a greater spatial area in office buildings than in schools or kindergarten. Typically the office area is 10 m^2 per occupant in a single office, and 15 m^2 per person in an open plan office. The indoor temperature was often found to be above the minimum recommended limit of 19 – 21°C and in the upper limit of the winter comfort range of 20 – 24°C. Too high winter temperatures are not recommended because they increase SBS symptoms which reduce the efficiency of employees. Measured temperatures are higher than those found in schools and homes. As expected, in Nordic countries the humidity was found to be below 30% RH during winter. Humidity levels in offices are lower than in the comparable studies of dwellings and schools due to higher ventilation rates and lower moisture generation indoors. However, Nordic countries do not have any minimum humidity requirements. Levels in other countries were mostly between 30 – 40%, which is within the range of the required values. Air velocities were below the limit values. However, it is not very clear where in the rooms the velocities were measured. Recorded noise levels were found to be too high compared to standards. Mean measured values were between 39 dB(A) in Finland and 55 dB(A) in the UK. They should be in the range of 35 – 40 dB(A).

1 Introduction

This is the report that summarises the results of Work package 5 under the HealthVent project. This work has been performed by REHVA – Federation of European Heating, Ventilation and Air Conditioning Associations. The report gives background information for the work towards the health based guidelines of ventilation for Europe. The focus to the whole work has been on indoor air quality and climate related questions.

1.1 HealthVent project in a nutshell

Every European citizen has right to indoor air quality (IAQ) that does not endanger the health. This is implicit in the basic right to grow up and live in healthy environments. Ventilation is the key technology to control IAQ including thermal conditions and humidity, structural moisture and mould growth, extraction and dilution of emissions from indoor sources and infiltration of ambient air pollution indoors. Ensuring optimal ventilation across the Member States is a key to reduce annual burden of disease, to improve productivity and quality of life, and to remove associated social disparities between population groups and among Member States.

HealthVent project will contribute to the overall strands on the European Health Strategy and by tackling key environmental health determinants it will contribute to prevention of major diseases, reduction of health inequalities and promotion of sustainable health investments at national and regional level. It will develop health-based ventilation guidelines reconciling health and energy impacts.

Experts from medicine, engineering, indoor air sciences, exposure assessment, energy evaluation and ventilation practices will collect, survey and critically review the information that is necessary to develop the health-based ventilation guidelines which will built on the experience, findings and recommendations of the previous projects funded by EC, the on-going development of the WHO IAQ Guidelines and all projects relevant to the topic.

Collected data will be integrated and used to develop health-based ventilation guidelines that take into account the building type (existing and new, and in particular homes, offices and public places such as schools and nursery homes), climate and trends in ventilation strategies for future built environments.

The work in the scope of this project was divided between three horizontal and five core work packages.

Horizontal wok packages:

- **WP1 – Coordination of the project.**
- **WP2 – Dissemination of the project.**
- **WP3 – Evaluation of the project.**

Core work packages:

- **WP4 – Health and ventilation.** Takes actions to define the correlation between diseases and ventilation as well as whether the existing ventilation standards are sufficient to minimize health risks.
- **WP5 – Existing buildings, building codes, ventilation standards and ventilation.** Takes actions to identify the relevant issues in ventilation standards and practices and to critically analyse the gathered information
- **WP6 – Ventilation strategies and technologies.** Takes actions to analyse the interaction between ventilation and energy use in buildings; to identify the strategies

and technologies for energy efficient ventilation; and to identify and assess the possibilities of integrating indoor air quality in energy related inspections and audits
- **WP7 – Health-based ventilation guidelines.** Takes actions to define the clusters (e.g. building types, climatic zones, type of ventilation) by which the health- based guidelines should be defined; to define the criteria by which the health-based guidelines should be defined; and to create the health-based guidelines
- **WP8 – Implementation and impact assessment of guidelines.** Takes actions to assess health impact of guideline implementation; to analyse the health-based ventilation guidelines on energy performance of buildings; and to analyse the interaction of future trends in the built environment and ventilation

Deliverables presented in this report are supposed to be used as input information for work packages WP4, WP7 and WP8.

1.2 Reporting tasks of Work Package 5

Objective of the work performed by the work package 5 under the HealthVent project was to critically evaluate rationale and requirements of existing ventilation standards and practices in Europe. This work included gathering information and giving judgement on the current ventilation standards, practices, techniques, rates and performance for the different climate zones, urban and rural environments, private and commercial buildings in the countries and regions of Europe.

General guidance with description of tasks under this Work package was given in *Annex II* of the *Grant Agreement for an Action*. The guidance specified three tasks to be performed by Work package 5, titled *Existing building, building codes, ventilation standards and ventilation*.

Task 1 - Identification of most commonly used ventilation systems in Europe

This task was completed by collecting information from international published material on ventilation systems. A directory with various ventilation systems used in the target buildings will be collected (**task 1.1**). The major sources for this work are: WHO guidelines on IAQ, moisture and ventilation, CEN standards, German and British handbooks, European text books of ventilation, and EU projects such as VentDisCourse. The systems are categorized in the classes such as:

- Natural ventilation
- Stack ventilation
- Mechanical exhaust
- Mechanical exhaust and supply
- etc.

Decentralized and centralized system will form a subcategories as well as systems with air conditioning. The similar classes will be defined as the records used for searching literature on ventilation and health in WP4. Based on this directory a questionnaire will be formulated and send to HealthVent partners and selected ventilation experts to be answered (**task 1.2**). The focus of this questionnaire is on how common the various systems are in the target building types, built in three time periods that will be defined later (e.g. before 1990, 1991-2000, 2001-present); these periods, if possible will be integrated with changes in building/energy codes in Europe. A summary will be done based on the answers. An additional effort will be made to collect information on how the EU policy on energy efficiency (EPBD directive) affects ventilation, ventilation systems and indoor air quality; thus through questionnaire it will be investigated how Member countries changed their respective ventilation guidelines as a result of EPBD (**task 1.3**).

Task 2 – Summary of ventilation standards and guidelines in Europe

This task focuses on ventilation rates required/defined in building codes, European (CEN) standards (**task 2.1**) and major guidelines and specific requirements on the properties of ventilation systems and equipment (both performance based and prescriptive requirements). This task will be done with questionnaires. A specific questionnaire will be designed focusing on ventilation rates required in selected countries (HealthVent partners and some additional REHVA member countries to ensure coverage of European regions with different climatic conditions/ventilation codes and strategies). Information on regulation on ventilation proxies (such as carbon dioxide) or indoor air pollutants used by Work package 4 in setting up the relationship between ventilation and health will be collected as well (**task 2.2**). The questionnaire will include the features of ventilation system. This list is complemented with the technical features that have been problematic in respect of indoor air quality and environment (**task 2.3**). The list will be reviewed/comment on by the ventilation engineers/experts. This questionnaire will be answered by the HealthVent project partners and selected REHVA members. Data presented in the European standard and guidelines will be collected. The questionnaire focuses on which of these features are regulated in the target countries. A summary will be made from the collected data.

Task 3 – Summary of performance data of existing systems in some European countries

Based on published data and EU sponsored studies like EnVIE or EUROVENT on the performance of ventilation systems a summary is made on:

- How well the measured performance of ventilation systems fulfil the requirements
- The problems identified in relation to indoor air quality

1.3 Methodology and reporting

Information for accomplishment of project tasks was gathered through desk research, questionnaires and engineering calculations. Questionnaires were sent out to project partners and experts to cover as many European countries as possible. The goal was to obtain answers from different countries through the Europe to ensure coverage of Europe with different geographical, cultural and climatic conditions. The feedback from the respondents was good so that well dispersed sample of responses was received, thus the project goal of good coverage of European regions was realized.

The purpose of the questionnaires was twofold. On one hand questionnaires served as a mean to collect opinions (like questionnaire on EPBD effect on IAQ), and on the other hand to overcome language barriers which make search for information in local regulation not possible for non-local speakers. Moreover, with only one respondent, it is very difficult to check the reliability of the data provided, at least that concerning information that can be found in local regulations. Where language allowed, data provided by respondents was additionally compared to local regulations by working team members. In countries where research team was not able to check the data some minor possibility of errors exists. However, as collected data is used just to get the overview of the situation in Europe, minor errors are not expected to have negative consequences in the research field.

The report consists of chapters, with each chapter reporting a specific task or subtask of the work package deliverable. The report is set up as followed:

Chapter 2 provides explanation of terms that are used consistently in this report.

Chapter 3 (reporting task 1.1) gives a classification of ventilation systems used in the target buildings according the requirements of task 1. Ventilation systems are presented with a descriptive schematic and short textual description.

Chapter 4 (reporting task 1.2) summarizes results of the questionnaire on the distribution of ventilation systems in Europe. The results are depicted in chart form while the raw data is shown in the Appendix C.

Chapter 5 (reporting task 1.3) presents results of the questionnaire, which investigates how EU policy on energy efficiency (EPBD) affects ventilation and indoor air quality in the responding countries.

Chapter 6 (reporting task 2.1) gives an overview of current CEN standards and technical reports on ventilation. Standards are classified into two groups, an IAQ-related one and not IAQ related one. For each IAQ related standard, a short descriptive summary is provided. Summaries of the non IAQ-related standards are provided in the Appendix B.

Chapter 7 (reporting task 2.2) presents the results of the questionnaire on ventilation rates, indoor air pollutants and required indoor comfort conditions. Results are presented in tabular and graphical form with charts.

Chapter 8 (reporting task 2.2 and 2.3) present the results of the questionnaire on technical features of ventilation systems. Questionnaire questions are presented and answers are presented in form of charts.

Chapter 9 (reporting task 3) reports how well the measured performance of ventilation systems complies with the requirements of national regulations. Results are based on the published papers. Summary of identified problems is given and conclusions are guidelines needed to improve the indoor air quality and performance of ventilation is given.

2 Terms and definitions

Adsorption. The capability of all solid substances to attract to their surfaces molecules of gases or solutions with which they are in contact. Solids that are used to adsorb gases or dissolved substances are called adsorbents; the adsorbed molecules are usually referred to collectively as the adsorbate. An example of an excellent adsorbent is the charcoal used in gas masks to remove poisons or impurities from a stream of air.

Aerosol. A suspension of liquid or solid particles in air.

Air change rate. Ventilation air flow rate divided by room volume. It indicates how many times, during a time interval, the air volume from a space is replaced with outdoor air.

Air change rate, nominal. The nominal air change rate is equal to the ventilation flow rate divided by the room volume.

Air changes per hour (ACH). Ventilation air flow divided by room volume. It indicates how many times, during one hour, the air volume from a space is replaced with outdoor air.

Air cleaner. Device used for removal of airborne particulates and/or gases from the air. Air cleaners may be added to HVAC systems or stand-alone room units.

Air cleaning. An IAQ controls 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 conditioning. A form of air treatment in which temperature is controlled, possibly in combination with the control of ventilation, humidity and air cleanliness.

Air conditioning system. A combination of all components required to provide a form of air treatment in which temperature is controlled or can be lowered, possibly in combination with the control of ventilation, humidity and air cleanliness. (EPBD, 2002/91/EC)

Air contaminant. Any material in the atmosphere that affects persons and their environment (pollutant includes materials such as liquids, solids, aerosols, gases and odours). The term is used interchangeably with air pollutant.

Air diffusion. Distribution of the air in a space by means of air terminal devices, in a manner so as to meet certain specified conditions, such as air change rate, pressure, cleanliness, temperature, humidity, air velocity and noise level.

Air extract, mechanical. The process of extracting air with the aid of powered air movement components, usually fans.

Air flow rate, mass. Mass flow of air over specified time, usually expressed in kg/s or kg/h.

Air flow rate, volumetric. Volumetric flow of air over specified time, usually expressed in l/s or m^3/h.

Air handling unit. Assembly consisting of sections containing a fan or fans and other necessary equipment to perform one or more of the following functions: air circulation, filtration, heating, cooling, heat recovery, humidifying, dehumidifying and mixing of air, and necessary controls functions.

Air leakage factor. The air leakage per unit envelope area.

Air pollutant. See Air contaminant

Air quality, indoor (IAQ). IAQ deals with the health and comfort of the air inside buildings and characterize the indoor climate of a building, including the gaseous composition, temperature, relative humidity, and airborne contaminant levels. IAQ is the expression for both the concentration of impurities in the air and an expression of how people signify their perception of the air (perceived air quality) in the form of e.g. smell and irritation (sensory measurements).

Air, exhaust. Air removed from a space and discharged to outside the building by means of mechanical or natural ventilation systems.

Air, indoor. The air in an enclosed occupied space.

Air, outdoor. Air taken from outside the building, which therefore has not previously circulated through the ventilation system.

Air, supply. Air delivered by mechanical or natural ventilation to a space, composed of any combination of outdoor air, recirculated air or transfer air.

Air, ventilation. Outdoor air supplied to a room for ventilation purposes.

Air-handling unit, decentralised. In contrast to the central air-handling units, these units are allocated to a single room or group of rooms, supplying secondary air or outdoor air to that room.

Allergen. A substance capable of causing an allergic reaction because of an individual's sensitivity to that substance.

Area, gross floor. The total area of all the floors of a building, including intermediately floored tiers,
mezzanine, basements, etc., as measured from the exterior surfaces of the outside walls of the building.

Area, net floor. A term used in the ISO standard to express the Interior Gross Area less the areas of all interior walls.

Area, occupied. Area within the heated or cooled surface occupied for long periods. Normally the floor area within 1,0 m from external walls-windows and HVAC equipment and 0.5 m from internal walls.

Area/space, living floor. Total area of rooms falling under the concept of rooms. (OECD Glossary of statistical terms)

Arrestance, filter. The amount of particles of non-specific size captured by the filter. The arrestance describes how well an air filter removes larger particles (total mass) such as dirt, lint, hair and dust.

Boiler. The combined boiler body and burner-unit designed to transmit to water the heat released from combustion. (EPBD, 2002/91/EC)

Boundary conditions. Values of physical parameters (e.g. temperature, heat flux, mass flux, velocity, etc.) that are specified at the boundaries of a solution domain and are required for solving the discretised equations in a CFD (computational fluid dynamics) solution or any other physical problem.

Building services. Services provided by technical building systems and by appliances to provide indoor climate conditions, domestic hot water, illumination levels and other services related to the use of the building.

Buoyancy. The vertical force exerted on a volume of air that has a density different from the ambient air caused by temperature differences.

Certificate, energy performance. A certificate recognised by the Member State or a legal person designated by it, which includes the energy performance of a building calculated according to a methodology based on the general framework set out in the Annex of Directive 2002/91/EC. (EPBD, 2002/91/EC)

Cleanliness. Cleanliness of the ventilation system and/or its components: the condition of the ventilation system and/or the components, in which the amount or concentration of contaminants is below a specified level.

Coil, cooling. Heat exchanger that extracts heat from the air stream by means of a heat transfer medium.

Coil, heating. Heat exchanger, which ads heat to the air stream by means of a heat transfer medium.

Comfort, thermal. The totality of conditions (air temperature, relative humidity, air velocity, pressure, clothing, activity) for which a person would not prefer a different thermal environment.

Commissioning. The testing of HVAC systems prior to building occupancy to check whether the system meets the operational needs of the building within the capabilities of the system design. Start-up of a building that includes testing and adjusting HVAC, electrical, plumbing, and other systems to assure proper functioning and adherence to design criteria. Commissioning also includes the instruction of building representatives in the use of the building systems.

Concentration. The quantity of one substance (gas or particles) dispersed in a defined amount of another substance (usually air or water).

Contaminant. An unwanted airborne constituent that may increase the health risks and reduce acceptability of the air.

Cooling load. The rate at which heat must be extracted from a space in order to maintain the desired temperature within the space.

Cooling tower. A heat transfer device, which cools warm water using outside air or water. Usually used to reject heat from the cooling process to the atmosphere.

Damper. The damper is a movable device, placed in the ductwork that opens and closes to control airflow. Dampers can be used to balance airflow in a duct system. They are also used in zoning to regulate airflow to certain rooms.

Dehumidification. The reduction of water content in the air.

Design criteria. Values of parameters that define indoor air quality, thermal and acoustical comfort, energy efficiency and the associated system controls that should be achieved by the design.

Diffuser. Air distribution device designed to direct airflow into desired patterns.

Draught. Human perceived sensation of local cooling of body caused by air movement and its temperature

Dual duct system. An air conditioning system that has two ducts for supply air, one is with heated air and the other is with cooled air, so that air of correct temperature is provided by mixing varying amounts of air from each duct.

Duct. A pipe or closed conduit made of sheet metal, fiberglass board, or other suitable material used for conducting air to and from an air handling unit or fan.

Duct, flex. Usually installed in a single, continuous piece between the register and plenum box, a flexible duct usually has an inner lining and an insulated coating on the outside.

Ductwork. Pipes or ducts that carry air throughout a building.

Efficiency (filtration). Removal of dust in a filter, expressed in %. (EN 779)

Energy audit. A systematic procedure to obtain adequate knowledge of the existing energy consumption profile of a building or group of buildings, of an industrial operation and/or installation or of a private or public service, identify and quantify cost-effective energy savings opportunities, and report the findings. (ESD, 2006/32/EC)

Energy consumption. The amount of energy consumed in the form in which it is acquired by the user. The term excludes electrical generation and distribution losses.

Energy performance of a building. Calculated or measured amount of energy delivered and exported actually used or estimated to meet the different needs associated with a standardized use of the building, which may include, inter alia, energy used for heating, cooling, ventilation, domestic hot water, lighting and appliances.(EN 15316-1:2007).

Energy Performance of Buildings Directive (EPBD). The Energy Performance of Buildings Directive, an EU Directive of late 2002 aiming at improving the energy performance of buildings, strengthened and accelerated in 2010 by the 'Recast EPBD'.

Envelope, building. Integrated elements of a building which separate its interior from the outdoor environment. (IUPAC International Union of Pure and Applied Chemistry - Compendium of Chemical Terminology 2nd Edition 1997).

Exfiltration. The air flowing through the building envelope from inside to outside due the pressure difference. In cold climates this may cause moisture damages in the constructions due to condensation of moist indoor air in the structure.

Fan coil. A component of HVAC system containing a fan and heating or cooling coil, used to distribute heated or cooled air.

Fan power, specific (SFP). The combined amount of electric power consumed by all the fans in the air distribution system divided by the total airflow rate through the building under design load conditions, in W/(m3·s).

Filter. Device for removing particulate material and gases from air.

Fire dampers. Components, which are installed in an air distribution system between two fire separating, compartments and are designed to prevent propagation of fire and/or smoke. Generally are kept open by mechanical restraint, whose effect is cancelled under specific conditions. The valve is then closed automatically.

Formaldehyde. Formaldehyde is a colourless water-soluble gas emitted from many building materials. It is frequently measured and evaluated separately from other volatile organic compounds (VOCs).

Gas, tracer. A detectable gas used in small concentrations to evaluate performance of ventilation such as air flows, local mean ages, air change efficiency etc.

Heat exchanger. A device in which heat is transferred between two mediums that don't come in contact.

Heat exchanger, rotary. A device incorporating a rotating cylinder or wheel for the purpose of transferring energy from one air stream to the other. It incorporates heat transfer material, a drive mechanism, a casing or frame, and includes any seals which are provided to retard the bypassing and leakage of air from one air stream to the other.

Heat pump. A machine, a device or installation that transfers heat from natural surroundings such as air, water or ground to buildings or industrial applications by reversing the natural flow of heat such that it flows from a lower to a higher temperature. For reversible heat pumps, it may also move heat from the building to the natural surroundings. (EPBD 2010)

Heat recovery. Heat utilized from a system, which would otherwise be wasted. (E.g. Heat transferred from exhaust air into supply air)

Heating load. The instantaneous heating rate required to keep the building "in balance" at a specific minimum comfort temperature level e.g. a design temperature of 21.0°C. (Without taking into account the effectiveness of the heating system). Expressed in W or W/m^2.

Humidification. Addition of water vapour to room air or supply air.

Humidifier. A device used for humidification.

Humidity, absolute. Absolute amount of water vapour in ambient air expressed in g/kg or g/m^3 dry air.

Humidity, relative. Pressure of water vapour in the air by volume divided by pressure of water vapour by volume at saturation at the same temperature.

Indoor environment quality (IEQ). IEQ encompasses all aspects of the indoor environment including air quality, thermal environment, lighting, and acoustic environment.

Infiltration. The transport of air through leakage paths in the envelope of a building, resulting from pressure (e.g. wind) and temperature differences.

Insulation. Any material that is used to reduce the heat flow or heat losses

Leakage. If the duct and air handling system is not airtight, air will leak from, or into, the system depending on the pressure in the system, and reduce the air delivery efficiency of the system.

Load calculation. A process to determine the heat gain and heat loss in a building so that properly sized air conditioning and heating equipment may be installed.

Noise rating (NR). The noise rating curves are developed by the International Organization for Standardization (ISO) to determine the acceptable indoor environment for hearing preservation, speech communication and annoyance.

Operation and maintenance. Actions taken after construction to ensure that facilities constructed will be properly operated and maintained to achieve conditions and efficiency levels specified at the design level.

Particulates. Small airborne particles found in indoor environments, which include fibrous materials, solid-state semi-volatile organic compounds, and biological materials.

Parts per million (ppm). The number of parts of a substance by volume in a million total parts.

PM_{10}. Total mass of suspended particles with diameter less than 10 µm in m^3 of air.

$PM_{2,5}$. Total mass of suspended particles with diameter less than 2.5 µm in m^3 of air.

Pollutant. See Contaminant

Pollution. Presence of undesired elements, which are deteriorating to the comfort, health and welfare of persons or the environment (pollution includes elements such as noise, vibration, odours and gases).

Predicted mean vote (PMV). Predicted Mean Vote is an index that predicts the mean value of the votes of a large group of persons on a 7-point thermal sensation scale with zero meaning thermal neutral state

Predicted percentage of dissatisfied (PPD). Index that predicts the percentage of a large group of people likely to feel thermally dissatisfied for the body as a whole, i.e. either too warm or too cool.

Productivity. Productivity is the amount of output created (in terms of goods produced or services rendered) per unit input used. It can be improved by increasing output (performance etc.) or decreasing input (cost and other resources).

Room, habitable. A room used for dwelling purposes but which is not solely a kitchen, utility room, bathroom, cellar or sanitary accommodation.

Sensor. Device, which converts a physical, chemical, biological property or quantity into a conveniently measurable effect or signal. In this context the term "sensor" is used to designate a "sensor system", which may consist of several components. Based on the functional properties, these components can be grouped in three different units: a sensing element, a transducer, a transmitter.

Sick Building Syndrome (SBS) symptoms. Non–specific symptoms experienced by building occupants which may include irritation of eyes, nose, and skin, headache, fatigue, and difficulty in breathing and are related to the characteristics of buildings and indoor environments. The symptoms improve when the occupant is away from the building and are not related to any known disease or exposure.

Sound attenuators. Components, which are inserted into the air distribution system and designed to reduce airborne noise propagated along the ducts.

Source control. A preventive strategy for reducing airborne contaminant levels in the air through removal of the material or activity generating the pollutants.

Sources of indoor air pollutants. Indoor air pollutants can originate within the building or be drawn in from outdoors. Common sources include people, fixtures and furnishings, photocopiers, plants, food, etc.

Space, conditioned. Enclosed space that is provided with climate control (temperature and air quality)

Space, unconditioned. A space that is neither directly nor indirectly conditioned space, which can be isolated from conditioned space by partitions and/or close able doors.

Split system. A two-component heating and cooling (heat pump) or cooling only (air conditioner) system. The condensing unit is installed outside, the air handling unit is installed inside (preferably in conditioned space). Refrigerant lines and wiring connect them together.

Stack effect. A condition resulting from the rise of heated air, which creates positive pressure near the top of the building and negative pressure toward the bottom.

Temperature asymmetry, radiant. Difference between the plane radiant temperature of the two opposite sides of a small plane element.

Temperature difference, vertical air. Air temperature difference between head and ankles of a person. NOTE: 0.1 and 1.1 m for sedentary and 0.1 and 1.7 m above floor for standing.

Temperature, room air. The average of air temperatures measured at 1.1 m high, positioned out of the main air current from any heating or cooling device

Terminal device. Devices located in an opening provided at the boundaries of the ventilated space to ensure a predetermined motion of air in this space.

Thermal environment. Characteristics of the environment, which affect the heat, exchange between the human body and the environment.

Threshold. The contaminant dose or exposure level below which there is no expected significant effect.

Total volatile organic compounds (TVOCs). A measure representing the sum of all VOCs present in the air to provide an approximate indication of pollutant levels. Indoor air typically contains hundreds of different VOCs in very low concentrations, some of which can have additive effects.

Validation. Procedure to test how accurately reality is represented.

Vapour. A substance in gaseous state, whose natural state is a liquid or solid form at normal atmospheric conditions

Variable air volume system (VAV system). A ventilation system where the airflow rates are continuously varied. The flow of a VAV system may vary according to a predetermined pattern or it may be determined by actual demand, e.g. demand controlled ventilation.

Velocity, mean air. The average value of the velocities

Ventilation effectiveness. Relation between the pollution concentrations in the supply air, the extract air and the indoor air in the breathing zone (within the occupied zone). (EN 13779)

Ventilation flow rate. The outdoor air flow arte supplied to a space to maintain acceptable indoor air quality.

Ventilation opening. An intentional opening in building envelope (e.g. trickle ventilator, louver, vent etc.) designed to allow air to flow into and/or out of the ventilated building.

Ventilation rate. Magnitude of outdoor air flow to a room or building either through the ventilation system or infiltration through building envelope. (EN 15251)

Ventilation system. A combination of appliances designed to supply interior spaces with outdoor air and/or to extract polluted indoor air. (EN 15251)

Ventilation, balanced. A ventilation system with mechanical supply and exhaust

Ventilation, cross. Natural ventilation in which the air flow mainly results from wind pressure effects on the building facades

Ventilation, demand controlled (DCV). Ventilation system with feed-back and/or feed-forward control of the air flow rate according to a measure demand indicator. Demand is decided by set values affecting thermal comfort and/or air quality.

Ventilation, exhaust. Mechanical removal of air from a building.

Ventilation, hybrid. Ventilation where natural ventilation may be at least in a certain period supported or replaced by mechanical ventilation.

Ventilation, mechanical. Ventilation with the aid of powered air movement components.

Ventilation, natural. Ventilation provided by thermal, wind, or diffusion effects through doors, windows or other intentional openings in the building.

Ventilation, purge. Manually controlled ventilation of rooms or spaces at a relatively high rate to rapidly dilute pollutants and/or water vapour. Purge ventilation may be provided by natural means (e.g. an open able window) or by mechanical means (e.g. a fan).

Volatile organic compounds (VOCs). Chemical organic compounds that vaporize (become a gas) at room temperature. Common sources which may emit VOCs into indoor air include housekeeping and maintenance products, and building and furnishing materials.

Zone. An area within the interior space of a building, such as an individual room(s), to be cooled, heated, or ventilated. A zone has its own thermostat to control the flow of conditioned air into the space.

Zone, occupied. That part of space designed for human occupancy and where the design criteria of indoor environment are required to be met. Normally the zone between floor and 1.8 m and 1.0 m from external walls-windows and HVAC equipment and 0.5 m from internal walls.

3 Classification of air types and ventilation systems

This chapter provides a classification of air types and ventilation systems that are used in the buildings, which are the focus of this project: homes, offices, schools and kindergartens. The results of this chapter report the task 1.1 of this work package deliverable.

3.1 Specification of types of air

The types of air in a building and in ventilation or air-conditioning system are specified by the list of functions provided below. Classification numbers given in the list below follow the classification provided in EN 13779 [**1**].

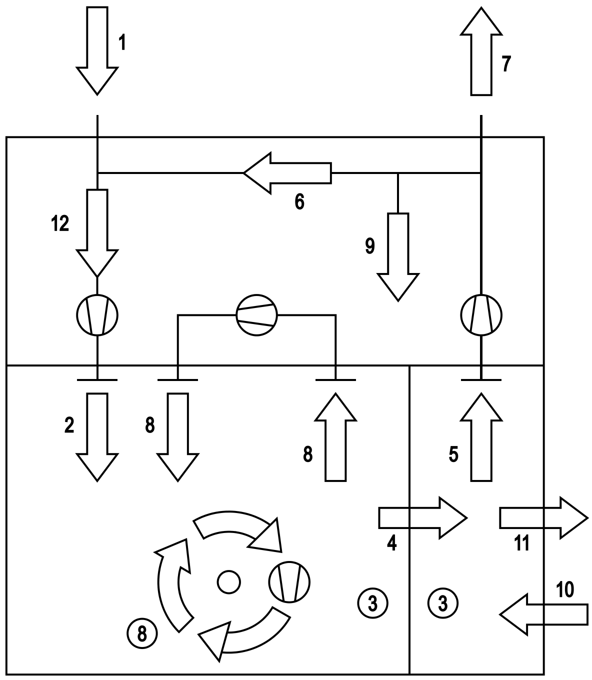


Figure 1: Specification of types of air

1. **Outdoor air** is used for ventilation, usually the term ventilation rate refers to the outdoor air flow taken outside the building and therefore not previously circulated through the ventilation system.

2. **Supply air** to the room can be conditioned (heated, cleaned, cooled, humidified or dehumidified). It can be 100% outdoor air or mixture of recirculation air (6) and outdoor air depending on the system. The supply air may not only be used for ventilation but also for temperature and humidity control of the room. Usually the air flow required for thermal control of the room is greater than that for ventilation (outdoor air flow).

3. **Indoor air** is the air in the ventilated space. In mixing air distribution systems, the indoor air quality is uniform in the space. In displacement ventilation systems the gradients of concentrations and temperature are intentionally created.

4. **Transfer air** is the air moving between adjacent rooms in the building. This air flow can be used to prevent pollutants from spreading from rooms with low air quality to rooms with better air quality, like tobacco smoke from smoking areas to non-smoking areas.

5. **Extract air** is the air extracted from the room. Extract air should be taken from the location in the room where the air has the lowest quality.

6. **Recirculation air** is a part of extract air (clean air), which is not exhausted from the building.

7. **Exhaust air** is extract air that is exhausted from the building and not recirculated.

8. **Secondary air** is the air which is circulated within one space (extracted and supplied), usually it is treated during circulation – secondary air can be used for example for heating a room or be circulated through an air cleaner. Secondary air handling units can be located outside the room or in the room.

9. **Leakage**. If the duct and air handling system is not airtight, air will leak from, or into, the system depending on the pressure in the system, and reduce the air delivery efficiency of the system.

10. **Infiltration** is the air flowing through the building envelope into the building. The infiltration depends on pressure difference over the structure and the flow paths. This may bring harmful pollutants into the building.

11. **Exfiltration** is the air flowing through the building envelope from inside to outside due the pressure difference. In cold climates this may cause moisture damages in the constructions due to condensation of moist indoor air in the structure.

12. **Mixed air** is the mixture of outdoor air and recirculation air. The amount of outdoor air is based on ventilation requirements of the space. Total supply air rate flow is based on cooling or heating requirements of the space.

3.2 Classification of ventilation systems

Ventilation intentionally introduces air from the outside into the indoor spaces of a building. Commonly used systems in Europe to achieve ventilation can be assigned to one of the main two categories: natural ventilation or mechanical ventilation. Each of the two main ventilation systems is further subdivided into more subsystems (Figure 2). This section provides a classification of ventilation systems commonly used in dwellings, schools, kindergartens and office buildings. Classification from this chapter is used in the entire project. This section provides criteria for classification of systems, descriptions with most common examples and simple schemes of systems showing the most important components and helping to distinguish easier between similar systems. Figure 2 shows a hierarchy diagram of decomposition of ventilation systems. The last level of decomposition is not shown in the figure, but it is described later in this chapter.

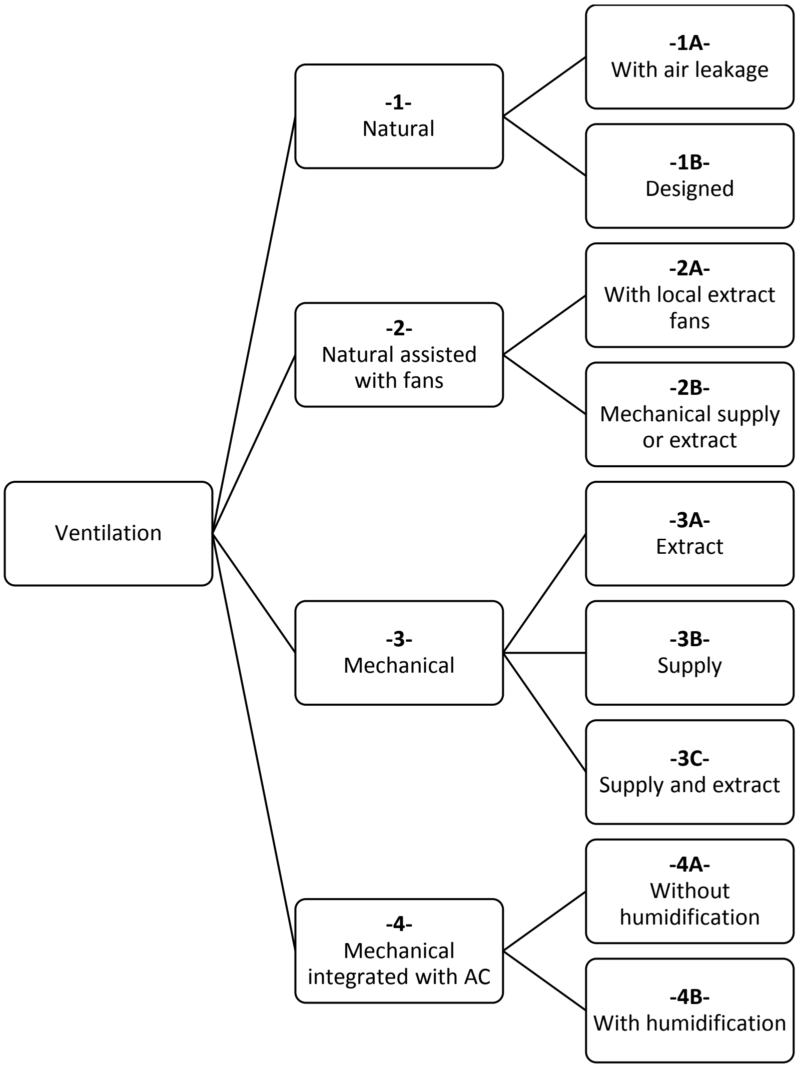


Figure 2: Classification of ventilation systems

Table 1 presents the minimum criteria for ventilation systems according to the classification developed in this report. In order to classify a ventilation system into one of the categories, system must include all the required components or characteristics, which are shown in the first column. A bolded cross in the column under the system number means that a corresponding component or characteristic of must be part of the ventilation system. The number of the system corresponds to the name of the system, provided further in the report.

Table 1: Minimum requirements for ventilation systems

<table>
<tr><th></th><th>1A1</th><th>1A2</th><th>1B1</th><th>1B2</th><th>1B3</th><th>2A</th><th>2B</th><th>3A</th><th>3B</th><th>3C1</th><th>3C2</th><th>4A</th><th>4B</th></tr>
<tr><td>air leakage</td><td>X</td><td>X</td><td></td><td></td><td></td><td rowspan="2">X</td><td rowspan="2">X</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>designed natural ventilation</td><td></td><td></td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>local hydronic AC units</td><td>X</td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>local heat pump units</td><td></td><td>X</td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>heat recovery</td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>supply fan</td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">X</td><td></td><td>X</td><td rowspan="2">X</td><td rowspan="2">X</td><td></td><td></td></tr>
<tr><td>exhaust fan</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>heating coil</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td>cooling coil</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td>humidifying unit</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>intermittent fan operation</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>constant fan operation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>integrated with air-conditioning</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
</table>

Legend of symbols used in schematics:

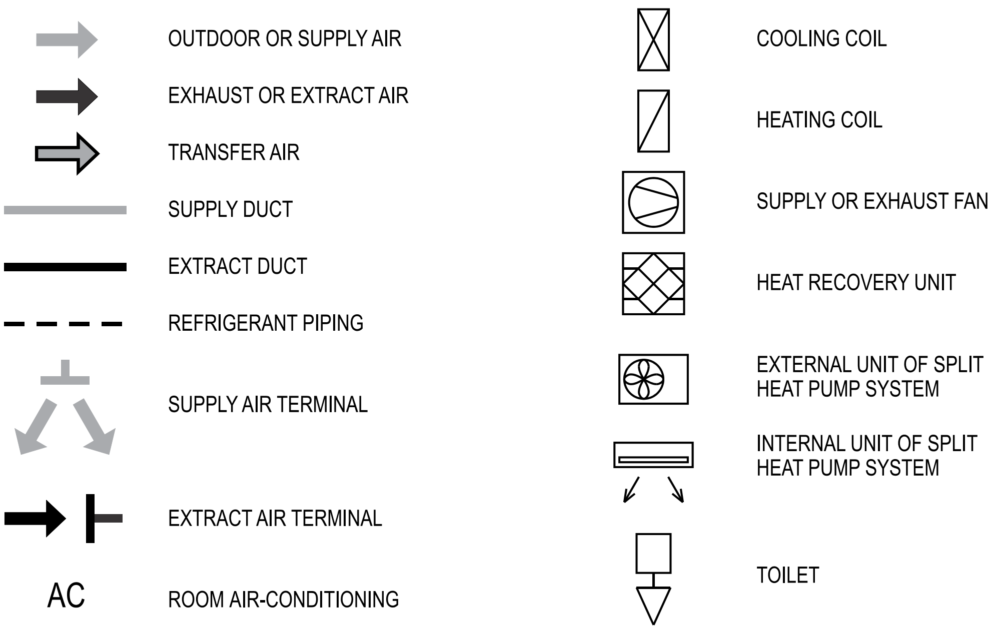


Figure 3: Legend of symbols used in schematics

1) Natural Ventilation

Natural ventilation is a type of indoor space ventilation, where air is supplied to and removed from the indoor space only by natural means. Ventilation only relies on pressure differences without the aid of powered air movement components. Natural ventilation has been extensively used in the past to provide ventilation in dwellings, schools, kindergartens and office building. Even though regulations in moderate and cold climates do not explicitly forbid natural ventilation, its use in new buildings is now declining as a consequence of more stringent energy regulations. The latter impose high energy performance demands of the whole building which is very difficult to achieve with natural ventilation.

1A) Natural ventilation with air leakage

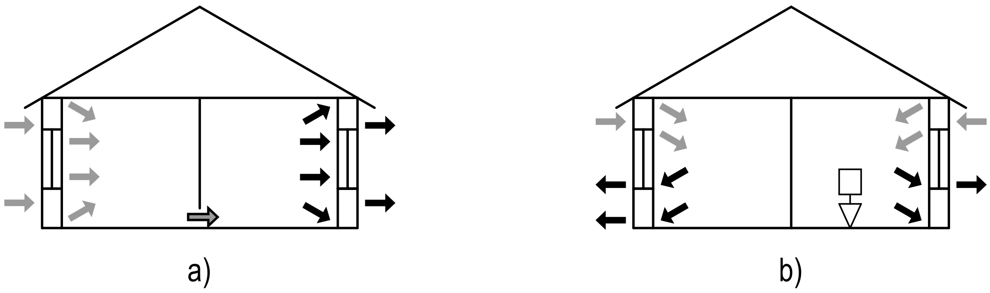


Figure 4: Ventilation system 1A: a) cross-ventilation; b) single-sided ventilation

Natural ventilation with air leakage relies solely on infiltration of outdoor air and exfiltration of indoor air. With infiltration, outdoor air flows to indoors through cracks and other unintentional openings in the building envelope and through the normal use of exterior windows and doors. Infiltration and exfiltration are driven by natural and/or artificially produced pressure differentials without the aid of powered air movement components. Ventilation can therefore be provided even if all doors and windows are closed and there are no ventilation openings in building envelope. Such kind of ventilation is very common in old buildings that are not as airtight as today's new buildings with airtight windows and doors.

1A1) Natural ventilation with air leakage and local hydronic AC units

This system has the same ventilation principle as system 1A – Natural ventilation with air leakage but has one or more additional local hydronic air-conditioning units installed in the building. A typical application of this kind are fan coil units in office buildings. They are not common in dwellings where the following system 1A2 is more dominant due to its cheap installation costs.

1A2) Natural ventilation with air leakage and heat pumps

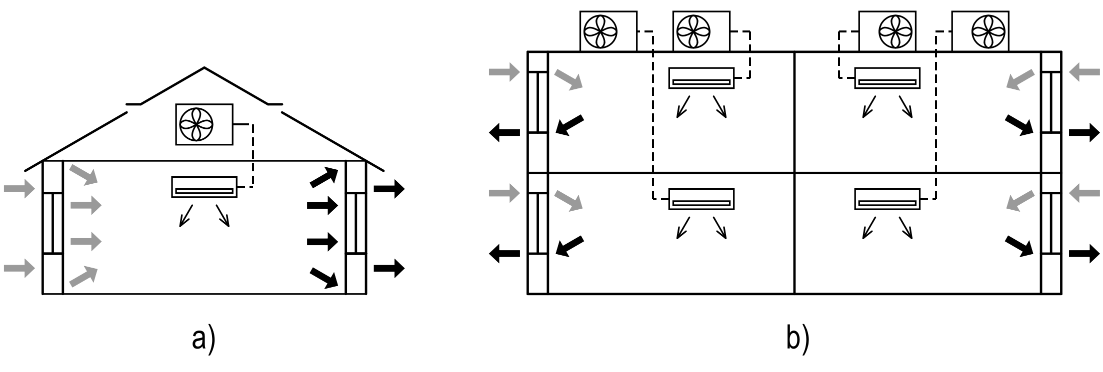


Figure 5: Ventilation system 1A2: a) house; b) office building

Also this system has the same ventilation principle as system 1A but has one or more heat pumps installed. Heat pumps are usually called split units and consist of separated internal and external compressor unit. Split systems mostly used today are reversible heat pump units, whereas in the past they were mostly only cooling mode heat pump units. Although the first are commercially known today as heat pumps, cooling only split units are also heat pumps. Heat pump systems in dwellings and offices where natural ventilation with air leakage is used have in most cases been installed after the building has been completed due to its low installation cost.

1B) Designed natural ventilation

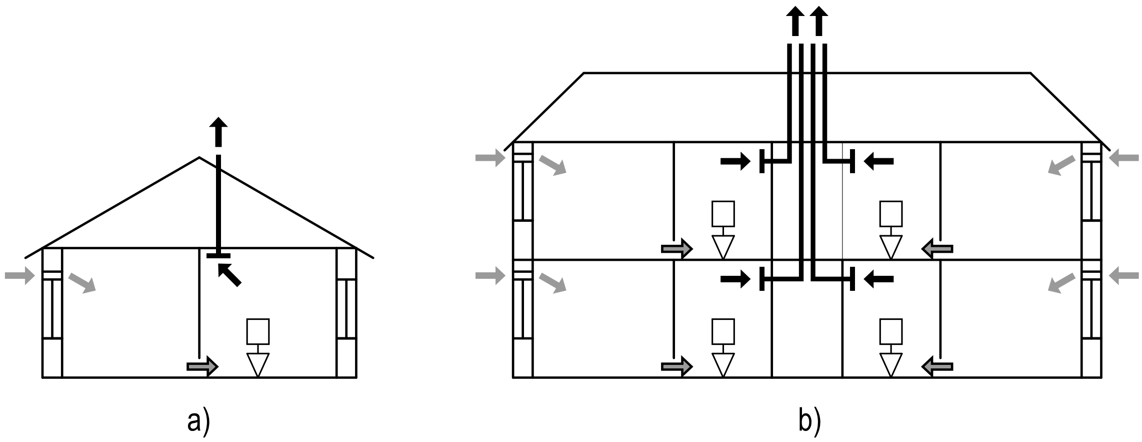


Figure 6: Ventilation system 1B: a) house; b) apartment building

Designed natural ventilation can provide ventilation even when infiltration does not occur (zero air permeability of building envelope). Ventilation still relies on pressure differentials without the aid of powered air movement components, but it uses ventilation openings to allow air pass through the building envelope (e.g. trickle ventilators). Ventilation openings are usually manually controlled, so that ventilating rates are within acceptable limits for most time of the year. A distinction can be made between cross ventilation and stack ventilation systems. In the case of cross ventilation the air volume flows mainly result from wind effects (wind pressures), the vertical lifting forces (buoyancy) within the building being of less importance. In the case of stack systems, the air volume flow result from the vertical lifting forces (buoyancy) within the building.

1B1) Designed natural ventilation with local hydronic AC units

This system description is the same as 1A1, except that natural ventilation system used has been designed and does not rely only on infiltration.

1B2) Designed natural ventilation with heat pump

This system description is the same as 1A2, except that natural ventilation system used has been designed and does not rely only on infiltration.

1B3) Designed natural ventilation with heat recovery

In buildings with designed natural ventilation and heat recovery, ventilation is provided with designed natural ventilation. Additionally, system also consists of a heat recovery unit recovering heat from the exhaust air and returning it to the supply air. Such systems are very rare in praxis as heat recovery units usually impose additional pressure drops in the systems, which are very difficult to overcome with naturally generated pressure potentials.

2) Fan assisted natural ventilation

Designed and not designed natural ventilation systems can be assisted with the aid of powered air movement components like small air extract fans in spaces with high generation of pollutants like toilets, bathrooms and kitchens or with central exhaust or supply fans. Ventilation assisted by powered components is also known as hybrid ventilation.

The main difference between fan assisted ventilation of this group and mechanical ventilation is, that operation of air movement components in fan assisted natural ventilation is used intermittently when natural air movement cannot provide required ventilation air rates, whereas mechanical ventilation is the only mean of providing required ventilation rates and runs whenever ventilation is required.

2A) Natural ventilation assisted with local extract fans in wet rooms and/or kitchens

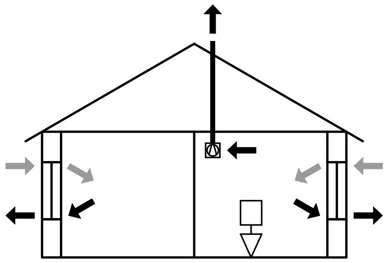


Figure 7: Ventilation system 2A in a house

In this system, natural ventilation (designed or with leakage) provides natural ventilation in habitable rooms at all times of the year. However, because air leakage, ventilation openings in building envelope or pressure stack vents cannot assure required ventilation rates in wet rooms, or when windows cannot be used for purge ventilation, local extract fans are installed. Operation of fans in such systems is limited to certain periods of time when boosted ventilation is needed (e.g. during cooking, bathing or toilet occupancy). Usage of fans is limited to the equipped room only. Such systems are very common in dwellings and some offices, where they were retrofitted.

2B) Natural ventilation assisted with mechanical extract or supply for intermittent operation (hybrid ventilation)

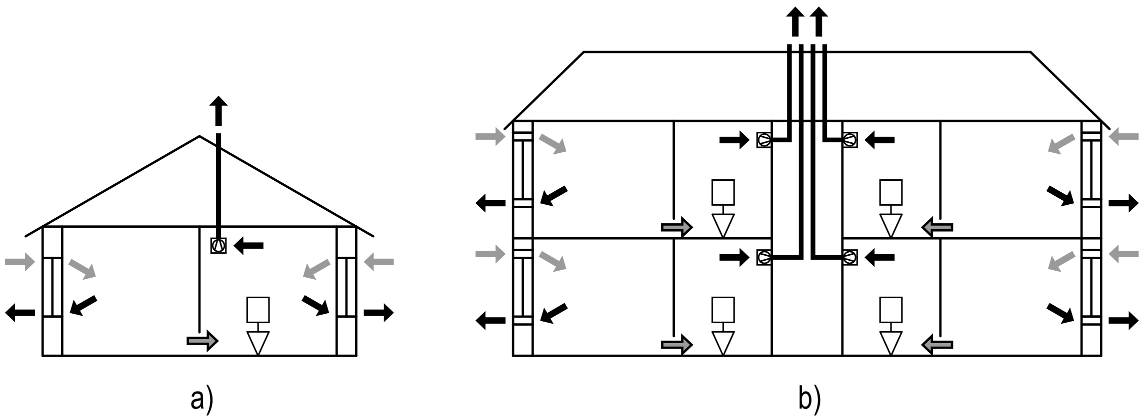


Figure 8: Ventilation system 2B: a) house; b) apartment building

This system operates as natural ventilation system for the most part of the year, but it is additionally equipped with powered air movement devices or fans. They are usually used because natural driving forces cannot provide required ventilation rates during all weather conditions. Such systems are also widely known as “hybrid” ventilation. Fans in such systems are usually installed in all wet rooms, whereas air enters the building through ventilation openings or air leakage in habitable rooms. Natural ventilation still occurs during the operation of fans but it is usually not considered as a factor during the design of mechanical part of the system, as its effect is small. Such fan assisted or hybrid systems are gaining popularity in dwellings but are not common in office buildings.

3) Mechanical ventilation

Mechanical ventilation systems rely on mechanical devices to intentionally move air into and out of a building using aid of powered air movement devices. Some natural ventilation through infiltration still occurs of ventilated rooms are in under-pressure in compared to the outdoor, but its influence is usually negligible and is not considered in the design phase (unless the building is untight).

Mechanical ventilation allows a certain control of the indoor climate and quality. Fans are almost exclusively used as the powered air movement devices. Mechanical ventilation systems are usually centralized with one fan or air handling unit serving several rooms in one or more floors. Duct air systems are used in centralized systems to convey the air and supply in to the rooms. Decentralized mechanical ventilation systems with fans or air handling units serving only one room or one apartment in apartment building are also used in practice. However, they are usually more costly to install compared to the centralized systems, and are therefore more popular in the retrofit applications where central systems cannot be installed. In houses, systems are usually centralized with one fan or AHU serving the whole building.

Mechanical ventilation systems are gaining popularity in dwellings, especially in combination with heat recovery. They have already been used in schools, kindergartens and offices, where natural ventilation cannot provide required ventilation rates. A very common component of mechanical ventilation systems is an air handling unit which usually comprises of fans, filters, heating coil and automatic control build into one unit. Air handling units are very common in commercial buildings as they can be delivered on site in modules and then easily put together. Lately, compact air handling units with all the components in one casing are becoming a standard in home ventilation.

The main difference between mechanical ventilation and fan assisted natural ventilation is that mechanical ventilation is the only designed ventilation system in the building to provide required ventilation and does not consider effects of forces driving natural ventilation in the design. Mechanical system runs during all the time when ventilation is required. System in dwellings usually run 24 hours a day, while systems in tertiary sector run constantly during occupancy and do not run or run at reduced rates during non-occupancy.

3A) Mechanical extract ventilation

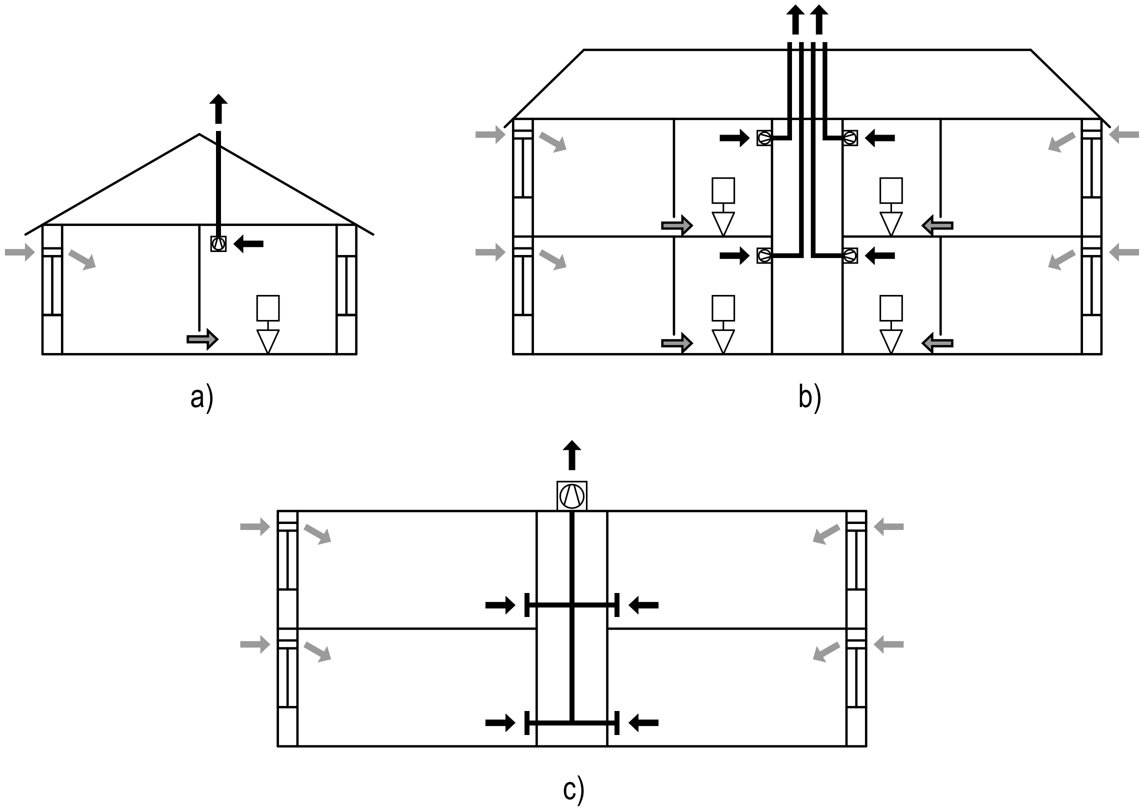


Figure 9: Ventilation system 3A: a) house; b) apartment building; c) office building

In mechanical extract ventilation a fan draws air from rooms, usually through a duct system and exhausts it to outdoors. Fresh outdoor air enters into rooms either through the leakage routes of building envelope or through ventilation openings in the building envelope. Mechanical exhaust ventilation system can serve one room, apartment or whole building (decentralized or central system). A common example of such system is mechanical ventilation of dwellings where air is extracted through wet rooms and supplied to habitable rooms.

3B) Mechanical supply ventilation

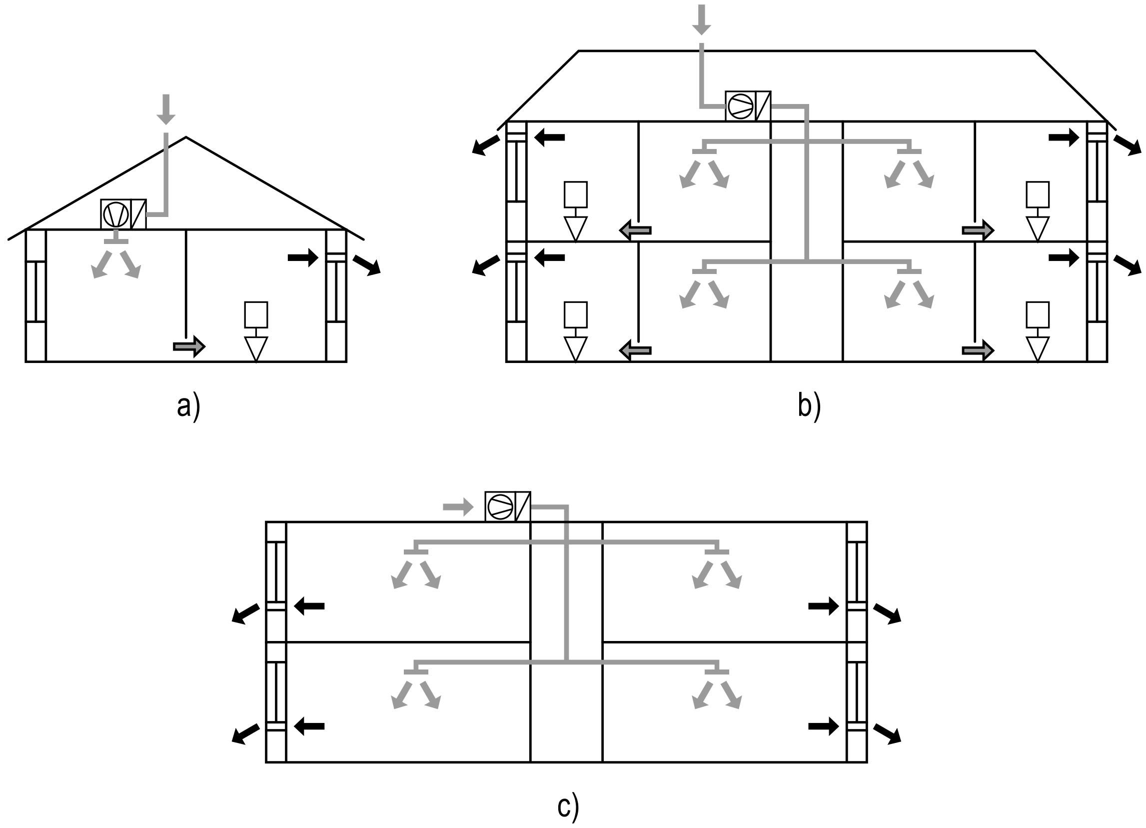


Figure 10: Ventilation system 3B: a) house; b) apartment building; c) office building

Mechanical supply ventilation system always consists of a fan to supply air to spaces and ventilation openings in building envelope that allow air to flow out of the building. A heating coil is usually applied in colder climates to heat the supply air to an acceptable temperature for supply to the room. Systems of this kind are usually used where high ventilation rates are needed and air has to be heated before entering the room. Applications of such systems can be found in some dwellings, schools and kindergartens but they are not very common. Mechanical extract ventilation is more common than supply ventilation in practice.

3C) Mechanical extract and supply ventilation

Mechanical extract and supply ventilation is a balanced ventilation system. It must always include a supply and a return air fan. An air heater is almost always installed in the supply air side. As other mechanical systems, also this one can be centralized or decentralized. Heat recovery units have become very common part of the extract and supply ventilation. They are usually installed as a part of the air handling unit. Mechanical exhaust and supply ventilation can be used to control pressure conditions in the rooms by adapting supply and exhaust ventilation rates. Moreover, air can also be recirculated if needed.

Mechanical extract and supply ventilation has been widely used in office buildings, schools and kindergartens. The most common are centralized systems in new buildings and decentralized systems in some of the retrofitted buildings where space does not allow for air duct networks. Nowadays such systems are also becoming very popular in dwellings, especially in moderate and cold climates where they also include heat recovery.

3C1) Mechanical extract and supply ventilation without heat recovery

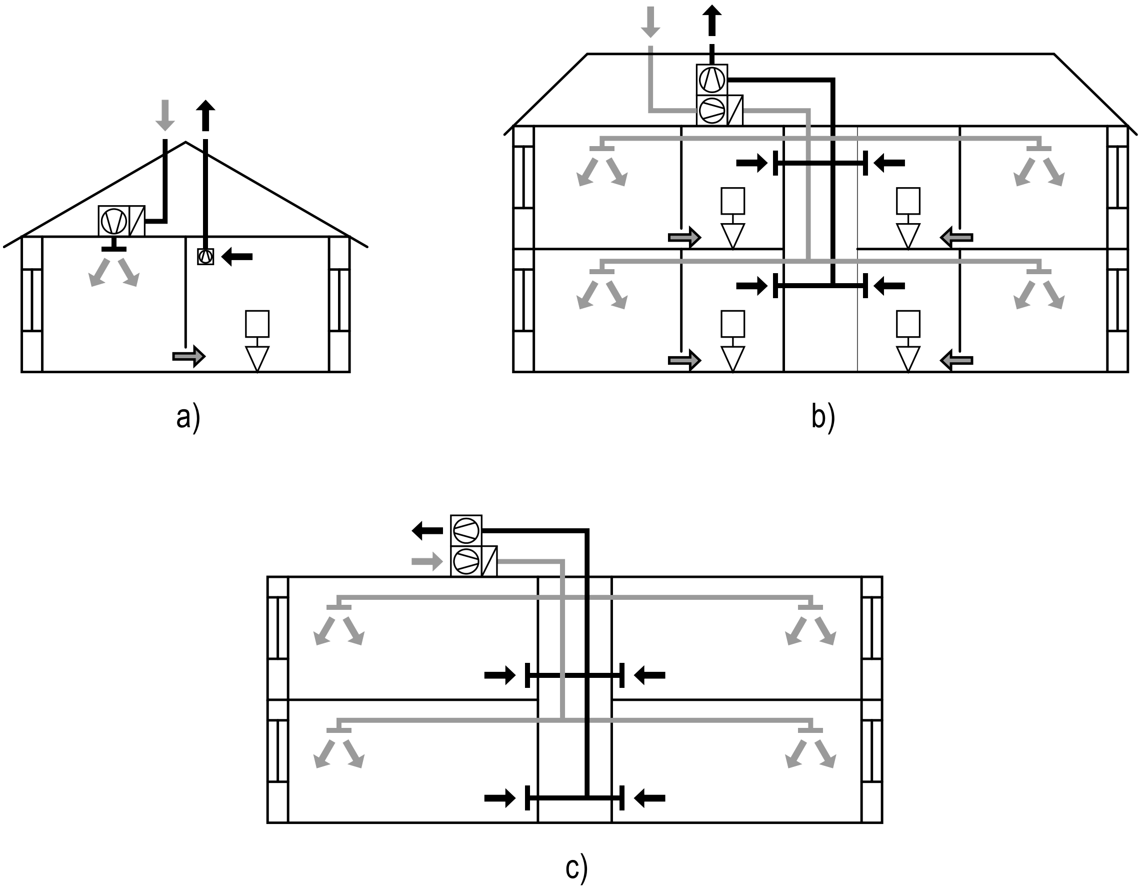


Figure 11: Ventilation system 3C1: a) house; b) apartment building; c) office building

This subsystem of mechanical supply and extract systems does not include heat recovery. Such systems have been common through all the Europe until more stringent energy codes and prices have forced investors and owners to start recovering exhaust air heat. Today, systems without heat recovery installed in new buildings practically cannot be seen in countries with moderate and colder climate, but they are still common in hot and humid climate.

3C2) Mechanical extract and supply ventilation with heat recovery

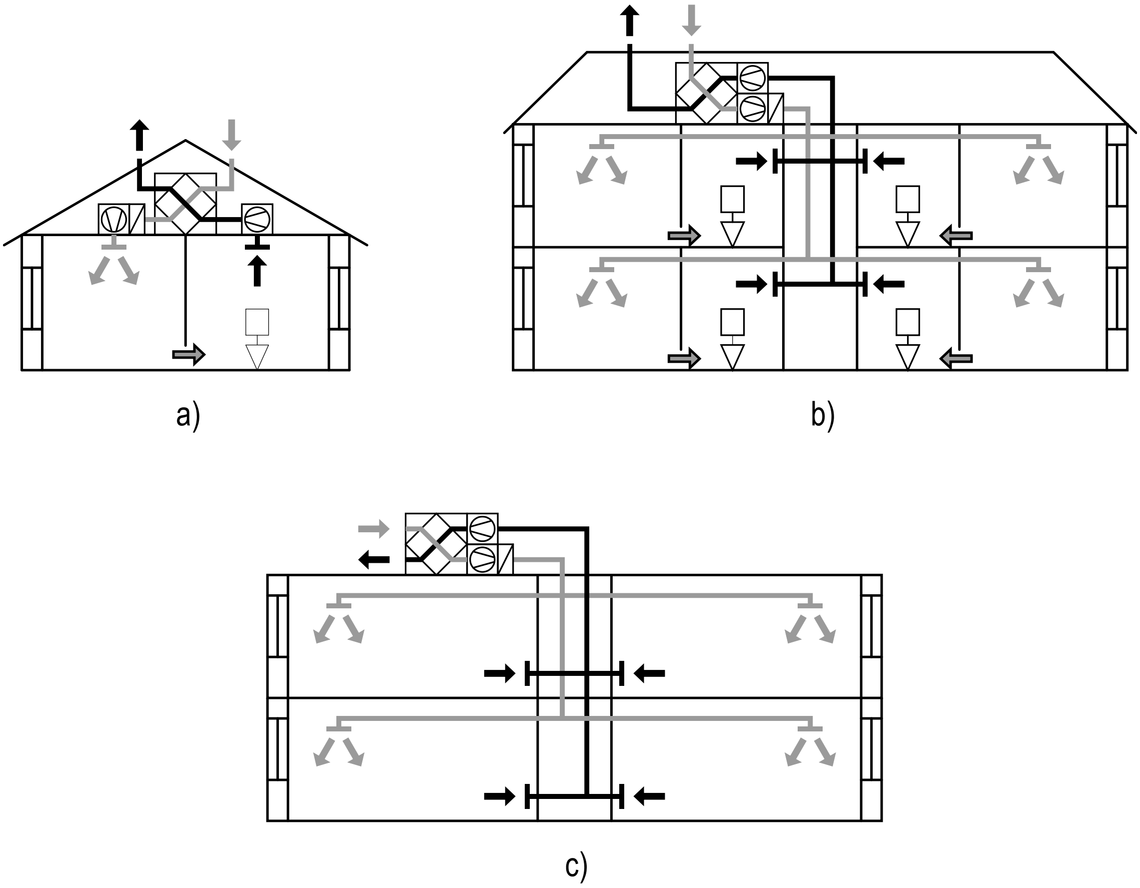


Figure 12: Ventilation system 3C2: a) house; b) apartment building; c) office building

This type of a mechanical extract and supply system does also include heat recovery. The most common are heat recovery exchangers used in air handling units. Almost all the supply and extract mechanical systems today in moderate and cold climate use heat recovery. There are several types of heat recovery types available on the market. They all work on the principle of temperature difference between exhaust and fresh air, so that in heating mode heat from the exhaust air flows in the direction of lower temperatures of the fresh air. Heat recovery is not so efficient in the cooling mode. This is also the reason why heat recovery is not common in countries with hot and humid climate.

4) Mechanical ventilation integrated with air-conditioning

Mechanical ventilation integrated with air-conditioning is very similar to the mechanical ventilation system 3C. However this system is not only used to provide required ventilation rates but also to control the temperature and/or humidity of the rooms it serves. The most common application of this system is with air handling units and supply and exhaust air. Decentralized systems are possible but are very rare in practice. In order to control the air temperature, ventilation rates are usually higher than those minimum required. Use of variable air volume rate (VAV) applications together with air recirculation is very common

Ventilation integrated with air-conditioning is used in some parts of Europe more than in others, but still such systems are very rare in comparison to the USA. In Europe it is widely used in hospitals and clean rooms where strict temperature and humidity levels exist, but such buildings are not in the scope of this project. This system does however occur in offices, schools and kindergartens, but it is extremely rare in dwellings.

4A) Ventilation integrated with air-conditioning without humidification

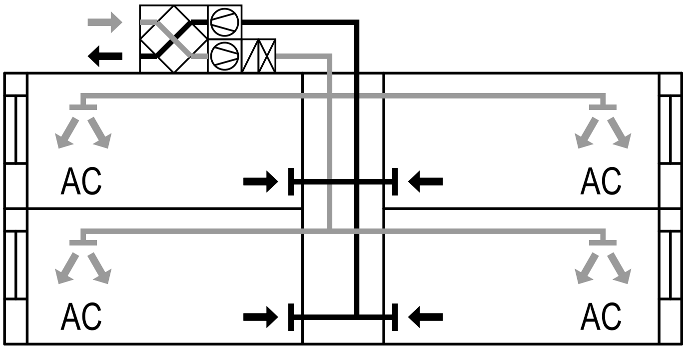


Figure 13: Ventilation system 4A

This subsystem has all the properties as described in under the definition of the system 4. However, it does not include humidification.

4B) Ventilation integrated with air-conditioning with humidification

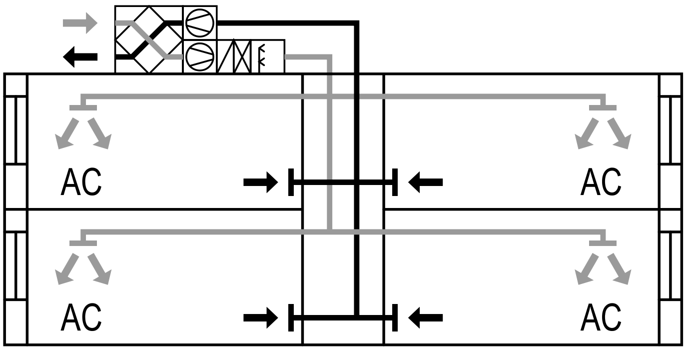


Figure 14: Ventilation system 4B

This subsystem has again all the properties as described in under the definition of the system 4, but does include humidification. Systems with humidification are rare however. They are expensive to operate and difficult to maintain. Such systems are widely used where humidity control is required (e.g. hospitals, clean rooms etc.) but not widely used in the buildings, which are the scope of the project, and humidity is usually not regulated, i.e. schools, offices and dwellings.

4 Ventilation systems in Europe

This chapter summarizes the results of the questionnaire on the distribution of ventilation systems in Europe. The numbers provided in this chapter are only estimates and should be treated with caution. They are not based on the systematic quantification but on the opinions and estimates collected through questionnaires.

4.1 Introduction

One of the tasks of this project was to carry out a survey of existing ventilation systems in Europe, with the aim to provide a broader picture of the type of ventilation systems used in different countries across Europe.

Throughout the years of development ventilation systems have been used differently across the EU countries. This is of significant importance for equipment manufacturers, who have to adapt to the various local practices and approach the market with a product, for which they know that it will fit well in the local habits, in order to be successful. Until now, there has been no detailed survey, which would analyse the ventilation systems across Europe and show how the practice differs from one European country to another.

The information gathered in this chapter provide data on the type of ventilation systems used in different EU member countries. The classification of ventilation systems is presented in section 3.2.

4.2 Questionnaire

The data were collected by a specially designed questionnaire (Appendix C) distributed to project partners and other national experts on ventilation. The questionnaire was built based on the definitions of ventilation systems, which are given in Chapter 3. The respondents were asked to estimate what type of ventilation system was used in different time periods in the past in the following buildings: houses, apartments, schools, kindergartens, and office buildings. The results are given as percentages. There were no predefined time periods and each respondent was asked to identify the changes as e.g. a result of change in the national codes and regulations.

The given responses were based either on national studies or national statistics and experts' own data. Where no official data were available and the respondents provided data based on their own estimates, the reliability of the given data is lower.

4.3 Results

Data from 11 countries were received from respondents from all parts of the Europe (Figure 15).

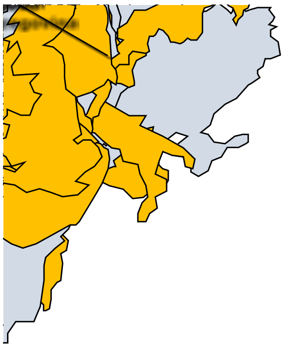


Figure 15: European countries which contributed information on national ventilation systems

The interpretation and comparison of the responses was difficult because each country provided data according to available reliable sources and specific construction year ranges. The data collected varied consequently depending on the available information in each country, some being more and some being less complete, as follows:

- Information for certain building types (Finland, France, Germany and Norway)
- Overall frequencies of ventilation types independently of building type (Bulgaria and Germany)
- No information, only indication of periods when changes to building regulations were introduced affecting ventilation requirements (Belgium, Greece, Italy, Portugal, Romania, United Kingdom)
- Overall frequencies of ventilation types and indication of periods when changes to building regulations were introduced (Finland, France and Norway)
- Frequencies of ventilation systems provided only for some systems; the remaining systems were considered as other systems to yield 100% (Norway)
- No information on frequencies of used ventilation systems only information on types of (Norway).

For some countries the information contained frequencies including more than one system category (e.g. for systems 1A, 1B, 2A & 2B). The frequencies for mechanical extract and supply ventilation systems were include generally the systems with and without heat recovery.

In order to improve the data collected by questionnaires, the results of the TABULA[1] project 2010 were used. TABULA contains statistics for existing building stock by building type (i.e. houses and apartment buildings). That method did not prove successful for all countries because the year ranges of the TABULA project do not match the year ranges for which the data was given in the questionnaires.

Data from questionnaires are presented in two groups, which both show that data sorted according to the considered building types:

a) Ventilation systems in building stock
b) Changes in the distribution of ventilation systems by construction year

The group a) under section 4.3.1 gives a good insight into the current status of ventilation systems that are installed in new buildings. These results are valid for the period since the last change of the ventilation regulations had been implemented in the respective countries. This period has different length since the changes of regulations occurred in different years. Nevertheless, these data give a good overview of the current situation concerning ventilation systems in new buildings.

The group b) under section 4.3.2 gives an insight into the development of ventilation systems for each country through years. The data are given as pie charts and the evolution (mainly due to changes in regulations) can be seen.

In total there are 15 systems and subsystems for which colours were designated (Table 2). The colours were chosen based on accurate visual distinction and on system and adjacent subsystems identification (i.e. different shades of the same colour).

Table 2: Ventilation systems and subsystems colour designation

(light green)	1A	Natural ventilation with air leakage
(green)	1B	Designed natural ventilation
(dark green)	1A, 1B	Natural ventilation
(light blue)	2A	Natural ventilation with local extract fans
(blue)	2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B)
(dark blue)	2A, 2B	Natural assisted with fans
(cyan)	1A, 1B, 2A, 2B	Natural ventilation with or without assisting fans
(light red)	3A	Mechanical extract ventilation
(red-brown)	3B	Mechanical supply ventilation
(dark brown)	3A, 3B	Mechanical ventilation
(yellow)	3C1	Mechanical extract and supply ventilation without heat recovery
(orange)	3C2	Mechanical extract and supply ventilation with heat recovery
(red)	3C1, 3C2	Mechanical with or without heat recovery

[1] TABULA – Typology Approach for Building Stock Energy Assessment. Project's official website: http://www.building-typology.eu/

	4A	Ventilation integrated with AC without humidification
	4B	Ventilation integrated with AC with humidification

4.3.1 Ventilation systems in existing building stock

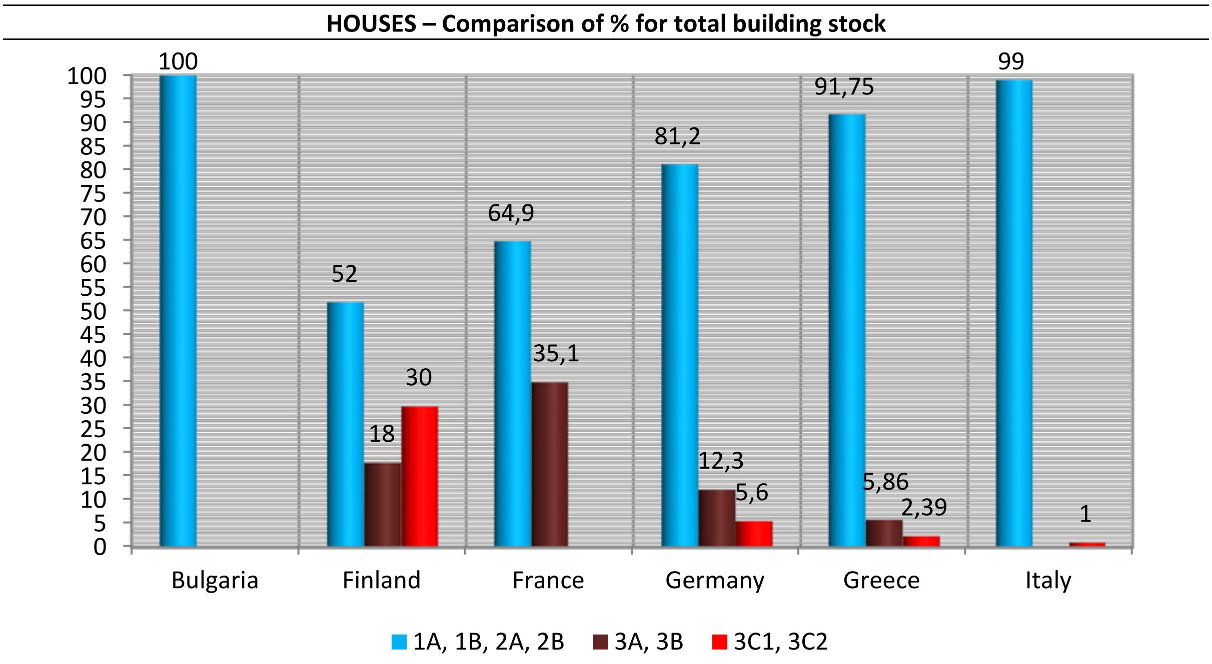
This approach integrates the overall percentages of the ventilation systems and subsystems presenting a comparison for the total existing building stock by building type. For these diagrams only the relevant systems and subsystems were taken in account (i.e. the ones for which data were provided) and only the countries for which the overall frequencies were provided or calculated. The collected and interpreted data is shown in Figure 16 and Figure 17. Data were received only for houses, apartment buildings, schools and kindergartens.

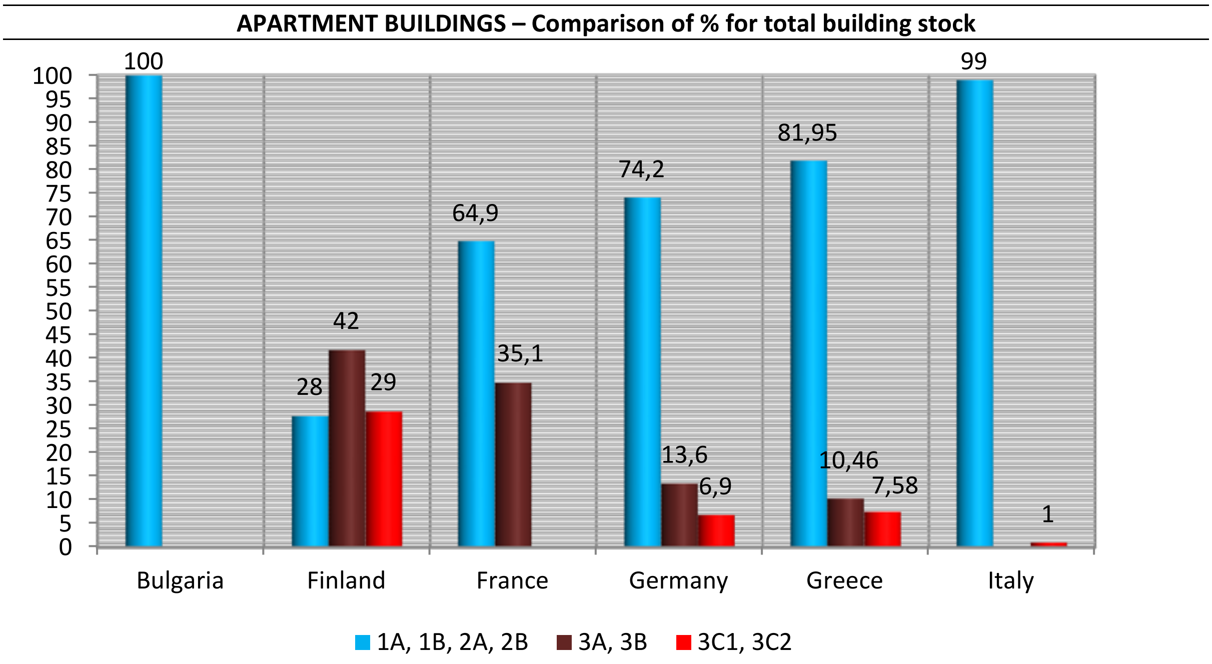
For **houses** the distribution of ventilation systems, presented in Figure 16, clearly shows that natural ventilation and fan assisted natural ventilation account for more than 50% of total existing systems. The values vary from Bulgaria with 100% natural to Finland with 52% natural and 48% mechanical.

For **apartment buildings**, also presented in Figure 16, the situation is almost the same with slight differences for Greece and Germany but with obvious domination of mechanical ventilation in Finland.

It is interesting to observe that France has only extract or supply mechanical ventilation whereas Greece and Germany have one third of the mechanical ventilation systems with extract and supply (frequencies given together for with or without heat recovery) and Finland has more than half of the houses and almost half of the apartments equipped with supply and extract mechanical ventilation.

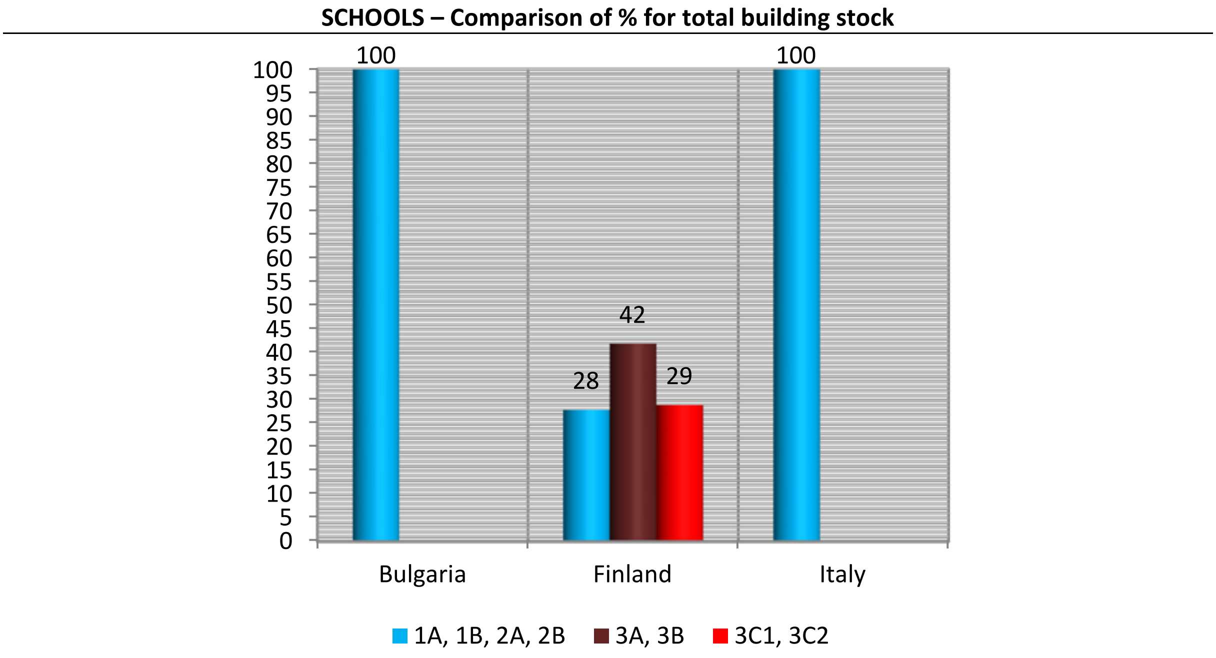
For **schools** and **kindergartens**, presented in Figure 17, only Bulgaria, Finland and Italy are have sufficient data for comparison. As well as for schools as for kindergartens, natural ventilation is the only ventilation system applied in Bulgaria and Italy. Finland on the other hand has again, as for the dwellings, more mechanical ventilation systems than natural ones. This can be seen especially in the case of kindergartens were 79% of systems are supply and extract mechanical ventilation and only 5% natural ventilation, leaving the rest of 16% also to mechanical ventilation but supply or extract.

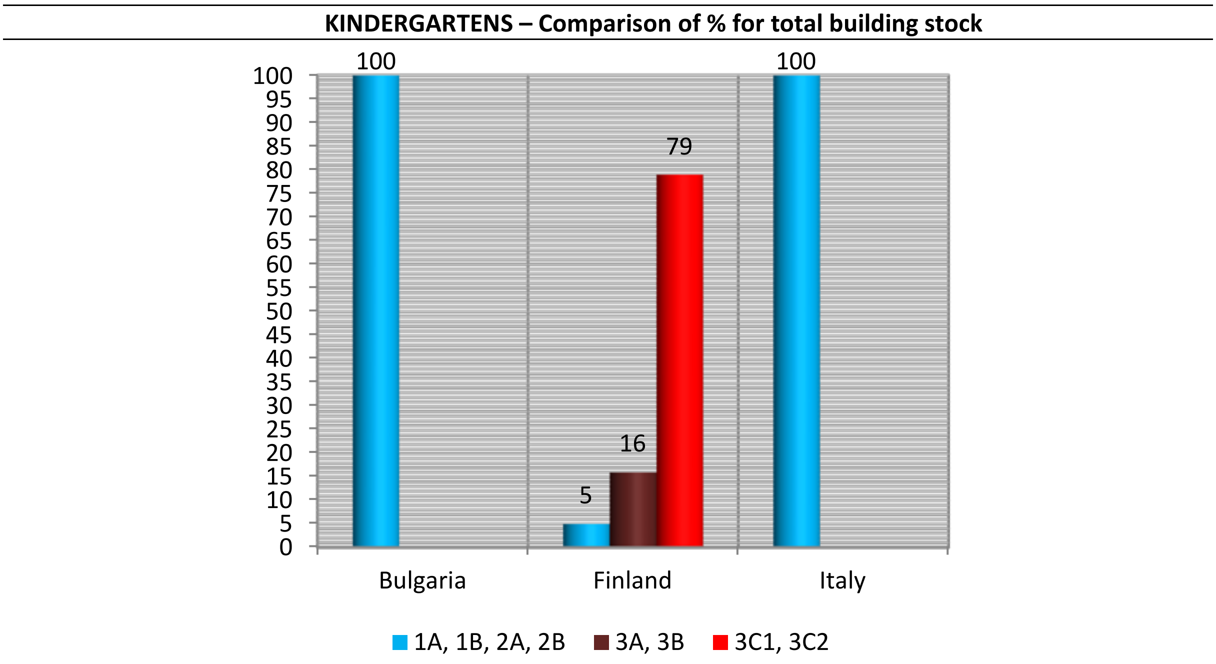




1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation with heat recovery;
3C2	Mechanical extract and supply ventilation without heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 16: Ventilation systems of all houses and apartment buildings in percentages of the floor area or of the number of buildings.





1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation with heat recovery;
3C2	Mechanical extract and supply ventilation without heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 17: Ventilation systems of all schools and kindergartens in percentages of the floor area or of the number of buildings.

4.3.2 Changes in the distribution of ventilation systems by construction year

This section illustrates the changes that occurred in the distribution of ventilation systems within the building stock during the years. The collected data are grouped first by the building type and second by the country. For each country the number of diagrams depends on the number of construction year periods reported by national experts (they vary from two up to six and reflect the changes in the building regulations and in the construction practice).

A Single family houses

Before 1980 mainly natural ventilation was used.

Finland was the first country to make a change, i.e. before 1959, by introducing mechanical supply and/or extract ventilation systems, i.e. 12% mechanical extract or supply ventilation and 8% mechanical extract and supply ventilation. Gradually the situation evolved reaching the point that all constructed buildings after 2004 have mechanical ventilation systems, i.e. 7% mechanical extract or supply ventilation and 93% mechanical supply and extract.

In **The United Kingdom** major changes took place between 1980 and 2010, during which the constructed buildings assured ventilation through natural ventilation with local extract fans or hybrid ventilation, and also mechanical supply and/or extract ventilation, i.e. natural ventilation with local extract fans and hybrid ventilation increased from 2% before 1980 to 75% between 2001 and 2010. After 2011 mechanical ventilation systems account for half of systems in constructed houses, i.e. 35% mechanical extract or supply ventilation and 15% mechanical extract and supply with heat recovery.

For **Greece** 1978 was the turning point after which more natural ventilation with local extract fans, hybrid ventilation and mechanical extract and/or supply systems were used. The situation has been evolving but natural ventilation accounts for half of the systems after 1978, i.e. 50% natural ventilation, 30% natural ventilation with local extract fans and hybrid ventilation, 15% mechanical extract or supply and 5% mechanical extract and supply without heat recovery.

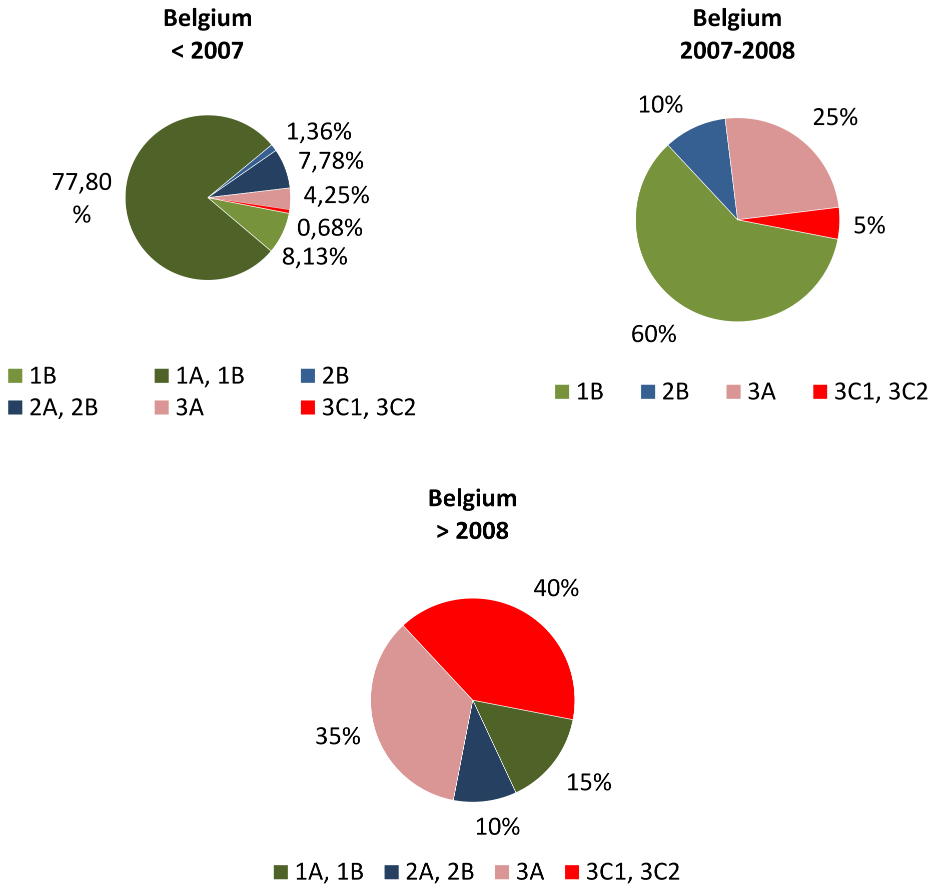
In **Belgium** there were more mechanical systems than natural ventilation systems after 2008, i.e. 15% natural ventilation, 10% natural ventilation with local extract fans and hybrid ventilation, 35% mechanical extract ventilation and 40% mechanical extract and supply.

Portugal - although having favoured natural ventilation with local extract fans over natural ventilation - introduced mechanical ventilation systems only as hybrid ventilation. Natural ventilation with local extract fans and hybrid ventilation increased from 10% between 1980 and 1990 to 80% after 2007, while the rest of the percentages accounted for natural ventilation.

Romania manifested an obvious migration after 2010, since when 20% of the constructed houses have mechanical ventilation systems. Until 2008 more than 99% of the buildings had natural ventilation systems.

In the case of **Norway** the collected data show decreasing use of natural ventilation in favour of other ventilation systems. The evolution was from approximately 59% natural ventilation before 1976 to approximately 11% natural ventilation between 1997 and 2007.

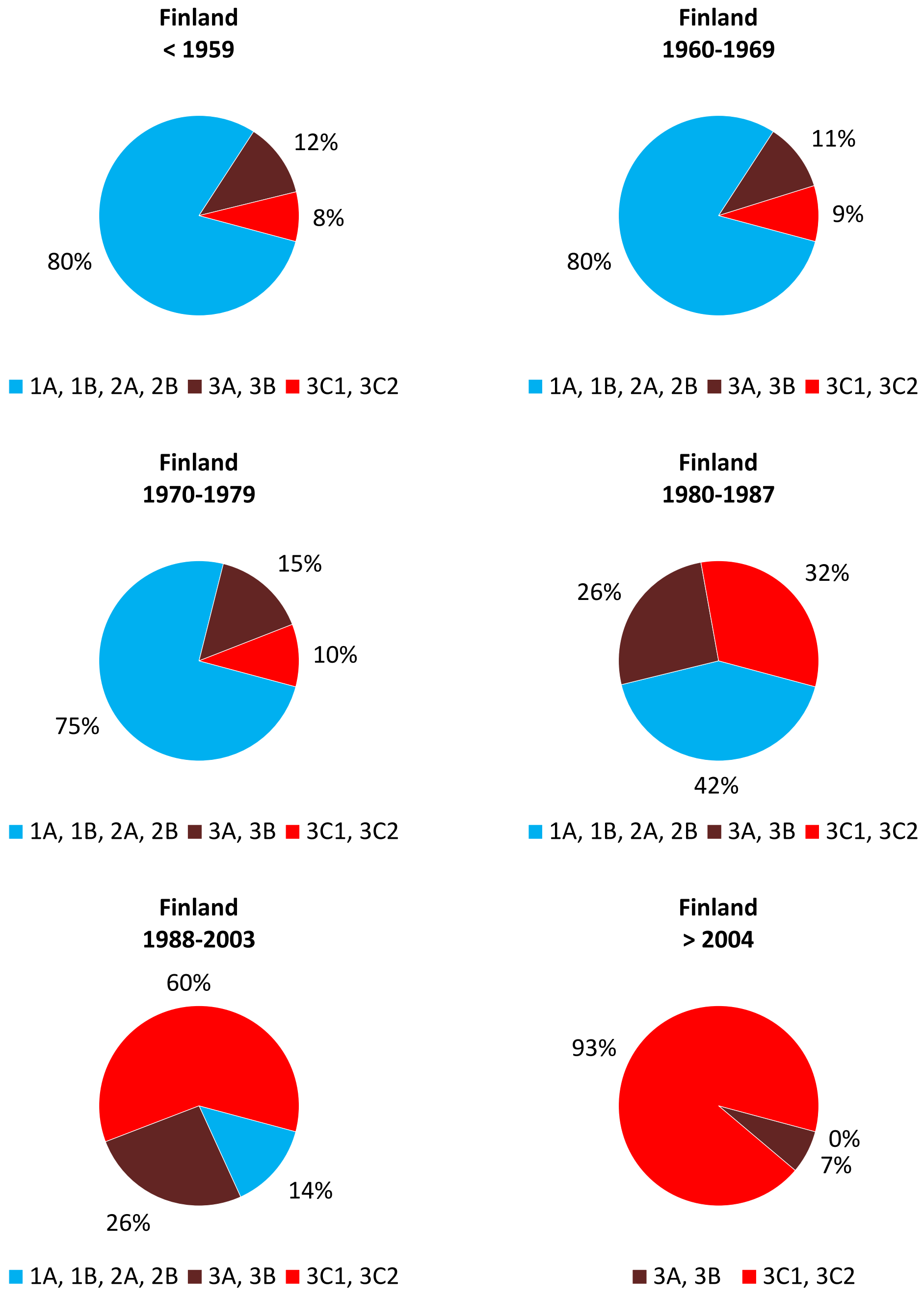
SINGLE FAMILY HOUSES – Evolution of % in Belgium



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

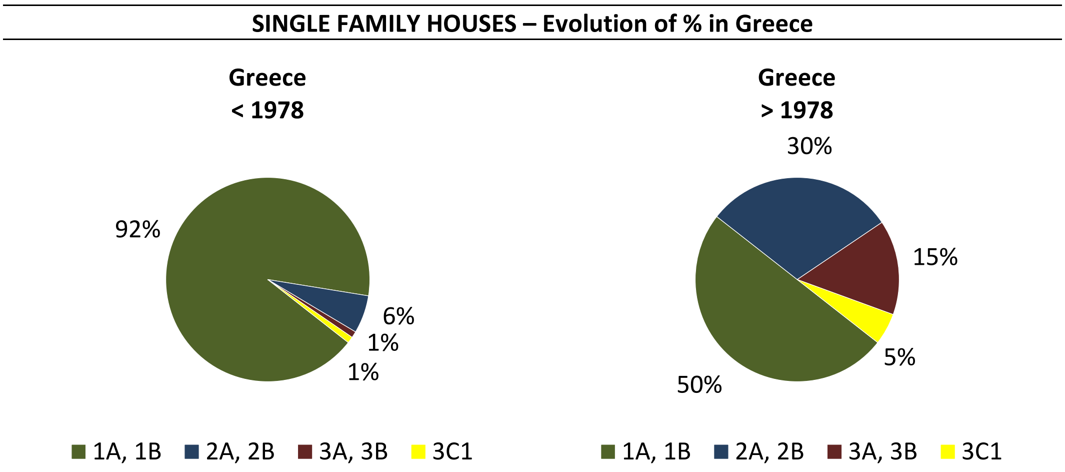
Figure 18: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in single family houses in Belgium.

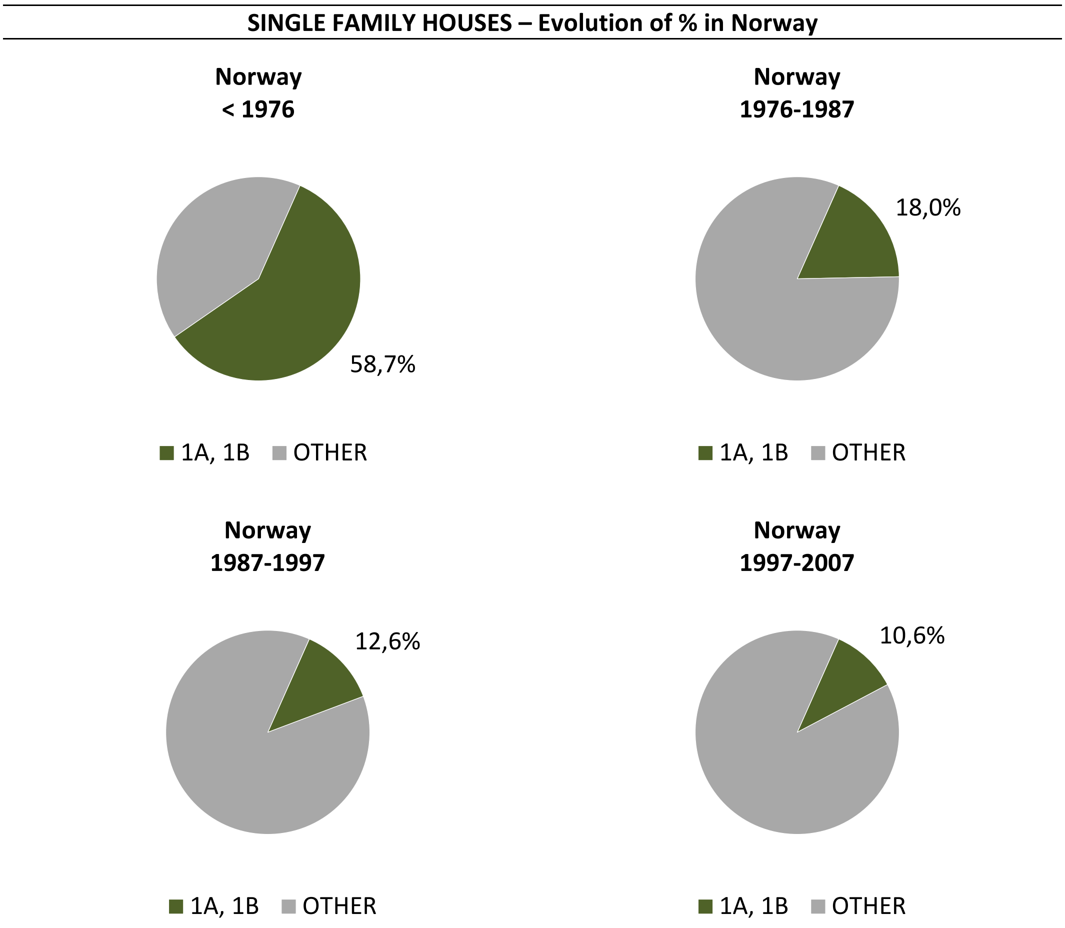
SINGLE FAMILY HOUSES – Evolution of % in Finland



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 19: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in single family houses in Finland.

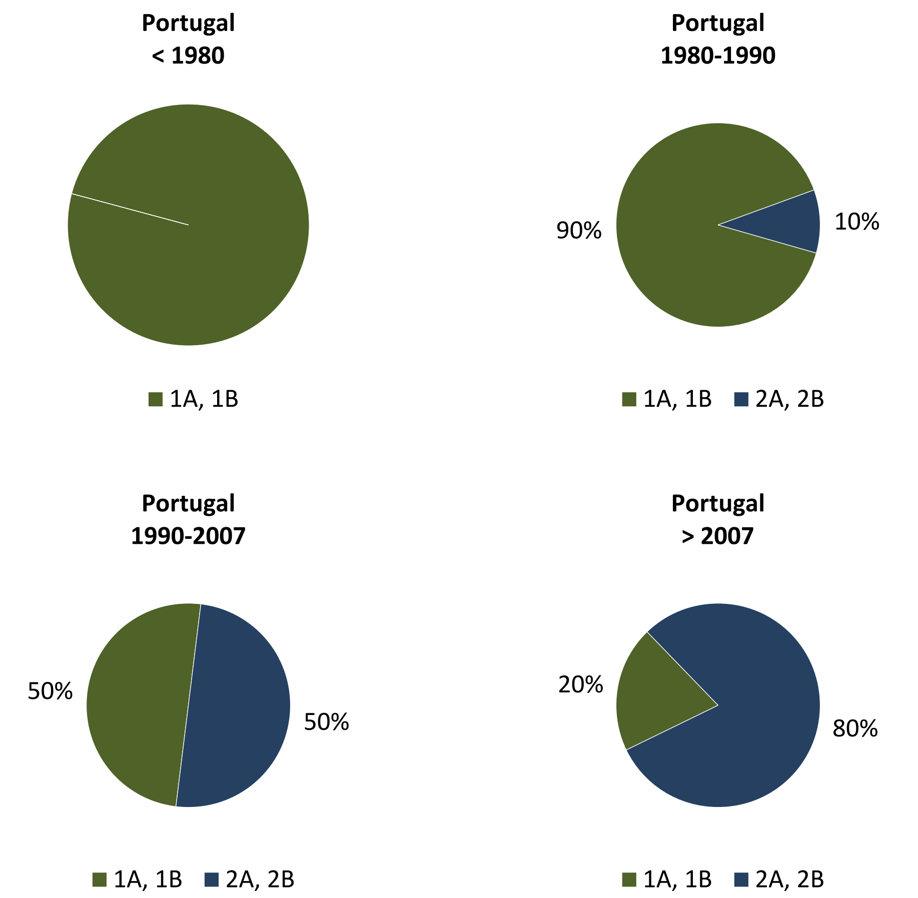




1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 20: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in single family houses in Greece and in Norway.

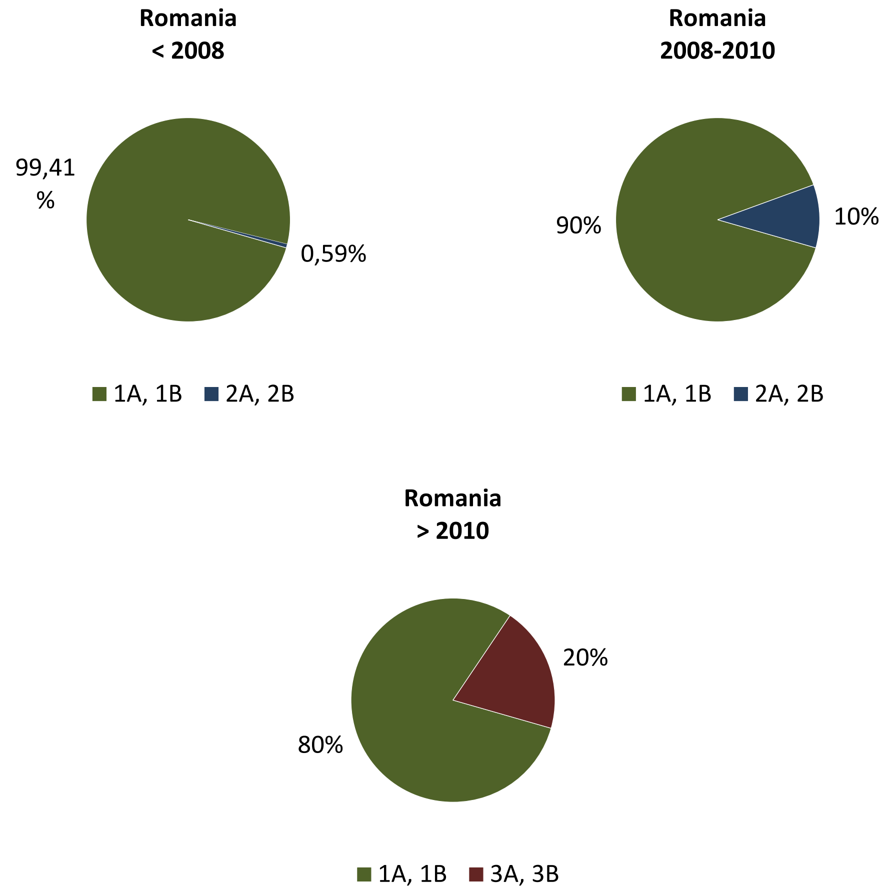
SINGLE FAMILY HOUSES – Evolution of % in Portugal



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

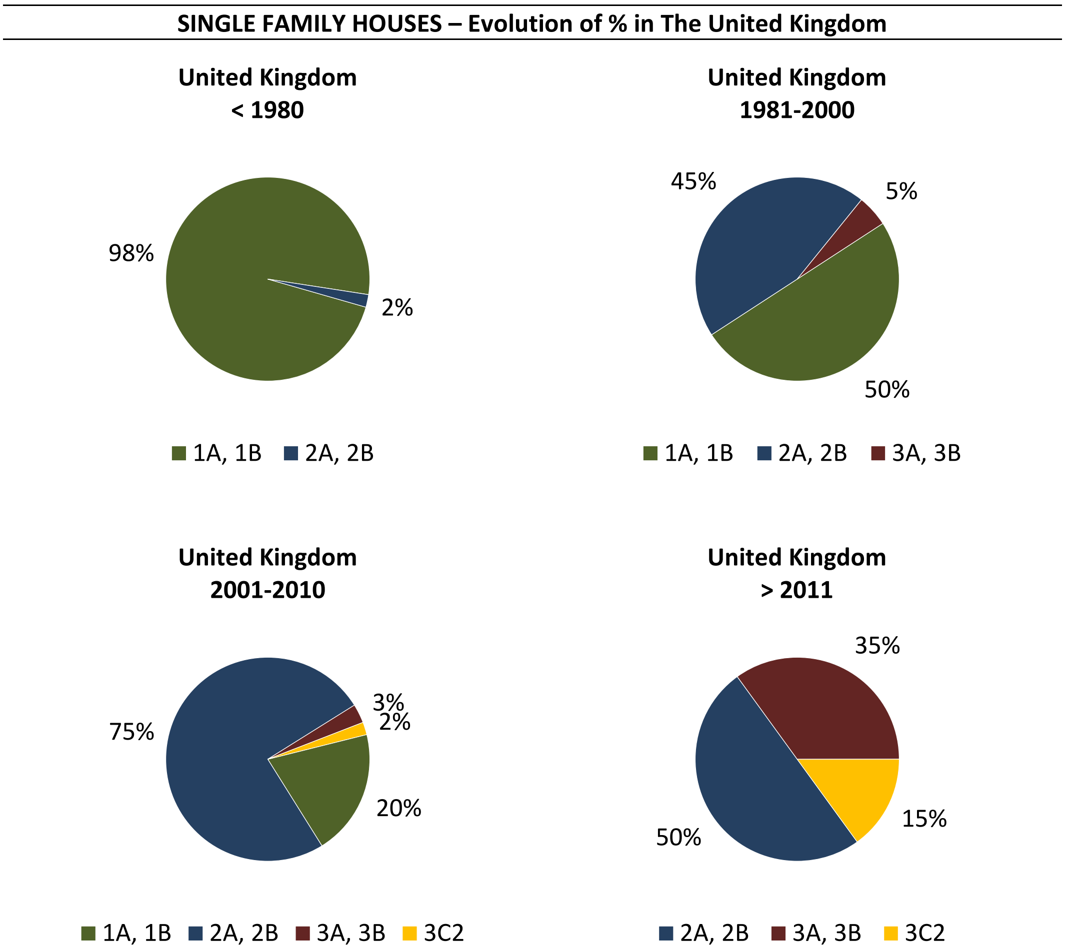
Figure 21: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in single family houses in Portugal.

SINGLE FAMILY HOUSES – Evolution of % in Romania



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 22: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in single family houses in Romania.



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 23: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in single family houses in The United Kingdom.

B Apartment buildings

Similarly to the single-family house the distribution of ventilation systems in apartment buildings shifted towards mechanical ventilation from natural ventilation. The distribution of ventilation system evolved with in a different way for each country:

In **Belgium** before 2007 the largest share of ventilation systems was assigned to natural ventilation systems with a percentage of approximately 88%. Mechanical extract ventilation accounted for most of the rest, leaving approximately 1,5% for mechanical extract and supply ventilation. After 2008 the percentages for natural ventilation decreased to 55% (40% hybrid ventilation) and the percentages for mechanical ventilation increased to 45% (10% mechanical extract and supply ventilation).

Finland after 2004 has 91% mechanical ventilation (i.e. 73% supply and extract and 18% extract or supply) and 9% natural ventilation. The distribution of ventilation systems evolved gradually from buildings before 1959 with 66% natural ventilation and 34% mechanical ventilation increasing mechanical ventilation, at first mechanical extract or supply ventilation and after 1988 mechanical extract and supply ventilation.

The distribution of ventilation systems changed in **Greece** after 1978. Before 1978 97% of ventilation systems were natural ventilation systems. After 1978 the percentage of natural ventilation systems decreased to 65% (25% hybrid ventilation). The mechanical ventilation systems accounts for 35% (15% mechanical supply and extract without heat recovery).

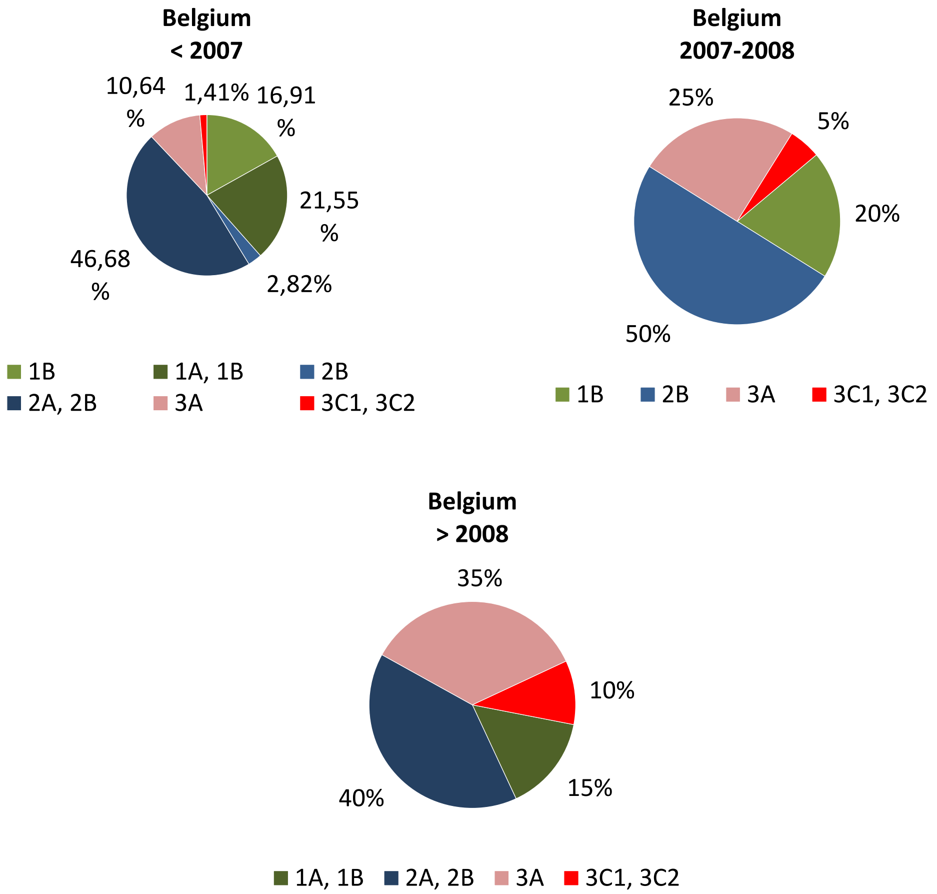
For **Norway**, as for houses, the data collected presents the decrease of natural ventilation systems in favour of other mechanical ventilation systems i.e. from approximately 59% before 1976 to approximately 11% between 1997 and 2007.

Portugal still has 100% natural ventilation systems. The evolution has been within natural ventilation systems from natural ventilation to natural ventilation with local extract fans or hybrid ventilation. Natural ventilation with local extract fans and hybrid ventilation have increased from 10% before 1980 to 100% after 2007.

In **Romania** after 2008 natural ventilation systems started to be replaced with hybrid ventilation or natural ventilation with local extract fans. After 2010 natural ventilation systems decreased to 80% leaving the rest of 20% for mechanical supply or extract ventilation.

In **The United Kingdom** before 2010 natural ventilation systems accounted for 100%. The percentages within the natural ventilation systems evolved from 20% natural ventilation with local extract fans before 1980 to 80% natural ventilation with local extract fans and 18% hybrid ventilation between 2001 and 2010. After 2010 hybrid ventilation accounts for 20% and the rest of 80% is distributed 60% mechanical extract ventilation, 15% mechanical supply and extract and 5% ventilation integrated with AC without humidification.

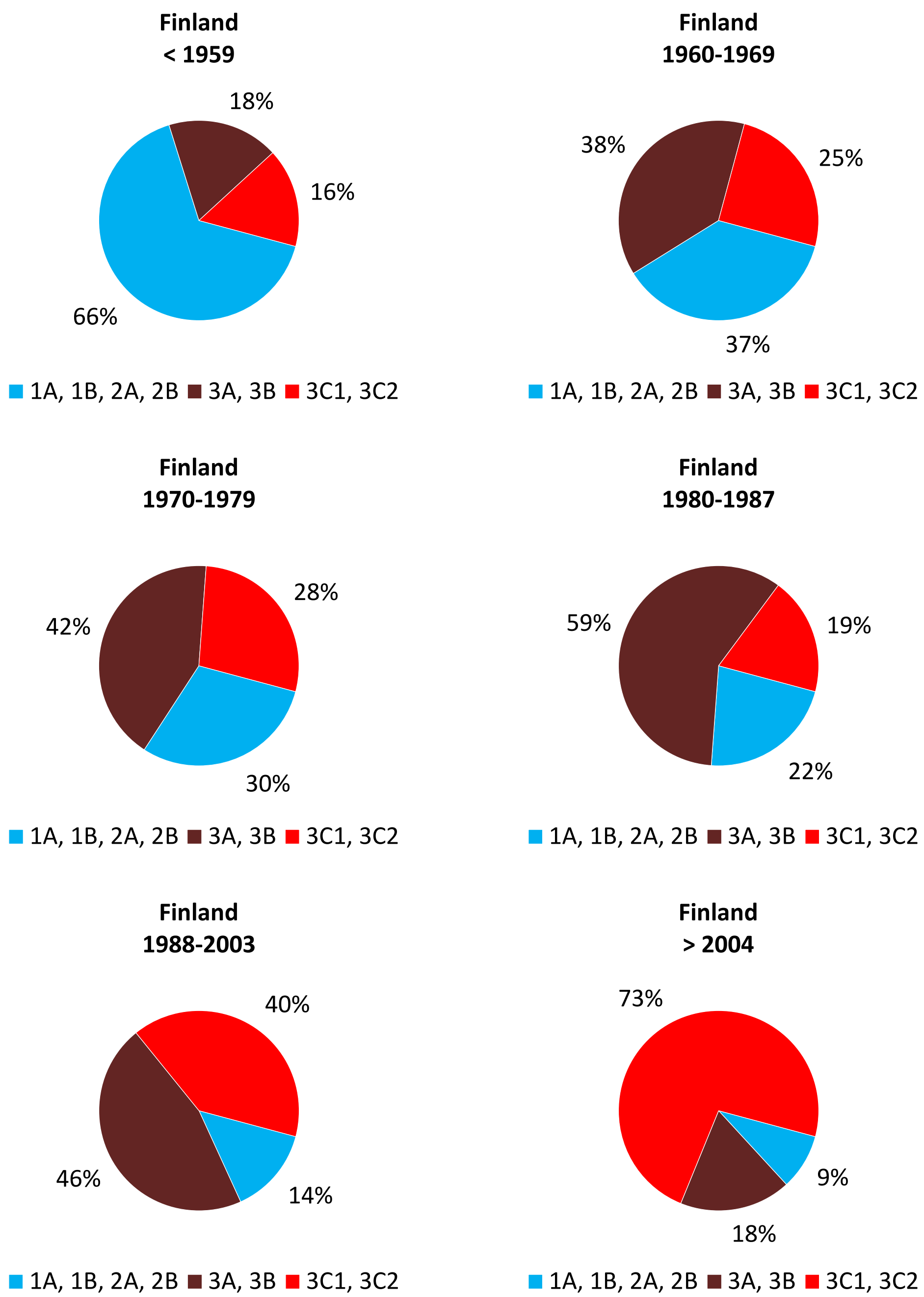
APARTMENT BUILDINGS – Evolution of % in Belgium



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 24: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in apartment buildings in Belgium.

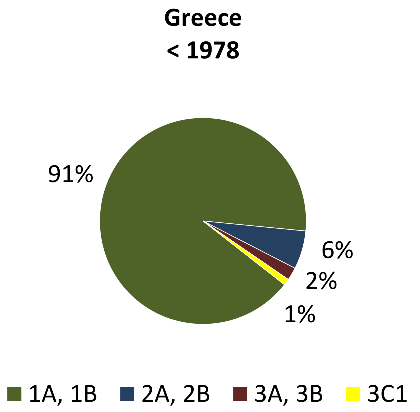
APARTMENT BUILDINGS – Evolution of % in Finland

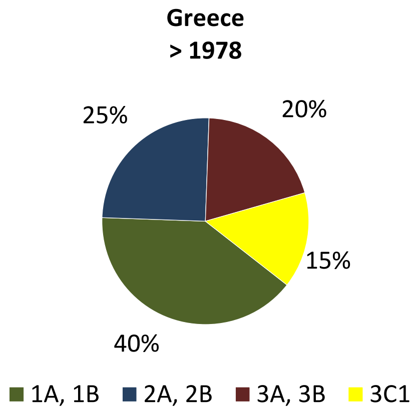


1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

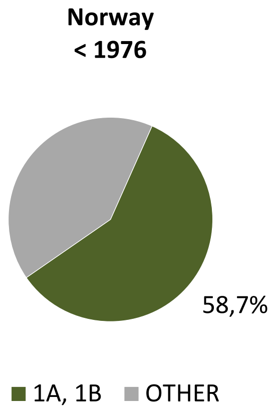
Figure 25: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in apartment buildings in Finland.

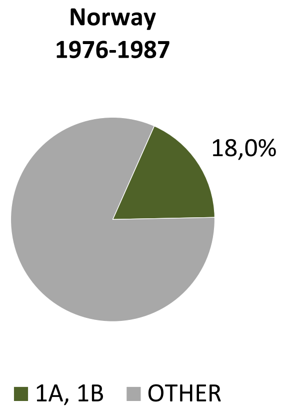
APARTMENT BUILDINGS – Evolution of % in Greece

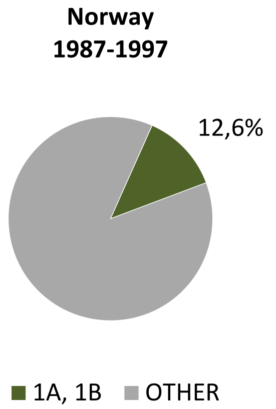


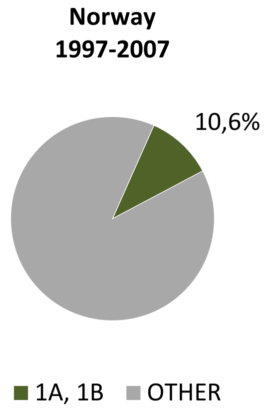


APARTMENT BUILDINGS – Evolution of % in Norway





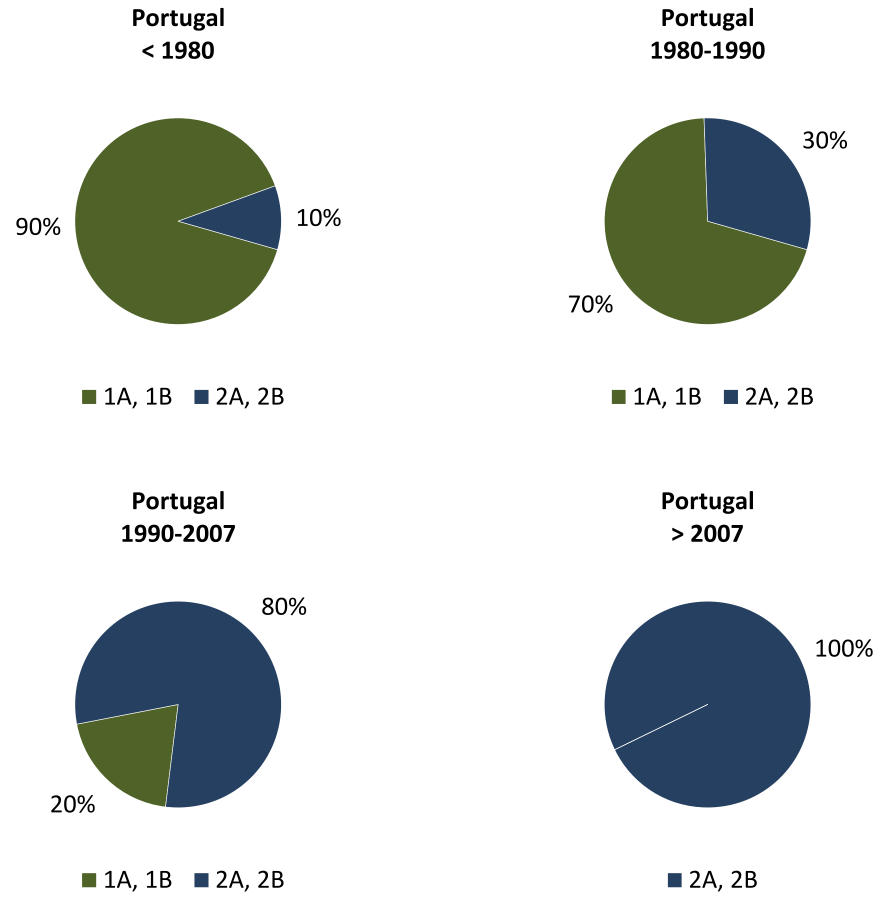




1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 26: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in apartment buildings in Greece and in Norway.

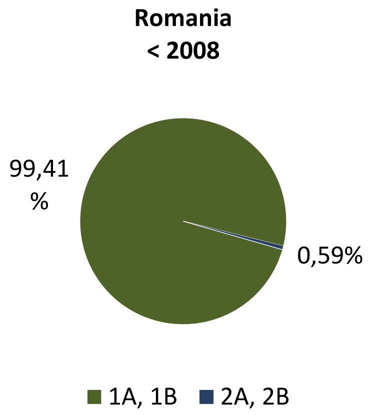
APARTMENT BUILDINGS – Evolution of % in Portugal

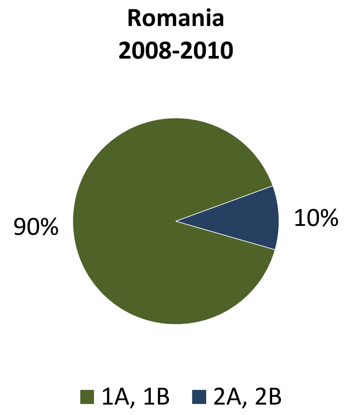


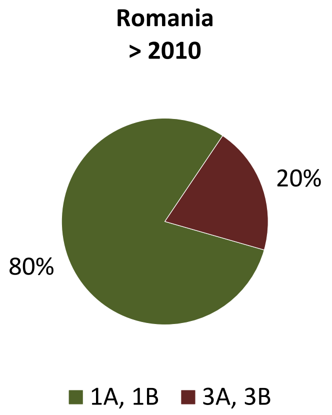
1A Natural ventilation;
1B Designed natural ventilation;
2A Natural ventilation with local extract fans;
2B Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A Mechanical extract ventilation;
3B Mechanical supply ventilation;
3C1 Mechanical extract and supply ventilation without heat recovery;
3C2 Mechanical extract and supply ventilation with heat recovery;
4A Ventilation integrated with AC without humidification;
4B Ventilation integrated with AC with humidification.

Figure 27: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in apartment buildings in Portugal.

APARTMENT BUILDINGS – Evolution of % in Romania

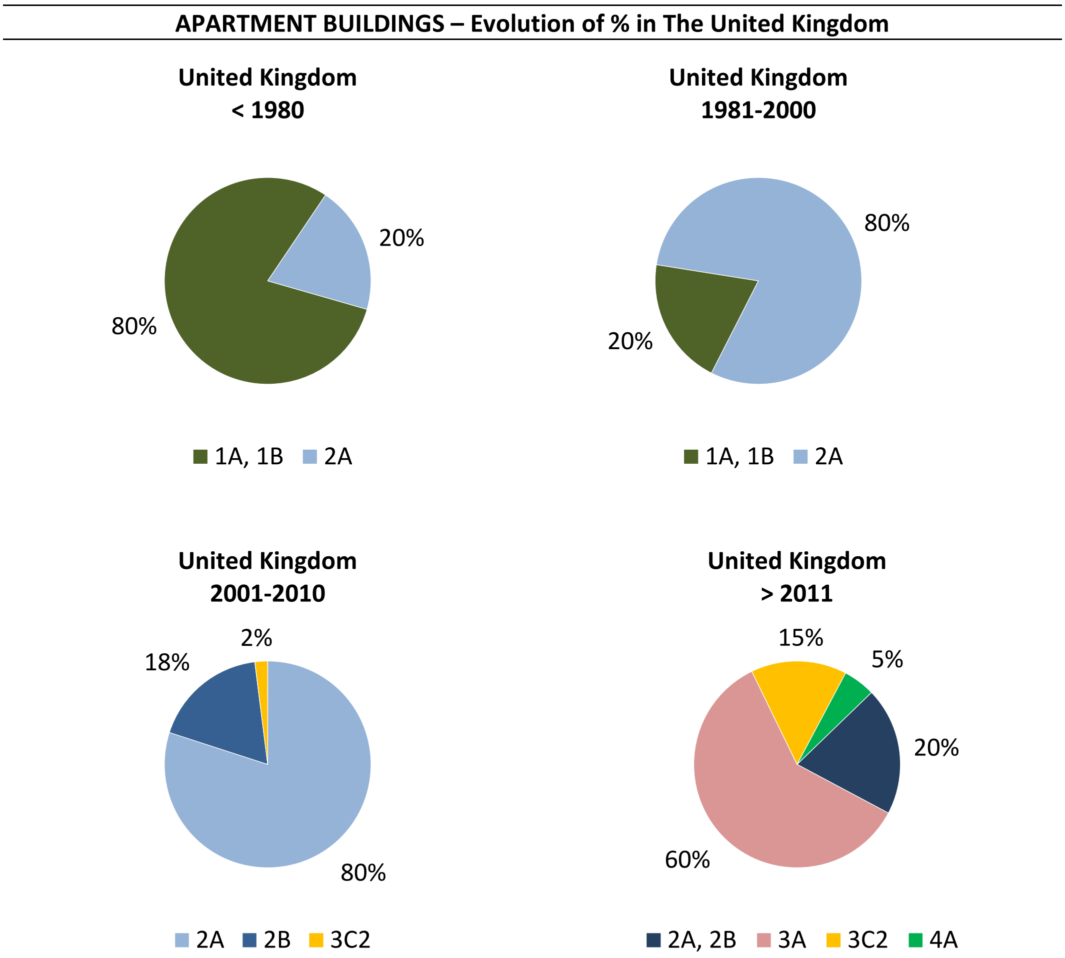






1A Natural ventilation;
1B Designed natural ventilation;
2A Natural ventilation with local extract fans;
2B Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A Mechanical extract ventilation;
3B Mechanical supply ventilation;
3C1 Mechanical extract and supply ventilation without heat recovery;
3C2 Mechanical extract and supply ventilation with heat recovery;
4A Ventilation integrated with AC without humidification;
4B Ventilation integrated with AC with humidification.

Figure 28: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in apartment buildings in Romania.



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 29: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in apartment buildings in The United Kingdom.

C Schools

In **Belgium** the share of natural ventilation systems decreased during the years from 99% before 1991 to 80% after 2008. After 2008 natural ventilation systems account for 80% (30% hybrid ventilation or natural ventilation with local extract fans) while mechanical ventilation accounts for 20%, i.e. 10% mechanical extract ventilation and 10% mechanical supply and extract ventilation (2% with heat recovery).

Finland focused on mechanical extract and/or supply ventilation from before 1959. Between 1960 and 1969 the share of natural ventilation systems decreased to 14% from 33% in schools built before 1959 and continued to do so between 1988 and 2003 when it accounted for 2% of the ventilation systems. After 2004 mechanical ventilation systems account for 100% i.e. 4% mechanical extract or supply ventilation and 96% mechanical extract and supply.

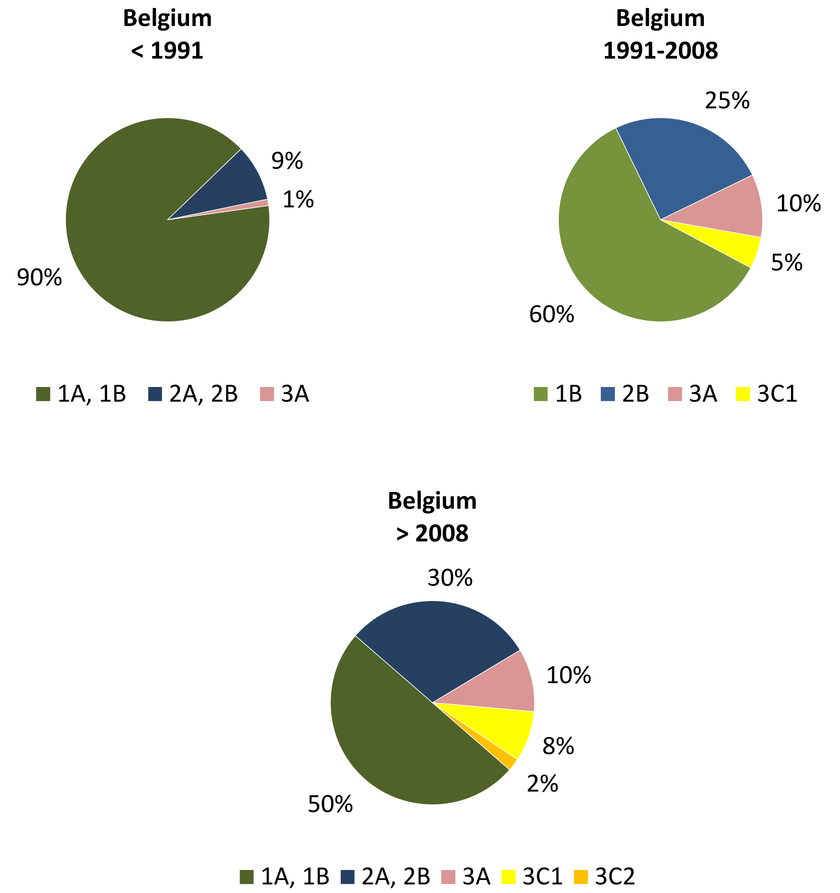
Mechanical extract ventilation increased from 40% between 1969 and 2002 to 95% after 2002, in **France**. Between 1969 and 2002 the other ventilation systems were natural ventilation systems i.e. 29% natural ventilation (also designed) and 30% hybrid ventilation and natural ventilation with local extract fans, and 1% mechanical supply and extract with heat recovery. After 2002 the rest of 5% represents mechanical supply and extract.

2007 was the year of changes in the distribution of ventilation systems in **Portugal** i.e. from 100% natural ventilation to 100% ventilation integrated with air conditioning without humidification.

The evolution in **Romania** was from natural ventilation (also designed), which accounted for 100% before 1998, to mechanical extract and supply ventilation with heat recovery, which accounted for 20% between 1998 and 2010 and accounts after 2010 for 30% of the ventilation systems.

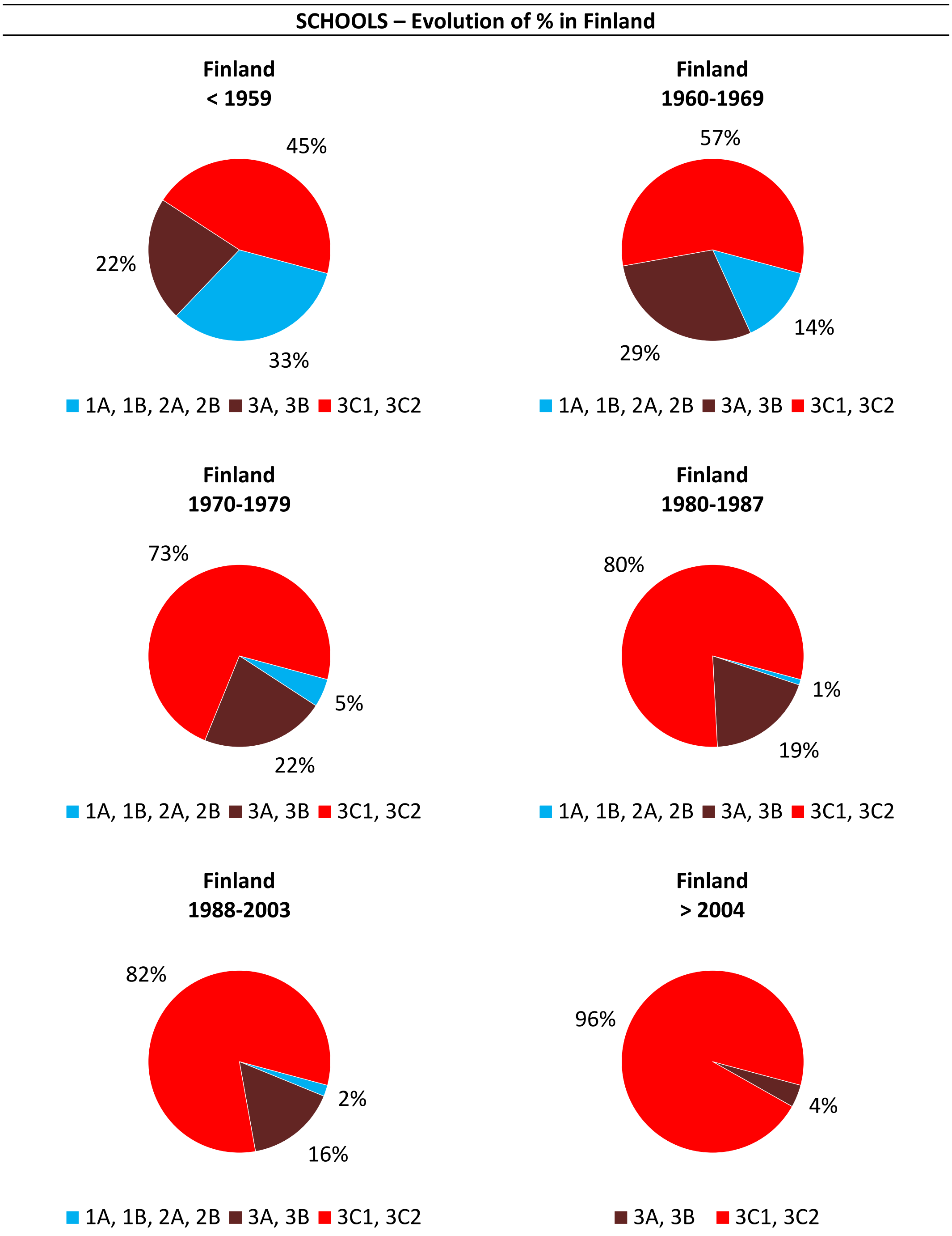
In the **United Kingdom** hybrid ventilation systems were installed between 1981 and 2000 when the shares became 80% hybrid ventilation, 10% mechanical extract ventilation and 10% mechanical extract and supply with heat recovery. After 2001 the shares of mechanical ventilation systems increased to 20% mechanical extract or supply ventilation and 20% mechanical extract and supply ventilation. After 2011 hybrid ventilation accounts for 30%, mechanical extract ventilation for 20% and the rest of 50% is accounted by mechanical supply and extract with heat recovery.

SCHOOLS – Evolution of % in Belgium



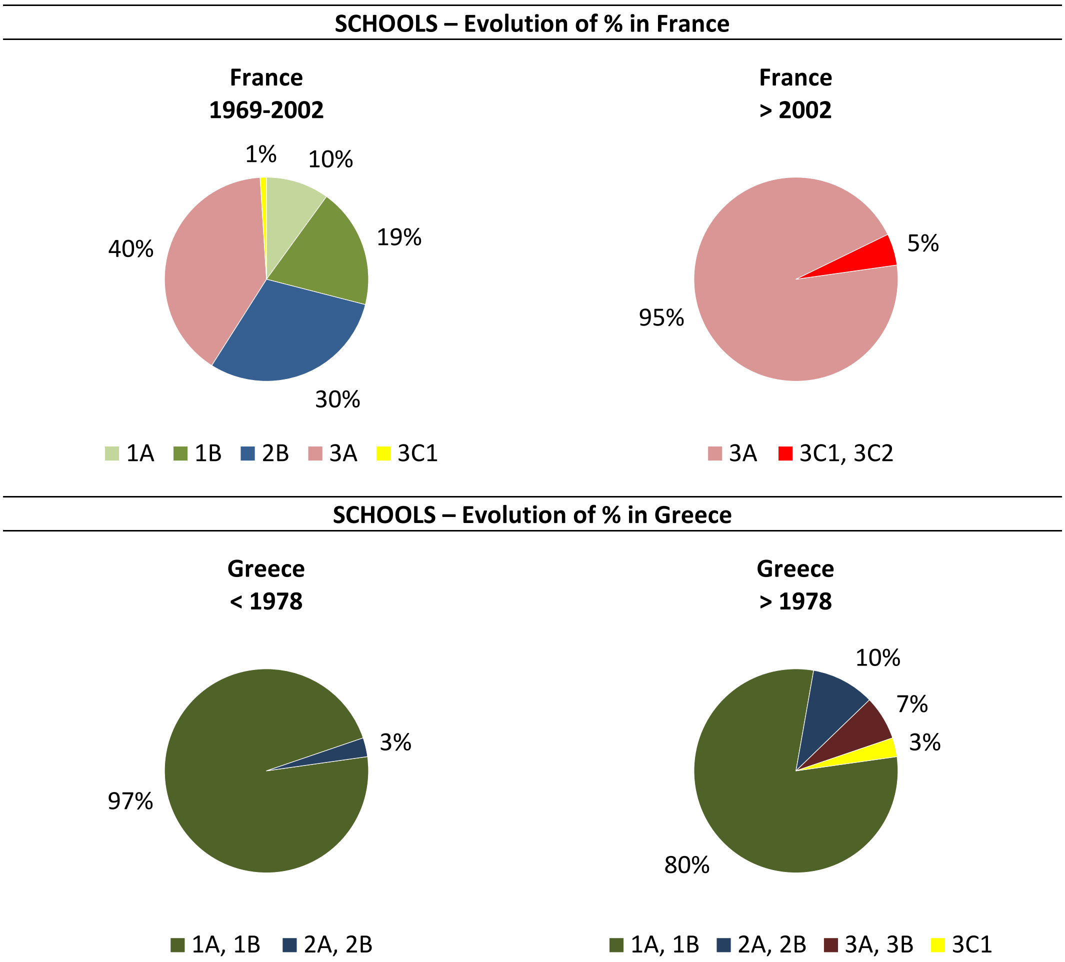
1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 30: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in schools in Belgium.



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

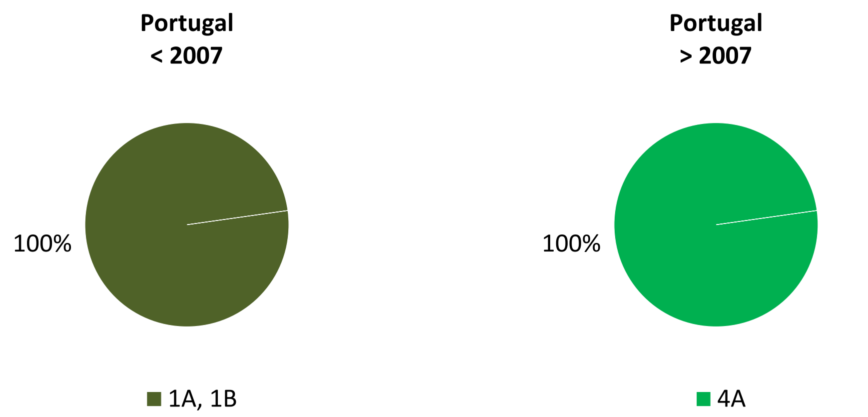
Figure 31: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in schools in Finland.



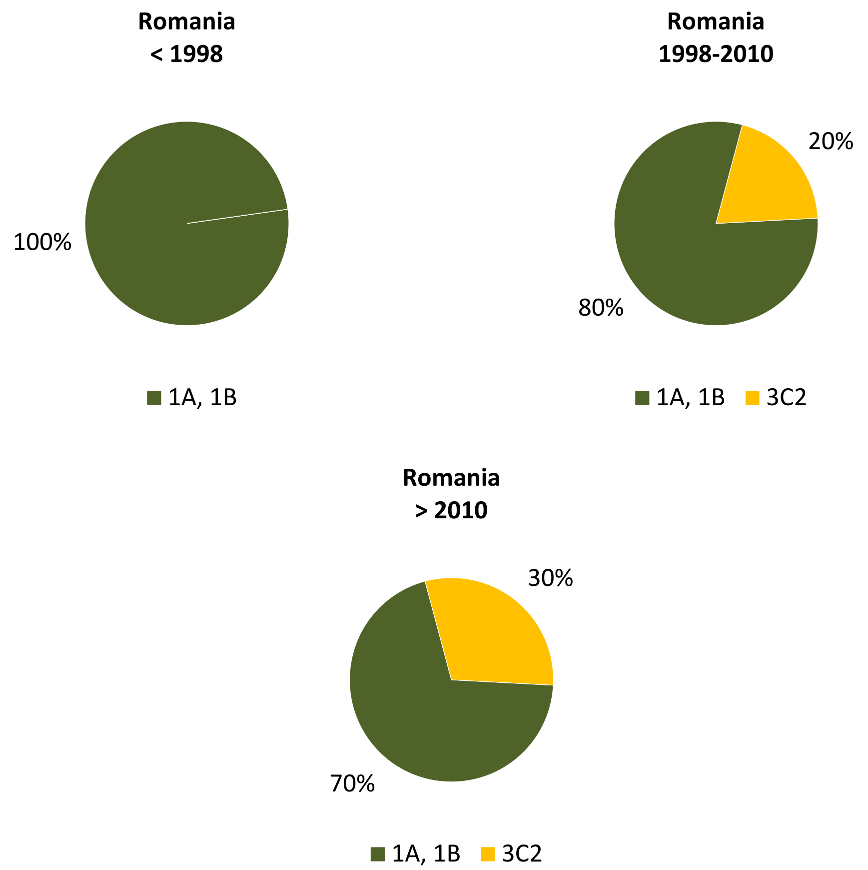
1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 32: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in schools in France and Greece.

SCHOOLS – Evolution of % in Portugal

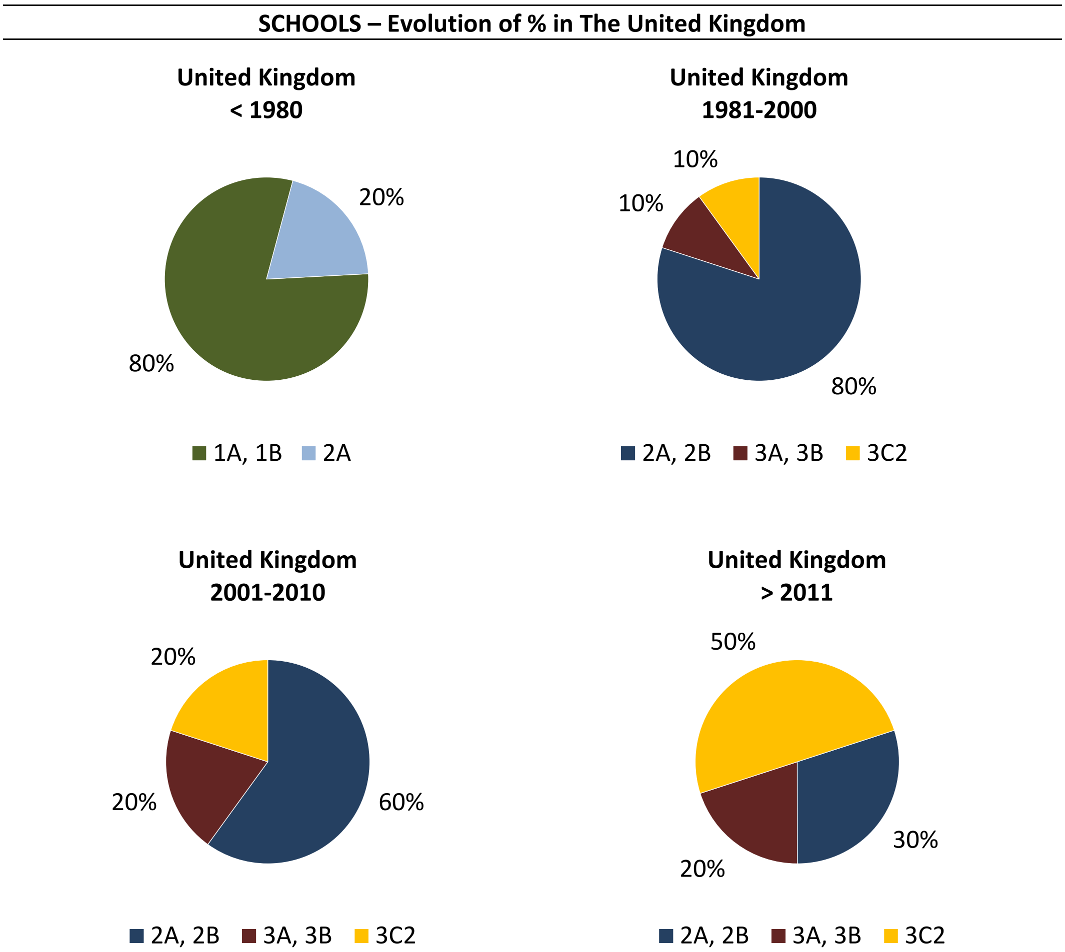


SCHOOLS – Evolution of % in Romania



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 33: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in schools in Portugal and in Romania.



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 34: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in schools in The United Kingdom.

D Kindergartens

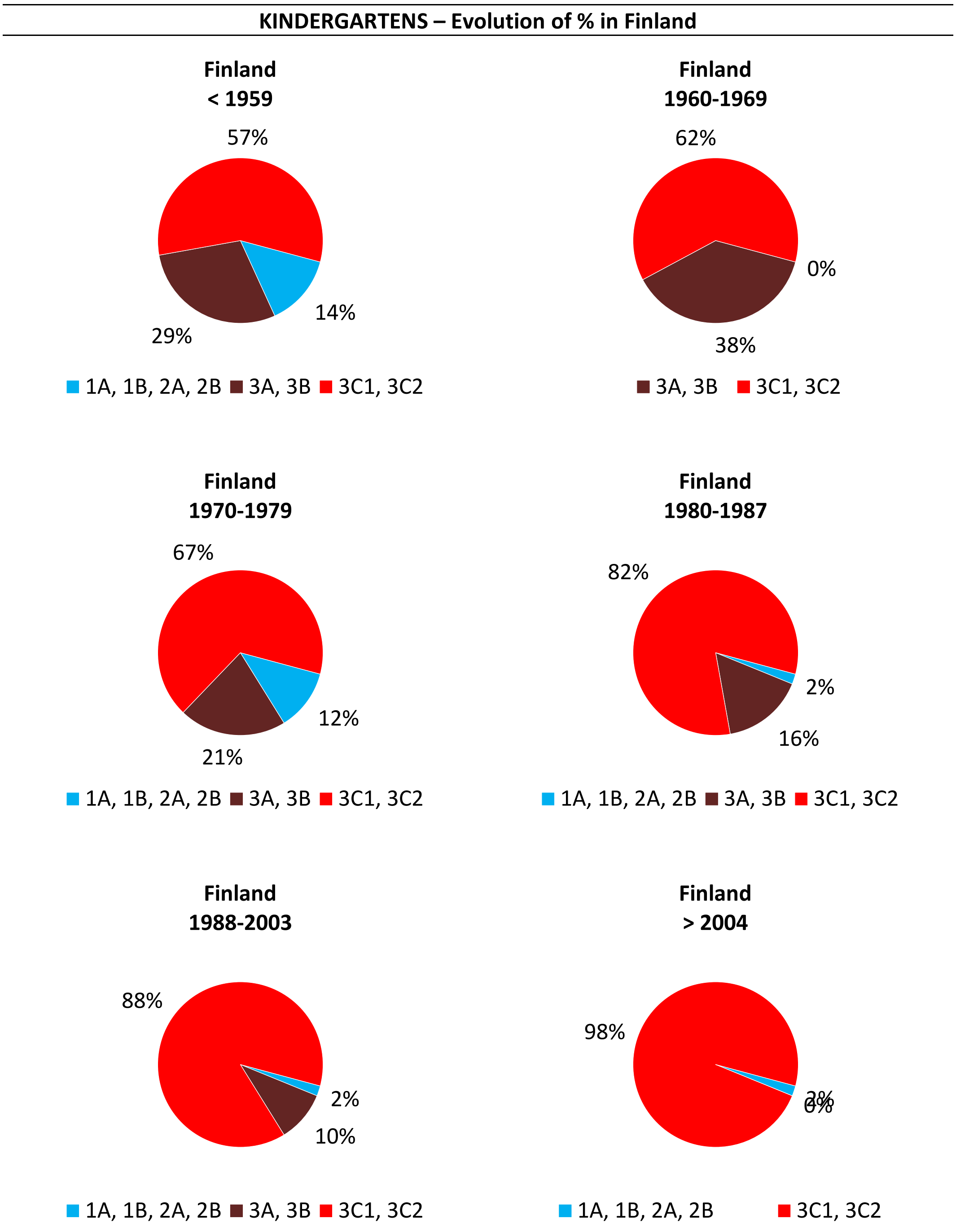
Finland used mechanical extract and/or supply ventilation from before 1959. After 1960 the natural ventilation systems share decreased gradually to 2% from 14% in schools built before 1959. At the same time mechanical ventilation systems increased from 86% before 1959 to 98% after 2004. It is worth mentioning that within the mechanical ventilation systems the mechanical extract or supply ventilation systems were gradually fully replaced with mechanical extract and supply ventilation systems (with or without heat recovery).

In **Greece**, natural ventilation systems account for 94% of ventilation systems after 1978 and accounted for 100% of ventilation systems before 1978. After 1978 the rest of 6% of ventilation systems is split between mechanical extract ventilation 5% and mechanical extract and supply ventilation with heat recovery 1%.

2007 was the year of dramatic changes in the distribution of ventilation systems in **Portugal** i.e. from 100% natural ventilation to 100% ventilation integrated with air conditioning without humidification.

The evolution in **Romania** was from natural ventilation (also designed), which accounted for 100% before 1998, to mechanical extract and supply ventilation with heat recovery, which accounted for 20% between 1998 and 2010 and accounts after 2010 for 30% of the ventilation systems.

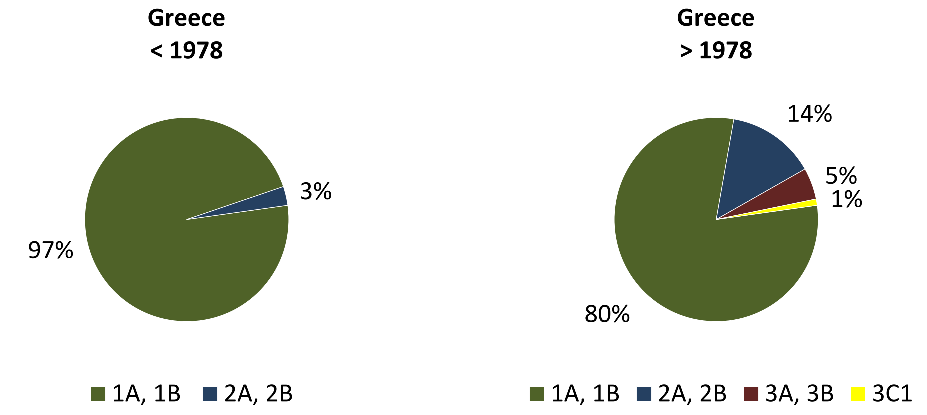
The United Kingdom developed hybrid ventilation systems between 1981 and 2000 when the shares became 80% hybrid ventilation, 10% mechanical extract ventilation and 10% mechanical extract and supply with heat recovery. After 2001 the shares of mechanical ventilation systems increased to 20% mechanical extract or supply ventilation and 20% mechanical extract and supply ventilation. After 2011 hybrid ventilation accounts for 30%, mechanical extract ventilation for 20% and the rest of 50% is accounted by mechanical supply and extract with heat recovery.



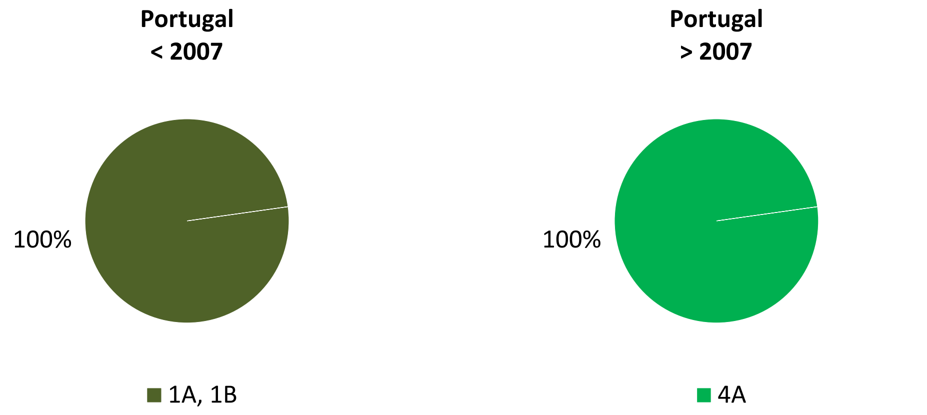
1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 35: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in kindergartens in Finland.

KINDERGARTENS – Evolution of % in Greece



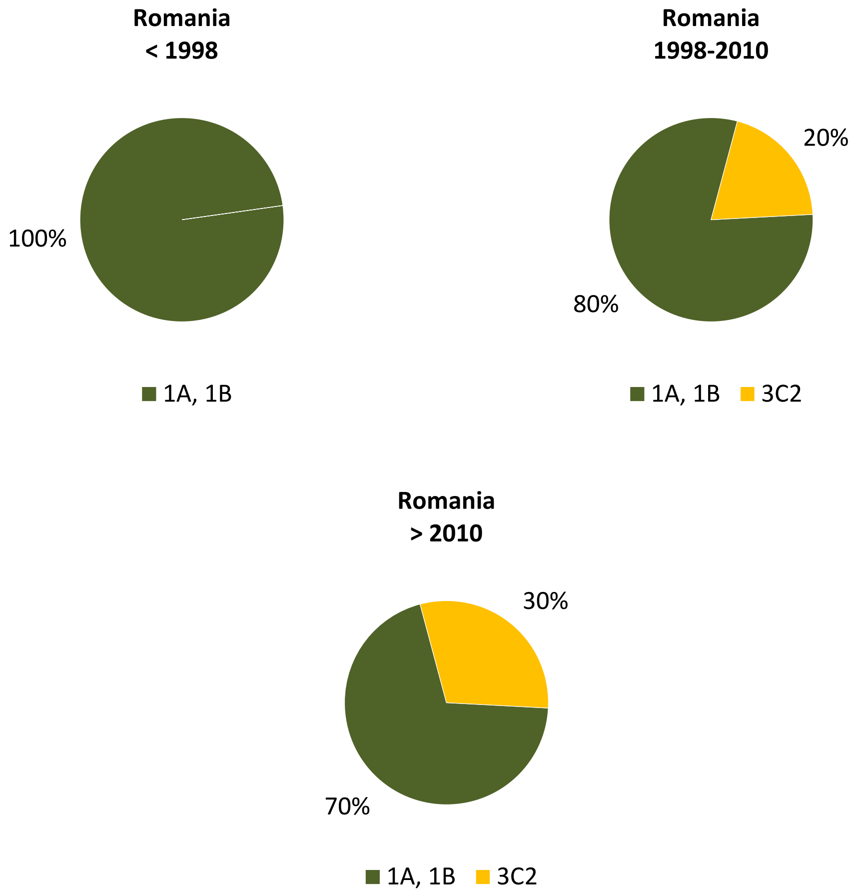
KINDERGARTENS – Evolution of % in Portugal



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 36: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in kindergartens in Greece and in Portugal.

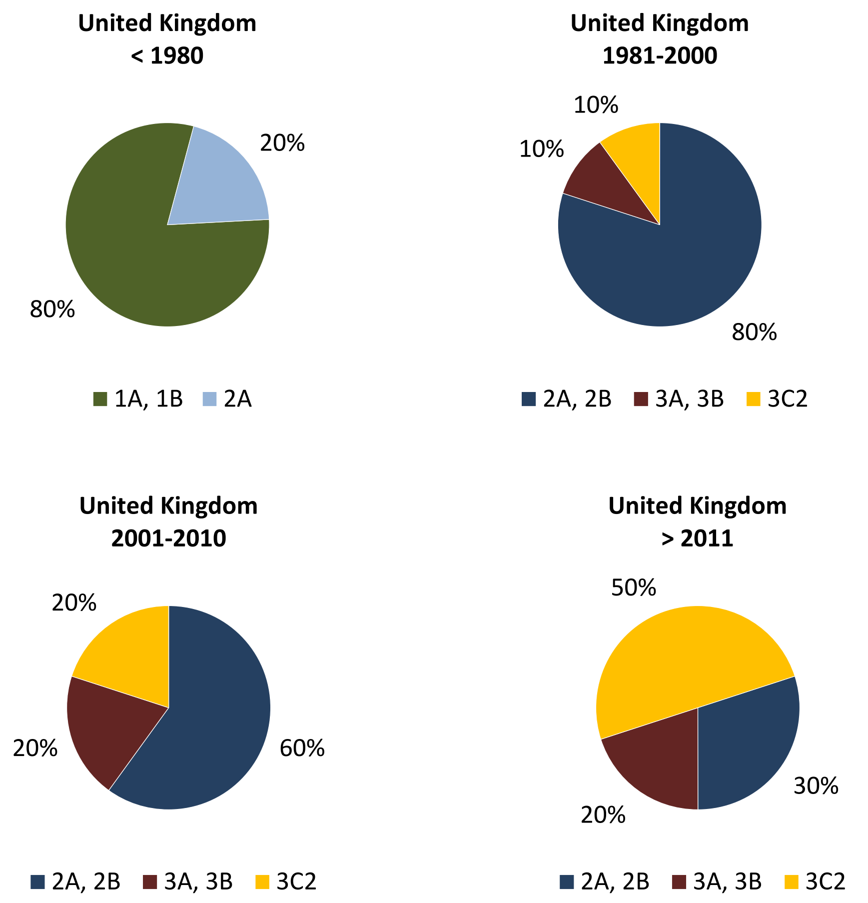
KINDERGARTENS – Evolution of % in Romania



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 37: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in kindergartens in Romania.

KINDERGARTENS – Evolution of % in The United Kingdom



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 38: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in kindergartens in The United Kingdom.

E Office buildings

In **Belgium** the distribution of ventilation systems changed significantly after 1996. Before 1996 natural ventilation systems accounted for 90% of ventilation systems, i.e. 75% natural ventilation and 15% hybrid ventilation, while mechanical extract ventilation for 10% of ventilation systems. After 1996 mechanical ventilation systems accounted for 100% of ventilation systems i.e. 60% mechanical extract ventilation and 40% mechanical extract and supply ventilation.

The share of natural ventilation systems in **Greece** decreased from 60%, i.e. 20% natural ventilation and 40% hybrid ventilation, before 1978 to 40%, i.e. 10% natural ventilation and 30% natural ventilation, after 1978. On the other hand the mechanical ventilation systems increased from 40%, i.e. 30% mechanical extract ventilation and 10% mechanical extract and supply ventilation without heat recovery, before 1978 to 60%, i.e. 40% mechanical extract ventilation and 20% mechanical extract and supply ventilation without heat recovery, after 1978.

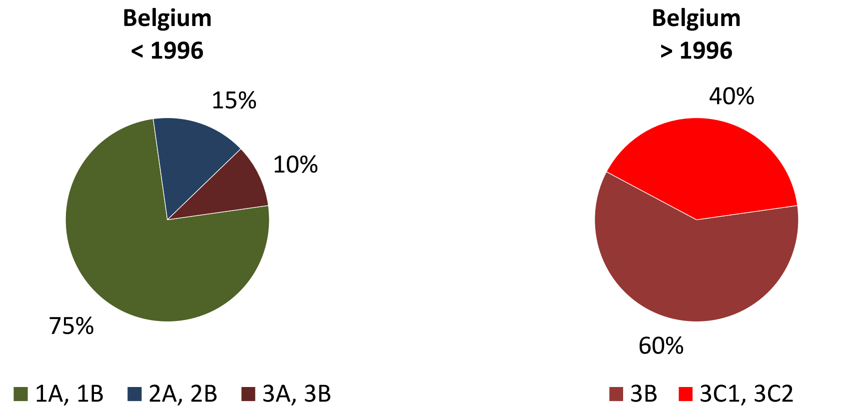
In **Italy** the evolution was gradually to more ventilation integrated with air conditioning with humidification. Before 1945 all ventilation systems were natural ventilation systems. After 1945 the share of ventilation integrated with air conditioning with humidification increased from 20% to 50% of ventilation systems, after 1991.

Natural ventilation decreased in **Portugal** from 70% before 1980 to 10% after 2007. The rest of the share of ventilation systems is taken by ventilation integrated with air conditioning without humidification, which increased from 30% before 1980 to 90% after 2007.

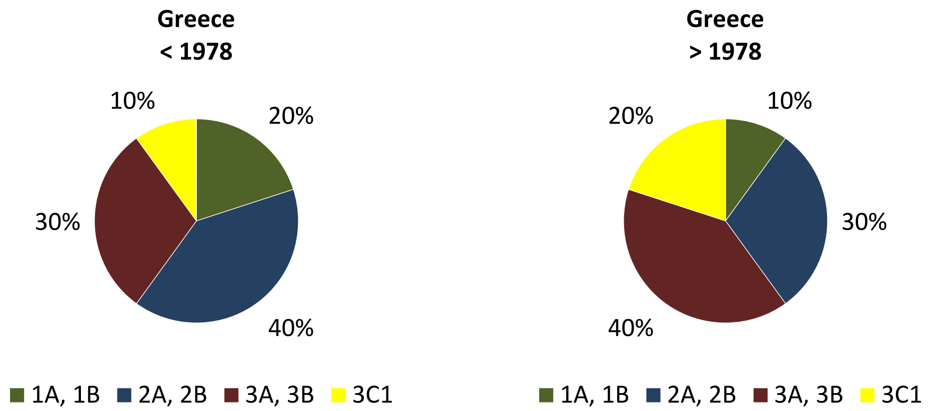
Before 1979 natural ventilation systems were installed in all office buildings in **Romania**. Between 1979 and 2010 natural ventilation systems accounted for 50% while the mechanical ventilation systems evolved from 30% mechanical extract ventilation, 10% mechanical extract and supply with heat recovery and 10% ventilation integrated with air conditioning without humidification (1979-1998) to 30% mechanical extract and supply ventilation with heat recovery and 20% ventilation integrated with air conditioning without humidification(1998-2010). After 2010 all ventilation systems are mechanical ventilation systems, i.e. 50% mechanical extract and supply ventilation with heat recovery and 50% ventilation integrated with air conditioning without humidification.

In **The United Kingdom** the main used ventilation systems are natural ventilation, hybrid ventilation, mechanical extract ventilation, mechanical extract and supply with heat recovery and ventilation integrated with air conditioning without and with humidification. During the years the mechanical ventilation systems increased while the natural ventilation systems decreased. The distribution between 1981 and 2000 was 21% hybrid ventilation, 32% mechanical extract ventilation, 32% mechanical extract and supply ventilation with heat recovery, 5% ventilation integrated with air conditioning without humidification and 10% ventilation integrated with air conditioning with humidification. After 2011 the major share is held by mechanical extract and supply, 70%, followed by hybrid ventilation and ventilation integrated with air conditioning with humidification, 10% each, and with the least share mechanical extract ventilation and ventilation integrated with air conditioning without humidification, 5% each.

OFFICE BUILDINGS – Evolution of % in Belgium

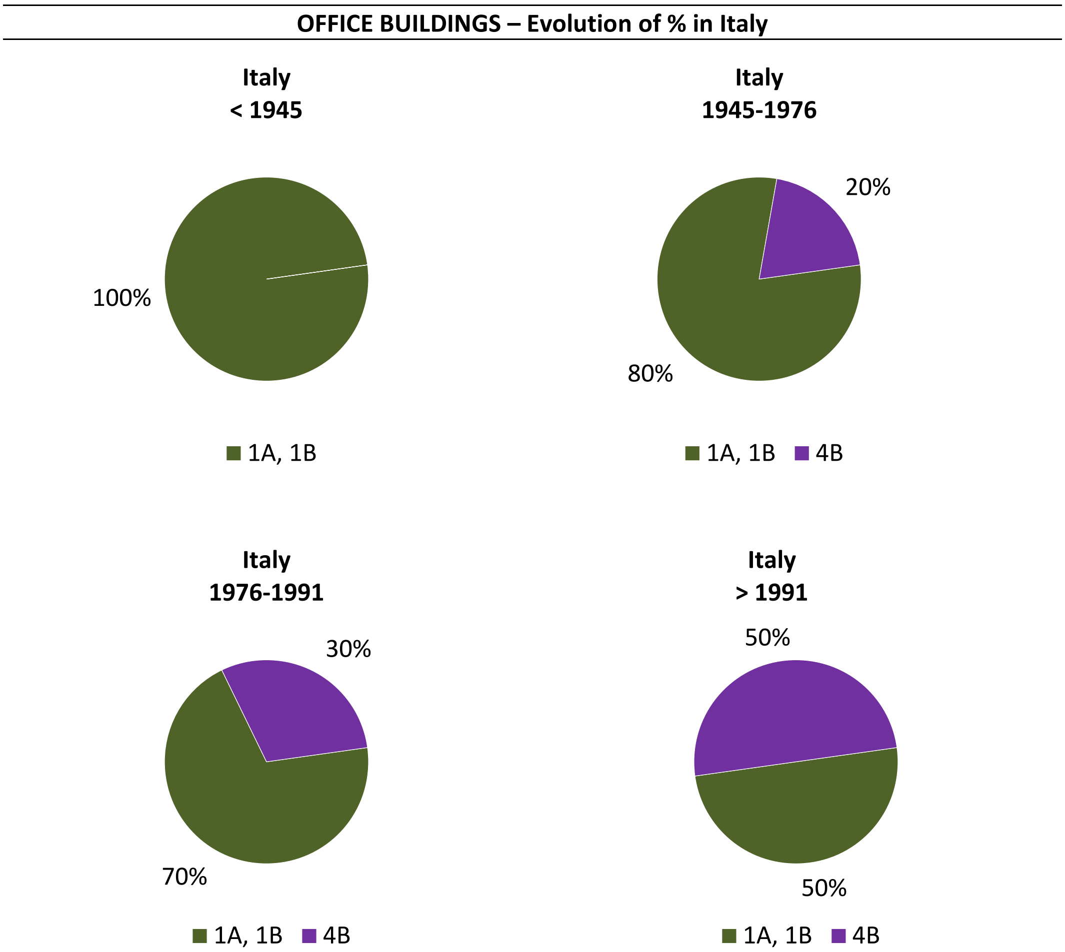


OFFICE BUILDINGS – Evolution of % in Greece



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

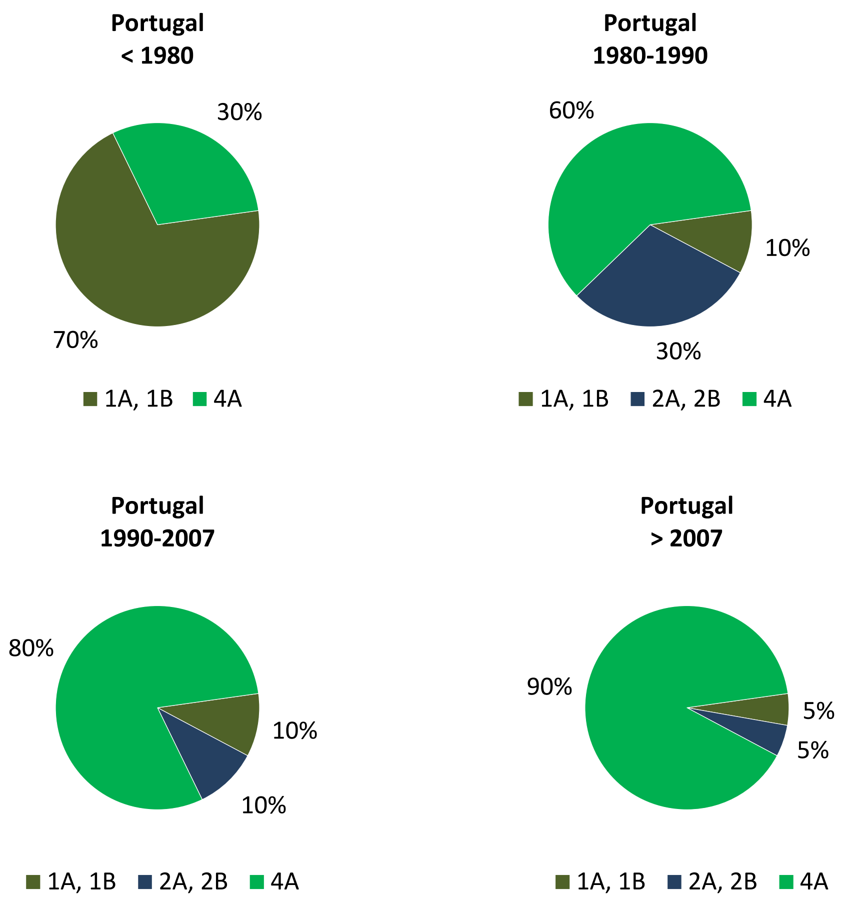
Figure 39: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in office buildings in Belgium and in Greece.



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

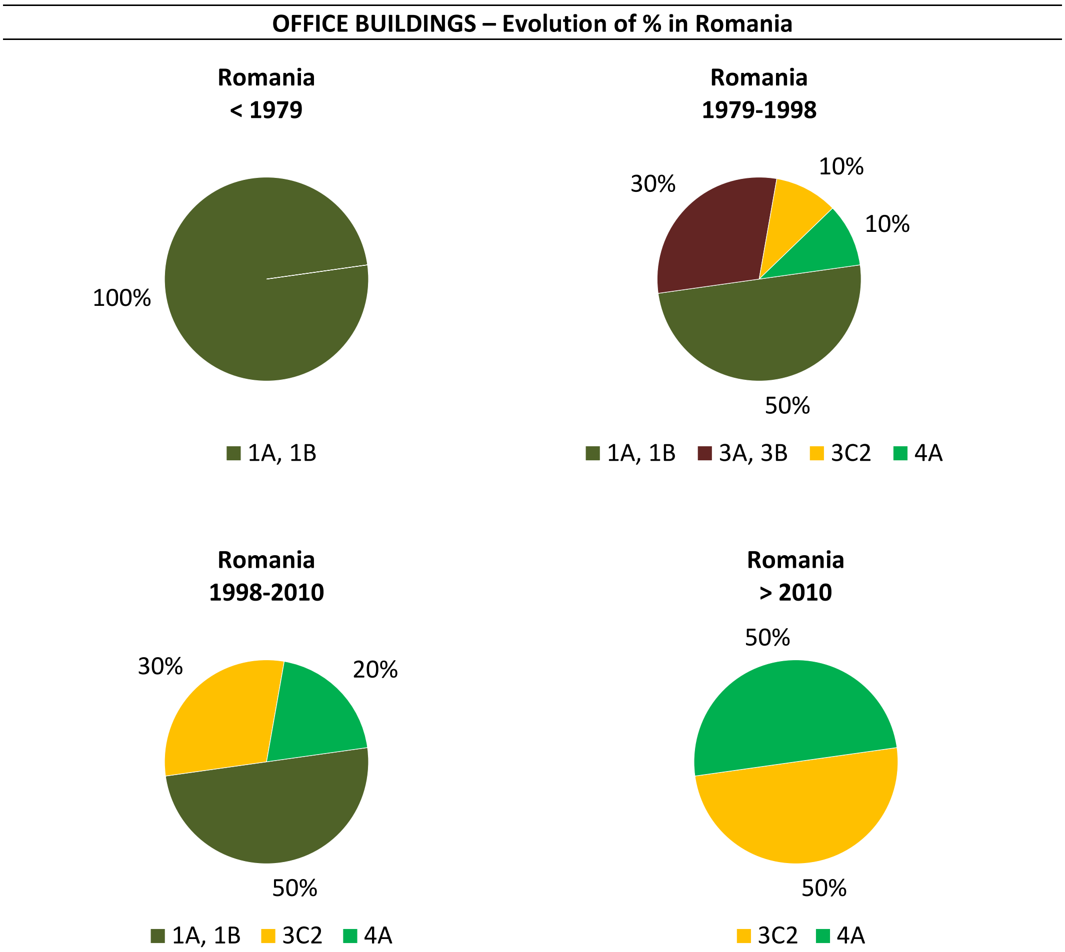
Figure 40: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in office buildings in Italy.

OFFICE BUILDINGS – Evolution of % in Portugal



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

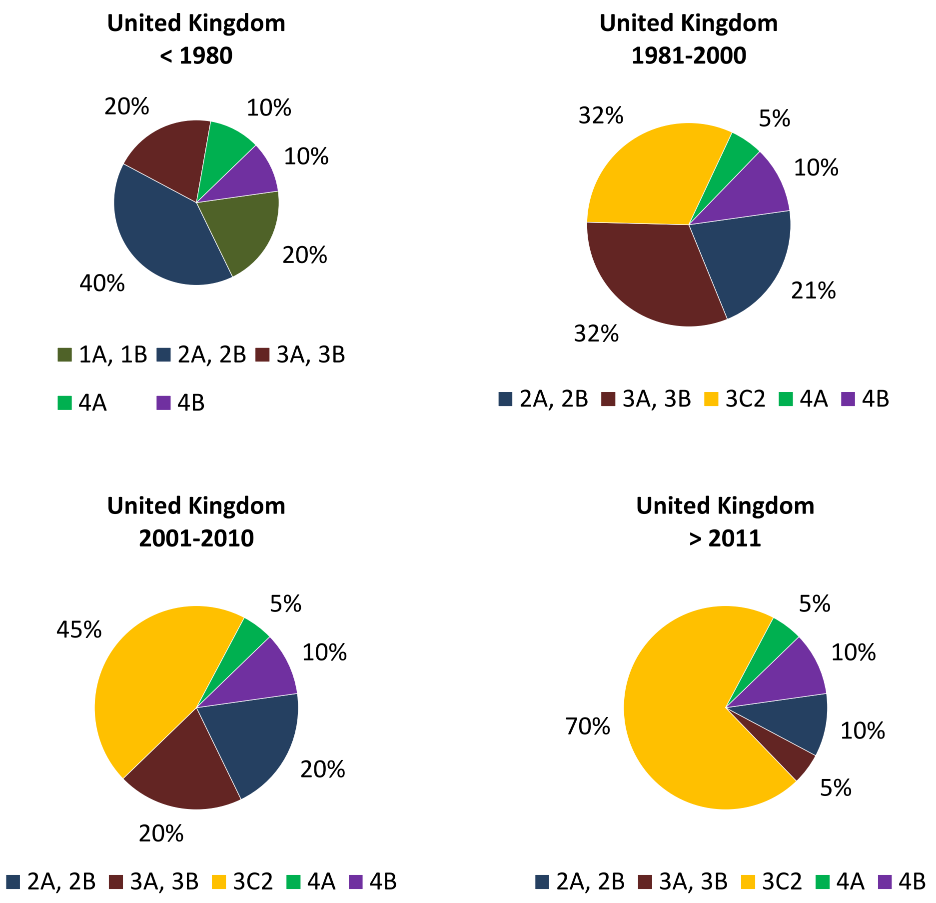
Figure 41: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in office buildings in Portugal.



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 42: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in office buildings in Romania.

OFFICE BUILDINGS – Evolution of % in The United Kingdom



1A	Natural ventilation;
1B	Designed natural ventilation;
2A	Natural ventilation with local extract fans;
2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B);
3A	Mechanical extract ventilation;
3B	Mechanical supply ventilation;
3C1	Mechanical extract and supply ventilation without heat recovery;
3C2	Mechanical extract and supply ventilation with heat recovery;
4A	Ventilation integrated with AC without humidification;
4B	Ventilation integrated with AC with humidification.

Figure 43: The distribution of ventilation systems in percentages (by number of buildings) by construction year periods in office buildings in The United Kingdom.

4.4 Summary and conclusion

The analysis shows that most of the buildings in EU are still naturally ventilated. However, the use of natural ventilation systems varies and is the highest in the southern European countries. Natural ventilation is mainly used in houses and apartments and to a lower extent in offices, schools and kindergartens. Data collected for Bulgaria, Finland, France, Germany, Greece and Italy for the current building stock show that in dwellings, natural ventilation systems are still dominating, ranging between 65% and 100%, except in Finland where the share of natural ventilation systems is only 28%.

The data show also that the number of buildings with mechanical ventilation system is gradually increasing. Often the increase in number of buildings with mechanical ventilation is associated with the change in the building regulations, especially when the ventilation requirements are more strict and cannot be met by installing other systems such as natural or hybrid ventilation systems. It has also been observed that instead of installing only mechanical extract or supply the trend is now to installed fully balanced mechanical system with both supply and exhaust (with or without heat recovery) in almost all types of buildings.

The highest proportion of buildings with mechanical ventilation systems is in the Northern European countries where the climate is cold, and much lower in the countries in southern Europe. In countries with continental climate and relatively cold winters such as Romania, the share of mechanical ventilation systems is also low. This may be due to economic situation of a country.

The survey clearly shows that there is large difference in the numbers of buildings with ventilation systems among European countries. This is despite the recent update of the ventilation and building regulations. Natural ventilation systems are still widely used in some countries and in some building types where the regulations recommend mechanical ventilation. This may suggest that the regulations are not being followed in practice and compliance with regulations is poor.

5 Effect of EPBD recast on ventilation regulations

5.1 Introduction

In 2010, the EU adopted the recast of the Directive on Energy Performance of Buildings (EPBD) [**2**]. This directive is a recast of an original EPBD directive from 2002 [**3**]. Among others, it sets more stringent requirements for insulation properties of building envelopes and requires that all new buildings in the EU to be nearly zero energy by 2020 [**4**]. Member States must transport the directive into national regulations by July 2012.

The directive itself is not descriptive and does not provide any suggestions how to achieve the adopted strict energy goals. A very probable scenario is that in order to limit overall building energy consumption, ventilation rates will be reduced as the most convenient way to reduce energy use. However at the same time a considerable amount of evidence exists, which allegedly links low building ventilation rates with health and comfort problems in building occupants. A fear exists, that implementation of EPBD recast will cause reduction of ventilation rates and consequentially related health and comfort problems for building occupants.

In order to get better picture on how the latest modifications of the EU legislation on energy use in buildings are expected to affect ventilation practice and indoor air quality in Europe, a questionnaire was sent to a group of experts on ventilation in several European countries. This chapter presents the results of the questionnaire survey.

5.2 Questionnaire

Questions in the questionnaire were formed to inquire specific point of interest to the project, which is how the EPBD recast will influence indoor air quality in buildings and use of ventilation technologies to cope with the stricter goals. The questionnaire comprised of 11 questions. Questions were the following:

1. **Do you expect:**

a) Problems related to indoor air quality to increase with recast EPBD, why?
b) Problems related to indoor air quality to decrease with recast EPBD?

2. **Regulations for ventilation will:**

a) Be revised to become more stringent – if yes when?
b) Stay as they are now from the year?

3. **Regulations for ventilation will be enforced:**

a) More?
b) Less?
c) As before?

4. **The following change will take place in ventilation systems:**

a) More natural ventilation will be used.
b) More controlled ventilation with mechanical supply and exhaust will be used.
c) More heat recovery from ventilation air will be used.
d) More hybrid ventilation systems will be used.

5. **Envelope of the building (walls, windows, etc.) will become:**

a) More airtight – what are the requirement for new buildings if any?
b) More leaky

6. Indoor air and climate of nearly zero energy buildings will get:
a) Enough attention?
b) Too little attention?

7. Requirements for indoor air quality will be included in regulations.
a) Yes.
b) No.
c) Maybe.

8. Are the requirements for indoor air pollutants controlled?
a) Yes.
b) No.
c) Partly.

9. Do current regulations allow lower ventilation rates if building materials are less polluting?
a) No
b) Yes, how much?

10. The following technologies are already included in your regulations?
a) Demand controlled ventilation (requirement to adjust the ventilation by ventilation demand).
b) Possibility to adjust ventilation rates based on pollution loads and needs.
c) Reduce ventilation rates when effective room air cleaning is used.
d) Reduce ventilation rates if ventilation efficiency is improved.
e) Heat recovery from ventilation air.
f) Ventilating rates are controlled by the outdoor air quality (less ventilation when outdoor air is polluted).

11. Do you think that the following technologies will be used in the future to achieve performance requirements of the future local energy regulations?
a) Demand controlled ventilation (requirement to adjust the ventilation by ventilation demand).
b) Possibility to adjust ventilation rates based on pollution loads and needs.
c) Reduce ventilation rates when effective room air cleaning is used.
d) Reduce ventilation rates if ventilation efficiency is improved.
e) Heat recovery from ventilation air.
f) Ventilating rates are controlled by the outdoor air quality (less ventilation when outdoor air is polluted).
g) Other technologies like:

5.3 Results

Data from 17 countries was received from respondents from all parts of the Europe. Questions 10 and 11 were added to the survey additionally and only 9 respondents provided these answers. Names of respondents answering the questionnaires are presented in the Appendix 3.

The charts presented below provide a review of answers which were provided on the received questionnaires. The reference year for the data was 2011. The analysis based on the results from the questionnaire gives the following results.

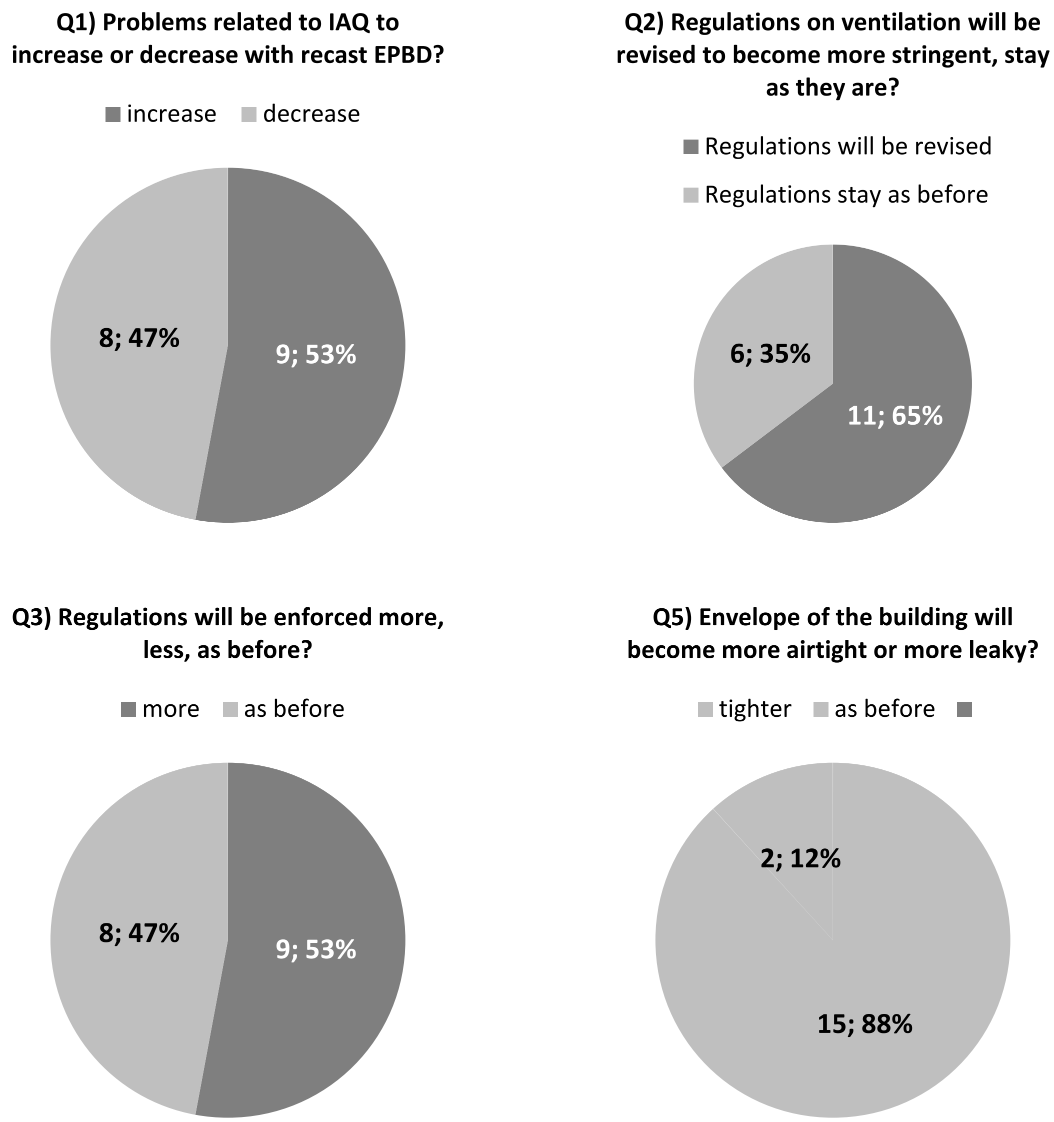


Figure 44: EPBD questionnaire: summary of answers on questions 1 – 5

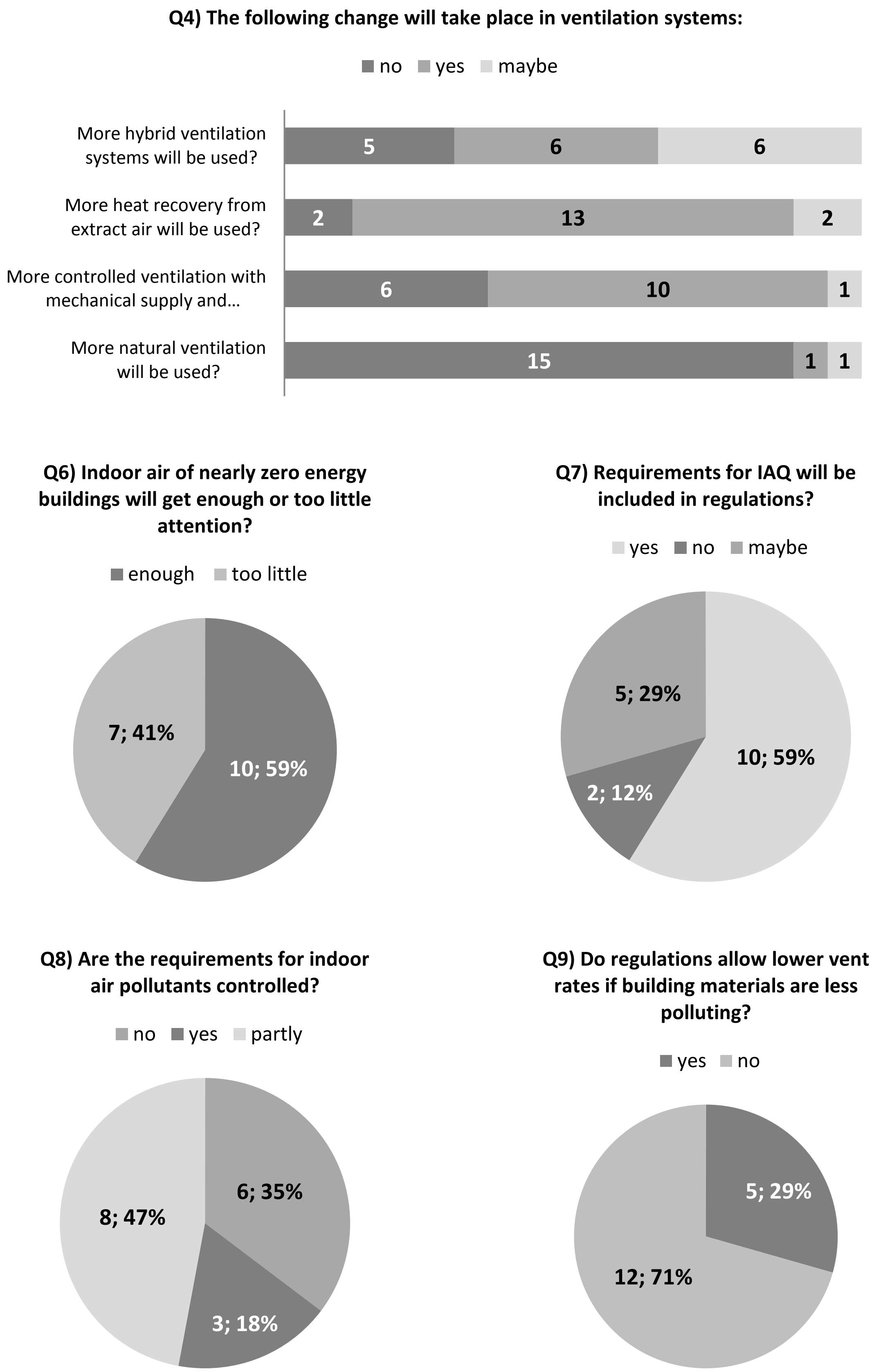
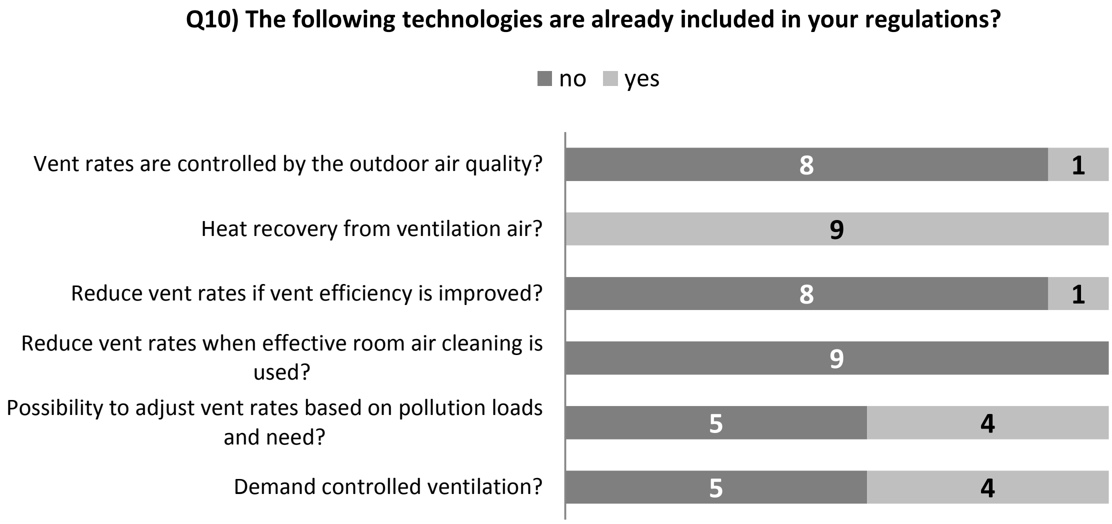


Figure 45: EPBD questionnaire: summary of answers on questions 5 - 9



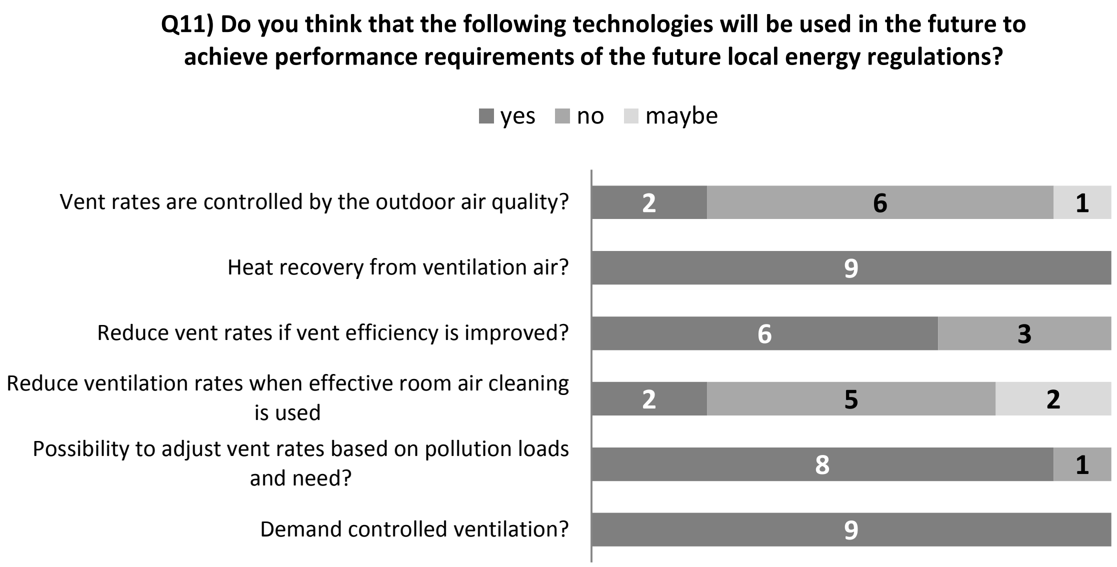


Figure 46: EPBD questionnaire: summary of answers on questions 10 and 11

5.4 Discussion

When asked the **question 1**, if they think problems related to IAQ will increase or decrease due to EPBD recast, slightly more respondents answered that they expect problems to increase. In Bulgaria a fear exists that IAQ related problem would increase because buildings will be too airtight and no ventilation openings provided to allow air entering the building and to be extracted by bathroom fan or kitchen exhausts. An opinion from Finland on the same question was that problems will increase because IAQ regulations are not integrated into EPBD like AC inspections. Respondent from Lithuania expects that ventilation rates will be reduced due to the EPBD and IAQ problems will increase based on the experiences from the USA during the first energy crisis during 1970s. Also in the Netherlands the comment states that requirements for energy efficiency might hamper ventilation needs for healthy IAQ. Also Norway, Romania and Slovakia share the same opinion, suspecting that tighter building envelopes are the one that will cause IAQ related problems to increase.

On the other hand in France, Portugal and Slovenia it is expected that IAQ problems will decrease due to the revised ventilation regulation to tackle the possible problem. Also opinion from Italy and the UK suggest that problems will decrease. In Italy due to the more use of ventilation, which will be required to fulfil EPBD requirements, and in the UK because more buildings are expected be better ventilated due to increase in need for heat recovery systems and increase of hybrid ventilation systems over natural ventilation.

Responding to **question 2**, majority respondents expect that regulations on ventilation will be revised. Most of those who do not expect regulations to be revised have already revised regulations in the past couple of years. Dates of existing regulations and expected regulations for countries, which provided answers, are presented in the list below.

- Czech Republic: were revised 2007 for working environment and 2011 for dwellings
- Denmark: will be revised in 2012
- Finland: were revised 2010, in force 2011
- Germany: will stay as today from 2009
- Hungary: will be revised in the end of 2011
- Netherlands: will stay as today from 2003
- Norway: will stay as today from 2007
- Portugal: will be revised in 2012
- Romania: will be revised after new CEN standards are validated
- UK: will stay as today from 2010 until next revisions in 2013/16

For **question 3**, slightly less than half of the respondents think that regulations will be enforced more and slightly less than half think that they will be enforced less. None has answered that regulations will be enforced as before.

Responses to **question 4** show which changes are expected in ventilation system due to the EPBD recast. The most prevalent answer is regarding the use of natural ventilation, which will decrease in the future. The second most prevalent answer was regarding the use of heat recovery where only Bulgaria and Greece answered with that they do not expect that the use of heat recovery systems will be increased.. These answers are somewhat expected as both countries have hot climate with little demand for heating. Answers regarding controlled ventilation and hybrid ventilation systems are not conclusive. The question on use of controlled ventilation with mechanical supply and exhaust may indicate that more ”controlled” ventilation will be used in the future.

Vast majority agrees that requirements on envelopes of building will get tighter (**question 5**). Only Denmark and Portugal expect that building tightness will stay as before. A handful of countries also provided their currently regulated values on building envelope tightness. Air leakage factor, expressed as air changes per hour or air flow per envelope area is shown for each of them in Table 2. The Netherlands has building envelope tightness requirements defined in the Dutch standard NEN 2686. Maximum value provided in the standard is for maximum airflow of 0.2 m^3/s.

Table 3: Requirements on tightness of building envelopes

Country	Residential	Non-residential
Finland	≤ 4 $m^3/h/m^2$ (envelope)	
Germany	≤ 1,0 ach	
Netherlands	air flow rate according to NEN 2686 not higher than 0.2 m^3/s	
Norway	≤ 2,5 ach	≤ 1,5 ach
Slovenia	≤ 3,0 ach	≤ 2,0 ach

When asked in **question 6** whether the respondents think that indoor air of nearly zero energy buildings will get too little or enough attention, majority of respondents answered that it will get enough attention. France made a special note mentioning that there is already a campaign going on in the country, where IAQ is monitored in several pilot buildings. Results of the monitoring will be used later when writing new ventilation regulations.

Under **question 7** the majority (ca. 60%) of respondents think that IAQ will be included in regulations. Additional 30% think that IAQ requirements may be included in their regulations in the future. Some ca. 10% of respondents think that IAQ requirements will not be included in the regulations. It is important to note, that the same respondents also expect that IAQ related problems will increase, IAQ of nearly zero building will get too little attention and that regulations will not be changed. Such an answer suggests that countries, which do not intend to change ventilation regulations and to include IAQ requirements, may face IAQ related problems in the future.

When asked in **question 8** whether the requirements for indoor air pollutants are controlled, slightly less than half of respondents (47%) answered “partly”, 35% answered “yes” and only three or 18% “no”. Only two of the respondents provided additional explanation to answers “partly” and “yes”. In Finland, the only two pollutants controlled are radon and CO_2. In Portugal, there are periodic IAQ audits of buildings in tertiary sector with a net floor area greater than 1000 m^2 (will be reduced to 500 m^2 in 2012).

Question 9 investigated whether regulations allow lower ventilation rates if less polluting building materials are used. Majority (71%) answered “no” to this question. Countries that allow lower ventilation rates in the case of on non-polluting materials used are presented in the list below, including some details provided by the respondents.

- Hungary: ventilation rates can be reduced based on EN 15251 which is included in national regulations
- Norway: in offices, ventilation rate can be reduced from 2 $l/s/m^2$ to 0,7 $l/s/m^2$
- Portugal: values given in regulations are for non-polluting materials, designers should increase values by 50% when polluting materials are used
- Slovenia: ventilation rates in regulations are given for low emission buildings and non-low emission buildings and for many building types, including offices, schools and kindergartens. For all three cases, required ventilation rate for building can be reduced from 2,9 to 1,4 $m^3/h/m^2$. The regulation does not mention lower ventilation rates in dwellings, where 0,5 is set as a minimum air change rate.

Questions 10 was asking respondents which of the stated technologies are already included in the regulations to be obligatory to use or install at least under some circumstances. In most countries, ventilation rates cannot be controlled by the outdoor air quality. It is also not possible to reduce ventilation rates if ventilation efficiency is improved or if effective room air cleaning is used. On the other hand, heat recovery from ventilation air is required in all countries responding to this question. The possibility to adjust ventilation rates based on pollution loads or needs and on demand-controlled ventilation is included in regulations of slightly less than half of the responding countries.

Question 11 is focused on the future use of technologies to achieve performance requirements of the future local energy regulations. All the respondents think that demand controlled ventilation and heat recovery will be used in the future. The answers are almost uniform also when asked about the possibility to adjust ventilation rates based on pollution loads and need. All except one (8:1) think that this technology is going to be used in the future. Two thirds of the respondents also think that reducing ventilation rates if ventilation efficiency is improved will be one of the future practices. Concerning the questions on ventilation rates controlled by the outdoor air quality and reducing the ventilation rates if effective room air cleaning is used, it is difficult to make reasonable predictions regarding their future use based on the responds received. Most of the respondents answered “maybe” for both answers.

5.5 Summary and conclusion

The 2010 recast of the Directive on Energy Performance of Buildings (EPBD) requires that all new buildings in the EU are built as nearly zero energy by 2020. A very probable scenario is that in order to reduce overall building energy use, the ventilation rates will be reduced, as the simplest but not the recommended way of reducing the energy use.

Experts are very concerned that this will lead to deterioration of indoor air quality and related health problems. In order to get better picture of how the latest modifications of the EU legislation on energy use in buildings are expected to affect ventilation practice and indoor air quality (IAQ) in Europe, a questionnaire was sent to a group of ventilation experts in several European countries.

Respondents returned the questionnaire from 17 countries. Analysis of answers leads to the following conclusions:

- IAQ related problems are expected to increase due to the tighter building envelopes, and because requirements for the IAQ quality are not included in the EPBD. On the other hand, slightly less than half of the respondents think that IAQ will be improved due to the revised ventilation regulations to tackle the IAQ problem.
- The majority of the respondents expect ventilation regulations to be revised in the near future. The rest do not expect that their regulations will change soon because they have recently been revised.
- There is no clear agreement regarding the future enforcement of ventilation regulation - one half of respondents foresee a reduction of the enforcement of the regulation and the other half an increase.
- According to the opinion of the majority, the future use of natural ventilation will decrease and the use of heat recovery will increase.
- Building envelopes will almost certainly become tighter and IAQ will probably get more attention in the future according to the respondents.
- The majority of the respondents consider that IAQ will certainly or probably be included in the future ventilation regulations; only 10% has different opinion.
- Comparing several answers of the respondents suggests that countries, which do not intend to change the ventilation regulations and include IAQ requirements, may face IAQ related problems.
- Most of the countries do not allow reducing ventilation rates by using less polluting materials, and also do not allow controlling ventilation rates based on the outdoor air quality.
- The majority of the respondents in the survey believe that reduction of the ventilation rates is not possible if not accompanied by improvement of ventilation efficiency or effective air cleaning.
- All respondents consider that demand controlled ventilation and heat recovery will be used in the future. The vast majority consider that any future adjustment of the ventilation rate will be based on pollution loads and needs of occupants.
- Two thirds of respondents consider that reducing ventilation rates will be one of the future practices if ventilation efficiency is improved.
- Use of heat recovery in hot climate is not expected to increase.

Comparing the answers from the different European countries does not show any relation between responses and climate, geographic location or construction practice. On the basis of answers provided by respondents we can conclude that the EPBD recast will have different effects in different European countries. The reason for that may be the fact that individual countries already have got very different regulations.

6 European Standards and Technical Reports on ventilation

6.1 Introduction

The European Standards on ventilation are published by the European Committee for Standardization (CEN). Standards are shaped by consensus among enterprises, public authorities, consumers, and trade unions, through a consultation process organised by independent, recognised standardisation bodies at national, European and international level. They are sets of voluntary technical and quality criteria for products, services and production processes, also called technical specification. Standards are voluntary to follow, except if they are referred or used as a part of national legislation.

The ventilation related work in the CEN is coordinated in technical committee CEN TC 156 – Ventilation for buildings. The development of standards is driven by business and experts competent in the specific field draft each of them. Before a final draft version is adopted as EN standard, it is submitted to 30 CEN Members for a weighted Formal Vote. After its adoption, each of the 30 National Standards Bodies publishes the new EN as an identical national standard and withdraws any national standards that conflict with it. Hence, one EN becomes a national standard in the 30 member countries of CEN.

A draft European Standard (prEN) is a standard under development. It is drafted by a Technical Committee and submitted to CEN members for a public enquiry. A prEN is not a European Standard. It is distributed for review and comments. It is subject to change without notice and shall not be referred to as a European Standard.

Besides standards, CEN also publishes Technical Reports (TR). A TR is a document that provides information on the technical content of standardization work. Technical Reports may be prepared when it is considered urgent or advisable to provide additional information to the CEN national members, the European Commission, the EFTA Secretariat or other governmental agencies or outside bodies.

EN standards are written by a group of experts from a specific field and describe the best available technology, which reached consensus among the stakeholders. They are regularly revised and updated if necessary. Consensus makes EN standards applicable throughout the CEN Member States and they could be used more often as a basis for national and local regulations.

6.2 Overview of Standards and Technical Reports

European Standards and Technical Reports on ventilation can be divided in two groups:

- Standards which provide direct requirements for indoor air quality (Table 4)
- Technical standards on ventilation (Table 5)

The standards may also deal with either residential buildings or non-residential or both (Table 6).

The first group of standards in Table 4 lists standards that are directly related to indoor air quality. That means that in some point in the text of the document they are directly addressing measures, which can help to improve indoor air quality. This list of standards mostly includes standards that deal with functional properties of ventilation systems or equipment.

Table 5 lists standards that are related to ventilation but do not specifically address measures that can influence indoor air quality. This list of standards mostly includes standards that deal with mechanical properties and testing of ventilation systems and equipment.

Table 4: Directly indoor air quality related standards

Reference	**Directly indoor air quality related standards**
CR 1752:1998 [**5**]	Ventilation for buildings - Design criteria for the indoor environment
EN 15251: 2007 [**6**]	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
EN 13779:2007 [**1**]	Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems
CEN/TR 14788:2006 [**7**]	Ventilation for buildings - Design and dimensioning of residential ventilation systems
EN 12097:2006 [**8**]	Ventilation for Buildings - Ductwork - Requirements for ductwork components to facilitate maintenance of ductwork systems
EN 13053:2006 [**9**]	Ventilation for buildings - Air handling units - Ratings and performance for components and sections
EN 15239:2007 [**10**]	Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of ventilation systems
EN 15240:2007 [**11**]	Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of air conditioning systems
EN 15665:2009 [**12**]	Ventilation for buildings - Determining performance criteria for design of residential ventilation systems
prEN 15780:2008 [**13**]	Ventilation for buildings - Ductwork - Cleanliness of ventilation systems
FprEN 779:2011 [**14**]	Particulate air filters for general ventilation - Determination of the filtration performance

Table 5: Technical standards on ventilation

Reference	**Technical standards on ventilation**
EN ISO 7730:2006	Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO 7730:2005)
EN 12237:2003	Ventilation for buildings - Ductwork - Strength and leakage of circular sheet metal ducts
EN 12239:2001	Ventilation for buildings - Air terminal devices - Aerodynamic testing and rating for displacement flow applications
EN 12599:2001	Ventilation for buildings - Test procedures and measuring methods for handing over installed ventilation and air conditioning systems
EN 12792:2003	Ventilation for buildings - Symbols, terminology and graphical symbols
	Ventilation for buildings – Performance testing of components/products for residential ventilation.
EN 13141-1:2004	Part 1: Externally and internally mounted air transfer devices
EN 13141-2:2010	Part 2: Exhaust and supply air terminal devices
EN 13141-3:2004	Part 3: Range hoods for residential use
EN 13141-4:2004	Part 4: Fans used in residential ventilation systems
EN 13141-5:2004	Part 5: Cowls and roof outlet terminal devices
EN 13141-6:2004	Part 6: Exhaust ventilation system packages used in a single dwelling
EN 13141-7:2010	Part 7: Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings
EN 13141-8:2006	Part 8: Performance testing of unducted mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for a single room
EN 13141-9:2008	Part 9: Externally mounted humidity controlled air transfer device
EN 13141-10:2008	Part 10: Humidity controlled extract air terminal device
EN 13142:2004	Ventilation for buildings – Components/products for residential ventilation – Required and optional performance characteristics
EN 13182:2002	Ventilation for buildings - Instrumentation requirements for air velocity measurements in ventilated spaces

EN 14134:2004	Ventilation for buildings - Performance testing and installation checks of residential ventilation systems
EN 15241:2007	Ventilation for buildings – Calculation methods for energy requirements due to ventilation systems in buildings
EN 15242:2007	Ventilation for buildings - Calculation methods for the determination of air flow rates in buildings including infiltration
EN 15243:2007	Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems
EN 15727:2010	Ventilation for buildings – Ducts and ductwork components, leakage classification and testing.
EN 15650:2010	Ventilation for buildings - Fire dampers
EN 15871:2009	Ventilation for buildings - Fire resisting duct sections

Table 6: Purpose based classification of ventilation standards

<table>
<tr><td rowspan="2">Purpose of EN standard</td><td colspan="2">Building type</td></tr>
<tr><td>Residential</td><td>Non residential</td></tr>
<tr><td>Criteria for indoor environment</td><td colspan="2">EN 15251:2007</td></tr>
<tr><td>Design and dimensioning of ventilation systems</td><td>CEN/TR 14788:2006</td><td>EN 13779:2007</td></tr>
<tr><td>Determining performance criteria of residential ventilation systems</td><td>EN 15665:2009</td><td></td></tr>
<tr><td rowspan="2">Calculation of ventilation rates</td><td colspan="2">EN 15242:2007</td></tr>
<tr><td>EN 13465:2004</td><td></td></tr>
<tr><td>Calculation of ventilation energy</td><td colspan="2">EN 15241:2007</td></tr>
<tr><td>Rating and performance characteristics</td><td>prEN 13142 Rev V7
on components/products for residential ventilation</td><td>EN 13052:2006
on air handling units</td></tr>
<tr><td>Performance testing of components and products</td><td>EN 13141-1 /air transfer devices
EN 13141-2 /exh. & supply air terminal devices
EN 13141-4 /fans
EN 13141-5 /cowls and roof outlets
EN 13141-6 /exh. ventilation system packages
EN 13141-7 /mech. supply & exh. units + HR for dwellings
EN 13141-8 /mech. supply & exh. units + HR for rooms
EN 13141-9 /ext. mounted RV-controlled air transf. device
EN 13141-10 /hum. controlled extract air terminal device</td><td>EN 1886:2007 /Mech. performance air handling units
ISO 5801:1997 /Industrial fans performance testing
ISO 12248 /Ind. fans tolerances & conversion methods
ISO 5221 /Acoustics, in duct radiated sound power level
ISO 5213 /Acoustics, casing radiated sound power level
EN 1751 /Aerodynamic testing of dampers & valves
EN 1216 /Performance testing heating/cooling coils
EN 779 /Determination of filtration performance
EN 308 / Performance testing air-to-air HR-devices</td></tr>
</table>

6.3 Standards related to IAQ

Among the listed standards, only few directly address the indoor air quality issues. Only EN 15251 is directly dedicated to indoor air quality while the others tackle only some specific IAQ related issues. The list below provides some insights into the contents of standards related to IAQ. Short descriptive summary of other standards not related to the IAQ, is presented in Appendix B.

CEN/CR 1752: 1998. Ventilation for buildings – Design Criteria for the indoor environment

This Technical Report specifies the requirements for, and methods of expressing the quality of the indoor environment for the design, commissioning, operation and control of ventilation and air-conditioning systems. This report does not have a status of a standard but has relevant information on indoor air quality and climate.

This Technical Report covers indoor environments where the major concern is the human occupation but excludes dwellings. It does not cover buildings where industrial processes or similar operations requiring special conditions are undertaken.

The practical procedures, including selection of parameters to be measured during commissioning, control and operation, are not covered.

- Development of design criteria (p. 9)
- Design criteria tables (activity, occupancy, category, operative temp. , maximum mean air velocity, sound pressure, ventilation rate, additional ventilation when smoking is allowed) (p. 9)
- Abstracts from Air quality guidelines for Europe (p. 57)
- Guidelines for low-polluting buildings (p. 71)

EN 15251: 2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

This European Standard specifies the indoor environmental parameters that have an impact on the energy performance of buildings. - The standard specifies how to establish indoor environmental input parameters for building system design and energy performance calculations. The values of indoor environmental parameters in this standard are based on CR 1752 and other earlier published standards. - The standard specifies methods for long-term evaluation of the indoor environment obtained as a result of calculations or measurements. - The standard specifies criteria for measurements, which can be used if required to measure compliance by inspection. - The standard identifies parameters to be used by monitoring and displaying the indoor environment in existing buildings. This standard is applicable mainly in non-industrial buildings where the criteria for indoor environment are set by human occupancy and where the production or process does not have a major impact on indoor environment. The standard is thus applicable to the following building types: single family houses, apartment buildings, offices, educational buildings, hospitals, hotels and restaurants, sports facilities, wholesale and retail trade service buildings. - The standard specifies how different categories of criteria for the indoor environment can be used. But does not require certain criteria to be used. This is up to national regulations or individual project specifications. - The recommended criteria in this standard can also be used in national calculation methods, which may be different to the methods referred to here. - The standard does not prescribe design methods, but give input parameters to the design of buildings, heating, cooling, ventilation and lighting systems -

The standard does not include criteria for local discomfort factors like draught, radiant temperature asymmetry, vertical air temperature differences and floor surface temperatures.

EN 13779:2007. Ventilation for non-residential buildings — Performance requirements for ventilation and room-conditioning systems

This European Standard applies to the design and implementation of ventilation and room conditioning systems for non-residential buildings subject to human occupancy, excluding applications like industrial processes. It focuses on the definitions of the various parameters that are relevant for such systems. The guidance for design given in this standard and its annexes are mainly applicable to mechanical supply and exhaust ventilation systems, and the mechanical part of hybrid ventilation systems. Applications for residential ventilation are not dealt with in this standard. CEN/TR 14788 is dealing with the performance of ventilation systems in residential buildings. The classification uses different categories. For some values, examples are given and, for requirements, typical ranges with default values are presented. The default values given in this standard are not normative as such, and should be used where no other values are specified. Classification should always be appropriate to the type of building and its intended use, and the basis of the classification should be explained if the examples given in the standard are not to be used. NOTE Different standards may express the categories for the same parameters in a different way, and also the category symbols may be different.

The general part of the standard includes chapters on terms and definitions and symbols and units. The main chapters of the standard are Agreement of design criteria, Classification, Indoor environment and annexes. Agreement of design criteria specifies the information needed to design the system. The criteria provide the common language between all the parties in the design and construction process and specify which issues must be agreed before or during the design process to avoid discrepancies between parties involved in the construction process. The classification provides specification of types of air, classification of air, system tasks and basic system types, pressure conditions in the room, specific fan power and heat recovery.

The chapter on Indoor environment defines design assumptions for the occupied zone, thermal environment, indoor air quality, indoor air humidity and acoustic environment. The section on indoor air quality provides typical values for human occupancy and recommends that emissions from sources other than human metabolism and smoking shall be specified as clearly as possible. For supply air flow rates it instructs to use ventilation rates as defined in EN 15251:2007.

CEN TR 14788:2006. Ventilation for buildings – Design and dimensioning of residential ventilation systems

This Technical Report specifies recommendations for the performance and design of ventilation systems serving single family, multi-family and apartment type dwellings during both summer and winter. It is of particular interest to architects, designers, builders and those involved with implementing national, regional and local regulations and standards.

Four basic ventilation strategies are covered: natural ventilation; fan assisted supply air ventilation; fan assisted exhaust air ventilation; fan assisted balanced air ventilation

Combinations of these systems are not excluded and a ventilation system may serve only one dwelling (individual system) or more than one dwelling (central system). The ventilation aspects of combined systems (ventilation with heating and/or cooling) are covered. The ventilation of garages, common spaces, roof voids, sub-floor voids, wall cavities and other spaces in the structure, under, over or around the living space are not covered.

EN 12097:2006. Ventilation for Buildings - Ductwork - Requirements for ductwork components to facilitate maintenance of ductwork systems

This European standard specifies requirements for dimension, shape and location for access panels for cleaning and service in ductwork systems, which conform to EN 1505, EN 1506 and EN 13180. National regulations shall always be followed, even when they deviate from requirements given in this standard.

EN 13053:2006. Ventilation for buildings - Air handling units - Rating and performance for units, components and sections

This European Standard specifies requirements and testing for ratings and performance of air handling units as a whole. It also specifies requirements, recommendations, classification, and testing of specific components and sections of air handling units. For many components and sections it refers to component standards, but it also specifies restrictions or applications of standards developed for standalone components. This standard is applicable both to standardised designs, which may be in a range of sizes having common construction concepts, and also to custom-design units. It also applies both to air handling units, which are completely prefabricated, and to units which are built up on site. Generally the units within the scope of this standard include at least a fan, a heat exchanger and an air filter. This standard is not applicable to the following: a) air conditioning units serving a limited area in a building, such as fan coil units; b) units for residential buildings; c) units producing ventilation air mainly for a manufacturing process.

EN 15239:2007. Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of ventilation systems

This standard develops the methodology required for the inspection of mechanical and natural ventilation systems in relation to its energy consumption. This standard applies to both residential and non-residential buildings. The inspection may include the following issues, in order to determine the energy performance of the building and its associated mechanical / electrical plant: - The system conformity related to the original and subsequent design modifications, actual requirements and the present building state. - Correct operation of the mechanical, electrical or pneumatic components. - Provision of an adequate and pure supply of ventilation air. - The functioning of all the controls involved. - Fan power absorbed and specific fan power. - Building air tightness. It is not the intention of the standard to provide a full ventilation system audit. Its purpose is to assess its functioning and its impact on energy consumption. It includes recommendations on possible system improvements. NOTE The inspection, performed by an independent person to assess the system performance relating to energy consumption, is different from the maintenance that is performed to the owner's requirements to maintain the optimum system performance. The standard insists on the fact that one of the results of the inspection shall be a list of proposals necessary to improve its energy efficiency. The list shall contain among others a list of adjustments to be made to ensure that it agrees with the design i.e. correct levels of thermal comfort, IAQ and energy usage.

EN 15240:2007. Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of air-conditioning systems

This European Standard describes the common methodology for inspection of air conditioning systems in buildings for space cooling and or heating from an energy consumption standpoint. The inspection can consider for instance the following points to assess the energy performance and proper sizing of the system: - System conformity to the original and subsequent design modifications, actual requirements and the present state of the building. - Correct system functioning. - Function and settings of various controls. - Function and fitting of the various components. - Power input and the resulting energy output. It is not intended that a full audit of the air conditioning system is carried out, but a correct assessment of its functioning and main impacts on energy consumption, and as a result determine any recommendations on improvement of the system or use of alternative solutions. National regulations and guidelines targeting energy efficiency and in line with the main objectives of this standard are also applicable. NOTE Provision of adequate ventilation and system balancing are dealt with in EN 15239. The qualification of the persons or organisation responsible for inspections is not covered by this standard, but the requirements for inspections are covered. The frequency of the mandatory inspection is defined on national level. Features affecting the frequency and duration of inspection are introduced in Annex C.

EN 15665:2009. Ventilation for buildings - Determining performance criteria for design of residential ventilation systems

This European Standard sets out criteria to assess the performance of residential ventilation systems (for new, existing and refurbished buildings) which serve single family, multi-family and apartment type dwellings throughout the year. This European Standard specifies ways to determine performance criteria to be used for design levels in regulations and/or standards. These criteria are meant to be applied to, in particular: - mechanically ventilated building (mechanical exhaust, mechanical supply or balanced system); - natural ventilation with stack effect for passive ducts; - hybrid system switching between mechanical and natural modes; - windows opening by manual operation for airing or summer comfort issues. This European Standard considers aspects of hygiene and indoor air quality. Health risk from exposure to tobacco smoke is excluded from this European Standard.

FprEN 15780:2011. Ventilation for buildings - Ductwork - Cleanliness of ventilation systems

This European Standard applies to both new and existing ventilation and air conditioning systems and specifies the assessment criteria of cleanliness, cleaning procedures of these systems, and the validation of the effectiveness of cleaning applies also to products, which conform to EN 1505, EN 1506, EN 13053, EN 13180 and EN 13403, used in air conditioning and ventilation systems for human occupancy defined in the scope of CEN/TC 156. This European Standard does not apply to installations for industrial processes. Cleanliness of ventilation systems is considered important for human comfort and health, energy consumption, system service life and for cleanliness of operations or processes carried out in the ventilated area. Considerations for change of component as an alternative for cleaning (e.g. in case of flexible ducts and air filters) are also included. This European Standard specifies general requirements and procedures necessary in assessing and maintaining the cleanliness of ducted ventilation, including: - cleanliness quality classification; - how to assess the need for cleaning (visual, measurements); - assessment frequency (general guidance); guidance of system inspections in accordance with EN 15239, and EN 15240 when relevant; - selection of cleaning method – to be in line with handing over documentation according to EN 12599; - how to assess the result of cleaning. This European Standard is a parallel standard to EN 12097, which specifies requirements for dimension, shape and location for access panels for cleaning and service in ductwork systems.

EN 15243:2007. Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems

The scope of this European Standard is - To define the procedure how the calculation methods to determine the temperatures, sensible loads and energy demands for the rooms shall be used in the design process. - To describe the calculation methods to determine the latent room cooling and heating load, the building heating, cooling, humidification and dehumidification loads and the system heating, cooling, humidification and dehumidification loads. - To define the general approach for the calculation of the overall energy performance of buildings with room conditioning systems - To describe one or more simplified calculation methods for the system energy requirements of specific system types, based on the building energy demand result from prEN ISO 13790, and to define their field of application. A general framework standard is given which imposes an hourly calculation for all cases, which cannot be covered by simplified methods, and gives requirements on what has to be taken into account. Input and output data are defined. The target audience of this standard is twofold: - Designers of HVAC systems, which are given an overview of the design process with the relevant references to the different involved standards (Clauses 5 to 12) - Developers of regulations and tools, which find requirements for calculation procedures to be used for the energy requirements according to the EPBD (Clauses 13 and 14). The idea followed by this standard is, that for the detailed approach one single calculation method is used for the different room related purposes such as room temperature calculation, room cooling and heating load calculation, and room energy calculation. This means, for the building type envisaged (buildings with room conditioning systems) it is an alternative to simplified calculation methods such as heating load according to EN 12831 and heating energy according to prEN ISO 13790.

FprEN 779:2011. Particulate air filters for general ventilation. Determination of the filtration performance

This European Standard refers to particulate air filters for general ventilation. These filters are classified according to their performance as measured in this test procedure. This European Standard contains requirements to be met by particulate air filters. It describes testing methods and the test rig for measuring filter performance. In order to obtain results for comparison and classification purposes, particulate air filters should be tested against two synthetic aerosols, a fine aerosol for measurement of filtration efficiency as a function of particle size within a particle size range 0.2 μm to 3.0 μm, and a coarse one for obtaining information about dust holding capacity and, in the case of coarse filters, filtration efficiency with respect to coarse loading dust (arrestance). This European Standard applies to air filters having an initial efficiency of less than 98 % with respect to 0.4 μm particles. Filters should be tested at an air flow rate between 0.24 m^3/s (850 m^3/h) and 1.5 m^3/s (5400 m^3/h). The performance results obtained in accordance with this standard cannot be applied quantitatively on its own to predict performance in service with regard to efficiency and lifetime. Other factors influencing performance to be taken into account are described in Annex A (Normative) and Annex B (Informative).

6.4 Summary and conclusion

Two lists of standards on ventilation can be considered. The first list comprises indoor air quality related standards that directly address the functional properties, which influence indoor air quality. The second list is related to ventilation but does not specifically address measures that can influence indoor air quality. The list of IAQ related standards mostly includes ventilation standards that deal with functional properties of ventilation systems or equipment, whereas the second list of non IAQ related standards mostly includes ventilation standards that deal with mechanical properties and testing of ventilation system and equipment.

The review of IAQ related standards revealed that *none of them is health based*. Standards, which can be used for determination of ventilation rates (EN 15251 and EN 13779) use different categories of comfort, based on documents EN ISO 7730 and CR 1752. The general rule applied to these documents is that a better indoor air quality requires higher ventilation rates. Indoor air quality in EN standards is not well defined. The standards only give some general guidance on air quality and mention numeric values only for concentration of CO_2 and humidity. These two are mentioned in EN 15251, whereas there are no other generally accepted criteria and measuring methods for other pollutants in the presently available ventilation standards

7 Requirements for ventilation rates and indoor environmental quality in some European countries

7.1 Introduction

A search was carried out on pollutant levels, ventilation rates, thermal and comfort requirements, and noise requirements in Europe, which are specified in regulations and used in practice where no regulations exist. To collect data from as many EU member states as possible and to overcome language barriers, a questionnaire was developed in English and then sent out to a group of experts on ventilation in different EU countries.

7.2 Questions

A questionnaire sent out to respondents, consisted 10 questions. Questions were as follows:

1. **What are the allowable maximum values (limits) of contaminants in residential buildings, schools, offices and kindergartens?**

a) No values given
b) Limits for residential buildings, schools, offices, kindergartens

2. **What are the minimum recommended ventilation rates for residences?**

a) Minimum air changes per hour (or in other units describing ventilation rates if provided)
b) Air flows to be exhausted from kitchen, toilet, bathroom

3. **What is the minimum recommended ventilation rate for classrooms?**

4. **What is the minimum recommended ventilation rate for playrooms in kindergarten?**

5. **What is the minimum recommended ventilation rate in office rooms?**

6. **What are the temperature limits?**

a) Not given
b) For summer
c) For winter

7. **What is the maximum allowable air velocity in residences and offices?**

a) Not given
b) For summer
c) For winter

8. **What are the limits for humidity in the indoor air?**

9. **What are the limits for ventilation noise?**

a) Not given
b) Residences (bedrooms)
c) Schools
d) Kindergartens
e) Offices

10. **The information given above is (if possible, please write the source of information besides answers).**

a) Mandatory, given in building regulations, please give the reference

b) Informative, given in non-mandatory guidelines or standards, please give the reference

16 respondents returned the questionnaire from all parts of Europe. The structure of responds gives a good coverage of building practices of all European regions.

7.3 Ventilation rates in EU dwellings

7.3.1 Introduction

Ventilation in dwellings is normally regarded as being required for one of the following purposes:

- Dilution and/or removal of pollutants such as substances emitted by furnishings, cleaning materials, odours, metabolic CO_2 and water vapour
- Dilution and/or removal of specific pollutants from identifiable local sources such as toilette and cooking odours, water vapour from cooking and washing, tobacco smoke and combustion products from fuel burning appliances
- Supply of oxygen to occupants for respiration and fuel burning appliances
- Control of indoor humidity
- Control of thermal conditions

7.3.2 Results

Ventilation rates in dwellings as required in national regulations and standards in selected EU countries are shown in Table 7. First column of the table provides the country and a reference (a code or a standard). Ventilation rates are shown in columns 2 to 5 Ventilation rates, which are written with normal font, provide mandatory values (published in regulations). Ventilation rates, which are underlined and italic are recommendations or are normally used by designers. Where no reference is given, the source of information was not provided. Ventilation rates are given in the units as published: ach, m^3/h, l/s, $m^3/h/p$ (per person), l/s/p (per person), $m^3/h/m^2$, $l/h/m^2$, etc..

Table 7: Ventilation rates in dwellings

Country and reference	Minimum air change rate for residencies	Exhaust air flow rates from kitchen	Exhaust air flow rates from toilette	Exhaust air flow rates from bathroom
Bulgaria Regulation 15/28.07.2005 except for min. air change rates for residences	*CEN/CR 1752:* *4 l/s per person* *(lowest group C)*	5 ach continuous; 50 l/s for non-continuous operation	10 l/s continuous; 25 l/s for non-continuous operation	10 l/s continuous; 25 l/s non-continuous operation
Czech Republic *CSN EN 15665*	*0.3 ach*	*100 m^3/h*	*25 m^3/h*	*50 m^3/h*
Finland Building Regulations Part D2, Indoor climate and ventilation, 2010	0.5 ach and 6 l/s/p	8 l/s and boosted 25 l/s; 20 l/s continuous	10 l/s if can be boosted; 15 l/s continuous	7 l/s if can be boosted; 10 l/s continuous
France arrêté du 24 mars 1982, modified 28 October 1983	r = room 1 r: 35 m^3/h 2 r: 60 m^3/h 3 r: 75 m^3/h 4 r: 90 m^3/h 5 r: 105 m^3/h 6 r: 120 m^3/h 7+ r: 135 m^3/h	r = room 1 r: 20 m^3/h 2 r: 30 m^3/h 3+ r: 45 m^3/h	r = room 1-3 r: 15 m^3/h 4+ r: 30 m^3/h	r = room 1-2 r: 15 m^3/h 3+ r: 30 m^3/h
Germany DIN 1946-6:2008	*nominal ventilation:* *55 m^3/h (30 m^2)* *...* *215 m^3/h (210 m^2)*	*45 m^3/h (200 boosted)*	*25 m^3/h*	*45 m^3/h*

Greece (TOTEE)2425/86, 20701-4/2010, 20701-1/2010 (KENAK) Legislation 3661	0.7 ach	min 34 m³/h recommended: 50 - 80 m³/h	min 34 m³/h recommended: 50 - 80 m³/h	min 34 m³/h recommended: 50 - 80 m³/h
Hungary EN 15251, cat. II	0.42 l/s/m²	20 l/s	10 l/s	15 l/s
1 **Italy** Dlgs 192/2005, Dlgs 311/2006, DPR 59/2009, DM 18/12/1975	0.3 ach	6 ach	6 ach	6 ach
Lithuania STR 2.09.02:2005; HN 42:2004	0.5 h^{-1}	72 m³/h	36 m³/h	54 m³/h
Netherlands The Dutch Building Code 2012	total living area: 0.9 l/s/m² each room: 0.7 l/s/m²	21 l/s	7 l/s	14 l/s
Norway Building Regulations Act, Technical regulations (TEK2010)	1.2 m³/h/m² when occupied 0.7 m³/h/m² when not used	36 m³/h or 108 m³/h forced	36 m³/h	54 m³/h or 108 m³/h forced
Poland PN-83/B-03430Az3:2000	total airflow is sum of local extract airflows	all units: m³/h WITH WINDOW: gas/coal stove: 70 el. stove: 30 (max 3 pers. in apartment) el. stove: 50 (>3 pers. in apartment) NO WINDOW: el. stove: 50 gas stove: 70	50 m³/h	50 m³/h
Portugal	*0.6 ach - practice*	*>5 ach - practice; for short periods*	*>5 ach - practice; for short periods*	*>5 ach - practice; for short periods*
Romania I5 normative	the procedure and requirements are the same as in France			
Slovenia ULRS 42/2002 SIST DIN 1946-6	0.5 h^{-1}	60 m³/h	30 m³/h	60 m³/h
United Kingdom UK Building Regulations Part F (2010)	0.3 l/s/m² or 13 l/s - 1 bedroom 17 l/s - 2 bedrooms 21 l/s - 3 bedrooms whichever bigger	13 l/s	6 l/s	8 l/s

Ventilation rates in Table 7 are given in many different units, which do not allow making direct comparison. To make them comparable two cases of dwellings with 50 and 90 m2 with kitchen, toilet and bathroom were proposed. For every case other properties, which are required by national regulations were defined to calculate air change rate or ventilation rate. Properties of the two test dwellings are shown in Table 8 and Table 9. Then the air change rates and exhaust ventilation rates were calculated for a given test case and they are shown in Figures 47 – 51.

Table 8: Properties of two test cases of dwellings

Properties	Dwelling case 1	Dwelling case 2
Area	50 m²	90 m²
ceiling height	2.5 m	2.5 m
number of main rooms	2: 1 living, 1 sleeping	4: 1 living, 1 sleeping, 2 children
number of kitchens	1 x 10 m²	1 x 15 m²
number of toilets	1 x 2 m²	1 x 2 m²
number of bathrooms	1 x 5 m²	1 x 5 m²
number of occupants	2	4
Notes	kitchen with window and electric stove	kitchen with window and electric stove

Table 9: Properties of test kitchen, toilet and bathroom

Properties	Kitchen	Toilet	Bathroom
area	10 m²	2 m²	5 m²
ceiling height	2.5 m	2.5 m	2.5 m

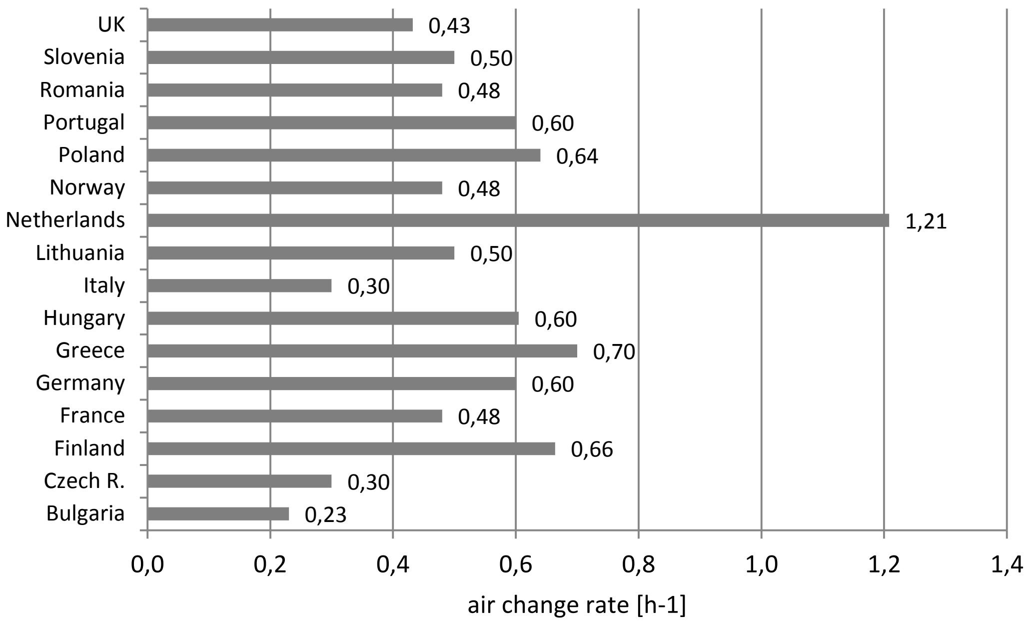


Figure 47: Air change rate in test dwelling case 1 - area 50 m²

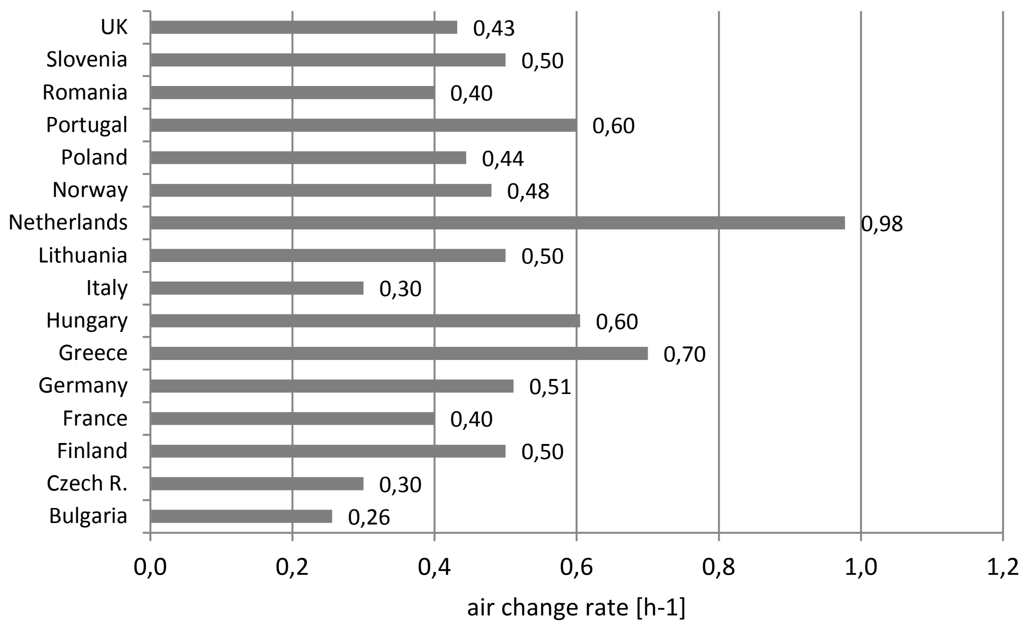


Figure 48: Air change rate in test dwelling case 2 - area 90 m2

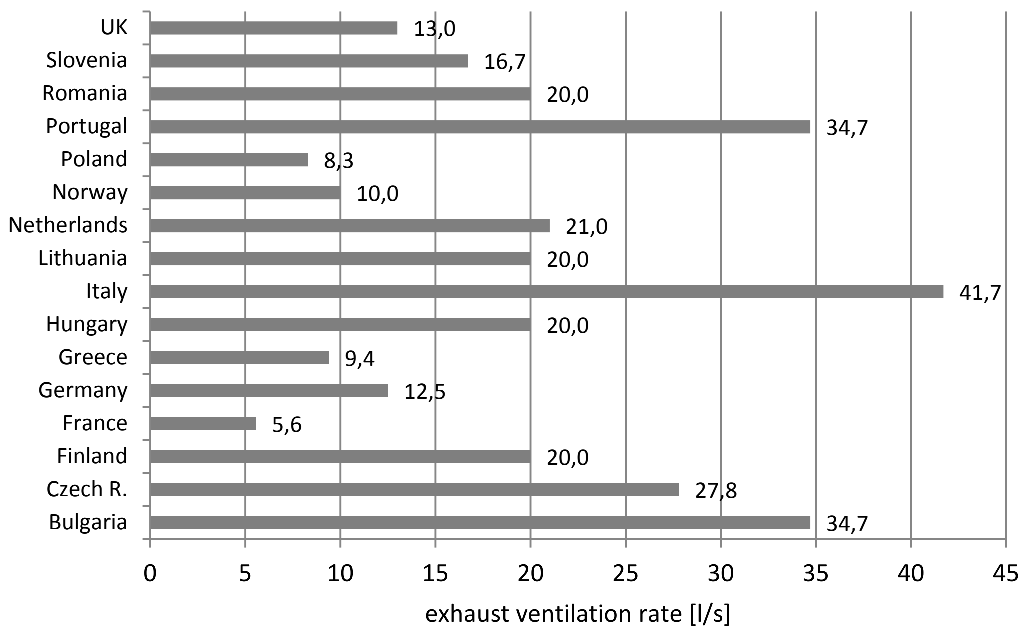


Figure 49: Exhaust ventilation rate for test case - kitchen 10 m2

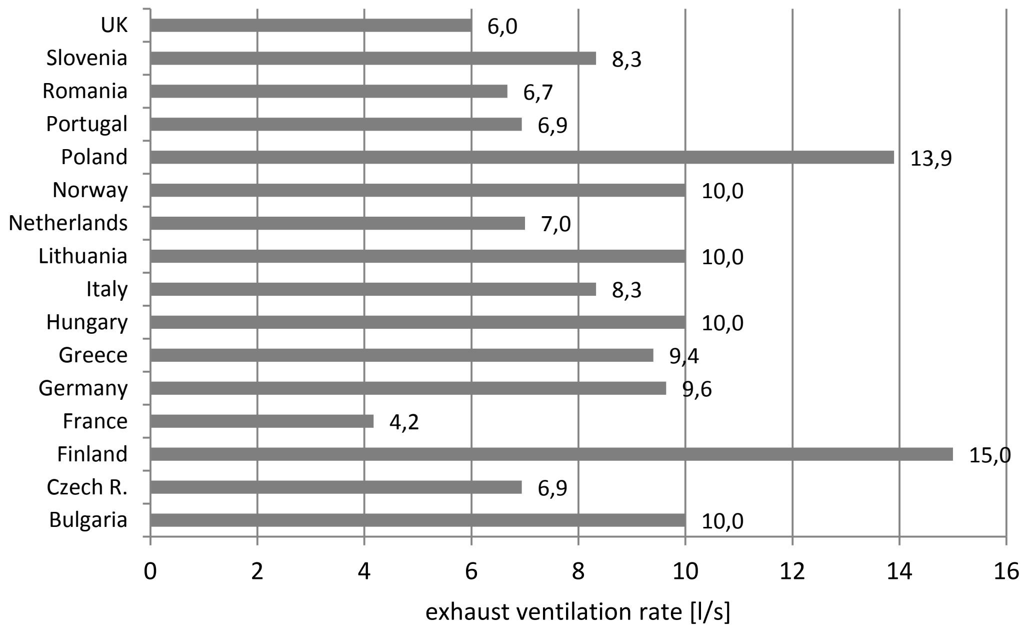


Figure 50: Exhaust ventilation rate for test case - toilet 2 m²

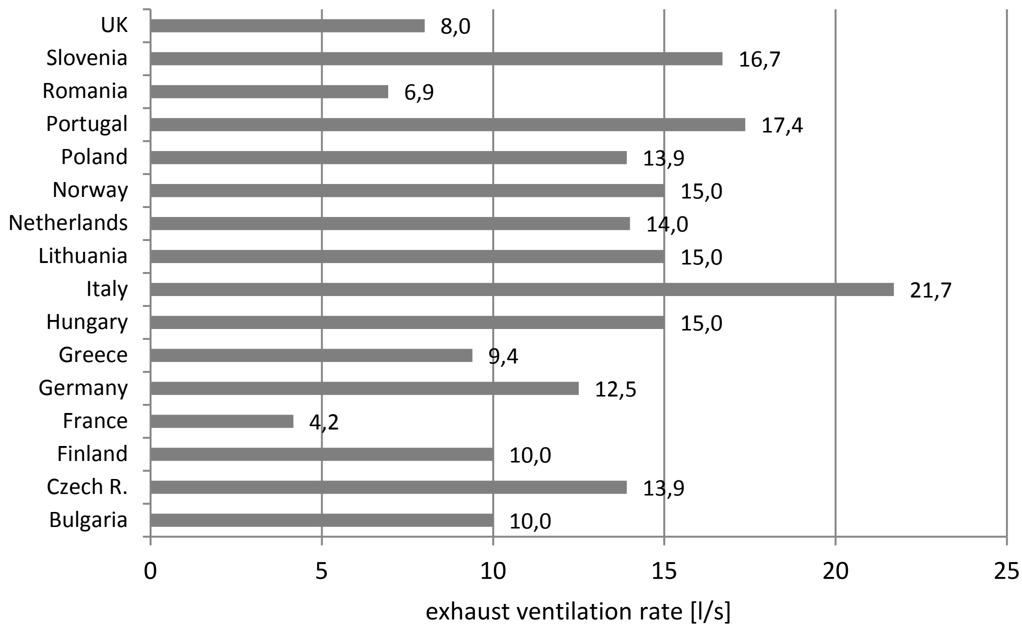


Figure 51: Exhaust ventilation rate for test case - bathroom 5 m²

7.3.3 Discussion

Normative requirements for ventilation of dwellings are given in regulations and standards in different units. Some are expressed as ventilation flow rates and others as air change rates. Units depend on the tradition of the country. Almost all countries use one of the following two units and their derivatives for ventilation rates: litres per second (l/s) or cubic metres per hour (m^3/h). Countries have taken different approaches to define ventilation rates in dwellings. Almost all countries have requirements based on a minimum supply ventilation rate for a dwelling as a whole and separate requirements for local exhaust rates from spaces like kitchen, toilet, and bathroom. Many countries lack a clear link between local exhaust rates and a ventilation rate of the whole dwelling. That makes the design and balancing of the system more difficult.

In regulations where the air change rates are used, it is not always clear whether ventilation system should ensure required air change rate as average ventilation rate in the whole dwelling or in every single room. If only simple definition of ventilation rate per dwelling as one zone is used, some rooms can get more fresh air than others (because of different volume), but the net air change rate can at the same time be ensured. If a minimum ventilation rate is given as an air changes per hour, it should be noted that the required minimum air change rate should be ensured in every room of the dwelling.

Calculation of air change rates for the two test cases of dwellings shows that there is a considerable difference in ventilation rates among different countries. The difference between the lowest and the highest rate can be as high as 1:5. Depending on the size of apartment, the ratio can be even higher. Such big differences in required ventilation rates imply that there is no common underlying principle for setting the ventilation rates.

Comparison of exhaust ventilation rates from kitchen, toilet, and bathroom shows that countries required ventilation rates are again very different in various countries. Exhaust rates in some countries can be as much as five times higher as in other countries, similar to the difference in the ventilation rates for the whole dwelling. Again these results imply lack of common theoretical background for setting the local exhaust rates.

Some countries have still no compulsory ventilation rates, as specified by codes; only values recommended by standards are used. Although all members of the EU adopted EN standards, which define ventilation rates, values prescribed in their national regulations may be different than the adopted EN standards. This may be confusing for designers, and contrary to the intention of creating common European standards. This clearly suggests that Europe needs a common regulation on ventilation rates, which would harmonize determination of rates among countries, and that the common underlying principle for setting the rates (for example based on health requirements) is used unlike the case in many existing regulations.

7.4 Ventilation rates in schools, kindergartens and offices

7.4.1 Introduction

Indoor environment in classrooms of schools, playrooms and kindergartens are dominated by high occupancy loads. The dominant pollutants are human bioeffluents (due to metabolism). Office environments are more like dwellings because occupancy is not a dominant factor and there are also other source of pollution that can be as dominant as human bioeffluents.

7.4.2 Results

Ventilation rates in classrooms of schools, playrooms of kindergartens, and offices, as required in national regulations and standards in selected EU countries are shown in Table 10. First column of the table provides the country and a reference (a code or a standard). Ventilation rates are shown in columns 2 to 4 Ventilation rates, which are written with normal font, provide mandatory values (published in regulations). Ventilation rates, which are underlined and italic are recommendations or are normally used by designers. Where no reference is given, the source of information was not provided.. Ventilation rates are given in the units as published: ach, m^3/h, l/s, $m^3/h/p$ (per person), l/s/p (per person), $m^3/h/m^2$, $l/h/m^2$, etc..

Table 10: Ventilation rates in schools, kindergartens and offices

Country and reference	Minimum ventilation rate for class rooms	Minimum ventilation rate for play rooms in kindergarten	Minimum ventilation rate in office rooms
Bulgaria Regulation 15/28.07.2005 CEN/CR 1752:1988	2.4 l/s/m²	2.8 l/s/m²	0.8 l/s/m²
Czech Republic Regulation 410/2005 Decree 361/2007	20 - 30 m³/h/p	20 - 30 m³/h/p	50 m³/h/p
Finland Building Regulations Part D2, Indoor climate and ventilation, 2010	6 l/s/p + 3 l/s/m²	6 l/s/p + 2.5 l/s/m²	1.5 l/s/m²
France arrêté du 24 mars 1982, modified 28 October 1983	15 - 18 m³/h/p	15 - 18 m³/h/p	25 m³/h/p
Germany EN 15251, cat. II	*4.9 l/s/m²* ** for non-low polluting building materials*	*5.8 l/s/m²* ** for non-low polluting building materials*	*2.1 l/s/m²* ** for non-low polluting building materials*
Greece (TOTEE)2425/86	min 17 m³/h/p recommended: 26 - 34 m3/h/p	min 17 m³/h/p recommended: 26 - 34 m3/h/p	min 25.5 m³/h/p recommended: 25.5 - 42.5 m3/h/p
Hungary EN 15251, cat. II	4.9 l/s/m² *for non-low polluting building materials	5.8 l/s/m² *for non-low polluting building materials	2.1 l/s/m² *for non-low polluting building materials
Italy DM 18/12/1975; UNI 10339	3.5 ach	*0.004 m³/s/p*	*0.011 m³/s/p*
Lithuania STR 2.09.02:2005; HN 42:2004	6 l/s/p	-	10 l/s/p
Netherlands The Dutch Building Code 2012	4.8 l/s/m² 1 student occupies 1.3 – 3.3 m²	2.4 l/s/m² (1 child 1.3-3.3 m²); 6.4 l/s/m² (1 child <1.3 m²)	1.0 l/s/m² (6 – 8 m² per p)
Norway Building Regulations Act, Technical regulations (TEK2010); Arbeidstilsynet 444	26 m³/h/p; 2.5 m³/h/m² used; 0.7 m³/h/m² not used	7 l/s; 10 l/s high activity	26 m³/h/p; 2.5 m³/h/m² if used; 0.7 m³/h/m² if not used; 3.6 m³/h/m² for undocumented materials
Poland PN-83/B-03430Az3:2000	ventilation: 20 m³/h AC: 30 m³/h	ventilation: 20 m³/h AC: 30 m³/h	ventilation: 20 m³/h AC: 30 m³/h
Portugal Decree law 79/2006	30 m³/h/p	30 m³/h/p	30 m³/h/p or 5 m³/h/m²; whichever is higher
Romania I5 normative	15 m³/h/p	15 m³/h/p	shared: 17 m³/h/p individual: 25 m³/h/p
Slovenia ULRS 42/2002	person: 7.2 m³/h/m² building: 2.9 m³/h/m³	person: 8.7 m³/h/m² building: 2.9 m³/h/m³	person: 1.5 m³/h/m² building: 2.9 m³/h/m²
United Kingdom UK Building Regulations Part F (2010)	10 l/s/p	10 l/s/p	10 l/s/p

Ventilation rates in Table 10 are given in many different units, which do not allow making direct comparison. To make them comparable cases for a classroom in school, playroom in kindergarten and an office were proposed. For every case other properties, which are required by national regulations were defined to calculate air change rate or ventilation rate Table 11). Then the air change rates and exhaust ventilation rates were calculated for a given test case and they are shown in 52-54.

Table 11: Properties of the test classroom, playroom and office

Properties	Classroom	Playroom	Office
area	50 m²	50 m²	12 m²
ceiling height	2.8 m	2.8 m	2.8 m
number of occupants	25	25	1

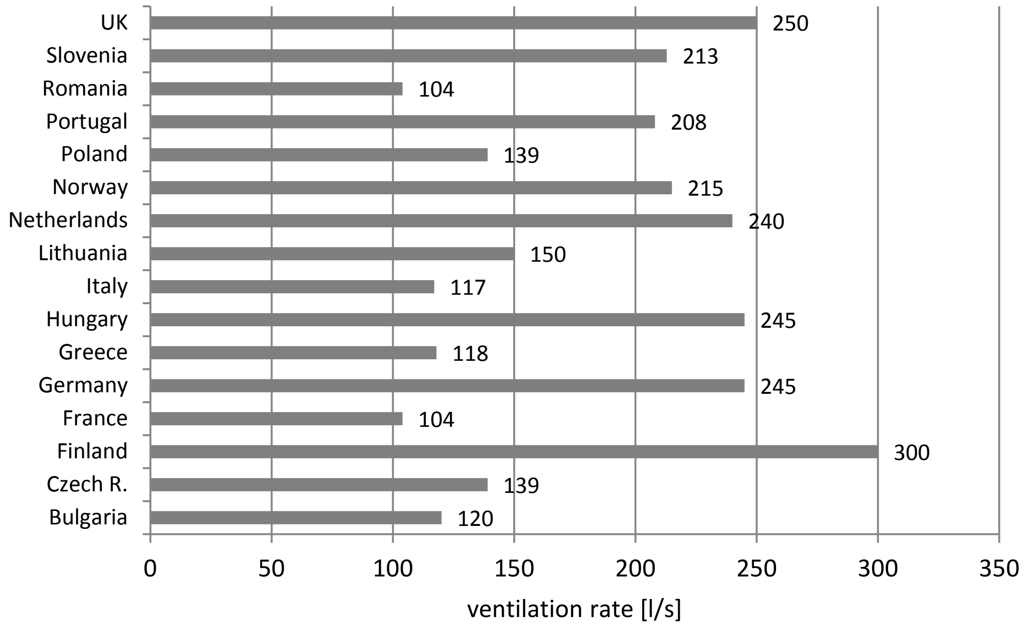


Figure 52: Ventilation rate in test case of a classroom

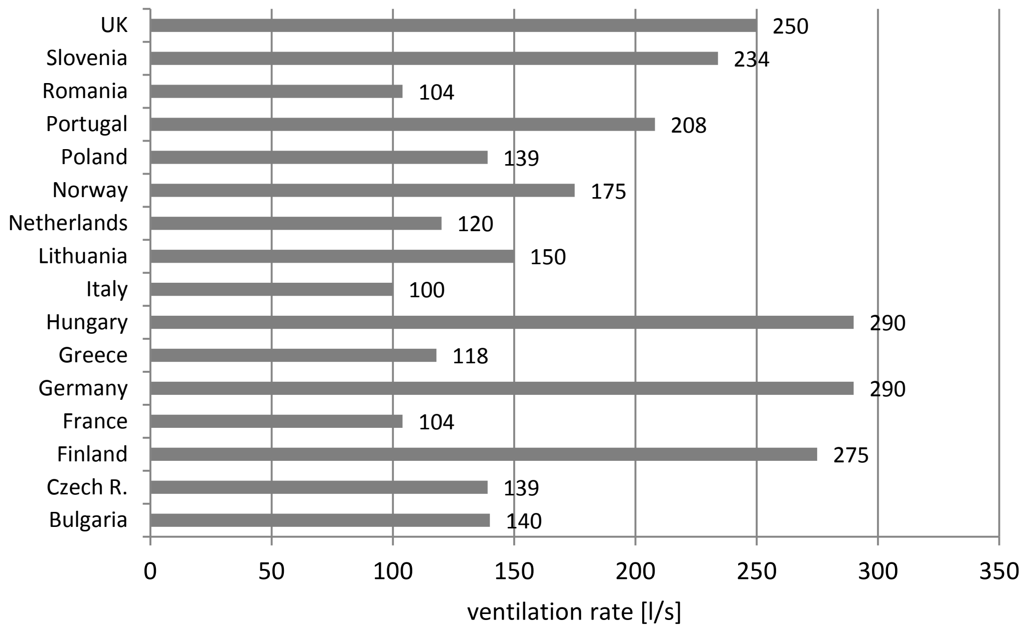


Figure 53: Ventilation rate in test case of a playroom

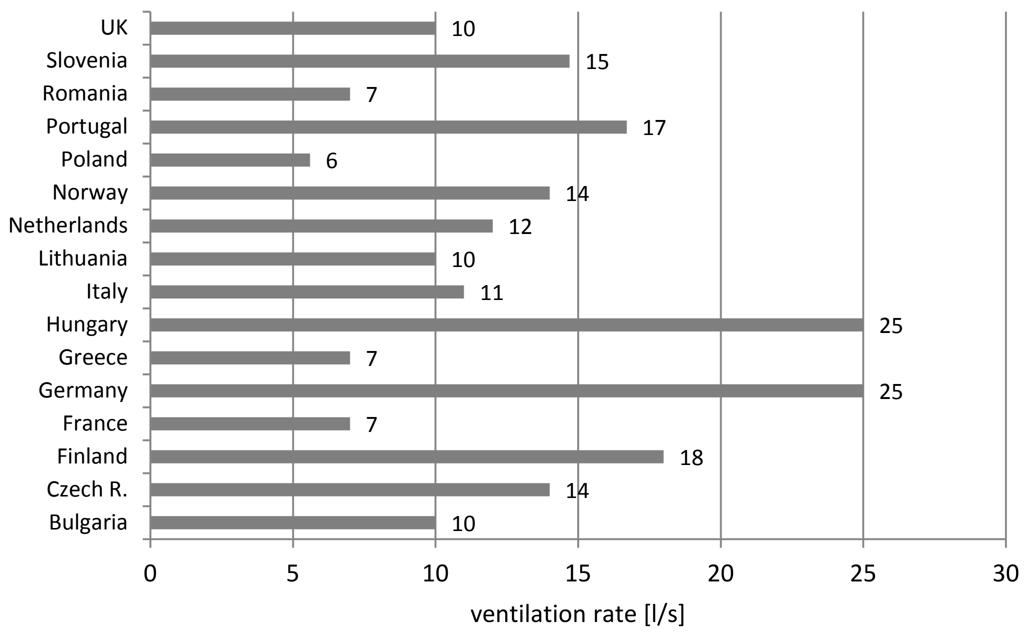


Figure 54: Ventilation rate in test case of an office

7.4.3 Discussion

As in the case of ventilation rates for dwellings, ventilation rates in classrooms, playrooms and offices are also expressed in different units. Almost all countries use one of the following two units and their derivatives for ventilation rates: litres per second (l/s) or cubic metres per hour (m^3/h).

Countries use two main approaches to define ventilation rate. One is based on the number of persons in the room and is usually expressed as l/s per person or m^3/h per person. The other one is based on the floor area of the room and is usually expressed as l/s per m2 or m^3/h per m2. The weakness of using the first approach is that it only considers number of persons and may overlook the pollution from other sources, which are included in the rate per area. The weakness of the second approach is that it determines ventilation rates per floor area. It does not consider that number of persons per unit of floor, except if ventilation rates are harmonised with regulations that define the minimum floor area per person. Some countries use a combination of both approaches, which considers number of persons, as well as floor area of the room. The two values are usually added.

Considering the sources of pollutants, the latter approach would seem most logical if exact required ventilation rates per person were known. Comparing ventilation rates for proposed cases of classroom, playroom, and office showed that ventilation rates vary considerably among countries. Figure 52 and Figure 53 show that there are basically two groups. One group is includes countries with ventilation rate in classroom and playroom around 250 l/s and the other group around 100 l/s. The first group corresponds to ventilation rates of 10 l/s per person. It includes the following countries: Finland, Germany, Hungary, the Netherlands, Norway, Slovenia and UK, i.e. is mainly formed of countries from Northern and Western Europe. The second group corresponds to rates of about 4 l/s per person and is formed by the following countries: Bulgaria, Czech Republic, France, Greece, Italy, Lithuania, Poland and Romania, which are countries from Eastern, Central and Southern Europe mainly. Two ventilation rates presented in Figures 52-53, for Germany and Hungary and calculated according to EN 15251. Although the above division in groups is suggested no consistent association between the rate and the region in Europe can be defined.

Although all the members of the EU have adopted standard EN 15251 as its national standard for indoor environmental input parameters for design of energy performance of buildings, national regulations (codes) prescribe values, which are different from the values recommended in this standard. Consequently as in case of dwellings it may be recommended that that ventilation rates in Europe should be harmonised.

7.5 Indoor pollutant levels

7.5.1 Introduction

Clean air to breathe is one of the fundamental human rights. Pollutant concentrations above certain level can represent health risks to the general public. They can also cause dissatisfaction, discomfort, unacceptable odours and sensory irritation. This sub-section investigates indoor pollutant levels as defined in national regulations. Historically, the primary objective in setting recommended limits was to minimize health risks to the general public or to sectors of the public, such as industrial workers or sensitive individuals.

Recognizing the need for the occupational exposure limit values, the EU first adopted a directive on the protection of workers from the risks related to exposure to chemical, physical and biological pollutants at work in 1980 [**16**], which obliged Member States to impose national limit exposure values. Since then the EU has adopted a series of new directives, adding new pollutants to the list and imposing their limit values. In parallel to the directives on occupational exposure limits, the EU has also adopted several air quality directives focused on the ambient air[2] quality, mostly based on the *Air Quality Guidelines* produced by the World Health Organization (WHO). The first EU directive was adopted in 1996 [**17**], followed by several others.

Despite the work done on occupational exposure limit values and outdoor air quality, much less work was done on the topic of indoor air quality and exposures especially in residential buildings. Although the EU has not adopted any directive, the WHO has stressed the importance of the problem of indoor exposure to air pollutants since the publication of the first edition of the *Air quality guidelines for Europe* in 1987 [**18**]. WHO published recently *Guidelines for indoor air quality* in 2009 [**19**] and 2010 [**20**]. The latter provides a thorough historic overview of developing of indoor air quality guidelines.

7.5.2 Occupational exposure values

To protect workers against the health risk and to ascertain safe exposures to chemical, physical and biological pollutants, the industrialized world has adopted the first occupational exposure values about 50 years ago. In Europe, these values are known as 'indicative occupational exposure limit values' (IOELVs)[3]. For practical reasons, the IOELVs are usually established in relation to a reference period of 8 hours (a typical working day), on a basis of a nominal 40-hour working week and for a working lifetime. Limits are expressed in units of ppm (volume/volume) or mg/m^3.

In the EU, the concept of IOELVs[4] on the Community level was first introduced in 1980 by adoption the Council Directive 80/1107/EEC [**16**]. The concept required that for any chemical pollutant for which an indicative occupational exposure limit value is established at the Community level, Member States shall establish national occupational exposure limit values, taking into account the Community limit value, determining its nature in accordance with national legislation and practice. However, the first list of 27 substances was not created until the Commission Directive 91/322/EEC in 1991 [**21**]. The latter required that Member States must implement national limits until 31 December 1993. At about the same time, the Commission assembled an advisory group of experts in the various disciplines concerned with the scientific and technical issues surrounding the derivation of occupational exposure limits, to advise the Commission. This group began work as the Scientific Experts Group (SEG) in 1990, but was transformed into Scientific Committee on Occupational Exposure Limits (SCOEL) in 1995. In 1998, the original directive 80/1107/EEC was repealed and replaced by a new Directive 98/24/EC [**22**]. The latter defines occupational exposure limit value as '*the limit of the time-weighted average of the concentration of a chemical pollutant in the air within the breathing zone of a worker over a specified reference period*'. There have subsequently been three directives, establishing three further lists of IOELVs[5]. The SCOEL recommended list (as for 2011) includes around 180 pollutants [**23**] and is regularly revised with new pollutants added to the list.

Community IOELVs are health-based, non-binding values, derived from the most recent scientific data available. They set threshold levels of exposure below which, in general, no detrimental effects are expected for any given substance after short term or daily exposure over a working lifetime. Socio-economic and technical feasibility factors are not taken into account

[2] According to the latest EU Directive 2008/50/EC [**71**] on ambient air quality, 'ambient air' shall mean outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC [**70**] where provisions concerning health and safety at work apply and to which members of the public do not have regular access. This report uses the term outdoor air instead.

[3] Widely used term is also a 'threshold limit value' (TLV), which is a reserved term of the American Conference of Governmental Industrial Hygienists (ACGIH)

[4] Until directive 98/24/EC a term 'indicative limit values' (ILVs) was used

[5] Commission Directives: 2000/39/EC; 2006/15/8EC; 2009/161/EU

when establishing IOELVs. Table 12 shows the IOELVs for selected pollutants. They will be later compared in this report with values of selected air pollutants found in national regulations.

Table 12: IOELVs for selected chemical pollutants [23]

Pollutant	8 hour time-weighted-average	
	mg/m3	ppm
Ammonia	14	20
CO2	9000	5000
Formaldehyde	0.25	0.2
Naphthalene	50	10

Besides SCOEL, there are other organizations preparing lists of occupational exposure values based on a similar concept like SCOEL's, however they usually also include values for pollutants that are not covered by SCOEL. Widely known are German MAK (Maximale Arbeitsplatz-Konzentrazion) and French VME (Valeur Moyenne d'Exposition) and VLE (Valeur Limite d'Exposition) limit values. These values usually serve national bodies preparing regulation for safety at the working place.

According to the EU legislation, every Member State in the EU must have adopted national regulations that impose occupational exposure values. Although these values are primarily intended for use to protect workers in industry, regulations of national states often make them valid also for workers in tertiary sector because regulations do not provide a detailed explanation of the term work place. This was national OEL become valid also in offices, schools and kindergartens.

7.5.3 Guidelines for indoor air quality in non-industrial buildings

Recognizing the need for recommended pollutant levels that will guarantee the absence of all adverse health effects to human population, the WHO Regional Office for Europe published the first edition of *Air quality guidelines for Europe* in 1987 [**18**], containing risk assessment of 28 chemical air contaminants. Second edition of the WHO guidelines was published in 2000, focusing on the pollutants considered in the first edition. A so-called "global update" was published in 2006 [**24**], focusing on a small group of pollutants and including a chapter on indoor air quality. However, the first edition of guidelines from 1987 was mostly focused on outdoor pollutants but also included a section on radon and an annex on tobacco smoke. The second edition from 2000 [**25**] already provided a section on indoor air pollutants. The edition of "global update" from 2005 drew attention to the large impact on health of indoor air pollution in developing countries. Finally in 2006 edition of "global update", guidelines were recommended for application in all microenvironments, except for occupational exposures. In Europe, the WHO guidelines are now seen as the key source on which the European Commission's directive on air quality is based.

Although much effort was put into the adoption of the directives on occupational exposure limit values and outdoor air quality, the EU has so far not adopted any directive on the indoor air quality and the work on assessing the health effects of indoor air pollution has lagged behind similar document on outdoor air pollution. According to WHO, this is mostly because, as follows: (1) the policy development in the air pollution field has focused on outdoor air pollution as a result of the correctly perceived need to deal with the high levels of outdoor air pollutants associated with coal smoke and photochemical smog; (2) it was easier to monitor concentrations of outdoor air pollutants on a large scale; (3) the focus of epidemiologists on defining coefficients linking outdoor concentrations of air pollutants with effects on health; and (4) because the science and policy communities have focused on the public health impacts of air pollution in wealthy developed countries, while often disregarding the larger burden of disease due to indoor air pollution from solid fuel burning in the developing world.

In 2009 and 2010, the WHO Regional Office for Europe published two *Guidelines for indoor air quality*. Indoor air quality guidelines for *Dampness and mold* [**19**] from 2009 were published first, followed by *Selected pollutants* in 2010 [**20**]; the selected pollutants guidelines are based on the previous version of air quality guidelines but indoor air pollutants in new guidelines are addressed specifically.

7.5.4 National regulations addressing indoor air quality

Results of the requirements on exposures in different countries and recommended values according to the WHO guidelines are presented in Table 13. Presented limit values are published in national regulations indicated in the table if available from the respondents..

Table 13: Maximum values of contaminants

Country and reference	**Maximum values of contaminants in the indoor in non-industrial buildings**
WHO Guidelines	Annual average: Formaldehyde: 0.1 mg/m^3 Naphthalene: 0.01 mg/m^3 NO_2: 40 μg/m^3 PM10: 20 μg/m^3
Bulgaria Regulation 15/28.07.2005	8 h OEL limit: Ammonia: 14 mg/m^3 Formaldehyde: 1 mg/m^3 CO: 40 mg/m^3 CO2: 9000 mg/m^3
Czech Republic	8 h OEL: Ammonia: 14 mg/m^3 Formaldehyde: 0.5 mg/m^3 CO: 30 mg/m^3 CO2: 9000 mg/m^3
Finland Building Regulations Part D2. Indoor climate and ventilation. 2010	Ammonium and amines: 20 μg/m^3 Asbestos: 0 fibres/cm Formaldehyde: 50 μg/m^3 CO: 8 mg/m^3 PM 10: 50 μg/m^3 Radon: 200 Bq/m^3 (annual average) Styrene: 1 μg/m^3 Carbon dioxide: 2160 mg/m^3 (1200 ppm)
France Target values	2 Asbestos: 5 fibres/dm^3 3 Formaldehyde: 10 μg/m^3 4 Benzene: 2 μg/m^3 5 Naphthalene: 10 μg/m^3 CO: 10 mg/m^3 (8 hour) Ozone: 0.2 mg/m^3 Trichloroethylene: 20 μg/m^3 Tetrachloroethylene: 250 μg/m^3

Germany GefStoffV 2005 – AGW MAK 2000	6 <u>8 h OEL:</u> 7 Ammonia: 14 mg/m³ 8 CO: 35 mg/m³ 9 CO2: 9100 mg/m³ Ozone: 0.2 mg/m³ $N0_2$: 180 mg/m³
Greece (TOTEE)2425/86. 20701-4/2010. 20701-1/2010	<u>8 h OEL:</u> Ammonium and amines: 0.35 mg/l Formaldehyde: 0.006 mg/l CO: 9 ppm PM10: 50 mg/m³ CO2: 1000 ppm
Lithuania Regulation HN 35:2007 (for residential environment)	Ammonia: 0.04 mg/m³ (daily) Asbestos: 0.1 mg/m³ (instant) Formaldehyde: 0.01 mg/m³ (daily) PM10: 0.05 mg/m³ (daily average) Ozone: 0.03 mg/m³ (daily) Styrene: 0.002 mg/m³ (daily)
Norway	Radon: should not exceed 100 Bq/m³ VOC: not given. previously 400 µg/m³ 10 Formaldehyde: 100 µg/m³ (30 min average) Asbestos: not exceeding 0.001 fibre/m MMMF: not exceeding 0.01 fibre/m CO: 10 mg/m³ (8 hour average) CO2: 1800 mg/m³ NO2: 100 µg/m³ (1 hour average)
Portugal Decree law 79/2006	PM10: 0.15 mg/m³ CO2 : 1800 mg/m³ CO :12.5mg/m³ O3 : 0.2 mg/m³ Formaldehyde: 0.1mg/m³ VOC: 0.6 mg/m³ Radon 400 Bq/m³ Legionella : 100 UFC/l
Romania I5 normative	<u>30 min avg:</u> CO: 6 mg/m³ Formaldehyde: 0.035 mg/m³ <u>annual avg:</u> Radon: 140 Bq/m³ <u>instant max:</u> CO2: 1600 mg/m³
Slovenia ULRS 42/2002	CO2: 3000 mg/m³ radon: 400 Bq/m³ ammonia: 50 µg/m³ formaldehyde: 100 µg/m³ TVOC: 600 µg/m³ CO: 10 mg/m³* O3: 100 µg/m³ PM10: 100 µg/m³

United Kingdom UK Building Regulations Part F (2010) Appendix	NO2: 40 µg/m³ (annual average) CO (public): 10 mg/m³ (8hr average) CO (occupational): 35 mg/m² (8hr average) TVOC: 300 µg/m³ (8hr average) O3: 100 µg/m³ (8hr average)

* Original document (regulation) cites value in µg/m³ but we adopted mg/m³ because we believe that original unit is a mistake

7.5.5 Discussion

Criteria for indoor air quality are mostly expressed as a measure of concentration by volume. Concentrations are expressed in micrograms, milligrams or grams per cubic meter of air. Less often and almost exclusively for CO_2 and CO criteria are expressed in terms of concentrations of pollutant in air per in parts per million (ppm).

The limit values in regulations, standards and guidelines represent different exposure situations. In most countries the only published limit values of pollutants are occupational exposure limit (OEL) values. OEL limit concentrations can be found in regulations defining exposure of workers to chemicals in industrial premises or to work places where chemicals are used routinely in the production process. Due to the broad definition of the term “working place” in national regulations, these limits are sometimes also valid for workers in non-industrial buildings.

When OEL values are calculated, it is supposed that worker is exposed to limit concentration for 8 hours. This is however not the case in practice, because people in developed countries, including all countries of the EU and EFTA, spend up to 90% or more of their time indoors. Besides that, exposure to any individual pollutant in offices and similar work places is typically much lower than in industry. Exposure is characterized by a wide spectrum of compounds at low levels from different building materials, room equipment, furniture, outdoor air and human metabolism.

Consequently it is rather impossible to directly apply occupational exposure values in the context of the regulations for ventilation as they have to be adapted to longer exposure times and should consider potential effects of combined exposures of several pollutants at once. It may be advisable that EU and countries should adopt new legislation, which would be focused solely on indoor air quality of homes and working spaces where workers are not exposed to chemicals from industrial processes, but to pollutants that stem from building materials and occupants.

As can be seen in the Table 13, some countries have already proposed limit concentrations of indoor pollutants in the context of ventilation requirements and codes. These limits are however inconsistent across different countries.

Very wide ranges of values can be found. PM_{10} values range from 0.05 to 0.15 mg/m³ in regulations, while WHO recommended value from 2006 is 0.02 mg/m³. Formaldehyde levels range from 0.04 to 0.1 mg/m³ in most countries. Bulgaria has high limit value of 1 mg/m³. The WHO recommendation from 2010 is 0.1 mg/m³ as from 2010. Limit values for ammonium and amines were found in the range from 0.02 mg/m³ in Finland to 14 mg/m³ in Bulgaria.

The present results suggest that there is need for a common guideline for indoor air quality. A new guideline should propose limit vales for some pollutants, for which minimum safety level in existing guidelines does not exist. Such levels should be adopted with a consensus among all the stakeholders. Requirements for indoor air quality should be included in national regulations of all European countries. National regulations should include a minimum number of pollutants and their limit levels. Current regulation on occupational exposure levels should only be used only for industrial working places rather than adopted for other buildings.

7.6 Thermal comfort requirements

7.6.1 Introduction

This section describes the values, which are used in national regulations and/or standards to define thermal environment. The values include indoor temperature, air velocity and relative air humidity.

7.6.2 Results

Values that are used in different European countries are shown in Table 14. First column of the table provides the country and a reference (a code or a standard). Temperature, air velocity and relative humidity are shown in columns 2 to 6. Values written with normal font provide mandatory values (published in regulations). Values that are underlined and italic are recommendations or are normally used by designers. Where no reference is given, the source of information was not provided. The hyphen means no values/requirements.

Table 14: Thermal and comfort requirements

Country and reference	**Temperature limits summer [°C]**	**Temperature limits winter [°C]**	**Maximum air velocity in residences and offices - summer**	**Maximum air velocity in residences and offices - winter**	**Limit value for humidity of indoor air (min winter/ max summer) [%rh]**
Bulgaria Regulation 15/28.07.2005 CEN/CR 1752:1988	office: 24.5±2.5 class: 24.5±2.5 kind.: 23.5±2.5	office: 22.0±3.0 class: 22.0±3.0 kind.: 20.0±3.0	office 0.25 m/s	office: 0.21 m/s	-
Czech Republic Regulation 410/2005 Decree 361/2007	office: 28 school: 26	office: 20 schools: 20	0.1 - 0.2 m/s	0.1 - 0.2 m/s	30 -70% RH
Finland Building Regulations Part D2, Indoor climate and ventilation, 2010	25	21	0.3 m/s	0.2 m/s	no humidification above 45% RH
France Code de la construction et de l'habitation	-	18	-	-	-
Germany EN 15251, cat. II	<u>*26*</u>	<u>*20*</u>	-	-	<u>*max 12 g/kg*</u>
Greece (TOTEE)2425/86	26	20	0.25 m/s	0.15 m/s	winter max: 40% RH summer max: 45% RH
Hungary EN 15251, cat. II	26	20	-	-	30 - 70%
Italy DM 18/12/1975; UNI 10339	-	20	-	-	<u>*45-55%*</u>
Lithuania HN 42:2004; HN 69:2003	24.5±1.5	22±2	0.3 m/s	0.2 m/s	max. 75% RH
Netherlands The Dutch Building Code 2012	-	-	0.2 m/s	0.2 m/s	-
Norway Building Regulations Act, Technical regulations (TEK2010); Arbeidstilsynet 444	work load: low. medium. heavy: 26	work load: low 19; medium 16; heavy 10	0.15 m/s	0.15 m/s	only recommendations to prevent dampness and mold growth

Portugal Decree law 79/2006	25	20	0.2 m/s in occupied areas	0.2 m/s in occupied areas	-
Romania I5 normative	residential: 25.5 - 27 offices: 25.5 - 27 kindergartens: 24.5 - 26	residential: 18 - 21 offices: 19 - 21 kindergartens: 15 - 17.5	20°C: 0.10 - 0.16 m/s 21°C: 0.10 - 0.17 m/s 22°C: 0.11 - 0.18 m/s 24°C: 0.13 - 0.21 m/s 26°C: 0.15 - 0.25 m/s		11 for 20 - 27°C RH = 30 - 70% upper max 12 g/kg
Slovakia Z.z. 259:2008	28	18	0.25 m/s	0.20 m/s	30 - 70% RH
Slovenia ULRS 42/2002	26	19	0.25 m/s	0.21 m/s	30 - 70% RH
United Kingdom UK Building Regulations Part F (2010)	28 for 1% annual occupied hours	19	0.15 m/s	0.15 m/s	-

7.6.3 Discussion

The parameters present in Table 14 are inconsistent among different countries. Some countries do not have any requirements for thermal environment.

Temperature limits for summer vary from 28 to 25°C and in winter from 18 to 21°C. It is interesting to observe that Finland, which is a country with the coldest climate among included countries, has the highest limit of the winter minimum temperature. Finland has also the lowest summer design temperature. One can notice that minimum air temperature limits is prescribed in more countries than maximum air temperature limit.

Maximum air velocities vary from 0.15 to 0.30 m/s. Majority of regulations only prescribe maximum air velocity without providing the temperature at which the limits are applicable.

Limits values of air humidity seem to be slightly more consistent. Limit levels of humidity are expressed as relative humidity (%) or absolute humidity (g/kg). Lower limits are at 30% while higher limits are 70% in all but one case when it is 75%. Humidity level is given in terms of absolute humidity to limit the highest amount of water in the air and is in both cases the same, i.e. 12 g of water per one kg of air.

It seems reasonable to propose common European regulation on thermal environment conditions, a minimum temperature during heating season and a maximum temperature during cooling season; temperature requirements will have to be adjusted to the climatic conditions in the country. Maximum air velocities in the regulations should be linked with the temperature.

7.7 Noise requirements

7.7.1 Introduction

This section described the limit values of noise from ventilation system in indoor environments. Values are from national regulations and standards. The limits are applicable for bedrooms in residences, classrooms in schools and offices.

7.7.2 Results

Limit values for noise are shown in 5. First column of the table provides the country and a reference (a code or a standard). Noise limits are shown in columns 2 to 5. Values written with normal font provide mandatory values (published in regulations). Values that are underlined and italic are recommendations or are normally used by designers. Where no reference is given, the source of information was not provided. The hyphen means no values/requirements.

Table 15: Requirements on limit indoor noise levels

Country and reference	**Limit values for ventilation noise in sleeping rooms of residencies**	**Limit values for ventilation noise in classrooms**	**Limit values for ventilation noise in playrooms**	**Limit values for ventilation noise in offices**
Bulgaria Regulation 15/28.07.2005 CEN/CR 1752:1988	-	40 dB(A)	40 dB(A)	45 dB(A)
Czech Republic Regulation 148/2006	40 dB(A)	45 dB(A)	45 dB(A)	50 dB(A)
Finland Building Regulations Part D2, Indoor climate and ventilation, 2010	28 dB(A) eq	33 dB(A) eq	28 dB(A) eq	33 dB(A) eq
France	30 dB(A)	38 dB(A)	38 dB(A)	-
Germany DIN 4109 VDI 2081	*35 dB(A)*	*40 dB(A)*	*40 dB(A)*	*40 dB(A)*
Greece (TOTEE)2425/86	NR 25	NR 35	NR 35	NR 35
Hungary EN 15251	26 dB(A)	35 dB(A)	40 dB(A)	35 dB(A)
Italy UNI 10339	*35 dB(A) eq*	*25 dB(A) eq*	*25 dB(A) eq*	*35 dB(A) eq*
Lithuania HN 33:2007	35 dB(A) eq 22-6h	40 dB(A)	40 dB(A) 6-18h	50 dB(A)
Netherlands The Dutch Building Code 2012	vent system: 30 dB(A)	vent system: 30 dB(A)	vent system: 30 dB(A)	vent system: 30 dB(A)
Norway NS 8175	35 dB(A)	35 dB(A)	35 dB(A)	35 dB(A)
Poland PN EN 15251	26 dB(A)	35 dB(A)	40 dB(A)	35 dB(A)
Portugal	-	-	-	-
Romania I5 normative EN 15251	20 - 35 dB	class rooms: 30 - 40 dB	30 - 45 dB	small: 30 - 40 dB landscape: 35 - 45 dB
Slovenia ULRS 14/1999 ULRS 07/2001	day/night: $L_{AF,max}$: 35/30 dB(A) L_{eq}: 40/35 dB(A)	day/night: $L_{AF,max}$: 40/40 dB(A) L_{eq}: 40/40 dB(A)	-	L_{eq}: 45 dB(A)
United Kingdom CIBSE recommended	*NR 25*	*NR 25-35*	-	*NR 35-45*

7.7.3 Discussion

Noise limits as defined in European regulations and standards are inconsistent. Inconsistency is also observed in the use of units in which values are given; some countries give noise levels as equivalent levels, while others do not. The former provide an average over a certain time interval while in the latter case they describe instantaneous levels. The two sound levels are not directly comparable. The third type of units for sound levels is noise rating curves, which are again not directly comparable with any of the two previous mentioned units.

Minimum equivalent level for bedrooms in dwellings is 28 dB(A) eq and minimum instantaneous level is 25 dB(A). Maximum levels are 35 dB(A) eq and 40 dB(A). Range for equivalent levels (min – max) for classrooms and playrooms is 28 to 40 dB(A) eq, and for instantaneous levels 30 to 45 dB(A). In offices values range for equivalent levels (min – max) 33 to 45 dB(A) eq and for instantaneous levels 35 to 50 dB(A). On average equivalent levels are usually 5 dB lower than instantaneous levels.

Many of the noise limit levels seem to be high, which is especially the case for bedrooms. To avoid confusion one regulation seems to be needed in Europe using also similar comparable units. Also the regulations should not prescribe tolerated limit sound levels as intervals but rather as fixed maximum allowable limits, which is not a current practice.

7.8 Summary and conclusion

7.8.1 General remarks

Review of the European regulations and standards on ventilation rates, indoor pollutants, and indoor environment criteria showed that the regulations are inconsistent across different countries. The majority of parameters are defined in the European Standards, which are accepted by CEN voting process of the national bodies, where many EU countries are participating. Nevertheless, the values found in the EN standards and those in regulations are not harmonized. This inconsistency may cause problems to designers and industry, and increase the construction cost. It contrasts with the efforts towards unification and standardisation in the European common market

It seems reasonable to recommend the development of a common European guideline, which would serve as a basis for uniform European regulations. A guideline should at minimum propose ventilation rates and technical properties and other parameters related to performance of ventilation.

7.8.2 Ventilation rates

A common factor of regulations of ventilation rates is the inconsistencies in the ventilation rates themselves, in the units in which they are given, and in the procedure for the calculation of ventilation. Almost all countries use one of the following two units and their derivatives for ventilation rates: litres per second (l/s) or cubic metres per hour (m^3/h). This is surprising considering that that members of the EU have accepted standards EN 15251 and EN 13779, which both define ventilation rates. Some countries do not have code requirements regarding ventilation rates and only use voluntary recommendations provided by standards.

Countries have taken different approaches to define ventilation rates in dwellings. To compare ventilation rates in different countries, different cases were created for different building types. Results show large differences in ventilation requirements between countries. The ratio between the lowest and highest ventilation rates in dwellings was found to be nearly 1:6, or expressed as a ventilation rate per floor area 0.23 $l/s/m^2$ to 1.30 $l/s/m^2$. It was discovered that many countries lack a clear link between local exhaust rates and the ventilation rate of the whole dwelling, which makes the design, and balancing of the system difficult in practice. Very large differences in the rates were also found also for classrooms, playrooms, and offices. One group of countries has a ventilation rate for the test cases of classroom and playroom from 10 l/s per person to about 4 l/s per person, higher rates generally in Nordic countries and lowers in Eastern Europe and Southern Europe.

7.8.3 Indoor pollutants

The EU has already adopted several directives on the quality of ambient air and occupational exposure limits of pollutants to protect the workers exposed to chemicals from industrial processes. These limits already had existed in national regulations before the first EU directive was prepared on the issue. Nevertheless EU Member States had to adopt them as common regulations. Research work on indoor air quality in non-industrial buildings, has however, lagged behind that on the ambient air quality and occupational exposures. The first extensive guideline by WHO, which was specifically devoted to indoor air quality was only published in 2010.

Some countries include requirements on indoor air quality in their ventilation regulations for non-industrial buildings, either based on occupation limit values or on national limit values. Limit values and the pollutants included in regulations vary greatly between the countries. This is probably because of a lack of common guideline, which would be used as a basis for creating national codes. Some European countries have not adopted any regulations regarding indoor air pollutants.

A wide range of pollutant limits is observed in regulations and they are not consistent either. A common European guideline would be needed proposing limit values of some pollutants, for which there is no minimum safety level in existing guidelines. Such levels should be adopted with a consensus among all countries in the EU. Requirements for indoor air quality should be included in the national regulations of all European countries. Current regulation on occupational exposure levels should be used only for industrial working places and not for non-industrial buildings.

7.8.4 Thermal comfort requirements

There are inconsistences as regards requirements for achieving comfortable thermal environments among different countries in Europe. Some countries do not have any requirements on thermal comfort at all. Temperature limits for summer vary from 28 to 25°C and in winter from 18 to 21°C.

Maximum air velocities vary from 0.15 to 0.30 m/s with often no link to air temperature. Humidity levels are more consistent with lower limits at 30% RH and higher generally being 70% RH (one exception of 75%). Consequently, common European regulation would be recommended.

7.8.5 Noise requirements

The noise level limits as defined in European regulations and standards are inconsistent, Inconsistency applies both for units and averaging time. The minimum noise levels range from 28 dB(A) eq in bedrooms to 33 dB(A) eq for offices (25 to 35 dB(A) if instantaneous measurements are taken) Consequently also in case of noise a common EU regulation would be advised defining maximum allowable noise levels.

8 Technical features of ventilation systems

8.1 Introduction

An extensive research concluded that ventilation is strongly associated with comfort (perceived air quality) and health (Sick Building Syndrome (SBS) symptoms, inflammations, infections, asthma, allergy, short-term sick leave) [**27**]. It was also concluded that the literature indicates that in buildings with air-conditioning systems there may be an increased risk of SBS symptoms compared with naturally or mechanically ventilated buildings. Technical features of ventilation systems were investigated which may cause the system to become one of the sources of the negative effects on occupants and the published conclusions [**28**] suggest that potential causes of adverse health effect due HVAC systems comprise among others of: poor maintenance; poor hygiene of the HVAC systems; intermittent operation of the HVAC systems; lack of moisture control; lack of control of HVAC system materials and used filters.

It was consequently investigated how national regulations of European countries describe technical features of ventilation systems, which can become potential sources of pollution and thus causing SBS and other negative health related symptoms. Information was collected with questionnaires.

Questions for the questionnaire were developed based on the hypotheses, which were used developed earlier [27,28]. Questionnaires were sent out to a group of different experts on ventilation in the EU.

8.2 Questionnaire

Questions in the questionnaire were specifically formed to investigate the parts in regulations concerning measures to prevent possible contamination of ventilation systems. The questionnaire comprised of 18 questions, which were as follows:

1. **Do you have requirements for preventing moisture and mold damages in the ventilation system, which:**

a) Prevent the rain and snow entering the system?
b) Prevent uncontrolled condensation in the system?
c) Prevent condensation on coils to cause damage?
d) Prevent droplet from humidification to spread in system?

2. **Do you have requirements on the location of outdoor intakes to prevent pollutants from local sources entering the building in ventilation air which define:**

a) Minimum distances from cooling towers?
b) Minimum distance from exhaust air openings?
c) Minimum distance from chimneys?
d) Minimum distance from sewage vents?
e) Minimum distance from other sources?

3. **Do you have requirements for the cleanliness of the ventilation system so that the system does not become a source of pollutants regarding:**

a) Fibres (from interior insulation)?
b) Microbes?
c) Dust?
d) Ozone?
e) Other chemicals?

4. Do you have requirement for filtering (cleaning) of air used for ventilation (outdoor air)? If yes,

a) What are the requirements?
b) Do you have any requirements for filter replacements?

5. Are the operation instructions for the ventilation system required?

6. Is regular maintenance of ventilation system:

a) Required?
b) Required and specified?

7. Is cleaning of ventilation system (ducts, outlets, air handling units) required?

a) At/just after construction stage?
b) During the life time of the ventilation system

8. Do you have any requirements for personnel qualifications?

a) Operation personnel?
b) Maintenance personnel?

9. Is recirculation of extract air (room air)

a) Allowed – limitations?
b) Recommended?

10. Do you have any requirements regarding the ventilation systems for residential buildings? Can ventilation be provided by:

a) Leakage of building envelope and window opening with no designed ventilation?
b) Designed natural ventilation with vertical stacks or atrium?
c) Decentralised mechanical exhaust?
d) Central mechanical exhaust?
e) Mechanical supply and exhaust?
f) Mechanical supply and exhaust with heat recovery?

11. Do you have any requirements regarding the ventilation systems for offices, schools, and kindergartens? Can ventilation be provided by:

a) Only on leakage and window opening?
b) Designed natural ventilation with vertical stacks?
c) Decentralised mechanical exhaust?
d) Central mechanical exhaust?
e) Central mechanical supply?
f) Mechanical supply and exhaust?
g) Mechanical supply and exhaust with heat recovery?

12. Are there any limitations where and when different ventilation systems can be used, regarding location in relation to outdoor pollution source (highways, industry, etc.)?

13. Is the balancing of air flows in a central ventilation system:

a) Required?
b) Required and controlled?

14. Do you have any requirements set for the pressure differences between rooms and outdoor air?

15. Do you have any requirement for follow up measurements (ventilation rates, IAQ etc.) during the lifetime of buildings?

16. Do you have any requirements regarding the leakage of extract air to the supply air in heat exchangers used for recovering heat from ventilation air?

17. Are there any other requirements regarding the type of heat recovery system?

18. Are there any requirements regarding regular inspections of ventilation systems?

8.3 Results

Data from 16 countries were received from the respondents from all parts of Europe. They are summarized in the following figures.

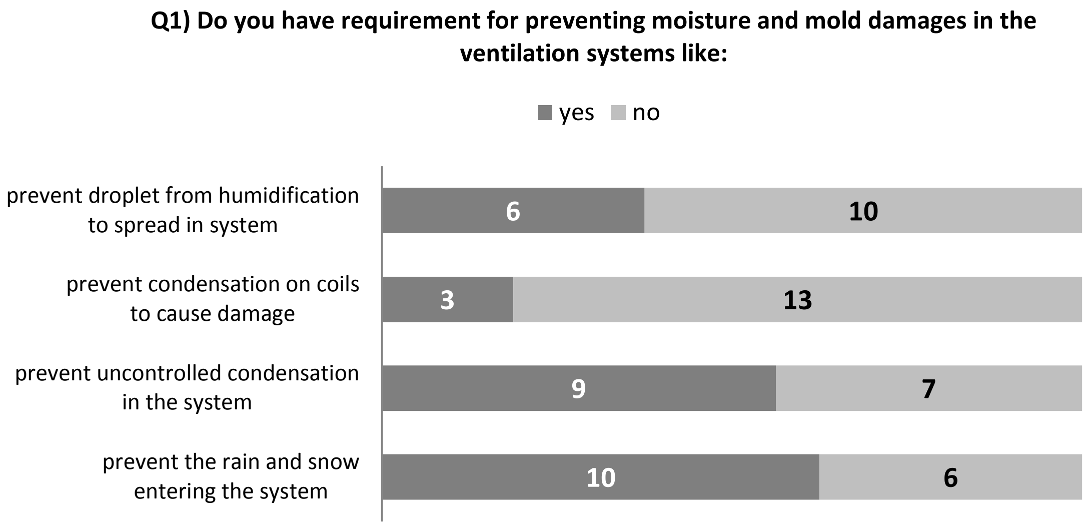


Figure 55: Technical features questionnaire: summary of answers on question 1

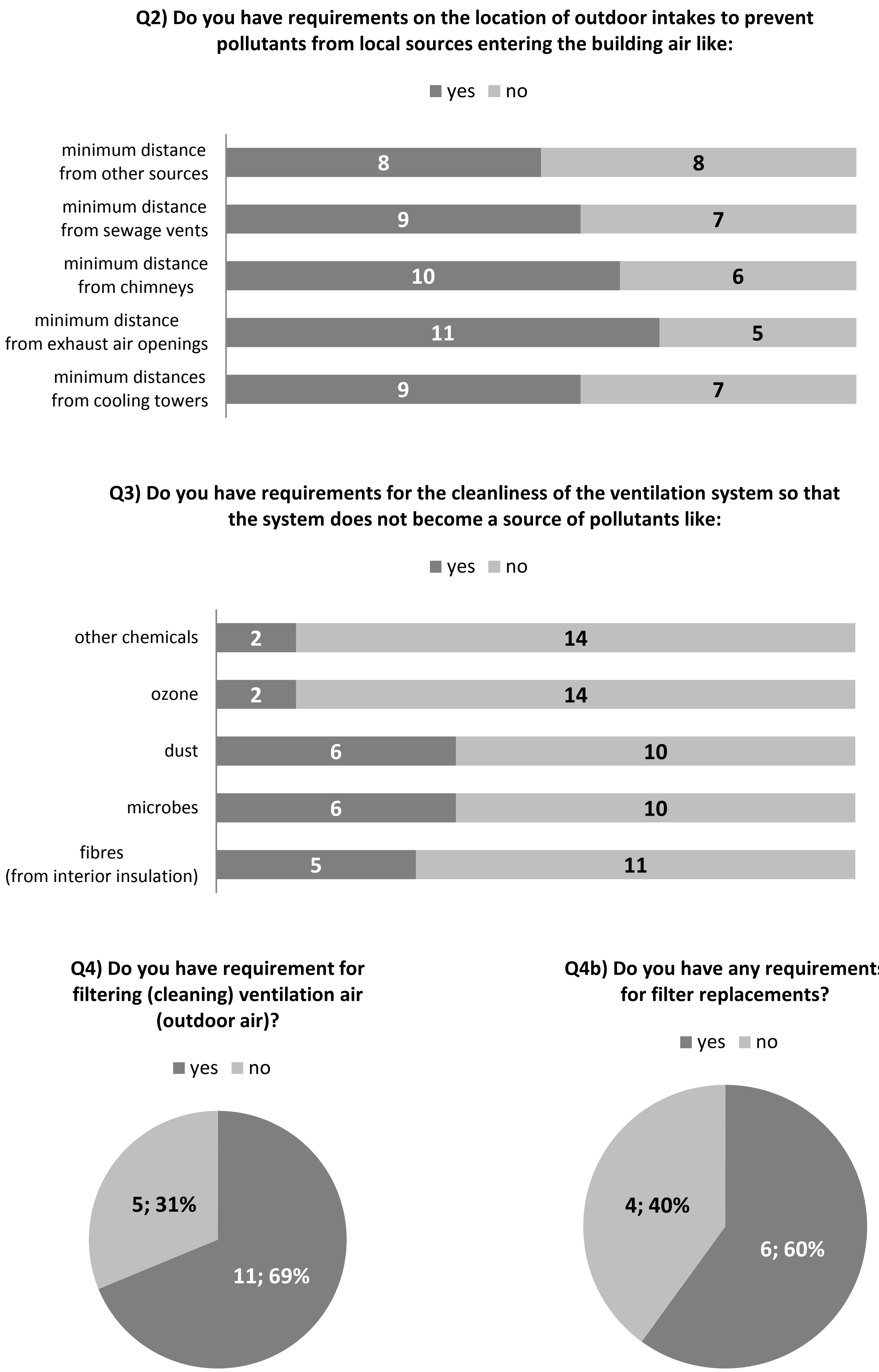


Figure 56: Technical features questionnaire: summary of answers on questions 2 – 4b

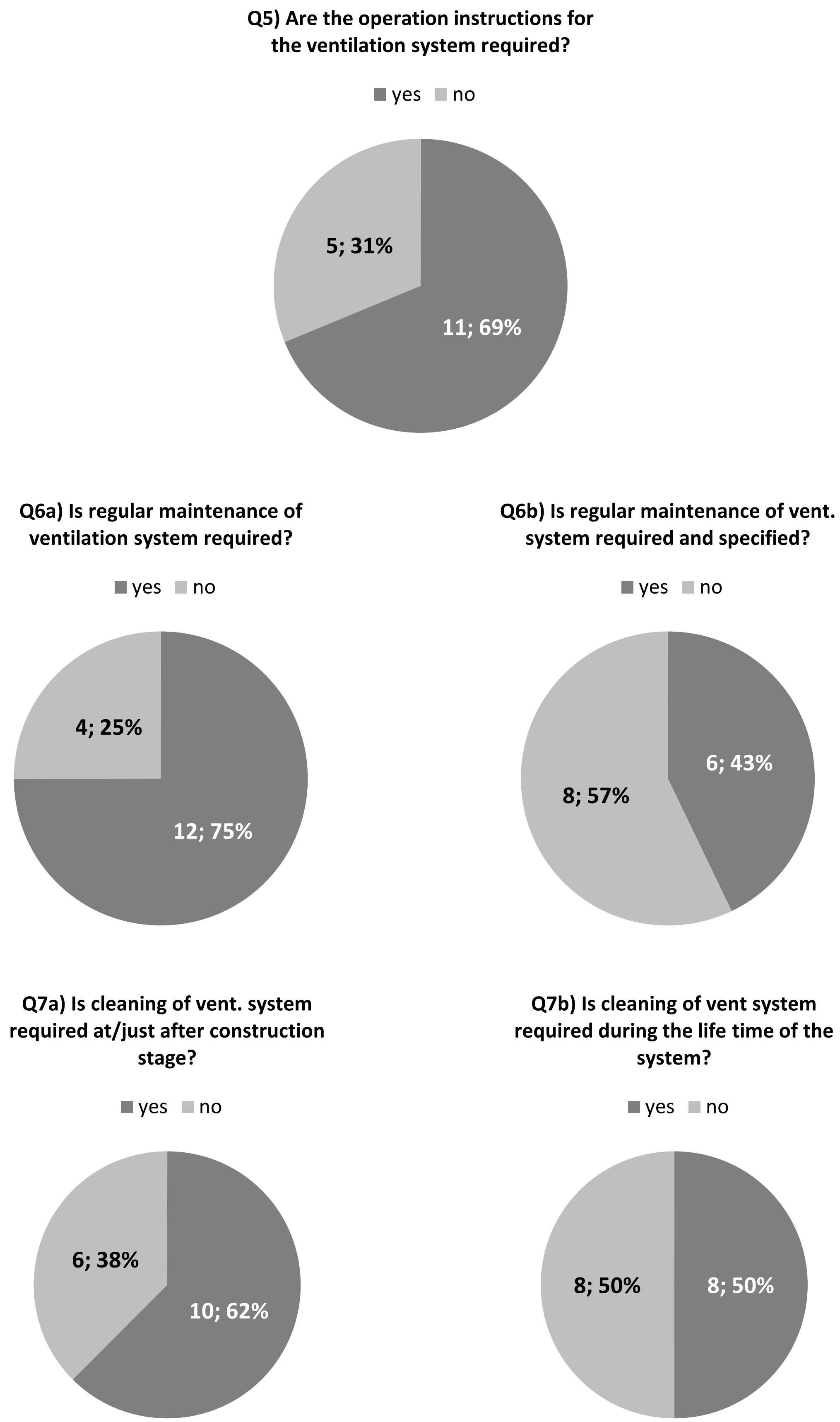
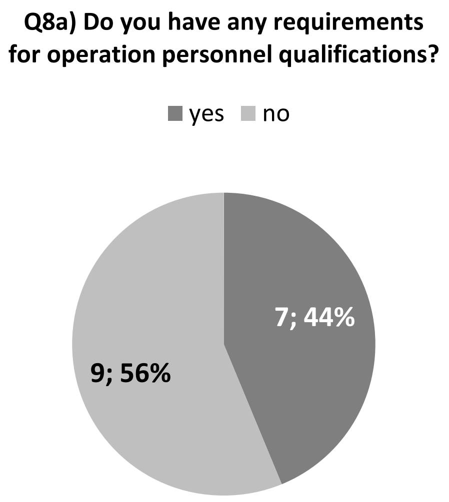
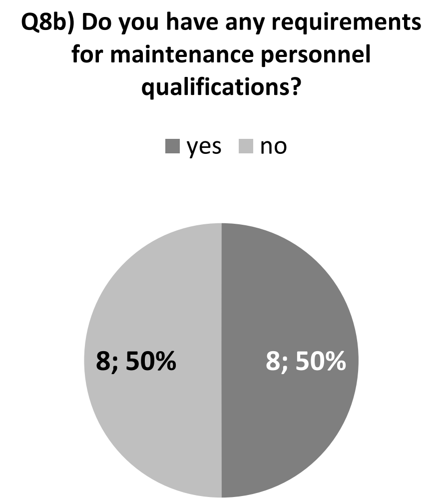
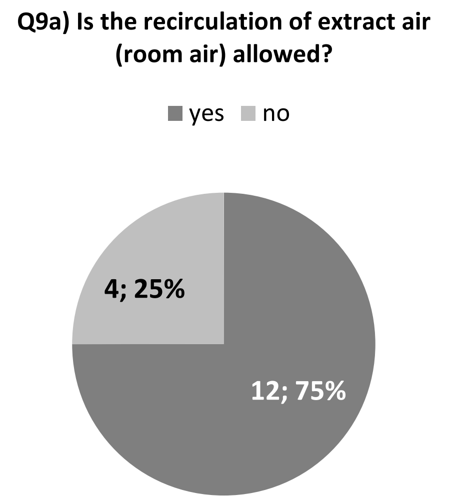
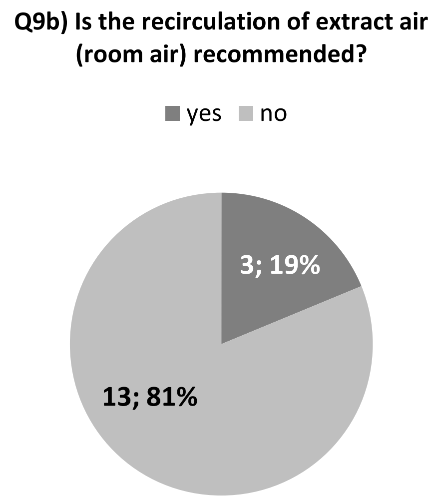


Figure 57: Technical features questionnaire: summary of answers on questions 5 – 7b









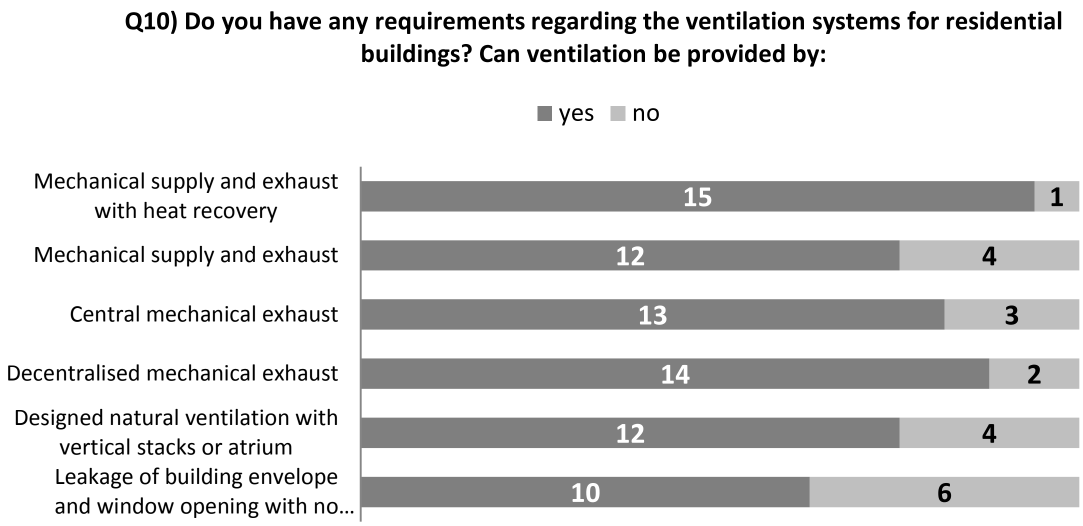
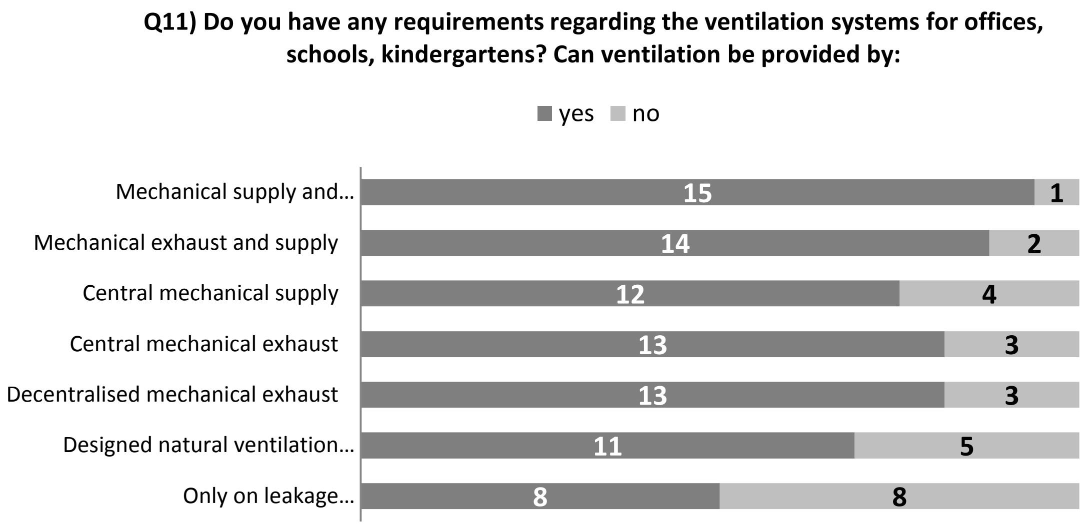
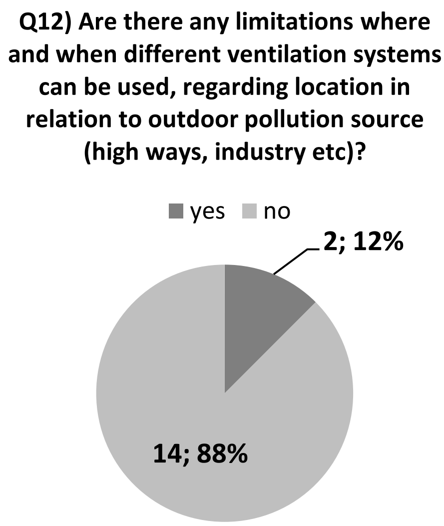
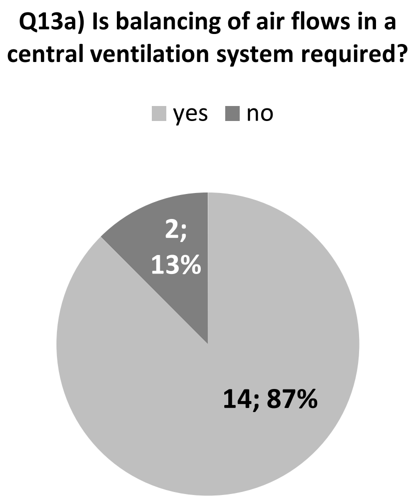


Figure 58: Technical features questionnaire: summary of answers on questions 8a – 10







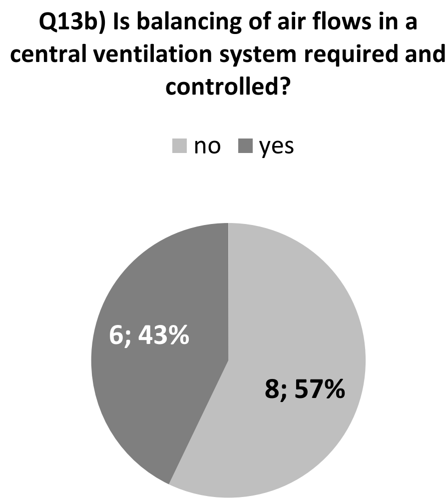


Figure 59: Technical features questionnaire: summary of answers on questions 11 – 13b

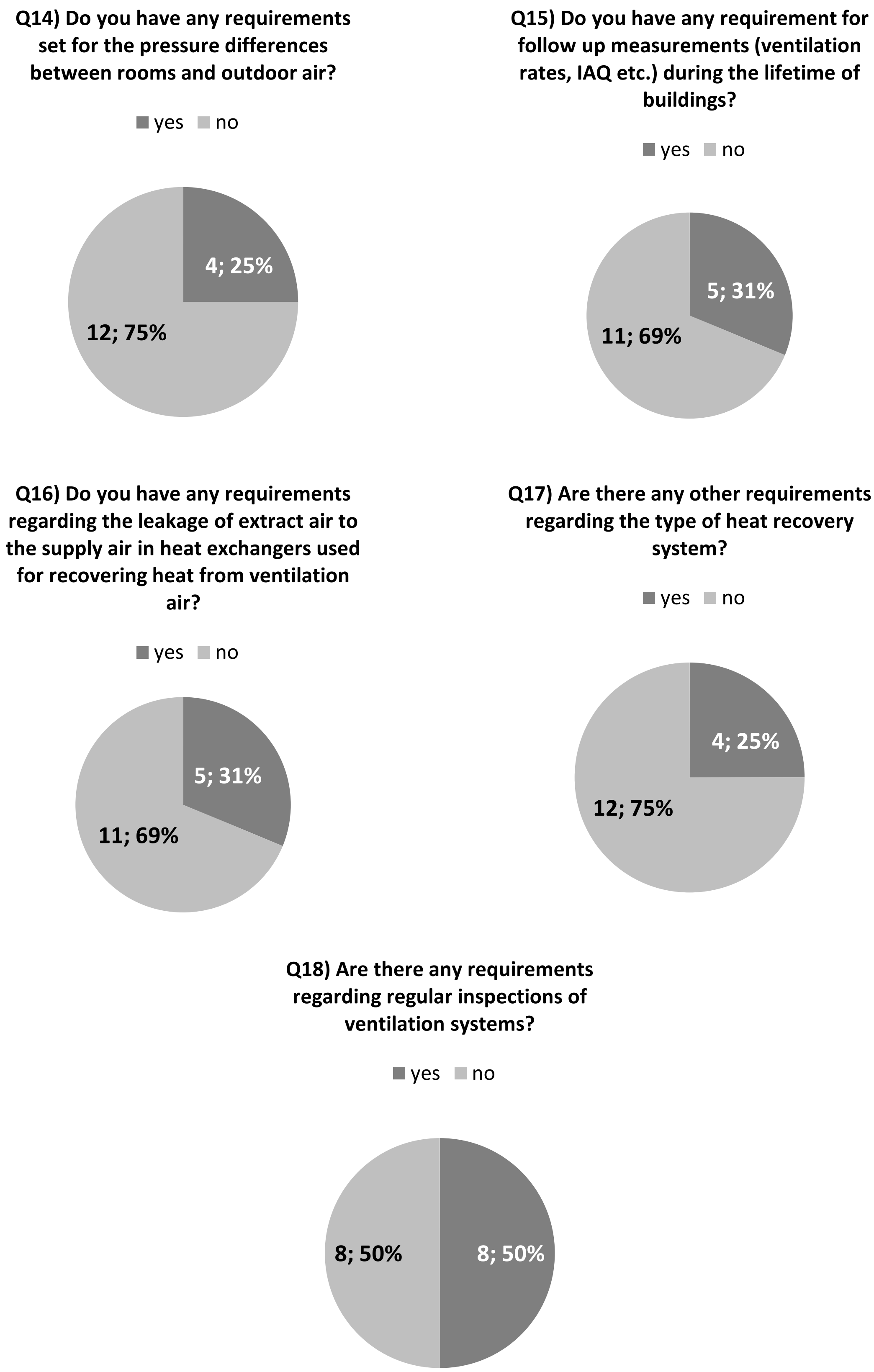


Figure 60: Technical features questionnaire: summary of answers on questions 14 – 18

Question 1 was based on the hypothesis that HVAC systems provide a refuge for biological pollutants, which may be introduced into the indoor environment. Water from rain, snow and condensation may create environment, favourable for survival and reproduction of biological pollutants. Summary of answers to this question shows that more than half of the countries do not have any requirements to prevent droplet from humidification to spread in system and to prevent condensation on coils to cause damage. More than half of countries have requirements to prevent uncontrolled condensation in the system and to prevent rain and snow from entering from entering the system. No information on the type of preventive measures was collected.

Question 2 was based on the hypothesis, that ventilation introduces outdoor air pollutants into the indoor environment. It was investigated how often regulations impose requirements on the location of outdoor intakes in relation to pollution sources. Results show that almost half of countries do not have any requirements regarding the location of intakes.

A hypothesis that served as a basis for **question 3** stated that ventilation introduces air pollutants originating within HVAC systems into the indoor environment. The answers suggest that requirements for cleanliness of system regarding dust, microbes and fibres for interior insulation are imposed in approximately two thirds of countries, while requirements for ozone and other chemicals are almost non-existent.

Question 4 was based on the hypothesis that existing filters reduce the concentration of particulate matter indoors. Results for the first part show that almost more than one third of participating countries do not have any requirement for air filtering (4a). Question was further extended for those who have requirements for air filtering (4b). Purpose of the question was to find out if countries, which require filtration, have any requirements for regular filter replacements. More than a half of countries do not have any requirements regarding frequency of filter change.

Question 5 was generated to find out if regulations require operation instructions for the ventilating system following the hypotheses suggesting that human factor (designer, manager, and occupant) is very important for proper operation of ventilation. These instructions are required in nearly two thirds of countries.

Question 6 was generated based on the hypothesis that lack of proper maintenance of HVAC systems results in increased strength of pollutants and/or more complaints among building occupants. Results show that regular maintenance is required in most countries but specification on what needs to be done in less than half of the countries participating in the survey.

In relation to the maintenance, the responses to **question 7** show that there are requirements to clean the system just at or just after the construction in most countries but not during the system lifetime (only in case of half of countries participating in the survey).

Question 8 was based on the hypothesis that human factor is important for proper operation of ventilation. The results show that some requirements are needed for personnel qualification but they are more common for maintenance personnel. Apparently half of the countries participating in the survey do not have any requirements regarding personnel qualification.

Question 9 was formulated based on the hypothesis that recirculation of indoor air has a negative impact on occupant health and well-being. The results show that recirculation is allowed in most countries but recommended only in few.

Questions 10 and 11 were investigating if countries have implemented any requirements regarding the type of ventilation systems for residential and tertiary buildings. The results show that in the countries participating in the survey two different approaches for specifying the requirements regarding the type of the ventilation system are used. One approach is usually called *prescriptive based*, where legislator mandates the use of a specific system based on the specific conditions. Second approach is called performance based, where legislator specifies requirements for *performance of ventilation* system (e.g. energy use during heating period). A designer can use any ventilation system, which fulfils all performance requirements.

Summary of answers for questions 10 and 11 show that all types of ventilation systems are more or less allowed. However, these results cannot be generalized. Many of the countries that for instance allow natural ventilation only based on leakage through envelope and windows do that under some additional requirements for building performance, which include among others minimum air change rates, maximum energy use, etc. Because of these additional requirements, it seems almost impossible to design and build naturally ventilated buildings relying only on leakages, and at the same time fulfil all the other requirements.

The purpose of **question 12** was to investigate if countries have any limitation regarding the location of ventilation systems in relation to outdoor pollution sources like heavy congested roads, industry areas etc. In the majority of the countries participating in the survey no such limitations exist.

Question 13 was asking about requirements of balancing airflows in central ventilation systems. Evidence from existing buildings show that ventilation systems are not balanced according to the suggested procedures and airflow rates at air terminal devices can vary greatly from the nominal values defined by the design. This may influence air quality in rooms because some rooms can be under ventilated. The answers show that balancing is required in majority of countries participating in the survey but it is controlled only in less than half of countries where balancing is required.

Question 14 was asking if there are any requirements regarding the pressure differences between rooms and/or between rooms and outdoor air. Unsuitable pressure differences can cause air from polluted areas to flow into clean areas, thus deteriorating air quality. Responses show that three quarters of countries participating in the survey do not have any requirements on this topic.

Question 15 was asking if there are any requirements for follow-up measurements of ventilation rates, IAQ etc. during the lifetime of buildings. Badly maintained and not cleaned ventilation systems can become sources of pollution, which deteriorates indoor air quality. Adaptations in duct network can destroy pressure balance in the system, resulting in changed air flow rates. The results show that in more than half of the countries participating in the review no such requirements are needed.

Question 16 was asking if there are any requirements regarding the leakage of extract air to supply air in the heat recovery exchangers. Construction of some heat exchangers like heat exchanger with the rotating wheel can promote leakage of air from the section with higher static pressure to the section with lower static pressure. In such systems, pollutants present in exhaust air can also adsorb on the wheel. When the wheel turns, the pollutants adsorbed can desorb to the air supplied indoors. The construction of some heat exchangers with rotating wheel includes molecular sieve coating, which shows high selectivity for adsorbing water molecules to avoid contamination [**29**]. The results of present survey show that there are no requirements regarding the leakage of air in the heat exchangers for heat recover in more than half of countries participating in the survey.

Question 17 was asking if there are any other requirements regarding the type of heat recovery system recommended by the regulations. Only one quarter of countries participating in the survey have such requirements. These requirements concern minimum efficiency of heat recovery exchangers and a minimum air volume flow when the heat recovery is to be used in the ventilation system.

Question 18 was asking if there are any requirements regarding regular inspections of ventilation systems. Half of the countries responding to the survey do have such requirements.

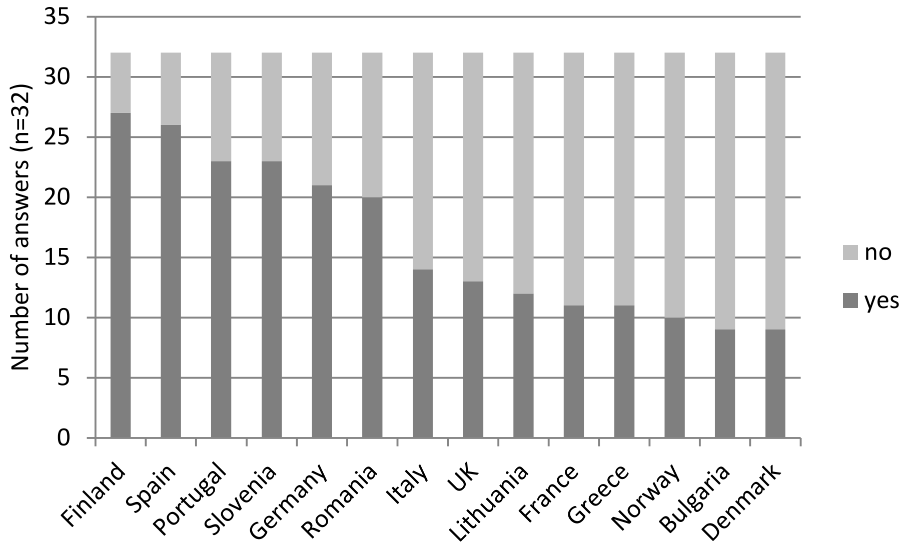


Figure 61: Number of "yes" and "no" responses by individual country

By summing up the number of "yes" and "no" answers for each country it is possible to estimate how good the regulations of individual countries deal with the technical features of ventilation systems, which are related to the health and comfort problems. Higher number of "no" answers suggests the shortcomings in the regulation and suggests the need for improvement (answers on questions 10 and 11 were excluded from summation as they are not related to the health and comfort problems). Figure 61 shows that the number of yes responses varies between 27 and 9 out of 32 possible answers. Finish regulation deals with 27 out of 32 problematic technical features of ventilation systems addressed in this questionnaire. Some other Nordic countries like Denmark and Norway are positioned on the bottom of the scale with regulations only dealing with 9 or 10 technical features, respectively.

It is important to note that regulations in both Finland and Denmark have just recently been updated, however Danish regulation does not include the same range of requirements for technical features as Finish regulations. All Nordic countries used to have a common body for harmonization of their ventilation regulations before they all joined European Union. It seems strange that 10 years after the body has been dissolved these Nordic countries have so different requirements in the regulations.

Results presented in Figure 61 also suggest that there is no relation between the number of technical features dealt by regulations and geographic location, climatic region or building practice in the area.

8.4 Summary and conclusion

Analysis of the responses received from experts in 16 European countries regarding the technical features in ventilation regulations show that:

- More than half of the countries participating in the survey do not have any requirements to prevent droplets from humidification to spread through system and to prevent condensation on the coils causing damage.
- Almost half the countries do not have any requirements regarding the introduction of outdoor air pollutants into the indoor environment.

- Requirements for cleanliness of the system regarding dust, microbes and fibres from interior insulation are not imposed in approximately one third of countries, while regulatory requirements for ozone and other chemicals are almost non-existent.
- More than one third of countries participating in the survey do not have any requirement for air filtering. Out of these that have requirements, more than half has no requirements for regular filter replacements.
- Approximately one third of countries still do not require operation instructions for the ventilation system.
- More than half of countries do not have requirements for cleaning the ventilation system during its lifetime.
- More than half countries participating in the survey have no requirements on the qualifications of the operation and maintenance personnel of ventilation systems.
- Recirculation of air is allowed in most countries and recommended in one fifth.
- Countries use two different types of regulations for ventilation systems: prescriptive and performance based. All types of mechanical ventilation can be used with prescriptive based regulations. Natural ventilation achieved by manual window opening is the exception. Countries with performance based regulations allow all types of ventilation systems as long as they are able to provide the required air change or air flow rates and fulfil energy regulation requirements.
- The majority of countries has no limits regarding the location of ventilation systems in relation to outdoor pollution sources like heavily congested roads, industrial areas etc..
- Balancing of ventilation systems is required most countries participating in the survey but it is controlled in less than half.
- Three quarters of the countries have no requirements regarding the pressure differences between rooms and/or between rooms and outdoor air.
- More than half of countries has no requirements on the follow-up measurements of ventilation rates, IAQ, etc. during the lifetime of buildings.
- More than half of the countries participating in the survey have no requirements regarding the leakage of extract air to supply air in the heat recovery exchangers.
- Half of the countries responding to this survey have requirements for regular inspections of ventilation systems.

9 Compliance with regulations and problems related to ventilation

9.1 Introduction

Buildings are planned and built according to regulations and standards. European building stock is predominantly old and many buildings were erected in the first half of the 20th century when regulations on ventilation were rare and not well defined. A questionnaire on regulation requirements on technical features of ventilation systems in chapter 8 shows that many of countries lack important regulatory requirements on indoor air quality and technical features of ventilation systems. As a consequence, ventilation systems do not operate as planned, which may result in dissatisfied building occupants and unhealthy indoor environment.

This chapter provides a review of studies reporting the performance of European ventilation systems in practice. The compliance with regulations was checked by reviewing studies on existing ventilation systems and summarized in peer-reviewed articles, reports prepared by government or research institutions, and reports of completed European projects. Review of the literature showed that only a limited number of information on this topic is available. Because several of the reports are published on a regional level in national European languages, it was necessary to review reports published in French, German, and Dutch, in order to collect as much data as possible.

The results are presented for dwellings, schools and kindergartens, and offices. For each building type the compliance with requirements regarding ventilation rates, pollutants, noise, temperature and technical features is reported.

9.2 Methods by which the ventilation measurements are carried out when examining the compliance

Ventilation rates and air change rates can be measured according to several different methods. There is no such method like "best method" available, which would meet the demands of any study. Which method is the most suitable for measurement of ventilation rates and air change rates in a specific situation depends on the requirements on accuracy of measurements, time scale and whether a variation of ventilation rates should be observed or not. A general overview of measurement techniques is available in ASHRAE Handbook 2009 - Fundamentals [**30**]. Tracer gas methods, which are the most often employed methods of ventilation rate measurements, are described in details in a guide published by the AIVC [**31**].

This section discusses measurement techniques employed for measuring ventilation rates in the studies reviewed in this report. Knowing the background of measuring techniques is important for proper evaluation of results.

Direct measurement

This method of measuring of air flows was used in some studies on ventilation performance in residential buildings. The supply or exhaust air flows are measured at the air terminal devices Measurements in this method are performed using hoods. The assembly of a measuring hood typically consists of a fabric hood section, a plastic or metal base, an airflow measuring manifold, a meter and handles for carrying and holding the hood in place. The hood is placed against the air terminal device and the fabric then captures and directs the airflow through the manifold. Manifold is equipped with air-flow sensors, which can include different types of anemometers (swinging vane, rotating vane or thermal e.g. hot-wire).

The hoods induce some back pressure on the air-handling system because the hood restricts flow out of the diffuser. This added resistance alters the true amount of the air. In most cases, this error is negligible and is less than the accuracy of the instrument. It is important that an appropriate size of the hood and manifold is used, so that velocity of air passing through the manifold is high enough for the sensor to work. This measurement technique only measures ventilation rates from the air terminal devices; infiltration is not included.

Tracer gas measurement

Tracer gas measurements allow measuring ventilation rates in all kinds of buildings, regardless of the ventilation principle (mechanically ventilated, naturally ventilated or a mixture of both).

Several tracer gas measurement procedures exist, all involving the release and monitoring of a non-toxic gas within the enclosure. As explained in the AIVC [**31**], the rate of change in concentration of the gas is given by the amount of gas leaving the space subtracted from the amount of gas entering the space. This is equal to the difference between the outdoor and indoor concentrations of the tracer multiplied by the rate at which air is exchanged with the atmosphere, plus a generation term, which is a measure of the rate at which the tracer is produced or injected.

The concentration of the tracer gas in the building is therefore monitored and related to the building's air exchange rate. ASHRAE [**30**] distinguishes three different tracer gas procedures for measuring air exchange rates, each with different manners of tracer gas injection: (1) decay or growth, (2) constant injection, and (3) constant concentration.

Decay is the simplest tracer gas measurement technique. A one-time small amount of tracer gas is injected into the space and it is allowed to mix with the indoor air. An advantage of this method is that only relative concentrations are needed, therefore the tracer gas injection rate does not have to be measured. However, it must be controlled, so that tracer gas concentrations are within the measuring range of the instrument that is monitoring the concentration. The concentration measuring equipment can be located on-site, or building samples can be collected in suitable containers, and analysed elsewhere. The growth tracer gas method is similar to the decay method except that the initial tracer gas concentration is low and the injected tracer gas is increased suddenly during the test.

Constant injection technique is very frequently used technique in which the tracer gas is injected at a constant rate. Governing equation of this approach is valid only when air exchange rate and airflow rate are constant, thus, this technique is only appropriate for systems at or near equilibrium. It is particularly useful in spaces with mechanical ventilation or with high air change rates. This method allows performing analysis on-site or to collect samples and perform analysis off-site. For short-term tests the air in the test space can be collected in any whole air sampling device (e.g. syringe or bag with a pump).

This technique also includes so-called *occupant generated carbon dioxide method*. The air change of an occupied space can be evaluated by monitoring internal and external carbon dioxide concentrations. If individual carbon dioxide production rates and the number of occupants are known or can be measured, air change rate can be evaluated. There are however two main difficulties with this approach: (1) CO_2 production rates vary from person to person and they are dependent on their activity level; (2) unless all air entering the space is from outside (i.e. no air entering from other internal spaces), there may be some difficulty in estimating the carbon dioxide concentration of the incoming air. This technique can give quite satisfactory results

This technique is also described in standard Nordtest NT VVS 118 [**32**], where it is called homogenous emission technique. NT VVS 118 is one of the most widely used methods for tracer gas measurements based on the constant injection principle in Europe and was also used in some studies reviewed in this report.

Constant concentration technique is the most demanding in terms of equipment and expertise. In this technique the tracer gas injection rate is adjusted to maintain a constant concentration within the measured zone. Because tracer gas injection is continuous, no initial mixing period is required. The amount of tracer gas, which must be injected, is directly proportional to the air change rate of the test area. Another advantage is that tracer gas injection into each zone of the building can be separately controlled. This procedure is best suited for long-term continuous monitoring of fluctuating ventilation rates or in ventilation ducts. The disadvantage is that it requires measurement of absolute tracer concentration and injection rates, involving sophisticated control mechanism.

Mixing

The continuity equation serving for calculation of air change rate is derived under the assumption that the ventilation air and tracer are well (perfectly) mixed. If this assumption is correct, then the tracer gas concentration will be constant throughout the whole measurement space. In real buildings, this is rarely the case. To overcome this problem, tracer gas concentrations are measured at several locations in the test space. It is assumed that the mean of these values is representative of the average concentration in the test space. The magnitude of errors caused by poor mixing is difficult to estimate, and there has been few analysis of this problem.

Reliability

For measuring air change rates, constant concentration technique is the most reliable. It allows measuring fluctuating ventilation rates and following their changes through time. Constant injection method is reliable with higher ventilation rates and systems near equilibrium regarding supply and extract air. It is not very reliable with low ventilation rates and short term measurements because of averaging. Decay method is the least reliable of all tracer gas methods (except for carbon dioxide method). It includes time averaging and is only applicable for long time measurements. The least reliable of all tracer gas methods is the occupant generated carbon dioxide method. The biggest limitation of all tracer gas measurement techniques is the assumption of well (perfectly) mixed air in the measured room, as described in the previous section. If this assumption is wrong for a given room, results of the ventilation rates following any of the named tracer gas methods can be very uncertain.

Direct measurements of ventilation rates can be very accurate. However, direct measurement only allows for measuring ventilation rates and not total air change rate, because infiltration cannot be measured. Direct measuring methods are therefore good for measuring air flow rate at the air terminal devices.

9.3 Dwellings

9.3.1 Ventilation rates

Measured ventilation rates were reviewed in the nine European studies. Studies have been mostly granted by the authorities, which use the results as a guidance to improve the regulation. Table 16 shows the results of the review.

The following abbreviations are used in the table:

DC – decay measurement technique
CI – constant injection measurement technique
CC – constant concentration injection measurement technique
DM – direct measurement of volumetric air flow with airflow-measuring hood
PFT – perfluorocarbon tracer gas
N20 – N_2O tracer gas
SF6 – SF6 tracer gas

BMV – balanced mechanical ventilation with heat recovery
ME – natural supply with mechanical exhaust ventilation

Table 16: Overview of ventilation rates in dwellings

Country Code	First author of the study and number of reference	Year	Vent. system type	Method	Unit of measurement	Reference value	Mean vent. rate	Standard deviation	Min. vent rate	Max. vent rate	Notes
AT	BVIT [33]	2004	80 mech. exhaust and supply with heat recovery in houses 9 decentralized mech. exhaust and supply in apartment blocs 3 central mech. exhaust in apartment blocs	DM	ach	0.5	0.44		0.3	0.8	dwelling sum
					m^3/h	60	47				living room
						50	23				bedroom
						25	21				child. bedroom
						60	35				exh. kitchen
						40	28				exh. toilet
						30	23				exh. WC
DK	Kvisgaard [34]	1987	14 natural ventilation	CC	ach	0.5	0.51	0.25			
			8 mechanically ventilated			0.5	0.97	0.30			
FI	Kurnitski [35]	2007	8 natural ventilation	CI PFT	ach	0.5	0.31	0.08			winter
			21 mech. exhaust			0.5	0.34	0.16			winter
			45 mech. exhaust and supply			0.5	0.41	0.14			winter
			30 mech. exhaust	DM		0.5	0.39	0.19			summer
			62 mech. exhaust			0.5	0.39	0.16			summer

Table 16: Overview of ventilation rates in dwellings (continued)

Country Code	First author of the study and number of reference	Year	Vent. system type	Method	Unit of measurement	Reference value	Mean vent. rate	Standard deviation	Min. vent rate	Max. vent rate	Notes
FR	OQAI [36]	2009	104 mech. exhaust – kitchen	DM	see foot-note[6]	1.0	0.93	0.64	0	3.20	minimum
			222 mech. exhaust – bathroom			1.0	0.83	0.67	0	3.34	
			172 mech. exhaust – WC			1.0	0.87	0.76	0	4.20	
			104 mech. exhaust – min total			1.0	0.77	0.48	0	2.24	all years
			55 mech. exhaust – min total			1.0	0.85	0.42	0.09	1.73	from 1982[7]
			26 mech. exhaust – min total			1.0	0.63	0.52	0	2.24	1969 - 1982
			23 mech. exhaust – min total			1.0	0.80	0.46	0	1.92	to 1969 but renovated
DE	Münzenberg [37]	2003	80 natural ventilation	DC SF6	ach	0.5	0.26				unoccupied
NL	BBA [38] [39]	2010	131 BMV, supply living room	DM	$l/s/m^2$	0.7	0.68	0.31	0.1	2.0	fan speed was set to the highest position
			439 BMV, supply bedrooms			0.7	0.71	0.39	0.0	3.1	
			99 BMV, kitchen exhaust		l/s	21	24.9	13.0	0.0	84.1	
			96 ME, kitchen exhaust			21	19.3	10.9	0.0	67.2	
			172 BMV, bathroom exhaust			14	14.8	6.8	0.0	35.8	
			149 ME, bathroom exhaust			14	16.5	7.4	0.0	40.3	
			187 BMV, toilet exhaust			7	9.1	5.1	0.0	41.1	
			164 ME, toilet exhaust			7	9.1	5.5	0.0	34.2	

[6] Due to the rather complicated procedure for determination of ventilation rates in French dwellings, which vary with number of rooms, the results are given in relative units. For example, value 0.93 means that the average measured ventilation rate was 93% of the required.

[7] A ministerial decree was adopted on 24 March 1982, which is still valid and used today for determination of ventilation rates in new buildings

NO	Granum and Haugen [**40**]	1986	10 mech. exhaust	DC N_2O	ach	0.5	0.45		0.2	0.7	
SE	Bornehag [**41**]	2005	239 natural ventilation	CI PFT	ach	0.5	0.37				
			52 mech. exhaust			0.5	0.32				
			32 mech. exhaust and supply			0.5	0.44				
UK	BRE [**42**]	2001	34 mech. exhaust 3 passive stack	CI PFT	ach	0.5	0.44	0.43	0.19	0.68	summer
						0.5	0.62	0.23	0.19	1.06	winter

The Austrian survey by BVIT [**33**] found ventilation rates per person relatively high. Rates per person in houses were just below 60 m^3/h. However, when compared with air change rates, these were on average only 0.44 h-1. Ventilation rates in bedrooms were more than 50% lower than required. All average ventilation rates were lower than required by the respective regulations.

The Danish study by Kvisgard et al. [**34**] - although relatively old - provides a good insight into the ventilation rates in houses, which were built in the 1980s. It was found that in 36% cases the total ventilation rate in the naturally ventilated houses was below 0.25 h-1 and in 76% cases it was below 0.5 h-1. For mechanically ventilated dwellings only in 1% cases the air changes rates were below 0.25 h-1 and in 23% cases under 0.5 h-1. Although there are no data on tightness of dwellings, their tightness with reasonable precision can be considered to be comparable with buildings erected nowadays.

The Finnish study by Kurnitski et al. [**35**] included houses of up to 3 years of age, except for naturally ventilated houses, which were older than 20 years. Airflow measurement at the design fan speed showed that only 57% of houses comply with regulations. The actual fan speeds when in operation were usually one speed lower than the designed speed. One possible reason for the use of ventilation units at low speed could be the noise generation of ventilation system (heard by occupants due to poor sound attenuation). The results also show that ventilation units were operating without breaks and the speed setting of fans was changed very seldom. Actual air change rate was equal or higher than the code value of 0.5 ach only in 18% of houses in the winter and 26% of houses in the summer.

The French national study [**36**] was performed on a sample of buildings, which was established on the data from the official French building stock. Results of the study therefore report the situation in the whole French building stock. In kitchens, 46% of minimum flow rates do not meet the regulations. Only 37% of ventilation rates in bathrooms and 38% in toilets provide required flow rates. In the total measured stock of 104 dwellings, in 56% of cases the minimal ventilation rates for the whole dwelling are lower than requirements. 49% of dwellings built after the new decree from 1982 cannot provide the required ventilation rates. There is a visible difference in compliance of minimum ventilation rates to regulatory values in building stock from 1969 – 1982 and after 1982. Renovated old housing stock from before 1969, which was retrofitted with mechanical exhaust system, shows almost the same rates of ventilation as buildings with ventilation systems originally built after 1982.

The German study performed by Münzenberg et al. [**37**] focused on natural ventilated buildings with retrofitted airtight windows. Measurements were performed in unoccupied buildings with closed windows to study the air change rates due to infiltration. It was found that in 90% of buildings air change lies below the required 0.5 h-1. 85% of buildings have air change rate below 0.4 h-1, 50% below 0.18 h-1 and 20% below 0.1 h-1.

BBA Binnenmilieu [**38**] performed a national study on ventilation rates in recently built Dutch houses. The study showed that air supply and exhaust rate are too low. The measured air supply rates were found insufficient in 45% of dwellings with balanced mechanical ventilation systems. The air supply rate in 85% of dwellings was found insufficient in one or more rooms. Air exhaust rates were found insufficient in 55% of dwellings with balanced system and 69% of dwellings with mechanical exhaust systems. The exhaust rates in one or more rooms did not comply with the requirements in 80% dwellings with balanced mechanical ventilation and 76% of dwellings with mechanical exhaust ventilation. One of the reasons for low ventilation rates is the problem of noise causing that building users lower the fan speed.

Norwegian study by Granum and Haugen [**40**] showed that fans were operating in only three houses. In other buildings they were blocked or switched off manually by the occupants. Occupants made it possible themselves to switch the fan off, if there was no switch available. In the houses where ventilation exhaust was used, none or only a few of window vents were opened.

The recent study performed in Sweden by Bornehag et al. [**41**] reports results which are similar with the results from the extensive 1992 Swedish Energy and Indoor Climate Survey [**43**]. The 1992 survey performed measurements in roughly 1200 dwellings by the means of constant injection tracer gas technique. The results showed that the variation in average ventilation rates were high (0.2 – 0.38 $l/s/m^2$). In both studies it was found that average ventilation rates are generally lower than required by regulations (0.35 $l/s/m^2$).

Crump et al. [**44**] reported results of the national study on indoor air quality and ventilation rates in English homes built since 1995. Statistical analysis showed that 68% of homes in winter had a whole house ventilation rate below the minimum designed value of 0.5 h-1. In summer, 30% of homes had a whole house air change rate below 0.5 h-1. The trickle vents were fully open only in 4 of the study dwellings and fully closed in 13. It was observed however, that homes where trickle vents were used “most of the time”, as recorded by the occupants, had significantly higher ventilation rates than other homes in the summer. The air change rates in the study were not correlated with the air leakage rate.

9.3.2 Indoor environment

Pollutants

Review of measurements of indoor air pollutants in dwellings included three national studies from France, Germany and the UK. All three studies are representative to determine the exposure of the whole nation to the measured pollutants. Table 17 reports mean concentration of selected pollutants. Values shown are average values of long-term measurements (24-h or more). Measured values are compared with values recommended by *WHO Guidelines for indoor air quality* and *VDI guideline 6022* because national regulations for selected countries only define occupational exposure values, which are valid for the exposure time of 8 hours.

Table 17: Mean concentration of indoor air pollutants

	France	Germany	UK	Recommended
Study and reference	OQAI [**45**]	BMU [**46**]	BRE [**44**]	WHO [**20**], VDI [**47**]
Number of samples	567	555	876	-
Benzene	2.1 μg/m³	1.9 μg/m³	-	-[8]
Formaldehyde	19.6 μg/m³	23.3 μg/m³	26 μg/m³	100 μg/m³ (WHO)
TVOC	-	290 μg/m³	160 μg/m³	300 μg/m³ (VDI 6022)[9]
PM_{10}	31.3 μg/m³	-	49.1 μg/m³	50 μg/m³ (WHO)
Tetrachloroethylene	1.4 μg/m³	-	-	250 μg/m³ (WHO)
Relative humidity	49.5%	-	52%	-

Average formaldehyde concentration in French dwellings is well below recommended value. 95th percentile concentration is 46.6 μg/m³. Peak level of formaldehyde in English dwellings exceeded WHO guideline in one home.

In summer, 24-h PM_{10} concentrations in kitchen exceeded recommended value at least once in 14 out of 34 English homes. In case of the peak levels, the air quality guideline for PM_{10} was exceeded only in one home with cigarette smoking, both in winter and summer.

Relative humidity in French buildings was found to be higher than 49% in 50% of dwellings. Relative humidity in 5% of dwellings exceeded 63% in bedrooms and 65% in other rooms. Humidity in English homes was higher in summer than in winter. One of the 5 homes, which had the lowest ventilation rate (0.19 h-1) and the lowest temperature (home average 13°C), had periods in winter when RH was higher than 70% for more than two hours.

Noise

The Dutch study by BBA [**38**] reports noise levels in the living room high (>30 dB(A)) in 72% of balanced mechanically ventilated (BMV) systems and 54% of mechanical exhaust (ME) systems. Measured noise levels were high (> 30 dB(A)) in one or more bedrooms in 86% BMV systems and 21% MV systems. The problem was that noise of the system was high at fan settings, which were able to provide the required/designed ventilation rate. This was mainly a problem in dwellings with balanced mechanical ventilation. The differences between BMV and MV were the biggest in bedrooms.

Korhonen also reported problems with noise in the Finnish study. Also in this study fan speed settings were set one speed lower than designed, thus providing lower ventilation rates. Occupant complaints about ventilation noise correlated with maximum noise levels in bedrooms but not with levels in living rooms. Many of the systems were unable to supply required ventilation rates and then the noise levels were lower or equal to 28 dB(A). One of the main identified causes for high noise levels was too short sound attenuator. The study concluded that ventilation noise is an important factor affecting the use of ventilation units.

The Austrian survey [**33**] also reports the complaints of too high noise among occupants. Investigation identified the following causes of too high noise levels: too short sound attenuators, missing rubber mount pads, duct pipes in direct contact with concrete construction causing structural noise, too high air velocity in duct pipes.

[8] WHO included benzene in guidelines for indoor air quality but notes that “No safe level of exposure can be recommended”.
[9] Recommended value by VDI 6022 [**47**] Part 3 for category of indoor air IDA 1 according to EN 13779

Temperature

The Austrian survey found average temperature of supply air at 21°C. This is due to the fact that the majority of systems are equipped with high efficiency heat recovery units. It was found that temperature of supply air depends on the duct network. Supply air temperature was near indoor air temperature even in the systems with low efficiency heat recovery unit because duct network was laid through heated spaces and close to the floor heating. Systems with high efficiency heat recovery units and not insulated duct network laid in cold spaces like cellar had quite low supply air temperatures. Overall, supply temperature was found too low in 12% of cases.

The French national IAQ survey [**45**] reports supply temperatures higher than 21°C in 50% of dwellings while 5% of dwellings had temperatures higher than 25.5°C in bedrooms and 24.8°C in other rooms.

9.3.3 Technical features

The Austrian survey [**33**] identified several shortcomings in parts of ventilation system. These include insufficient air inlet size with a loss of pressure being too high, missing condensate drain for the in-ground air heat exchanger and/or ventilation device, no insulation of ducts conveying cold air (condensate is formed in pipes), bad maintenance of filters, low class of filtration, missing sound attenuators, insufficient cross-sections of ducts (air flow too slow or too fast), inappropriate material of pipes (flexible tubes). Systems without regulation of air flows were found to be hardly ever balanced, but also systems with speed regulation had similar problems. The survey even found cases when central dust vacuuming system was connected to exhaust duct of the air handling unit. Even more problematic were cases, where flue gases from gas boiler were connected to extract duct before air handling unit in order to recuperate heat of the flue gases. It was found out that in one quarter of all cases units using burners had some kind of influence on indoor air quality.

Systems were found insufficiently balanced in one third of all cases, thus causing that ventilation rates were insufficient in individual rooms. Position of inlet opening of outdoor air was found not appropriate in 17% of cases. Distances between supply and exhaust air openings were almost always without short circuit. Only in 4% of cases short circuit was possible. Position of exhaust air opening was adequate in 94% of cases. Filters in supply air were found to have lower class than F5 in 46% of cases.

The Dutch study by BBA [**38**] identified several shortcomings related to the indoor air quality. The most common shortcomings with occurrence of 30% or more in the vested dwellings are presented in Table 18. Inspections also found that ventilation units are mounted in positions, which are susceptible to noise. Units were found mounted in a build-in cupboard in a bedroom or on a light-weight walls without proper vibration.

Table 18: Common failings related identified in the Dutch study [38]

Technical shortcoming	% dwellings with failings	
	balanced mech. vent.	mech. exhaust
Insufficient control options	81	70
Supply and exhaust valves in one room are situated too close together (<1m)	53	n/a
Visible dirt in air supply ducts	67	n/a
Recirculation of exhaust air	59	n/a
Filters are visibly not clean	43	n/a
Visible dust and dirt in air supply ducts	77	n/a
Filter is changed less than twice per year	47	n/a
No annual inspection of overall functioning of ventilation unit	66	82
Improper use of control switches	96	96
No oral instruction is given about the operation and functioning of the ventilation system (according to the dwellers).	42	43

The French study [**45**] reported condition of the supply and exhaust air terminal units. It found that 87% of the supply air openings and 85 % of exhaust air openings were in a good condition. The rest was divided among cases where openings were blocked, covered by furniture or soiled. More than 70% of minimum extract air flows for the whole dwelling, that did not meet the regulations was caused by poor condition of air terminal devices or because the air terminal devices were missing in certain rooms, or because that the system is switched off.

Commissioning report by CSTB in France [**48**] discusses problems of air flow demand control systems used in French dwellings. In France two types of control systems are mainly used; manual switch between normal and high flow rate, and automatic humidity control. Inspections showed that the main problem of automatic system is poor maintenance of the system by occupants.

9.3.4 Discussion

Measurements of ventilation rates in dwellings were all performed on a relatively large number of samples. In some countries like France and Sweden the measurements were performed is specially selected dwellings that represent the whole national building stock. Dwellings in these studies were selected according to the year of construction and the type of ventilation system. Other studies were not so systematic but still give a good overview of the conditions in dwellings in the respective countries..

The results from studies in naturally ventilated dwellings show that dwellings are retrofitted with new airtight windows, without assuring adequate ventilation. These actions suggest that the energy cost is the main driving force for renovations, but at the same time ventilation is being neglected probably because the public is not informed about the impact of the airtight envelopes on ventilation and of the impact of low ventilation rates on comfort and health. Reviewed studies do not specifically identify buildings with the designed natural ventilation. However, it seems quite obvious, that a building designed with natural ventilation and later retrofitted with new windows, cannot provide the designed airflow.

Ventilation rates in mechanically ventilated buildings are on average lower than the requirements. Almost all studies show that the measured ventilation rates have large standard deviation. The reason for that can be poor balancing achieved mainly only when building had been constructed. As shown in the study from the Netherlands, poor balancing causes that almost every house has at least one room where ventilation rate is too low. Results from the Netherlands also show that net ventilation rate for the whole dwelling may be sufficient, but at the same time ventilation rates in individual rooms may be too low. These results show that definition of air change rate for the whole dwelling may not be appropriate due to poor balancing of ventilation systems.

Apart from poor balancing, noise is another important cause why ventilation rates are lower than the requirements. As shown in the studies from Austria, the Netherlands and Finland, systems are often able to provide the total required ventilation rates but are operated at a lower fan speed to ensure lower noise levels. Too little attention is probably paid to reduce noise during the design and construction phase, mostly because lack of knowledge among all stakeholders involved in construction of buildings and lack of proper regulations. Finnish study suggests that existing noise limits may be too high. Finland has one of the lowest regulatory limits for noise in bedrooms, which in practice still seems to be too high.

Generally the measured pollutants did not exceed the values recommended by cognisant authorities. In some cases the recommended levels were exceeded though. Humidity was generally at 50% rh, except for some case with relative humidity elevated above 63%. The English study showed that indoor relative humidity during summer is higher than during winter.

Indoor air temperatures in buildings were found to meet the minimum requirements and sometimes higher. With majority of buildings nowadays equipped with central heating systems, air temperature does not seem to be problem in buildings. This is also supported by the results of questionnaires returned by occupants in some surveys. Supply air temperatures were measured extensively only in the Austrian survey. Results show that the supply temperature depends on the type of ventilation system and the location of ductwork; not insulated ducts in cold spaces should be avoided.

Two surveys also extensively inspected the shortcomings of technical features of ventilation systems. Studies report that many of the system faults were similar to these discussed by Wargocki et al. [**28**]. The probable reasons for these shortcomings are lack of knowledge and experience among architects, designers, and contractors, missing regulations, and lack of knowledge among building owners and occupants. The latter are not informed about importance of changing the filters and having their systems regularly inspected and services, while the former are responsible for all functional shortcomings. Results from Finland, where balanced mechanical ventilation systems have been standard practice for the last twenty years, suggest that such problems are not due to the fact that the systems are new; the anecdotic evidence from Finland suggests occurrence of the same problems even after 20 years of practice.

9.4 Schools and kindergartens

9.4.1 Ventilation rates

Ventilation rates in schools are usually estimated using CO_2 as a proxy. Several studies exist where indoor air quality is measured in one or a few schools and ventilation rates are estimated based on the CO_2 concentrations. These studies were not included in the present review. Literature research returned 5 extensive studies, which were performed on a sample of at least 8 schools. The results are summarized in Table 19.

Table 19: Overview of ventilation rates in schools

Country Code	First author of the study and number of reference	Year	No. of schools	No. of classrooms	Method	Unit of measurement	Reference value	Mean vent. rate	Standard deviation	Min. vent rate	Max. vent rate	Notes
FI	Kurnitski [**49**]	1996	20	natural ventilation	CI	l/s/p	6	1.6				
				mech. exhaust			6	2.3				
				mech. supply and exhaust			6	5.5				
FR	OQAI [**50**]	2003	9	13 natural ventilation	DM	m³/h/p	15	5.5		3.2	14.5	
IS	Hellsing [**51**]	2009	15	74 classrooms	CO_2	l/s/p	8	4.7	5.2	1.5	39.7	
SE	Smedje [**52**]	1996	11	20 mech. supply and exhaust 4 mech. exhaust 4 natural ventilation	CO_2	l/s/p	8	6.9		0.1	19	
SE	Wålinder [**53**]	1998	12	natural ventilation mechanical ventilation	DC	l/s/p	8	4.4		1.1	9.0	
SE	Wålinder [**54**]	1997	15	natural ventilation		l/s/p	8	2.5				
			12	mechanical ventilation		l/s/p	8	8.9				
UK	BRE [**55**]	2005	8	16 natural ventilation	CI	l/s/p	3			0.5	20.9	

Notes:
CI – constant injection measurement technique
CO2 – occupant generated carbon dioxide method
DM – direct measurement of volumetric air flow with airflow-measuring hood

In Austria, the Federal Ministry for Transport, Innovation and Technology published a national study on evaluation of mechanically ventilated classrooms [**56**]. The examined database contained 16 recently built or renovated schools and kindergartens with ventilated classrooms. The report lists numerous studies from Austria, Germany and Switzerland dealing with indoor air quality. They show that natural ventilation of classrooms by using windows cannot provide required indoor air quality, i.e. high indoor CO_2 levels are generally observed for the whole school year. The studies show that the reasons for such a situation are due to the lack of experience of designers and planners and to insufficient specifications made by the clients[10].

The results showed that only 4 systems out of 16 were able to ensure that CO_2 levels were below 1,200 ppm, what corresponds to class of indoor IDA 3 according to EN 13779:2007. Class IDA 2 was not achieved by any of the system. The reason for high CO_2 levels was not properly dimensioned ventilation system; also it could be due operation of a system at lower speed to reduce noise levels. Ventilation rates were between 10 – 50 m^3/h/p (2.8 – 13.9 l/s/p). Measurements of CO_2 levels showed that in order to keep indoor CO_2 level below 1,000 ppm, ventilation rates should be at least 35 m^3/h (10 l/s) per person.

Study in 20 Finnish schools showed that the type of ventilation system had significant impact on the quality of indoor air and the incidence of complaints and health symptoms. Occurrence of reported draft was approximately 50% lower in schools with mechanical ventilation systems. Average indoor CO_2 concentrations in naturally ventilated classrooms were 1,285 ppm, and in classrooms with mechanical exhaust 1,181 ppm, while in classrooms with balanced mechanical supply and exhaust 836 ppm.

The study from France [**57**] included three mechanically ventilated schools. Two of them had ventilation rates in the range of 1 – 4 m^3/h, which is much less than required 15 m^3/h. In the

[10] No regulations on ventilation rates exist in Austria. Standards like EN 13779 and EN 15251 are usually used to determine air flow rates.

third school, half of classrooms reached the required ventilation rate. The study showed that in general ventilation rates do not meet the requirements.

The study performed in Iceland [**51**] show that 87% of schools had mean personal flow rate below recommended 8 L/s[11]. All the schools however had an air change rate that exceeded the recommended minimum in regulations set at 0.8 -1.

In the UK study the measurements in naturally ventilated schools in England were carried out by BRE for Office of the Deputy Prime Minister [**55**]. Ventilation rates were measured by the constant injection tracer gas technique. In one of the schools average ventilation rates per person were in range from 4.9 to 8.7 l/s due to the fact that staff used windows for ventilation due to warm weather. Still they were lower than the new requirement of 10 l/s per person set by the UK Building Regulations Part F (2010). In each school participating in the study there were occasions when the ventilation rates were below the minimum requirement of 3 l/s. In total, 50% of measurements were below this value. Results of this study show that natural ventilation is insufficient for providing required ventilation rates.

9.4.2 Indoor environment

Indoor air quality in schools is an important concern of public authorities, mostly because of care for the health of children. Many studies have already been published on this topic, the majority of them only measuring and reporting concentrations of CO_2. Only few of them though performed measurements in numerous classrooms in different schools and broad range of pollutants. Although studies measuring indoor levels of carbon dioxide in schools are quite frequent, this report focuses mainly on studies in which other parameters besides CO_2 were also measured including ventilation rates, temperature, humidity and other pollutants. Only large studies were reviewed reporting measurements in Europe.

Carbon dioxide – CO_2

Table 20 shows the results from the studies reporting CO2 measurements performed mainly in winter unless reported otherwise.

Table 20: Mean concentrations of CO_2 in schools

Country	Study	Num. of schools	Average [ppm]	Range [ppm]	Required or rec. value [ppm]	Notes
DE	Niedersachsen [**58**]	7	766	-	1500	natural ventilation in summer
			1652	-		natural ventilation in winter
FI	Kurnitski [**49**]	20	1285	-	1200	natural ventilation
			1061	-		mech. exhaust only
			836	-		mech. supply and exhaust
FR	OQAI [**50**]	9	1196	517-1935	1000	in summer
IS	Hellsing [**51**]	15	1510	621-2353	1000 (max) 800 (mean)	1 mech. ventilation 14 natural ventilation
NL	van Dijken, 2004 [**59**]	11	1580	450-4700	1000	-
SE	Norback, 1995 [**60**]	6	1320	700-2700	1000	-
UK	BRE [**55**]	8	1315	578-2356	1000	natural ventilation in autumn

[11] No regulations on ventilation rates exist in Iceland. Value of 8 l/s from ASHRAE standard 62.1-2007 was taken as a reference by the author of the report.

According to the report of the German survey, performed in schools in Niedersachsen, 32% of measurements of CO2 in summer exceeded DIN recommended value of 1,500 ppm. In winter they were exceed in 89% cases. The 95th percentile during winter was 2,521 ppm. Eight measurements (out of the total of 58 measurements) were performed in mechanically ventilated classrooms. No data are available for these specific classrooms.

Finnish study reports the results of measurements performed in classrooms with different ventilation systems. Naturally ventilated classrooms had the highest levels of CO_2, followed by the mechanical exhaust and balanced mechanical exhaust and supply ventilation.

In Iceland, 87% of all measured CO_2 values were above limit of 1,000 ppm. 800 ppm was exceeded in 93% of schools. The school having the lowest average concentration at 621 ppm, was the only mechanically ventilated school included in the survey. All other schools were naturally ventilated. That school also had also the lowest number of pupils per square meter flow.

In British schools, approximately 40% of classrooms had mean CO_2 concentrations at 1,000 ppm or lower and approximately 88% of classrooms had mean CO_2 concentrations at 2,100 ppm or lower.

Formaldehyde - HCOH

Only two of the studies on indoor air quality in schools carried out the measurements of formaldehyde levels together with ventilation measurements.. Results are presented in Table 21.

Table 21: Mean concentrations of formaldehyde in schools

Country	Study	Num. of schools	Average [μg/m³]	Range [μg/m³]	Required or recommended value	Notes
FR	OQAI [**50**]	9	38.4	13.6-66.8	100 μg/m³ (WHO)	0 exceedances
UK	BRE [**55**]	8	25	max 65		0 exceedances

Both studies report average formaldehyde levels below values recommended by WHO. Formaldehyde levels in British study were measured for 30 minutes and are published as 30-minute averages. Neither in the British, nor in the French studies were any classrooms where the recommended 24-h limit values were exceeded.

Noise

Report on noise levels was only included in the Austrian study of ventilation systems in schools. Noise levels in classrooms were found mostly in the range 35 – 45 dB(A). Measured values were generally higher than recommendations in ÖNORM standards being set at 30 dB(A) for classrooms. Seven out of eleven classrooms had recorded noise level above 30 dB(A). Some air handling units were found to be running with a lower fan speed due to excessive noise in classrooms.

Humidity

Indoor air humidity in German schools with natural ventilation was found to depend on outdoor air humidity in summer and on the combination of external humidity and indoor temperature in winter. Mean indoor humidity in winter was 49% and in summer 54%. 95th percentiles for winter were at 53% and for summer at 58%. Mean values of indoor humidity in mechanically ventilated classrooms were found low in cold winter weather being 30% and less for several consecutive days. Germany has no legal limits for minimum or maximum air humidity.

Relative humidity in British schools ranged between 30 – 75%. For optimum comfort the levels should be between 40 and 75% RH and these levels were achieved for the majority of the school day. Low values of humidity were usually recorded during first hours of the first school day in a week. British regulations do not impose any regulatory value of indoor relative humidity.

The mean relative air humidity in classrooms of Icelandic schools was 33%, ranging between 17 – 55%. Three of 15 schools had a mean humidity below 30%. School with the lowest humidity was also school with lowest number of pupils per square meter. Iceland has no legal limit of minimum or maximum indoor air relative humidity.

Temperature

Reported mean temperatures in German schools during summer were 22.9°C, 95th percentile at 24.1°C. Mean indoor air winter temperature was 20.9°C, 95th percentile at 22.5°C. The highest temperatures were reached in two schools, which had not properly operated or missing solar shading protection. In case of one of these two schools, high temperatures were recorded even in the time of relatively low outdoor temperatures. Germany has no regulatory requirements regarding indoor air temperatures in schools. In practice EN and DIN standard recommended values are used during the design process.

The study on British schools reported measured temperature ranges between 17 and 25°C. Lower temperatures were usually recorded on Monday mornings, after heating was turned off during weekend. After several hours temperature raised to 19 to 21°C. Minimum requirement for indoor air temperature in classrooms according to UK Building regulations Part F from 2010 is 19°C.

Mean recorded indoor air temperature in classrooms of schools in Iceland was 21.7°, ranging from 18.3 to 25.5°C. Mean temperatures of all classrooms in separate schools ranged between 20.4 and 22.8°C. All measurements were performed in winter. Iceland does not have legal requirements on minimum or maximum indoor air temperature.

9.4.3 Technical features

The Austrian school survey [**56**] was the only one which investigated whether the ventilations systems had some technical problems. The following problems were identified:

- Intakes of outdoor air were positioned too close to the ground, thus allowing snow to enter the system, or they were positioned too close to parking lots.
- Main air intakes and exhausts were found to be in a distance less than 3 m from each other, thus allowing possible short-circuit between supply and exhaust. This was particularly the case in case of decentralised air handling units.
- Half of the decentralized units had F6 filter class.
- Majority of filters in air handling units were found to be dirty (soiled).
- Condensate drains in cases of decentralised air handling units were missing.

9.4.4 Discussion

Extensive studies on indoor air quality in schools are rare. Many of them report only CO2 rather than actual ventilation measurements. Many of them show a lack of information on how ventilation rates were estimated. The few large studies show comparable results regarding different parameters of indoor environment. Schools with balanced mechanical supply and exhaust system are very rare, followed by slightly more schools with just mechanical exhaust system. Schools are mainly ventilated by opening windows.

Natural ventilation by opening of windows in school classrooms cannot provide required ventilation rates during school year, because windows are closed in winter to prevent draft and cold. Intensive airing through open windows during breaks cannot secure required ventilation rates. Consequently pupils are exposed, especially in winter to the unsatisfactory indoor air quality.

Mechanically ventilated schools have better air quality and less draft problems in winter compared to naturally ventilated schools. Still measured (or estimated using CO2) ventilation rates in existing schools do not meet the regulatory requirements. Mechanical systems can become a potential source of other problems in indoor environment. Noise and draft are the most common ones. Low quality of design and construction, caused by lack of experience by designers and contractors, could be the main reason. It may be suggested that in the countries, where regulation regarding ventilation in schools does not exist tenders should include more specific requirements regarding indoor air quality and performance of ventilation system. Poor maintenance of ventilation systems is also a problem, especially poor maintenance of filters, which seems to be a common problem of all ventilation systems.

The most often measured pollutant in schools is carbon dioxide. The studies provide incomplete measurements because they lack important information on the type of ventilation system where measurements were taken, or report results for all types of ventilation systems without differentiating them for various systems. Results show that CO_2 levels are high in most schools, both naturally and mechanically ventilated, the latter having lower CO2 levels in winter. Generally CO_2 levels were high in winter and transient periods. If windows cannot be opened all the time during school hours natural ventilation can't secure the low levels of CO_2.

Formaldehyde was measured in two studies along with ventilation measurements.. The levels in classrooms did not exceed the maximum recommended values, despite relatively low ventilation rates in both cases, suggesting no strong sources of formaldehyde.

Noise levels were measured in only one study, found being too high. In some cases air handling units are running with a lower fan speed to reduce noise levels in classrooms. It seems that noise is a problem related with mechanical ventilation systems in classrooms, similarly as in case of dwellings.

Relative humidity levels were mostly in the range between 40 and 70%. None of the countries where measurements were performed have legal requirements regarding humidity levels in schools. Too high humidity was not reported as a problem in none of the studies. Some studies found low humidity levels in mechanically ventilated classrooms with balanced supply and exhaust during cold weather.

Temperature was in the comfort range and complied with requirements in case such requirements existed. Only during first hours of the first school day after the break (weekend) were the temperatures too low.

The problems of technical features of mechanical systems were similar as in case of dwellings. Poor maintenance causes dirty (soiled) particle filters. The daily maintenance of the air handling units including the replacement of air filters, is often done by janitors, who may not be adequately educated to perform such tasks.

9.5 Offices

9.5.1 Ventilation rates

There are few large studies on European offices that include measurements of ventilation rates using tracer gas methods. The studies reviewed in this report are summarized in Table 22.

Table 22: Overview of measured ventilation rates in offices

Country Code	First author of the study and number of reference	Year	No. of buildings	Type of ventilation system	Method	Unit of measurement	Reference value	Mean vent. rate	Standard deviation	Min. vent rate	Max. vent rate
12 NL 13 DK 14 UK 15 GR 16 FR 17 CH FI NO DE	Bluyssen [**61**]	1996	56	12% natural ventilation	CO_2	l/s/m²		1.0			
				2% exhaust system only 5% supply system only 9% balanced VAV system 20% dual ducts balanced 18% induction units 30% simple balanced 4% other systems	CO_2	l/s/m²		2.1		0	4.4
FI	Jaakkola and Miettinen [**62**]	1995	14	10 MES [12]	HW[13]	l/s/p	10	10,6			
				4 MES (air-conditioning)[14]				16,5			
FI	Teijonsalo [**63**]	1996	33	all types		l/s/p	10	17.2	11.6		
SE	Sundell [**64**]	1994	160	10 natural ventilation	DM, DC	l/s/p	10	4	2		
				23 mech. exhaust			10	9	8		
				191 MES total			10	15	11		
				131 MES with recirculation			10	12	9		
				320 MES with heat exchanger			10	20	15		
				275 MES with rotary heat exch.			10	20	15		

Note:
MES – mechanical exhaust and supply
HW – direct measurement with hot wire anemometer
DM – direct measurement of volumetric air flow with airflow-measuring hood
DC – decay tracer gas measurement method
CO_2 – carbon dioxide as a tracer gas
EU – study included by Bluyssen measurements in NL, DK, UK, GR, FR, CH, FI, NO, DE

A European Audit Project by Bluyssen et al. [**61**] measured ventilation rates in 9 European countries. Various methods for ventilation rate measurements were used to assess ventilation rates. Many uncertainties occurred due to mixing problems in open offices; they ranged from 5% to 200% being a big limitation of that study. Eighty per cent of mechanically ventilated buildings had ventilation rates higher than 1.0 l/s/m2. These ventilation rates were only measured in 20%

[12] Partial heating of supply air but no cooling.
[13] Direct measurements with hot wire anemometer
[14] Ventilation system also provides air-conditioning

of naturally ventilated buildings. Average ventilation rate considering all types of ventilation systems was 1.9 l/s/m2 or 25 l/s per person.

In the study by Jaakkola and Miettinen [**62**], ventilation rates were below 5 l/s/p in 13% of cases and above 15 l/s in 56% of cases. The results indicate that ventilation rates generally met the acceptable limits but probably in 25% of cases the ventilation rates did not meet the requirement of 10 l/s per person.

In the survey on the Helsinki office environment and health conducted by Teijonsalo et al. [**63**], ventilation rates were measured in working rooms with 1782 persons in 33 randomly selected buildings. The air flow was on average 17.2 L/s per person. The variation of air flows between different buildings, and also within buildings, was considerable. The standard deviation of all of the air flows was 11.6 l/s per person. In ten buildings, the standard deviation of the air flows was higher than half of the mean value of the air flows, in which case the balancing of ventilation can be considered to be insufficient (Figure 62).

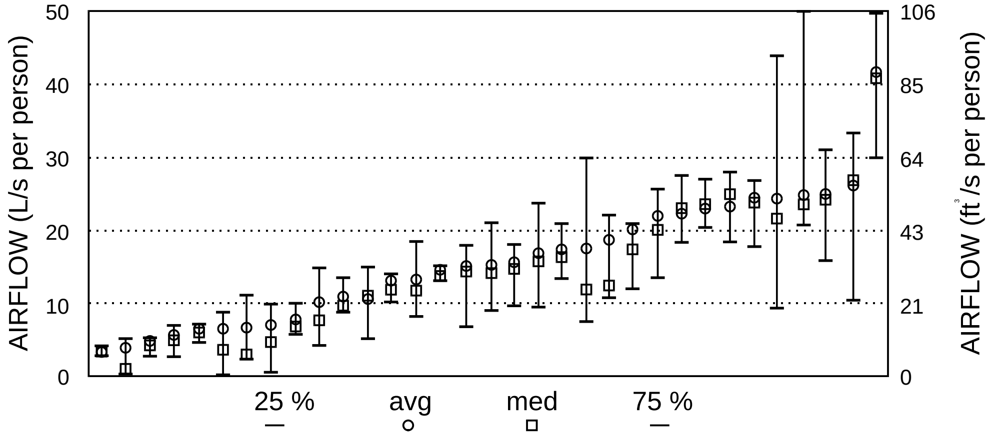


Figure 62: Range of outdoor air flows in 33 randomly selected mechanically ventilated office buildings in the Helsinki metropolitan area.

The study performed in Swedish offices by Sundell et al. [**64**] measured ventilation rates in buildings with all types of ventilation systems. Ventilation rates in buildings with entirely natural or entirely mechanical exhaust systems had significantly lower air flow rates than buildings with both mechanical exhaust and supply systems. Ventilation rates varied between buildings.

9.5.2 Indoor environment

Measurements of indoor environmental parameters were performed in the above-cited Audit Project by Bluyssen et al [**61**]. Tables 23 and 24 give an overview of average values of measured indoor environmental parameter in the study. Measurements were performed in the heating season of 1993 – 1994.

Table 23: Overview of the average values of measured CO_2 in the Bluyssen et al. study

	NL	DK	UK	GR	FR	CH	FI	NO	DE
CO_2 [ppm]									
offices	656	736	516	587	778	744	737	628	674
outside air	418	382	327	400	344	382	473	440	402

Mean indoor levels of carbon dioxide were found in all countries below 1,000 ppm.

Indoor temperatures met regulatory requirements being between 19 and 21°C. The measured temperature was found in the upper range of the recommended wintertime temperatures, from 20 to 24°C.

Humidity was found to be lowest in the Nordic countries, where average values were below 30%. Nordic countries do not prescribe minimum winter indoor humidity levels. Values in other countries were generally between 30% and 40%, which is typical for winter, i.e. above the required minimum winter humidity of 30%.

Maximum measured mean air velocity was 0.12 m/s, which is below the limits of 0.15 to 0.20 m/s in most of the countries or close to 0.10 m/s in the case of Finland.

Measured noise levels were measured during the minimum period of 2 minutes. Mean measured values are between 39 dB(A) in Finland and 55 dB(A) in the UK which is higher that the requirements being between 33 and 45 dB(A), where the former limit of 33 dB(A) is for Finland.

Table 24: Overview of the average values of indoor environment parameter in the Bluyssen et al. study

	NL	DK	UK	GR	FR	CH	FI	NO	DE
Air temperature [°C]									
offices	22.3	23.7	22.9	23.5	23.5	22.9	22.3	23.4	21.7
outside air	6.6	5.6	10.4	14.7	12.4	7.2	-	– 0.6	-
Relative humidity [%]									
offices	31	29	36	33	44	39	19	17	41
outside air	57	71	74	40	54	68	-	-	-
Air velocity [m/s]									
offices	0.10	0.07	0.11	0.08	0.07	0.12	0.08	0.07	0.06
Noise [dB(A)]									
offices	48	46	55	54	46	45	39	42	51

9.5.3 Technical features

There are limited reports that describe the condition of existing ventilation systems in office buildings in Europe. Commissioning procedures were reported by CSTB in France [**48**]. This report is mainly for dwellings but some notes are also regarding offices. It indicates the problem of proper setting of schedules in controls of air handling units. The setting of schedules is mainly performed by the in charge of the operation of building. The main problem, according to the original report, appears to be poor understanding of how to properly set schedules. Operation instructions are not adapted to the low technical skills of operation personnel.

Some information on technical features is also available from the HARMONAC project[15]. The project included numerous field studies[16] in existing air conditioning systems, which also included ventilation systems. Inspections of air-conditioning systems included ventilation systems if air-conditioning and ventilation systems were coupled. Project report [**65**] found that filters in systems were dirty (soiled) in 51% of all inspected cases.

In many cases, ventilation systems that are installed in office buildings are similar to these in schools in dwelling so the problems in these systems may be similar as in case of schools and dwellings.

[15] Project web site: www.harmonac.info
[16] Database of studies and cases: http://paginas.fe.up.pt/~harmonac/site/?option=case

9.5.4 Discussion

Extensive studies on ventilation rates in office buildings are limited except for the Audit project. in contrast to the USA where the EPA Building Assessment Survey and Evaluation (BASE) study involved indoor environmental measurements in 100 US office buildings, using tracer gas methods to measure ventilation. Due to the different practices of ventilation systems in Europe and USA the US results are not representative for Europe; still some data can be useful. Persily [**66**] reports high ventilation rates with mean value of about 55 l/s per person, however this is due to low occupant density in offices and use of economizer, i.e. increasing outdoor air flow rate in mild weather to condition indoor spaces. Economizers are very rarely used in Europe. The study reports that ventilation rates between the 25th and 75th percentile were respectively 13 l/s/p and 68 l/s.

Ventilation rates in naturally ventilated office buildings were found to be about 4 l/s per person with a standard deviation of around 2 l/s per person. Ventilation rates in mechanically ventilated buildings were much higher, mean values ranging from 9 to 25 l/s per person, often exceeding minimum required rates. The reason for this may be that ventilation rates for offices are designed based on a nominal number of occupants, which usually are less during building operation.

Indoor levels of CO_2 were in all cases below the recommended value of 1,000 ppm corresponding well with the high ventilation rates Indoor temperature were above minimum recommended limits of 19 – 21°C Measured temperatures are higher than these found in schools and dwellings. Relative humidity was found below 30% in Nordic countries. Humidity levels are lower than in dwellings and schools. Air velocities met the requirements. Noise levels were between 39 dB(A) and 55 dB(A) Thus higher than the recommended 35 to 40 dB(A).

9.6 Questionnaire for sensitive group of occupants

A special questionnaire was developed to investigate what is the experience of a sensitive group of building occupants, such as asthmatic patients, regarding ventilation in buildings. Questionnaire was sent to EFA, an association representing European national associations of allergy and airway disease patients. The detailed analysis is presented in Appendix A.

Two countries with very different building practice and climate returned the questionnaire: Italy and Sweden. Responses clearly indicated that pollution from building materials, new buildings and new furniture in all buildings is a common problem. A common problem in dwellings was dampness and microbial growth. Complaints for apartment buildings included environmental tobacco smoke from neighbours. Respondents reported carpets and new furniture as sources of pollution in offices.

9.7 Example of good practice: Swedish mandatory inspections of ventilation systems

In Sweden, mandatory inspections of ventilation systems have been in use since 1991. According to the national regulation, all buildings shall be inspected. The verification of the performance is done at regular intervals by qualified experts, except of one- and two-family houses requiring only an initial survey. The intervals vary depending on the type of system and building, and various types of systems require different qualifications of the inspector.

The goal of inspections is to investigate whether the ventilation system is satisfactory and meets the requirements set by the time the facility was built. If an inspector finds serious faults in operation or performance, such system does not pass an inspection. The owner is then obliged to correct the identified shortcomings or he faces a penalty.

Review of the results of the inspections in 1998 showed that only 34 % of 5,625 systems evaluated passed the test criteria mainly based on regulations that applied when the system was brought into operation [**67**]. Systems without satisfactory operational and maintenance instructions had 50 % more faults in performance compared with those with satisfactory instructions.

Swedish authorities constantly monitor the effect of inspection procedures. The following shortcomings of the system were identified in report on effectiveness of a system [**68**]:

- It is only checked whether ventilation system complies with the requirements that were in use at the time when the building was taken in operation. It is thus not controlling whether the quality corresponds to the actual use of the building at the time of the inspection.
- All buildings are not part of the protocol. Some buildings can therefore operate with faulty systems. Such approach is not appropriate especially as regards public buildings like schools and kindergartens.
- Results are collected locally by the municipalities and are not kept in a central register. In order to make statistical analyses possible, results should be kept in a central register and/or in electronic form.
- Municipal authorities are in charge of inspections; they are at the same time the owners of buildings that are part of inspections (as regards for example schools and kindergartens). Inspections should be made by independent body.

It seems reasonable that ventilation inspection procedures should be obligatory in all European countries. Swedish experience can be used for development of inspection procedures. Inspections could for example be integrated with energy auditing and inspections of air-conditioning systems.

9.8 Summary and conclusion

9.8.1 General remarks

Studies on ventilation rates, indoor air quality and the condition of ventilation systems in Europe, which are based on large number of buildings, are rare. Studies in some countries were performed on a sample of buildings, which represents the whole national building stock.

The reviewed studies show that ventilation rates, indoor environmental parameters and noise do not generally comply with regulations. Differences between measured and required values are considerable and actions are needed. A new European guideline is needed, which would serve as a base document for legislators in EU countries or in the European Commission. The guideline should provide guidance on suitable design, construction, maintenance and inspections of ventilation systems. For improved efficiency, the inspection of ventilation systems could be merged with the inspection of air-conditioning systems and energy auditing. More effort should be put into education of all parties involved in the design, construction and operation of ventilation systems.

9.8.2 Dwellings

Dwellings in Europe are retrofitted with new airtight windows, without ensuring adequate ventilation. Resulting air change rates are almost always below the required values. Energy cost is still the main driving force for renovations, but at the same time. Mean ventilation rates in all studies in mechanically ventilated dwellings are lower than the requirements. Where ventilation rates for dwellings were prescribed as air volume flow per floor area the ventilation rates for the whole dwelling were sufficient, but ventilation rates in individual rooms were too low. The definition of the air change rate for the whole dwelling may not be appropriate due to poor balancing of systems.

Ventilation rates in dwellings were reviewed in nine European studies. The mean air change rates and ventilation rates were found to be too low in all studies. In case the required air change rate is at 0.5 h-1-, the mean measured air change rates are as low as 0.3 h-1. Air change rates are higher in dwellings with balanced mechanical ventilation system still the means not exceeding 0.45 h-1; 76% of buildings did not achieving required rates. Old dwellings, retrofitted with new windows, achieve a mean air change rate as low as 0.25 h-1; 50% of buildings have an air change rate below 0.18 h-1 when unoccupied.

Noise in mechanical ventilation systems is a common problem. Even though systems are often able to provide the required ventilation rate, the occupants reduce fan speed because of the noise disturbance. Too little attention is paid to noise during the design and construction phases.

Measured few pollutants did not exceed the recommended values; there were though cases where average values were exceeded in individual dwellings. Surveys confirm that concentrations of VOCs are higher in the recently renovated and new buildings. Humidity was not reported to be a problem in any of the studies.

Indoor air temperatures in buildings were found to be consistent with minimum requirements or they were higher. Results show that air supply temperatures depend on the type of ventilation system and on the location of ductwork.

Studies report many shortcomings in the technical features of ventilation systems. The most probable reason for these shortcomings is the lack of knowledge and experience among all parties involved in the design and construction of buildings. Technical shortcomings appear even in countries where mechanical ventilation systems have been a standard practice for the last twenty years, therefore they are not due to the relative inexperience with such systems.

9.8.3 Schools and kindergartens

Natural ventilation cannot provide the required ventilation in schools for the entire school year. As a result that school buildings in Europe are mostly naturally ventilated, pupils are exposed, especially in winter, poor indoor air quality. Ventilation rates in existing schools generally do not meet the regulatory requirements. Studies show that ventilation rates in mechanically ventilated schools are higher than in naturally ventilated schools and that levels of CO_2 are not exceeded.

Ventilation rates in schools were below as low as 3 l/s per person in naturally ventilated classrooms. The lowest recorded ventilation rates in naturally ventilated classrooms were 0.5 l/s per person. Mechanical ventilation systems were able nominally to provide the required ventilation rates. However in practice, some mechanical systems provide only one fifth of required ventilation rate.

The most commonly pollutant in schools is carbon dioxide. Results show that CO_2 levels are high in the majority of all schools, both in naturally and mechanically ventilated, lower in the latter though.

In none of the surveys formaldehyde levels in classrooms exceeded the maximum recommended values, despite relatively low ventilation rates.

Noise levels were found to be too high.

Relative humidity levels were mostly within the comfort range, i.e. between 40 – 70%. In none of the countries where measurements were performed there are any legal requirements regarding humidity levels in schools. Temperatures met the requirements were met for most of the time.

Some shortcomings in technical features of ventilation systems were observed probably due to lack of knowledge and experience among stakeholders involved in the design and construction of school buildings.

9.8.4 Offices

Ventilation rates in naturally ventilated office buildings were 4 l/s per person with a standard deviation of around 2 l/s per person. Ventilation rates in mechanically ventilated buildings were ranging from 9 to 25 l/s per person, often exceeding the minimum required rates. This is comparable with the findings from the US. High ventilation rates can be results of lower than designed density of occupation.

Shortcomings in the technical features of ventilation systems in offices are similar to these in schools and dwellings. A new guideline could be recommended listing measures to avoid problems with the systems.

Indoor levels of CO_2 were below 1,000 ppm as ventilation rates were high Indoor temperatures were often above the minimum recommended limit of 19 – 21°CRelative humidity was below 30% in winter in Nordic countries. Levels in other countries were mostly between 30 and 40%, which is within the range of the required values. Air velocities met the requirements. Noise levels were too high.

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Appendix A: Questionnaire survey for asthma patients

Asthma is a common chronic disease, affecting some 300 million people worldwide. It is diagnosed on the basis of symptoms of wheeze, dyspnoea, cough, and by evidence of variable airflow reductions. There has been an increase in prevalence in the last 30 years. The reason for the increase is yet unknown, but it is being unmasked as a result of environmental changes. Considering that occupants in developed regions, where the growth of prevalence of asthma is the highest, can spend more than 90% of their time indoors, the indoor environment is a considerable factor for asthma.

Some risk factors for the development of asthma in adults in children like house dust mite can be related to ventilation. Mite densities tend to be high in hot and humid climates. Besides house dust mites there are also pollutants in air that can cause negative impact on health of asthma patients: environmental tobacco smoke, ozone, formaldehyde etc. Ventilation can be seen as one of the measures to control mite densities, indirectly by controlling temperature and humidity, and a control measure for directly control concentration of air pollutants in the air by dilution.

To get guidance on how to focus the future work in developing guidelines for health based ventilation it was important to get feedback from association representing asthma patients. A special questionnaire was developed to investigate what is the experience of asthmatic patients regarding ventilation in buildings. Questionnaire was sent to EFA, an association representing European national associations of allergy and airway disease patients. Collected responses were analysed and guidance for other work packages in the scope of HealthVent project was prepared.

Questionnaire

The purpose of the questionnaire was to try to get guidance on how to focus the future work in developing most useful guidelines for ventilation in the scope of the HealthVent project. The questionnaire comprised of 7 questions, which were the following:

1. **What are the most common complaints related to indoor air quality and climate:**

a) Single family residential buildings (houses)?
b) Apartments?
c) Classrooms in schools?
d) Day-care canters and kindergartens?
e) Offices?

2. **What are the most common indoor air problems in new buildings:**

a) Single family residential buildings (houses)?
b) Apartments?
c) Classrooms in schools?
d) Day-care canters and kindergartens?
e) Offices?

3. **What are the most common indoor air problems in new buildings:**

a) Single family residential buildings (houses)?
b) Apartments?
c) Classrooms in schools?
d) Day-care canters and kindergartens?
e) Offices?

4. **What are the most common mistakes or shortcomings related to the installation of ventilation?**

5. **What are the most serious problems with ventilation regulations in your country?**

6. **What kind of ventilation regulations are needed in the future (what should be included in the regulations)?**

7. **What is the effect/expected effect of energy saving policy on indoor air quality and ventilation?**

Responses

The responses from Italy and Sweden are summarised below:

Question 1. Respondents noted that in houses of some rural areas, stagnation of smoke coming from chimneys and wood burning stoves may be a problem. Pet allergens, dampness and mold spores are also considered as general problems. The most common complaints regarding indoor air in apartments include dampness, mold spores and environmental tobacco smoke from neighbours. Some complaints are also regarding comfort, such as too high or too low indoor air temperature during the heating season. Complaints about classrooms include poor cleaning, poor ventilation, pet allergens and tobacco smoke entering naturally ventilated classrooms from school yards. The same answers were provided also for kindergartens. The most common complaints for offices are regarding pollution from building materials and furniture, poor cleaning, perfumes and scents, and outdoor pollution sources. There are still problems due to tobacco smoke because despite the law, smoking in some small private companies is still a common practice.

Question 2. The most common source of indoor air problems for asthmatics in new buildings are pollutants from building materials and furniture, which are present in all types of buildings. However, like it was reported for existing buildings, there are also problems of dampness and mold spores in houses, tobacco smoke from neighbours in apartments, pet allergens and poor ventilation in schools and kindergartens, and poor cleaning, perfumes and scents in offices.

Question 3. This question was asking about problems with ventilation in buildings. Respondents noted too low ventilation rates as common problem in houses, leakage of tobacco smoke and scents/perfumes from neighbours in apartments, too low ventilation rates in schools and kindergartens and "dry" and polluted air in offices.

Question 4. The most common mistakes or shortcomings related to the installation of ventilation were noted as lack of insulation for condensation, dampness in ventilation systems and filters due to lack of protection from weather influence (rain, snow) and wrongly placed outdoor air intakes.

Question 5. Regarding the most serious problems with ventilation regulation in countries, the only answer was provided by Sweden. It stated that the problems are too low ventilation rate, lack of regulations and supervision of ventilation systems.

Question 6. Respondents think that in the future, more research should be done about ventilation rates and what good indoor air quality really is. They think that limit values for pollutants in indoor air should be found and that there is a need for more regulations and supervision of management of ventilation systems, not only if ventilation system is working as claimed when it was build, but also that ventilation system fulfils the requirements for indoor air quality.

Question 7. Regarding the question what is the observed or expected effect of energy saving policy on indoor air quality and ventilation, the respondents answered that energy saving could affect health in a bad bay if it will be done the wrong way. It was also noted that extreme focusing on energy saving can pose threat for IAQ and that a reasonable balance between IAQ and energy saving should be found.

Summary and conclusion

Two countries with very different building practice and climate returned questionnaires: Italy and Sweden. The answers of respondents should be treated by care, because they are more or less based on anecdotic evidence and personal observations of people who are not specialists in the field of ventilation. Some answers state that higher airflow rates should be required but they do not provide any arguments in favour of those requirements.

The responses clearly indicated that pollution from building materials new buildings and new furniture in all buildings is a common problem. This indicates that ventilation rates may be too low to reduce pollutant levels, caused by today's standard materials, and a strong need to use low polluting materials in order to keep ventilation rates low.

A common problem for houses is dampness and mold spores. Dampness in houses is caused by insufficient (i.e. too low) ventilation rates. Mold spores originate from mold that can grow on wet indoor surfaces, often caused by uncontrolled condensation. Uncontrolled condensation on indoor surfaces is often a consequence of too high indoor humidity, which can be prevented by sufficient ventilation rates. Ventilation rates should therefore be high enough to prevent uncontrolled condensation on indoor surfaces.

Complaints about apartment buildings include environmental tobacco smoke from neighbours. If exhaust and supply of air is done on the façade then this problem is difficult to avoid, because the apartment in higher floors can capture the exhaust air from the lower apartment. This is the case with window-only ventilated apartments and mechanically ventilated with exhaust and supply on a façade. The most effective solution for that is to have exhaust air opening on the roof, away from the supply air opening.

Complaints about ventilation in schools and kindergartens include poor cleaning, which cannot be controlled by means of ventilation. A complain for this buildings was also that ventilation rates are too low but the relation to asthma was not reported. Too low ventilation rates in classrooms can cause high humidity levels and high CO_2 levels among other negative effects of low ventilation rates.

Respondents reported carpets and new furniture as sources in pollution in offices. This can be prevented by using low polluting materials or by increasing ventilation rates. Other complaints were also regarding scents and perfumes. This can indicate that ventilation is not sufficient enough to cope with pollution caused by humans. Ventilation rates and effectiveness of ventilation should be increased to cope with this problem.

Respondents agree that indoor air quality should not be compromised in the name of energy efficiency and that a compromise should be found between the two goals: low energy consumption and good indoor air quality.

Appendix B: Descriptive list of ventilation standards

EN ISO 7730:2006. Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO 7730:2005)

This International Standard presents methods for predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments. It enables the analytical determination and interpretation of thermal comfort using calculation of PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) and local thermal comfort criteria, giving the environmental conditions considered acceptable for general thermal comfort as well as those representing local discomfort. It is applicable to healthy men and women exposed to indoor environments where thermal comfort is desirable, but where moderate deviations from thermal comfort occur, in the design of new environments or the assessment of existing ones. Although developed specifically for the work environment, it is applicable to other kinds of environment as well. It is supposed to be used with reference to ISO/TS 14415:2005, 4.2, when considering persons with special requirements, such as those with physical disabilities. Ethnic, national or geographical differences need also to be taken into account when considering non-conditioned spaces.

EN 12237:2003. Ventilation for buildings - Ductwork - Strength and leakage of circular sheet metal ducts

This standard specifies requirements and test methods for strength and air leakage of circular ductwork used in air conditioning and ventilation systems in buildings. The standard is intended to establish the mechanical strength and leakage required to verify the fitness for the intended service as installed ductwork. The standard is primarily intended for in-situ measurements, but provisions are also made for its use in laboratory testing. The requirements and methods are applicable also to rectangular ductwork in respect of air leakage.

EN 12239:2001. Ventilation for buildings — Air terminal devices – Aerodynamic testing and rating for displacement flow applications

This European Standard specifies methods for the laboratory aerodynamic testing and rating of low velocity air terminal devices for displacement flow applications, including the specification of suitable test facilities and measurement techniques. The standard gives only tests for the assessment of characteristics of the air terminal devices under non-isothermal conditions. This standard applies to Class IV air terminal devices as defined in EN 12238.

EN 12599:2001. Ventilation for buildings - Test procedures and measuring methods for handing over installed ventilation and air conditioning systems

This European Standard specifies checks, test methods and measuring instruments in order to verify the fitness for purpose of the installed systems at the stage of handing over. The Standard enables the choice between simple test methods, when sufficient, and extensive measurements, when necessary. The Standard applies to mechanically operated ventilation and air conditioning systems as specified in CR 12792 and comprising any of the following: - air terminal devices and units; - air handling units; - air distribution systems (supply, extract, exhaust); - fire protection devices; - automatic control devices.

EN 12792:2003. Ventilation for buildings - Symbols, terminology and graphical symbols

This European Standard specifies symbols, units and terminology ventilation systems for buildings.

EN 13141-1:2004. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 1: Externally and internally mounted air transfer devices

This European standard specifies laboratory methods for testing externally and internally mounted air transfer devices operating under pressure differences. It applies to any devices located between two spaces (between one room and outside, or between two rooms) such as: - devices with fixed opening(s); - devices with manually adjustable opening(s); - devices with pressure difference controlled opening(s). It describes tests intended to characterize the following: - flow rate/pressure; - air diffusion; - air leakage (for closable externally mounted air transfer device); - sound reduction; etc.

EN 13141-2:2010. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 2: Exhaust and supply air terminal devices

This European Standard specifies laboratory methods for testing exhaust and supply air terminal devices operating under pressure differences. It applies to devices used in mechanical and natural residential ventilation systems, of the following types: - device with a manually adjustable opening; or - device with a fixed opening; or - pressure difference controlled device. It describes tests intended to characterize: - flow rate/pressure; - air diffusion characteristics (for supply air terminal devices); - noise production for components of systems; - insertion loss of component of systems; - sound insulation.

EN 13141-3:2003. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 3: Range hoods for residential use

This European standard specifies methods for measuring the main performance characteristics of range hoods for residential use. It applies to recirculating range hoods, air extraction range hoods incorporating a fan and air extraction range hoods without fan. This standard does not specify values for performance characteristics. Safety Requirements are specified in EN 60335-2-31.

EN 13141-4:2004. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 4: Fans used in residential ventilation systems

This European standard specifies performance test methods for fans used in the residential ventilation. These methods primarily concern: a) Ventilation fans installed on a wall or in a window without any duct; b) Ventilation fans installed in the downstream of a duct; c) Ventilation fans installed in the upward stream of a duct; d) Ventilation fans installed in a duct; e) Encased fans having several inlets. This standard defines for each type of fan, the acoustic testing methods. The following method can be used: a) In duct method; b) Reverberant field method; c) Free field or semi-reverberant method.

EN 13141-5:2004. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 5: Cowls and roof outlet terminal devices

This document specifies methods for measuring the aerodynamic and acoustic characteristics of cowls and roof outlets used in both natural and mechanical ventilation. Only those cowls and roof outlets fitted onto ducts, which project above the roof surface, are covered by the present standard. Regarding assisted cowls, only the fan-assisted ones are covered by the present standard, other types (such as injection assisted cowls) being too recent to be adequately considered for the time being. The performance testing of the "assistance" provided by the auxiliary fan of an assisted cowl is excluded for the scope of this standard.

EN 13141-6:2004. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 6: Exhaust ventilation system packages used in a single dwelling

This European standard specifies laboratory methods for measuring the aerodynamic and acoustic performance characteristics and energy consumption of assembled exhaust ventilation system packages for single dwelling. The object of this standard is to provide tested characteristics for a system package in extreme conditions to enable the user to be assured that the same values will be achieved on site when the system package is installed in accordance with the manufacturer's instruction and within these limits of the test conditions.

EN 13141-7:2010. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 7: Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings

This part of EN 13141 specifies the laboratory test methods and test requirements for the testing of aerodynamic, thermal and acoustic performance, and the electrical performance characteristic of a mechanical supply and exhaust ventilation units used in a single dwelling. It covers unit that contain at least, within one or more casing: - supply and exhaust air fans; - air filters; - air-to-air heat exchanger and/or Extract Air-to-Outdoor Air heat pump for extract air heat recovery; - control system. Such unit can be provided in more than one assembly, the separate assemblies of which are designed to be used together. The different possible arrangements of heat recovery heat exchangers and/or heat pumps are described in Annex A. This standard does not deal with non-ducted units or reciprocating heat exchangers. This standard does not deal with units that supply several dwellings. This standard does not cover ventilation systems that may also provide water space heating and hot water. This standard does not cover units including combustion engine driven compression heat pumps and absorption heat pumps. Electrical safety requirements are given in EN 60335-2-40 and EN 60335-2-80.

EN 13141-8:2006. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 8: Performance testing of un-ducted mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for a single room

This European Standard specifies the laboratory test methods and test requirements for the testing of aerodynamic, thermal and acoustic performance, and the electrical power of a un-ducted mechanical supply and exhaust ventilation unit used in a single room. In general, such a unit contains: ¾ supply and exhaust air fans; ¾ air filters; ¾ air to air heat exchanger for exhaust air heat recovery; ¾ control systems. Such equipment can be provided in more than one assembly, the separate assemblies of which are designed to be used together. This European Standard does not deal with ducted units or units with heat pumps. Safety requirements are given in EN 60335-2-80.

EN 13141-9:2007. Ventilation for buildings - Performance testing of components/products for residential ventilation - Part 9: Externally mounted humidity controlled air transfer device

This European Standard specifies laboratory methods for testing humidity controlled air inlets operating under pressure differences. It applies to all devices located between one room and outside and controlled on indoor humidity. For instance, devices of the following types: humidity controlled devices with fixed setting; manually openable or closable humidity controlled devices; humidity controlled devices self-adjusting on pressure difference. It describes tests intended to characterise: aero and hygro-dynamic performance; air tightness when closed (for closable humidity controlled air inlet); air diffusion in the occupied zone; sound insulation; time response. This European Standard does not apply to the evaluation of air filtration, condensation risk and noise production.

EN 13141-10:2008. Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 10: Humidity controlled extract air terminal device

This European Standard specifies laboratory methods for testing humidity controlled exhaust air terminal devices. This European Standard applies to all controlled devices on indoor humidity, used in mechanical and natural powered residential ventilation systems. For instance, devices of the following types: humidity controlled devices with a manually adjustable opening; humidity controlled devices with fixed setting; humidity controlled devices self-adjusting on pressure difference. This European Standard describes tests intended to characterize: aero and hygro-dynamic performance; acoustic characteristics (including noise production of the device; insertion loss of the device; sound insulation); time response.

EN 13142:2004. Ventilation for buildings – Components / products for residential ventilation - Required and optional performance characteristics

This European Standard specifies the component/product performance characteristics which may be necessary for the design and dimensioning of residential ventilation systems to ensure the predetermined comfort conditions of temperature, air velocity, humidity and sound in the occupied zone. It defines those performance characteristics which shall be measured and presented according to relevant test methods, and other performance characteristics which are optional but which may be required, e.g. to comply with local or national regulations.

EN 13182:2002. Ventilation for buildings - Instrumentation requirements for air velocity measurements in ventilated spaces

This standard specifies the main characteristics of air velocity measuring devices. This includes requirements for thermal velocity probes, recalibration and the signal processing of measurements in a ventilated space, including those in the air jet and in the occupied zone. Other types of velocity measuring devices should fulfil the performance parameters stated but appropriate calibration techniques should not necessarily be used which are described in this standard.

EN 14134:2004. Ventilation for buildings - Performance testing and installation checks of residential ventilation systems

This European Standard specifies checks and test methods in order to verify the fitness for purpose of installed ventilation systems in dwellings. It can be applied to commissioning of new systems and performance testing of existing systems. The standard enables the choice between simple test methods, when sufficient, and extensive measurements, when necessary. The standard applies to mechanical and non-mechanical (natural) ventilation systems comprising any of the following: - passive stack ventilation ducts, - air terminal devices (supply, exhaust), etc.

EN 15241:2007. Ventilation for buildings - Calculation methods for energy losses due to ventilation and infiltration in commercial buildings

This European Standard describes the method to calculate the energy impact of ventilation systems (including airing) in buildings to be used for applications such as energy calculations, heat and cooling load calculation. Its purpose is to define how to calculate the characteristics (temperature, humidity) of the air entering the building, and the corresponding energies required for its treatment and the auxiliaries electrical energy required. This standard can also be used for air heating and cooling systems when they assure the provision of ventilation, considering that prEN 15243 will provide the required heating or cooling load and the corresponding air flows and/or air temperatures.

EN 15242:2007. Ventilation for buildings - Calculation methods for the determination of air flow rates in buildings including infiltration

This European Standard describes the method to calculate the ventilation air flow rates for buildings to be used for applications such as energy calculations, heat and cooling load calculation, summer comfort and indoor air quality evaluation. The ventilation and air tightness requirements (as IAQ, heating and cooling, safety, fire protection…) are not part of the standard. For these different applications, the same iterative method is used but the input parameter should be selected according to the field of application. For specific applications a direct calculation is also defined in this standard. A simplified approach is also allowed at national level following prescribed rules of implementation. The method is meant to be applied to: - Mechanically ventilated building (mechanical exhaust, mechanical supply or balanced system). - Passive ducts. - Hybrid system switching between mechanical and natural modes. - Windows opening by manual operation for airing or summer comfort issues. Automatic windows (or openings) are not directly considered here. Industry process ventilation is out of the scope. Kitchens where cooking is for immediate use are part of the standards (including restaurants..) Other kitchens are not part of the standard. The standard is not directly applicable for buildings higher than 100 m and rooms where vertical air temperature difference is higher than 15K. The results provided by the standard are the building envelope flows either through leakages or purpose provided openings and the air flows due to the ventilation system, taking into account the product and system characteristics.

EN 15243:2007. Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems

The scope of this European Standard is - To define the procedure how the calculation methods to determine the temperatures, sensible loads and energy demands for the rooms shall be used in the design process. - To describe the calculation methods to determine the latent room cooling and heating load, the building heating, cooling, humidification and dehumidification loads and the system heating, cooling, humidification and dehumidification loads. - To define the general approach for the calculation of the overall energy performance of buildings with room conditioning systems - To describe one or more simplified calculation methods for the system energy requirements of specific system types, based on the building energy demand result from prEN ISO 13790, and to define their field of application. A general framework standard is given which imposes an hourly calculation for all cases which cannot be covered by simplified methods, and gives requirements on what has to be taken into account. Input and output data are defined. The target audience of this standard is twofold: - Designers of HVAC systems, which are given an overview of the design process with the relevant references to the different involved standards (Clauses 5 to 12) - Developers of regulations and tools, which find requirements for calculation procedures to be used for the energy requirements according to the EPBD (Clauses 13 and 14). The idea followed by this standard is, that for the detailed approach one single calculation method is used for the different room related purposes such as room temperature calculation, room cooling and heating load calculation, and room energy calculation. This means, for the building type envisaged (buildings with room conditioning systems) it is an alternative to simplified calculation methods such as heating load according to EN 12831 and heating energy according to prEN ISO 13790. This standard does not describe any detailed methods for the sensible room based.

EN 15727:2010. Ventilation for buildings – Ducts and ductwork components, leakage classification and testing

This European Standard applies to technical ductwork products, intended for installation in ductwork conforming to EN 1505 and EN 1506, used in air conditioning and ventilation systems defined in the scope of CEN/TC 156. This document specifies the leakage requirements for technical ductwork products, i.e. components in the ductwork that has more functions than conveying air, such as sound attenuators, filter boxes and duct fans, etc. The following products are not within the scope of this document: - ductwork components like bends, reducers and T-pieces. EN 12237 and EN 1507 apply; - flexible ducts according to EN 13180; - ducts made of insulation duct boards according to EN 13403; - dampers according to EN 1751; - air handling units according to EN 1886. This document is a parallel standard to EN 12237, EN 1507 and EN 1751, based on the same leakage classification.

EN 15650:2010. Ventilation for buildings - Fire dampers

This European Standard applies to fire dampers that are to be used in conjunction with fire separating elements to maintain fire compartments. This standard specifies requirements and gives reference to the test methods defined for fire dampers, which are intended to be installed in Heating, Ventilating and Air Conditioning (HVAC) installations in buildings. All fire dampers close automatically in response to raised temperatures indicating fire. Details are given for the provision of evaluation of conformity and marking of fire dampers. To avoid duplication reference is made to a variety of other standards. To this end it is advised to read this standard in conjunction with EN 1366-2 and EN 1363-1 for details of the fire resistance testing and EN 13501-3 for classification. Fire dampers meeting requirements of this standard may be considered suitable for both ducted and unducted applications. This standard has not considered in detail the detrimental and/or corrosive effects that may be caused by chemical processes present in the atmosphere, which are drawn through the system intentionally or inadvertently and therefore does not apply to fire dampers used in such applications. An indication of salt spray corrosion may be determined using the method described in Annex B.

EN 15871:2009. Ventilation for buildings - Fire resisting duct sections

This European Standard applies to fire resisting duct sections, placed on the market and intended to operate as part of heating, ventilation and air conditioning (HVAC) system. This standard specifies requirements and gives reference to the test methods defined for fire resisting duct sections and their associated components, which are intended to be installed in heating, ventilation and air conditioning (HVAC) systems in buildings. It also provides the evaluation of conformity of the products to the requirements of this standard. Furthermore, marking and information on installation and maintenance of these products are also given in this European Standard. This standard is to be read in conjunction as well as with EN 13501-3 for classification and EN 1366-1 and EN 15882-1 for details of the fire resistance testing. This European Standard also governs associated components used together with fire resisting duct sections such as turning vanes and silencers, and access panels, which are covered by separate standards. Duct sections for use other than in fire resisting heating, ventilation and air conditioning (HVAC) systems are not covered by this standard.

Appendix C: Ventilation in Europe

Belgium

Table 25: Ventilation systems in Belgium

Building type	Construction years (design)	Natural ventilation - no fans Systems 1A & 1B	Natural ventilation - assisted with fans Systems 2A & 2B	Mechanical supply or Mechanical extract ventilation Systems 3A & 3B	Mechanical extract & supply ventilation		Ventilation integrated with air-conditioning	
					Without heat recovery System 3C1	With heat recovery System 3C2	Without humidification System 4A	With humidification System 4B
Houses	< 1991	90%	9%	3A=1%				
	1991-2008*	1B = 60%	2B = 10%	3A = 25%	5% **			
	>2008	15%	10%	3A = 35%	40% **			
OVERALL								
Apartment buildings	< 1991	30%	65%	3A=5%				
	1991-2008*	1B = 20%	2B = 50%	3A = 25%	5% **			
	>2008	15%	40%	3A = 35%	10% **			
OVERALL								
Schools	< 1991	90%	9%	3A = 1%				
	1991-2008*	1B = 60%	2B = 25%	3A = 10%	5%			
	>2008	50%	30%	3A = 10%	8%	2%		
OVERALL								
Kindergartens	< 1991							
	1991-2008*							
	>2008							
OVERALL								
Office buildings	< 15/02/1996	75%	15%	10%				
	> 15/02/1996			3B – 60%	40%			
OVERALL								

*: 1991: release of national standard on ventilation system (NBN D50-001)
2008: review of the certificate of energy performance (CEP)

**: no further indications on heat recovery

Bulgaria

Table 26: Ventilation systems in Bulgaria

Building type	**Construction years (design)**	**Natural ventilation - no fans**	**Natural ventilation - assisted with fans**	**Mechanical supply or Mechanical extract ventilation**	**Mechanical extract & supply ventilation**		**Ventilation integrated with air-conditioning**	
					Without heat recovery	**With heat recovery**	**Without humidification**	**With humidification**
		Systems 1A & 1B	**Systems 2A & 2B**	**Systems 3A & 3B**	**System 3C1**	**System 3C2**	**System 4A**	**System 4B**
Houses								
OVERALL		95%	5%					
Apartment buildings								
OVERALL		95%	5%					
Schools								
OVERALL		100%						
Kindergartens								
OVERALL		100%						
Office buildings								
OVERALL		75%	5%	6%	4%	2%	5%	3%

Finland

Table 27: Ventilation systems in Finland

Building type	Construction years (design)	Natural ventilation [A] - no fans and assisted with fans Systems 1A, 1B, 2A, 2B	Mechanical supply or Mechanical extract ventilation Systems 3A & 3B	Mechanical extract & supply ventilation [B] Without and with heat recovery Systems 3C1 & 3C2	Ventilation integrated with air-conditioning Without humidification System 4A	Ventilation integrated with air-conditioning With humidification System 4B
Houses [1]	-1959	80%	12%	8%		
	1960-1969	80%	11%	9%		
	1970-1979	74%	15%	10%		
	1980-1987	42%	26%	32%		
	1988-2003*	14%	26%	60%		
	2004-**	0%	7%	93%		
OVERALL		52%	18%	30%		
Apartment buildings [1]	-1959	67%	18%	16%		
	1960-1969	37%	38%	25%		
	1970-1979	30%	42%	28%		
	1980-1987	22%	59%	19%		
	1988-2003*	14%	47%	40%		
	2004-**	9%	18%	73%		
OVERALL		28%	42%	29%		
Schools [2]	-1959	33%	22%	45%		
	1960-1969	14%	29%	57%		
	1970-1979	5%	22%	73%		
	1980-1987	1%	19%	80%		
	1988-2003*	2%	16%	82%		
	2004-**	0%	4%	96%		
OVERALL		21%	23%	56%		
Kinder-gartens [3] ***	-1959	14%	29%	57%		
	1960-1969	0%	38%	62%		
	1970-1979	12%	21%	67%		
	1980-1989	2%	16%	82%		
	1990-1999	2%	10%	88%		
	2000-	2%		98%		
OVERALL		5%	16%	79%		
Office buildings	-1959					
	1960-1969					
	1970-1979					
	1980-1987					
	1988-2003					
	2004-					
OVERALL						

A No data available to separate the fan assisted and non-assisted systems.
B No data available to separate the systems with and without heat recovery. Majority of systems should include the heat recovery thought.
1 Based on a questionnaire study performed by THL in year 2006 (ALTTI study, over 1200 replies).
2 Based on a questionnaire study performed by THL in year 2007 (over 1100 schools).
3 Based on a Radon study done by Säteilyturvakeskus (direct communication with Tuomas Valmari, STUK). Report available *http://www.stuk.fi/julkaisut/stuk-a/stuk-a221.pdf*
* New building code
** New building code
*** Different year structure because of the available data

France

Table 28: Ventilation systems in France

Building type	**Construction years (design)**	**Natural ventilation - no fans** **Systems 1A & 1B**	**Natural ventilation - assisted with fans** **Systems 2A & 2B**	**Mechanical supply or Mechanical extract ventilation** **Systems 3A & 3B**	**Mechanical extract & supply ventilation**		**Ventilation integrated with air-conditioning**	
					Without heat recovery **System 3C1**	**With heat recovery** **System 3C2**	**Without humidification** **System 4A**	**With humidification** **System 4B**
Houses	old	1A = 10%	2B = 19%	3A = 40%	1%			
	new			3A = 95%	5%			
OVERALL								
Apartment buildings *								
OVERALL								
Schools	1969 – 2002	1A = 10% 1B = 19%	2B = 30%	3A = 40%	1%			
	> 2002			3A = 95%	5%			
OVERALL								
Kinder-gartens								
OVERALL								
Office buildings								
OVERALL								

Germany

Table 29: Ventilation systems in Germany

Building type	Construction years (design)	Natural ventilation - no fans Systems 1A & 1B	Natural ventilation - assisted with fans Systems 2A & 2B	Mechanical supply or Mechanical extract ventilation Systems 3A & 3B	Mechanical extract & supply ventilation: Without heat recovery System 3C1	Mechanical extract & supply ventilation: With heat recovery System 3C2	Ventilation integrated with air-conditioning: Without humidification System 4A	Ventilation integrated with air-conditioning: With humidification System 4B
Houses								
OVERALL		81,2 %	Unknown (nearly zero)	12,3%	5,6 % (mostly 3C2)	Unknown (nearly zero)		
Apartment buildings								
OVERALL		74,2 %	Unknown (nearly zero)	13,6%	6,9 % (mostly 3C2)	Unknown (nearly zero)		
Schools								
OVERALL		no statistic known						
Kindergartens								
OVERALL		no statistic known						
Office buildings								
OVERALL		no statistic known						

Greece

Table 30: Ventilation systems in Greece

Building type	Construction years (design)	Natural ventilation - no fans Systems 1A & 1B	Natural ventilation - assisted with fans Systems 2A & 2B	Mechanical supply or Mechanical extract ventilation Systems 3A & 3B	Mechanical extract & supply ventilation Without heat recovery System 3C1	With heat recovery System 3C2	Ventilation integrated with air-conditioning Without humidification System 4A	With humidification System 4B
Houses	<1978	92%	6%	1%	1%			
	>1978	50%	30%	15%	5%			
OVERALL								
Apartment buildings	<1978	91%	6%	2%	1%			
	>1978	40%	25%	20%	15%			
OVERALL								
Schools	<1978	97%	3%	0%	0%			
	>1978	80%	10%	7%	3%			
OVERALL								
Kindergartens	<1978	97%	3%	0%	0%			
	>1978	80%	14%	5%	1%			
OVERALL								
Office buildings	<1978	20%	40%	30%	10%			
	>1978	10%	30%	40%	20%			
OVERALL								

Italy

Table 31: Ventilation systems in Italy

Building type	Construction years (design)	Natural ventilation - no fans	Natural ventilation - assisted with fans	Mechanical supply or Mechanical extract ventilation	Mechanical extract & supply ventilation		Ventilation integrated with air-conditioning	
					Without heat recovery	With heat recovery	Without humidification	With humidification
		Systems 1A & 1B	Systems 2A & 2B	Systems 3A & 3B	System 3C1	System 3C2	System 4A	System 4B
Houses	before 1945	100%						
	1945-1976	100%						
	1976-1991	100%						
	After 1991	99%				1%		
OVERALL								
Apartment buildings	before 1945	100%						
	1945-1976	100%						
	1976-1991	100%						
	After 1991	99%				1%		
OVERALL								
Schools	before 1945	100%						
	1945-1976	100%						
	1976-1991	100%						
	After 1991	100%						
OVERALL								
Kindergartens	before 1945	100%						
	1945-1976	100%						
	1976-1991	100%						
	After 1991	100%						
OVERALL								
Office buildings	before 1945	100%						
	1945-1976	80%						20%
	1976-1991	70%						30%
	After 1991	50%						50%
OVERALL								

Norway

Table 32: Ventilation systems in Norway

Building type	Construction years (design)	Natural ventilation - no fans	Natural ventilation - assisted with fans	Mechanical supply or Mechanical extract ventilation	Mechanical extract & supply ventilation		Ventilation integrated with air-conditioning	
					Without heat recovery	With heat recovery	Without humidification	With humidification
		Systems 1A & 1B	Systems 2A & 2B	Systems 3A & 3B	System 3C1	System 3C2	System 4A	System 4B
Houses	< 1976	58,7%						
	1976-1987	18%						
	1987-1997	12,6%						
	1997-2007	10,6%						
	> 2007					X (70%)		
OVERALL			66,7%					
Apartment buildings	< 1976							
	1976-1987	Included in houses						
	1987-1997							
	1997-2007							
	> 2007					X (70%)		
OVERALL								
Schools	< 1976		Natural or mech.					
	1976-1987			x				
	1987-1997			x				
	1997-2007				x			
	> 2007					X (70%)		
OVERALL								
Kindergartens	< 1976		Natural or mech					
	1976-1987			x				
	1987-1997			x				
	1997-2007				x			
	> 2007					X (70%)		
OVERALL								
Office buildings	< 1976		Natural or mech					
	1976-1987			x				
	1987-1997			x				
	1997-2007				x			
	> 2007					X (70%)		
OVERALL								

Relevant Acts: Planning and Building Act (1965, 1985, 2010); Work Environment Act (1977);
Technical regulations (1976, 1987 1997, 2007, 2010)
For non-residential buildings heat recovery is increased from 2010 to 80%

Portugal

Table 33: Ventilation systems in Portugal

Building type	Construction years (design)	Natural ventilation - no fans	Natural ventilation - assisted with fans	Mechanical supply or Mechanical extract ventilation	Mechanical extract & supply ventilation		Ventilation integrated with air-conditioning	
					Without heat recovery	With heat recovery	Without humidification	With humidification
		Systems 1A & 1B	Systems 2A & 2B	Systems 3A & 3B	System 3C1	System 3C2	System 4A	System 4B
Houses	<1980	100%	0%	0%	0%	0%	0%	0%
	1980-1990	90%	10%	0%	0%	0%	0%	0%
	1990-2007	50%	50%	0%	0%	0%	0%	0%
	>2007	20%	80%	0%	0%	0%	0%	0%
OVERALL								
Apartment buildings	<1980	90%	10%	0%	0%	0%	0%	0%
	1980-1990	70%	30%	0%	0%	0%	0%	0%
	1990-2007	20%	80%	0%	0%	0%	0%	0%
	>2007	0%	100%	0%	0%	0%	0%	0%
OVERALL								
Schools	<1980	100%	0%	0%	0%	0%	0%	0%
	1980-1990	100%	0%	0%	0%	0%	0%	0%
	1990-2007	100%	0%	0%	0%	0%	0%	0%
	>2007	0%	0%	0%	0%	0%	100%	0%
OVERALL								
Kindergartens	<1980	100%	0%	0%	0%	0%	0%	0%
	1980-1990	100%	0%	0%	0%	0%	0%	0%
	1990-2007	100%	0%	0%	0%	0%	0%	0%
	>2007	0%	0%	0%	0%	0%	100%	0%
OVERALL								
Office buildings	<1980	70%	0%	0%	30%	0%	30%	0%
	1980-1990	10%	30%	0%	0%	0%	60%	0%
	1990-2007	10%	10%	0%	0%	0%	80%	0%
	>2007	5%	5%	0%	0%	0%	90%	0%
OVERALL								

* Refers to extraction from bathrooms and kitchen hoods, typically working only a few hours per day – not considered as "generalised" ventilation.

Romania

Table 34: Ventilation systems in Romania

Building type	Construction years (design)	Natural ventilation - no fans	Natural ventilation - assisted with fans	Mechanical supply or Mechanical extract ventilation	Mechanical extract & supply ventilation		Ventilation integrated with air-conditioning	
					Without heat recovery	With heat recovery	Without humidification	With humidification
		Systems 1A & 1B	Systems 2A & 2B	Systems 3A & 3B	System 3C1	System 3C2	System 4A	System 4B
Houses	< 1979 *	100%						
	1979 – 1998*	100%						
	1998 – 2010*	90%	10%					
	> 2010 *	80%		20%				
OVERALL								
Apartment buildings	< 1979 *	100%						
	1979 – 1998*	100%						
	1998 – 2010*	90%	10%					
	> 2010 *	80%		20%				
OVERALL								
Schools	< 1979 *	100%						
	1979 – 1998*	100%						
	1998 – 2010*	80%				20%		
	> 2010 *	70%				30%		
OVERALL								
Kindergartens	< 1979 *	100%						
	1979 – 1998*	100%						
	1998 – 2010*	80%				20%		
	> 2010 *	70%				30%		
OVERALL								
Office buildings	< 1979 *	100%						
	1979 – 1998*	50%		30%		10%	10%	
	1998 – 2010*	50%				30%	20%	
	> 2010 *					50%	50%	
OVERALL								

* According to the years in which I5 has been modified. I5 – norm for the design, manufacture, and operation of ventilation and climate control systems

United Kingdom

Table 35: Ventilation systems in UK

Building type	Construction years (design)	Natural ventilation - no fans Systems 1A & 1B	Natural ventilation - assisted with fans Systems 2A & 2B	Mechanical supply or Mechanical extract ventilation Systems 3A & 3B	Mechanical extract & supply ventilation		Ventilation integrated with air-conditioning	
					Without heat recovery System 3C1	With heat recovery System 3C2	Without humidification System 4A	With humidification System 4B
Houses	< 1980	98% - 1A local htg	2%					
	1981-2000	50% - 1A central htg	45% central htg	5%				
	2001 - 2010	20%	75%	3%		2 %		
	> 2011		50%	35% +		15 % and increasing		
OVERALL								
Apartment buildings	< 1980	80%	20% 2A					
	1981-2000	20%	80% 2A					
	2001 - 2010		80% 2A	18% 2B		2 %		
	> 2011		20%	60% 3A		15%	5%	
OVERALL								
Schools	< 1980	80%	20% 2A					
	1981-2000		80%	10%		10%		
	2001 - 2010		60%	20%		20%		
	> 2011		30%	20%		50% +		
OVERALL								
Kindergartens								
	Similar to Schools							
OVERALL								
Office buildings	< 1980	20%	40%	20%			10%	10%
	1981-2000		20%	30%		30% +	10%	10%
	2001 - 2010		20%	20%		45%	5%	10%
	> 2011		10%	5%		70%	5%	10%
OVERALL								

Appendix D: List of respondents

Respondents representing European countries and providing data are presented in Table 36. Crosses in the table present in which questionnaires respondent was involved. It is important to stress that some questionnaires were answered by joint knowledge and experience of two experts. The sum under the column with crosses therefore does not represent sum of crosses but total number of received questionnaires.

Returned questionnaires were received back between March and May 2011. Data obtained with questionnaires thus represents the state of national regulations and personal opinions at latest on May 2011. Changes after this date are not accounted in this report.

Table 36: Respondents answering the questionnaires

Country	**Respondent**	**Institute / company**	**Ventilation systems**	**EPBD**	**Ventilation rates**	**Technical features**
Belgium	Guillaume Goeders	REHVA	x			
Bulgaria	Detelin Markov	Technical University of Sofia	x	x	x	x
Czech Republic	Daniel Adamovsky	Czech Technical University in Prague		x	x	
Denmark	Pawel Wargocki	Technical University of Denmark		x	x	
Finland	Arja Asikainen	THL			x	x
	Olli Seppänen	REHVA	x	x		
France	Francis Allard	University of La Rochelle	x	x	x	x
Germany	Thomas Hartmann	ITG	x	x	x	x
Greece	Margarita-Niki Assimakopoulus	University of Athens	x	x	x	x
Hungary	Zoltan Magyar	University of Pécs		x	x	
Italy	Stefano Corgnati	Politecnico di Torino	x	x	x	x
	Paolo Tronville				x	x
Lithuania	Egidijus Juodis	Vilnius Gediminas Technical University		x	x	x
The Netherlands	18 Cor van den Bogaard 19 Piet van Luik	Dutch Ministy for Infrastructure and Environment		x	x	x
Norway	Bjarne Malvik	SINTEF	x	x	x	x
Poland	Pawel Wargocki	Technical University of Denmark			x	
Portugal	Vitor Leal	University of Porto	x	x	x	x
Romania	Ioan Silviu Dubosi	Dosetimpex	x	x	x	x
	Andrei Litiu	REHVA				
Slovakia	Dusan Petras	Slovak University of Technology		x		x
Slovenia	Vincenc Butala	University of Ljubljana		x	x	x
	Nejc Brelih	REHVA				
United Kingdom	Derrick Braham	Member of CIBSE Council	x	x	x	x
Total received questionnaires			11	17	15	16

Appendix E: Overview of all questionnaires

Ventilation systems in Europe:

Building type	Construction years (design)	Natural ventilation (A - no fans and assisted with fans Systems 1A, 1B, 2A, 2B	Mechanical supply or Mechanical extract ventilation Systems 3A & 3B	Mechanical extract & supply ventilation (B	Ventilation integrated with air-conditioning	
				Without and with heat recovery Systems 3C1 & 3C2	Without humidification System 4A	With humidification System 4B
Houses						
Apartment buildings						
Schools						
Kinder-gartens						
Office buildings						
OVERALL						

Asthma patients:

1. **What are the most common complaints related to indoor air quality and climate:**

f) Single family residential buildings (houses)?
g) Apartments?
h) Classrooms in schools?
i) Day-care canters and kindergartens?
j) Offices?

2. **What are the most common indoor air problems in new buildings:**

f) Single family residential buildings (houses)?
g) Apartments?
h) Classrooms in schools?
i) Day-care canters and kindergartens?
j) Offices?

3. **What are the most common indoor air problems in new buildings:**

f) Single family residential buildings (houses)?
g) Apartments?
h) Classrooms in schools?
i) Day-care canters and kindergartens?
j) Offices?

4. **What are the most common mistakes or shortcomings related to the installation of ventilation?**

5. **What are the most serious problems with ventilation regulations in your country?**

6. **What kinds of ventilation regulation are needed in the future (what should be included in the regulations)?**

7. **What is the effect/expected effect of energy saving policy on indoor air quality and ventilation?**

Effect of EPBD recast on ventilation regulations:

1. Do you expect:
c) Problems related to indoor air quality to increase with recast EPBD, why?
d) Problems related to indoor air quality to decrease with recast EPBD?

2. Regulations for ventilation will:
c) Be revised to become more stringent – if yes when?
d) Stay as they are now from the year?

3. Regulations for ventilation will be enforced:
d) More?
e) Less?
f) As before?

4. The following change will take place in ventilation systems:
e) More natural ventilation will be used.
f) More controlled ventilation with mechanical supply and exhaust will be used.
g) More heat recovery from ventilation air will be used.
h) More hybrid ventilation systems will be used.

5. Envelope of the building (walls, windows, etc.) will become:
c) More airtight – what are the requirement for new buildings if any?
d) More leaky

6. Indoor air and climate of nearly zero energy buildings will get:
c) Enough attention?
d) Too little attention?

7. Requirements for indoor air quality will be included in regulations.
d) Yes.
e) No.
f) Maybe.

8. Are the requirements for indoor air pollutants controlled?
d) Yes.
e) No.
f) Partly.

9. Do current regulations allow lower ventilation rates if building materials are less polluting?
c) No
d) Yes, how much?

10. The following technologies are already included in your regulations?
g) Demand controlled ventilation (requirement to adjust the ventilation by ventilation demand).
h) Possibility to adjust ventilation rates based on pollution loads and needs.
i) Reduce ventilation rates when effective room air cleaning is used.
j) Reduce ventilation rates if ventilation efficiency is improved.
k) Heat recovery from ventilation air.
l) Ventilating rates are controlled by the outdoor air quality (less ventilation when outdoor air is polluted).

11. Do you think that the following technologies will be used in the future to achieve performance requirements of the future local energy regulations?

h) Demand controlled ventilation (requirement to adjust the ventilation by ventilation demand).
i) Possibility to adjust ventilation rates based on pollution loads and needs.
j) Reduce ventilation rates when effective room air cleaning is used.
k) Reduce ventilation rates if ventilation efficiency is improved.
l) Heat recovery from ventilation air.
m) Ventilating rates are controlled by the outdoor air quality (less ventilation when outdoor air is polluted).
n) Other technologies like:

Requirements for ventilation rates and indoor environment in some European countries:

1. **What are the maximum values of contaminants in for residential buildings, schools, offices and kindergartens?**

c) No values given
d) For residential buildings, schools, offices, kindergartens

2. **What are the minimum ventilation rates for residences?**

c) Minimum air change rate in air changes per hour (or other values if they are provided)
d) Exhaust air flow rates from kitchen, toilet, bathroom

3. **What is the minimum ventilation rate for class rooms?**

4. **What is the minimum ventilation rate for play rooms in kindergarten?**

5. **What is the minimum ventilation rate in office rooms?**

6. **What is are the temperature limits?**

d) Not given
e) For summer
f) For winter

7. **What is the maximum air velocity in residences and offices?**

d) Not given
e) For summer
f) For winter

8. **What is the limit value for humidity in the indoor air?**

9. **What are the limit values for ventilation noise?**

f) Not given
g) Residences (sleeping rooms)
h) Schools
i) Kindergartens
j) Offices

10. **The information given above is (if possible, please write source of information besides answers).**

c) Mandatory, given in building regulations, please give the reference
d) Informative, given in non-mandatory guidelines, please give the reference

Technical features of ventilation systems:

1. **Do you have requirement for preventing moisture and mold damages in the ventilation system like:**

e) Prevent the rain and snow entering the system?
f) Prevent uncontrolled condensation in the system?
g) Prevent condensation on coils to cause damage?
h) Prevent droplet from humidification to spread in system?

2. **Do you have requirements on the location of outdoor intakes to prevent pollutants from local sources entering the building in ventilation air like:**

f) Minimum distances from cooling towers?
g) Minimum distance from exhaust air openings?
h) Minimum distance from chimneys?
i) Minimum distance from sewage vents?
j) Minimum distance from other sources?

3. **Do you have requirements for the cleanliness of the ventilation system so that the system does not become a source of pollutants like:**

f) Fibres (from interior insulation)?
g) Microbes?
h) Dust?
i) Ozone?
j) Other chemicals?

4. **Do you have requirement for filtering (cleaning) ventilation air (outdoor air)? If yes:**

c) What are the requirements?
d) Do you have any requirements for filter replacements?

5. **Are the operation instructions for the ventilation system required?**

6. **Is regular maintenance of ventilation system:**

c) Required?
d) Required and specified?

7. **Is cleaning of ventilation system (ducts, outlets, air handling units) required?**

c) At/just after construction stage?
d) During the life time of the ventilation system

8. **Do you have any requirements for personnel qualifications?**

c) Operation personnel?
d) Maintenance personnel?

9. **Is the recirculation of extract air (room air)**

c) Allowed – limitations?
d) Recommended?

10. **Do you have any requirements regarding the ventilation systems for residential buildings? Can ventilation be provided by:**

g) Leakage of building envelope and window opening with no designed ventilation?
h) Designed natural ventilation with vertical stacks or atrium?
i) Decentralised mechanical exhaust?
j) Central mechanical exhaust?

k) Mechanical supply and exhaust?
l) Mechanical supply and exhaust with heat recovery?

11. Do you have any requirements regarding the ventilation systems for offices, schools, kindergartens? Can ventilation be provided by:

h) Only on leakage and window opening?
i) Designed natural ventilation with vertical stacks?
j) Decentralised mechanical exhaust?
k) Central mechanical exhaust?
l) Central mechanical supply?
m) Mechanical supply and exhaust?
n) Mechanical supply and exhaust with heat recovery?

12. Are there any limitations where and when different ventilation systems can be used, regarding location in relation to outdoor pollution source (high ways, industry etc.)?

13. Is the balancing of air flows in a central ventilation system:

c) Required?
d) Required and controlled?

14. Do you have any requirements set for the pressure differences between rooms and outdoor air?

15. Do you have any requirement for follow up measurements (vent rates, IAQ etc.) during the lifetime of buildings?

16. Do you have any requirements regarding the leakage of extract air to the supply air in heat exchangers used for recovering heat from ventilation air?

17. Are there any other requirements regarding the type of heat recovery system?

18. Are there any requirements regarding regular inspections of ventilation systems?