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Sustainable Industrial Policy –
Building on the Ecodesign Directive –
Energy-Using Product Group Analysis/2

Lot 6: Air-conditioning and ventilation systems

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Draft Report Task 3

User Requirements, Infrastructure

Ventilation Systems

Prepared by VHK

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1 Introduction

1.1 Scope and subtasks

This is the draft report for Task 3 on the Ventilation Systems, as part of the preparatory study on Air Conditioning and Ventilation Systems in the context of the Ecodesign Directive: '**ENTR Lot 6 – Air Conditioning and Ventilation Systems.**

This study is being carried out for the European Commission (DG ENTR). The consortium responsible for the study is Armines (lead contractor), BRE and VHK. Subcontractor for the underlying report is VHK.

1.2 Task 3

Task 3 deals with the real-life energy consumption, as depending on consumer behaviour and infrastructure. In this case the general scope is ventilation in collective residential buildings and ventilation in non-residential buildings. General guidance on this task is given by the MEEUP methodology study (VHK 2005).

For this product group the offer of the consortium distinguishes 3 subtasks for Task 3:

Subtask 3.1 User Requirements

This subtask will gather information on what relevant building characteristics in the tertiary and residential sector, including typical ventilation requirements are.

Building-types to be distinguished are for example:

- residential buildings (flats, apartment blocks, elderly homes, care homes)
- offices
- schools and other educational buildings
- sports centres, gyms
- café's, bars and restaurants (with and without smoking facilities)
- hotels
- hospitals
- ecclesiastic buildings
- etc.

For each building type the following items are to be identified:

- Number of buildings
- Heated Gross Floor Area (m^2) and/or building volume (m^3)
- Number of occupants (determines ventilation requirement)
- Typical occupancy in time (setback and peak periods for ventilation)
- Activities and processes in as much as they are relevant for (special) ventilation needs

Under certain circumstances also the employment of certain materials may be relevant. For example, the abatement of radon emissions through ventilation in Greece.

Furthermore, in this subtask information will be gathered on:

- the user-perception of the mechanical ventilation systems (preferences and nuisances).

- health and productivity of the occupants/employees in relation to IAQ and ventilation systems;
- the decision making process in the various market, i.e. drivers and barriers for the introduction of more efficient ventilation.

Subtask 3.2 – User requirements in the use phase (current situation)

The objective of this subtask is to assess the typical physical and operating conditions of the ventilation systems in Europe.

Information will be gathered concerning:

- residential and tertiary buildings characteristics (amongst which air tightness, A/V-ratio)
- penetration of mechanical and natural ventilation systems versus no ventilation systems
- the average IAQ (Indoor Air Quality) and comfort levels in these buildings
- typical physical characteristics of the different building types in Europe

This statistical information will be used to represent typical buildings and their associated ventilation systems and IAQ-levels.

These data will be used at a later stage/task to model energy consumption in typical operating conditions of ventilation systems. It will integrate not only air change systems but also heat recovery and various kinds of controls.

Finally, this subtask will try to gather information on the energy losses that are caused by improper maintenance (or no maintenance at all) of the ventilation systems.

Subtask 3.3 –End-of-Life behaviour

This subtask will gather information on the end-of-life phase of mechanical ventilation systems .The recyclability of related products and components will be assessed as well as the environmental waste related to these products and components. The information, if available, will be gathered nationally via professional national association (questionnaire).

1.3 Methodology and reporting

Information was gathered through desk research, questionnaires (information request to stakeholders May 2010) and engineering calculations. As data availability is poor, both on ventilation systems and on the tertiary sector, it will often not be possible to derive the required data directly from European (Eurostat) statistics.

Instead, the contractors have tried to construct the information on the building stock from a multitude of sources. The most important source for setting a general framework is the VHK Business & Public Sector Statistics project. This project is a comprehensive internal VHK assessment of the number of EU-companies at NACE 5-digit level. The project on started in autumn of 2007 as an internal research project. It pulls together the data not just from Eurostat, but mainly from national NACE statistics. Although the project is still on-going, it is –to our knowledge—the only source that reaches this level of detail for all EU-25 countries, whereby Romanian and Bulgarian data are added through an overall multiplier in order to arrive at the EU-27. The statistics are the property of Van Holsteijn en Kemna B.V. (VHK), but –as VHK is part of the consortium—it was decided to make the data at least on EU totals available to the public domain.

On the basis of these statistics, subsequent specific sources concerning ventilation were used to depict the current situation and the actual ventilation need.

In the report, but also in the research, the subtasks 3.1 and 3.2 were combined and discussed per sector (residential, public & community sector, services sector, etc.). Subtask 3.3 is treated in a different chapter.

Per sector the aim is to provide answers to three questions:

- How (much) are people ventilating their buildings today?
- How much energy is involved with that?
- What would be ideally --given the functional demands and the infra-structural possibilities-- their ventilation need?

Task 1 provides most part of the input for the third question, in terms of the ventilation need in m³/h (or m³/s) per person, per m² gross floor area or per m³ heated building volume. Furthermore, the prescriptive parts provide some inputs into pressure drops that can be expected, minimum efficiency standards at national level, etc..

Task 2 results will provide part of the answer to the second question, i.e. the part that deals with the EU electricity consumption and design data of mechanical ventilation units. However, the bulk of the effort will be to determine the real-life use (control) of the equipment and above all the heating energy loss through ventilation.

How much energy would or should then be used in the ideal situation is subject to the technical possibilities and economic criteria in Tasks 4 and Task 5 respectively. Nonetheless, the Task 3 will already provide a first estimate.

Tasks 2 and 3 provide the inputs for Tasks 4 and 5, but also for the scenario analysis in Task 7/8 and it will be very relevant for the Impact Assessment report that the European Commission ultimately will have to provide in case of Ecodesign legislation.

The report is set up as follows:

Chapter 2.1 gives a general introduction into the available ventilation systems, as well as the main drivers and barriers for efficiency improvements.

Chapter 2.2 supplies estimates of ventilation-demand on the basis of some general EU-wide parameters: number of persons and buildings, ventilation losses as a part of total heat loss. And it gives some very interesting examples of the few cases where it was possible to retrieve exactly the right data.

Chapters 3.1 (multi-family dwellings), 3.2 (public sector buildings), 3.3 (services) and 3.4 (primary and secondary sector) discuss the building stock and ventilation-requirements in greater detail. Especially Chapter 3.2 on public sector buildings is interesting and contains a considerable amount of original material. It makes plausible that the public sector is performing under par in the field of energy efficient ventilation.

A summary of the ventilation demand is given in chapter 3.5. The 'Miscellaneous' chapter 4.1 reports on information found through the Lot 6 information request and touches on subjects like the end-of-life, the influence of climate on heat recovery, leakage of ductwork and the (lack of data on) controls and control settings. Chapter 5 deals with a number of case studies for typical buildings, in preparation of Task 4.

2 Subtask 3.1 User requirements

2.1 General

2.1.1 Ventilation systems basics

As mentioned in the Task 1 report on ventilation, there are basically 4 types of central ventilation systems that are currently used and referenced in standards and building regulations (EPB):

- Natural ventilation (' System A')
- Supply ventilation (' System B')
- Exhaust ventilation (' System C')
- Balanced (supply & exhaust) systems ('System D'), often with heat recovery

Furthermore, ventilation systems that are based on local heat recovery ventilation (LHRV) units are increasingly referred to as 'System E'.

System B is rare for 'ventilation only' products for the residential sector, but in non-residential it is a solution that can mostly be found in AHU's, i.e. where ventilation is combined with air cooling (see par. 2.2).

System D in the residential sector (currently mostly in individual dwellings) is always combined with heat recovery, but in the non-residential sector still around half of the AHU's, where ventilation is combined with air-cooling, is delivered without a heat recovery unit.

Any of these above systems may and sometimes –e.g. for residential configurations of System E-- must be supplemented by simple local extraction fans for occasional use in the 'wet rooms' (kitchen, bathroom, toilet). Kitchen hoods are not part of 'comfort ventilation', but in most standards and building regulations they are perceived as 'process ventilation' and taken into account with default values for an overall ventilation calculation of a building. Also other types of process ventilation, like the ventilation of operating theatres, clean-rooms and mines (see Annex I), extraction of toxic fumes in industrial processes, etc. are not regulated through building regulations and are outside the scope of the underlying study.

The diagrams on the next page show the principle.

In terms of energy efficiency and ventilation effectiveness the 5 systems are (very) different:

- System A has the advantage that there is no electricity consumption, except perhaps for some simple extraction fans in case the passive stack (if it is foreseen) does not provide sufficient ventilation. But the ventilation heat losses are very high. In order to work properly, infiltration openings in outer doors, inner doors and in window frames are a necessary part of the building design. Infiltration rates of 0,6 m^3/h per m^3 building volume are quite the normal standard. On top of that the inhabitants will have to open all windows periodically (best practice*, DE. 'Stosslüften'*) or leave a small window open (worst practice), adding another 0,6 to 0,8 m^3/h per m^3. The driving force behind sufficient natural ventilation is the pressure difference between opposite sides of a building. In other words: the wind. And the wind has some disadvantages: It is highly unpredictable and it usually blows only in one –unknown— direction.

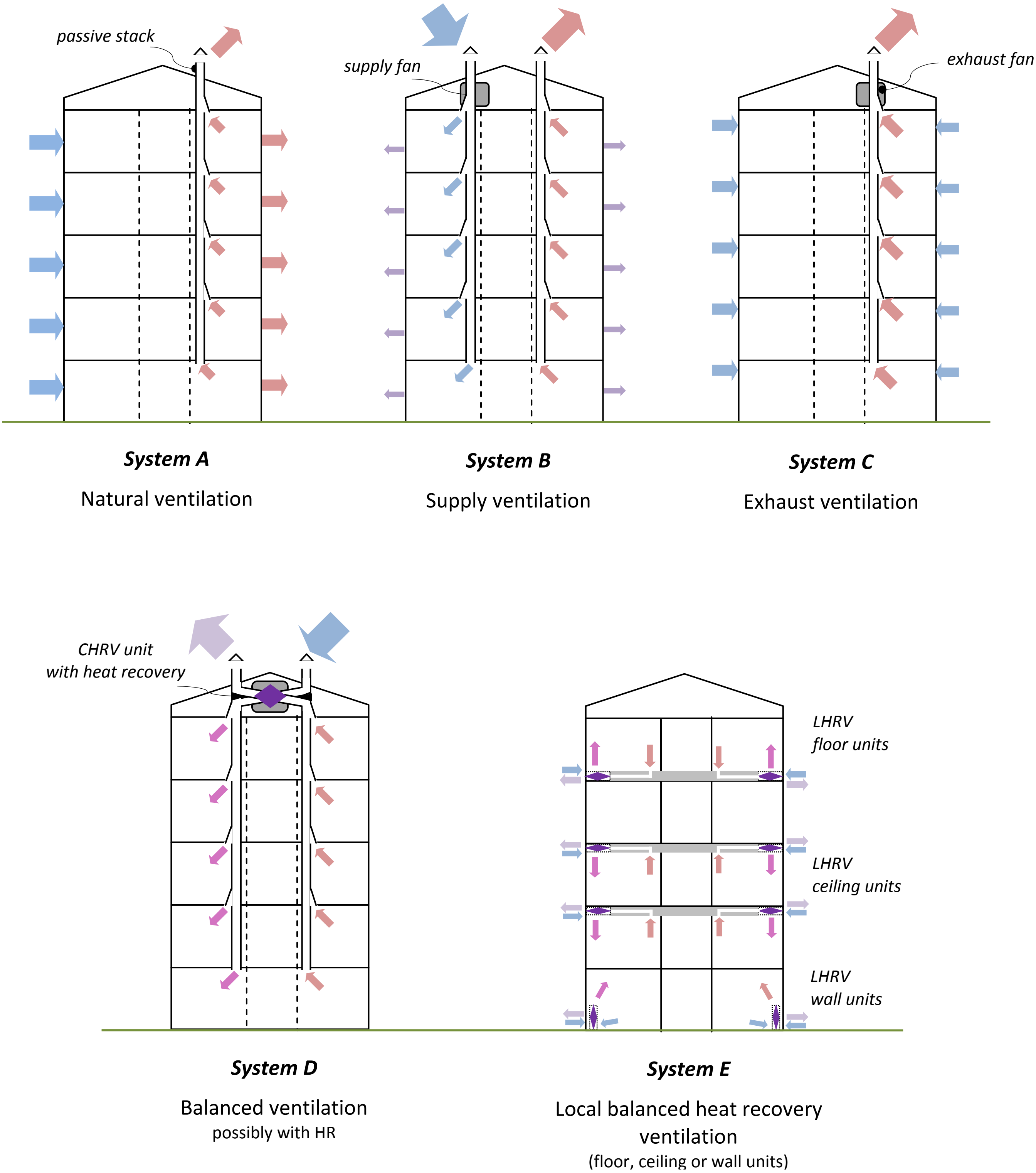

Figure 3 - 1. Basic ventilation systems

So in order to make sure that under all circumstances there is enough ventilation for a healthy indoor climate, the building regulation are very generous in prescribing the size of infiltration openings needed. System A provides a low level of comfort. If there is no wind, ventilation tends to be insufficient. If there is too much wind, there are cold drafts.

- **System B** in a normal building and used for 'ventilation only' is not an energy efficient way to ventilate a building. The over-pressure (with respect to outdoors) increases the infiltration losses and in order to guarantee a proper functionality under the worst circumstances (i.e. the wind blowing hard against the façade) the fan has to be fairly over-dimensioned. Therefore it is only used in legacy air-conditioning systems or in special ('process ventilation') circumstances, e.g. in operating theatres of hospitals where it is important to keep the bugs out.

- Until recently, **system C** has been THE central mechanical ventilation system for residential dwellings (multi-family or not). Air enters living- and bedrooms though special openings (grids, usually with noise damper to keep out outdoor noise) and is extracted through special openings in the wet rooms (kitchen, bathrooms) by a central exhaust fan. In non-residential buildings the exhaust openings are usually placed in the corridor. Unlike system A, its performance does not depend on the wind and in theory (most people leave the fan at mid-position all year round) there is the possibility of flow-rate control. These qualities allow buildings to be as air-tight as possible (with the exception of the special openings in the façade), thereby saving considerably on the infiltration heat losses and gaining in comfort and IAQ. On the downside, system C consumes electricity. It may not be very much with respect of the heating losses avoided, but it still counts. On the performance side, the possibility to control the airflow is rarely used. In non-residential buildings there may be a night-setback timer switching back from 100% (!!) to 50% capacity, but in (multi-family) buildings the fan is running in a mid-position (60% capacity) all year around. Furthermore, the special openings lead to cold drafts as well and in many occasions people keep these openings closed, resulting again in bad air quality with CO_2-levels well over 1200 ppm (example: NL primary schools).

- **Systems D** and E, when combined with heat recovery, represent the most efficient ventilation solution today. State-of-the-art heat exchangers reach an (initial) heat transfer effectiveness of close to or over 90%. This means that the incoming air is almost completely preheated (or pre-cooled in summer) to the room temperature. System D is the system of choice in air handling units (AHU's) for (larger) non-residential buildings. But the traditional reason was not energy efficiency but comfort, i.e. it is the best solution to provide comfortable air-conditioning (air cooling). For that reason, although 80% of AHU's has balanced ventilation only half of currently sold units are equipped with a heat recovery (HR) module, ignoring the strong pressure from legislation in the Northern parts of Europe. In 2005 the share of HR in German AHU sales was only 29% and therefore the stock of HR units will probably be no more than 20-25%. For the smaller public sector buildings there are some developments pushed by legislation whereby the construction industry is realizing balanced ventilation with special 'ventilation only' centralized heat recovery ventilation units, typically in a range between 500 and 4000 m^3/h. But there is still a long way to go.

- **System E** has the advantage of heat recovery (>80%) as system D, but it has a number of extra advantages: Mainly –depending on type—it is easier to retrofit in existing buildings (no ductwork) and it is easier to realize local control. Local control means that the ventilation unit can take into account the occupancy and the user preferences per room/workplace, using local CO_2 and humidity sensors and local manual override options. These features can be realized with system D (centralized systems) and C, e.g. by using VAV terminal boxes per room and local sensors/actuators that communicate with the CPU, but it is a solution that comes at a cost-penalty and requires well-trained staff. On the performance side, system E has the advantage of very little –if any- ductwork, which usually is easy to clean. A disadvantage of system E versus system D is that it is usually not suitable for use in tall, single shell office buildings (>6 to 8 floors), which might experience a high wind load on the upper floors. For buildings with a double façade, which may be a good choice for other reasons as well, there is no problem; alternatively, some central ductwork may be required.

The diagram below gives a qualitative impression of the primary energy losses associated with the currently most used systems A, C and D/E.

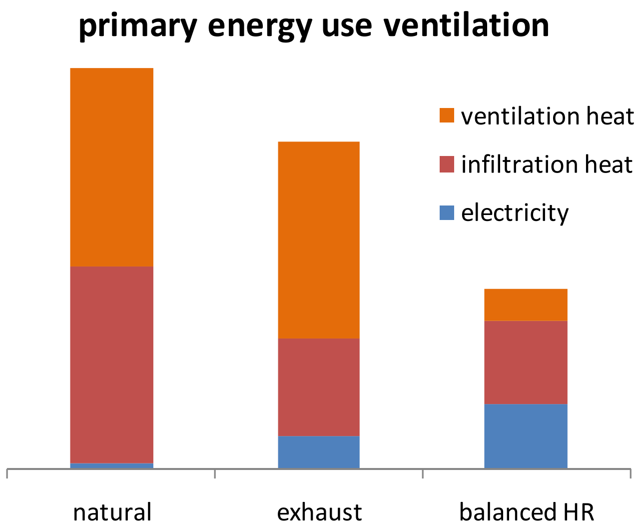

Figure 3 - 2. Primary energy use ventilation, qualitative estimate

Please note that these are average efficiencies. Within each category the best practice in terms of controls and ductwork can give a >30% improvement. This is to be further elaborated in the Technical Analysis (Task 4/6).

2.1.2 Ventilation requirements

The task 1 report gives the ventilation requirements according to the European standards. The IAQ-level III corresponds with CO_2-level of ca. <1200 ppm (800 ppm higher than the outdoor CO_2-level)

Table 3- 1 . EN 15251:2007. IAQ category III (IDA3), Low-polluting building. Examples of recommended air flow for ventilation per m² or m³ heated floor area**

Type of building or space	floor area in **m²/pp**	for occupancy **l/s/m²**	for building **l/s/m²**	TOTAL **l/s/m²**	TOTAL **m³/h/m²**	floor height*	TOTAL* **m³/h/m³**
Single office	10	0,4	0,4	0,8	2,88	3,60	0,80
Land-scaped office	15	0,3	0,4	0,7	2,52	3,60	0,70
Conference room	2	2	0,4	2,4	8,64	4,20	2,06
Auditorium	0,75	6	0,4	6,4	23,04	15,00	1,54
Restaurant	1,5	2,8	0,4	3,2	11,52	4,20	2,74
Class room	2	2	0,4	2,4	8,64	4,20	2,06
Kindergarten	2	2,4	0,4	2,8	10,08	4,20	2,40
Department store	7	0,9	0,8	1,7	6,12	6,00	1,02

*= floor height and therefore recommended air flow in m³/h/m³ are VHK estimates

**= ventilation excluding infiltration. For new buildings the standard infiltration is around 0,25 m³/m³.h.

IDA3 is the CO_2-level most commonly used in energy performance legislation for non-residential buildings. IDA2 can be found in Scandinavian recommendations for certain building-types (e.g. schools). IDA1 is found in some hospitals and laboratories. The required air flow in operating theatres and cleanrooms, which are considered process ventilation and outside the scope, are far beyond the IDA1 level in terms of hourly air-flow (10-20 m³/m³) and for the requirements of air purifications are a class of their own. At the lower end, there are several applications in heavy industries and mining, where the IDA3 level cannot be reached and –with specific rules for temporary exposure—workers have to settle for IDA4 or worse.

The IDA-3 level is given for 'low-polluting' buildings without smokers. It should be mentioned that many ventilation systems in the stock are designed for occupancy by smokers. Furthermore, in countries where synthetic carpets and curtains dominate the residential and non-residential interior design (e.g. UK), the ventilation rates may be higher because the building no longer qualifies as 'low polluting'.

For (multi-family) dwellings the minimum recommended ventilation flow rate is 0,9 l/s/m² (ca. 1 m³/m³).

2.1.3 Drivers and barriers

Most Europeans, apart from those suffering respiratory diseases, will only think of 'ventilation' in case of bad smells, drafts or steamed up mirrors, usually remedied by opening the windows. In very new houses, people will be aware of excess humidity, because the cement is still drying out. But after a few months that problem is over and the focus is just on the kitchen, bathroom and toilet areas, where some may or may not use a small extraction fan to get rid of smells and vapour.

Few are aware to have 'ventilation', i.e. that their residence or work-place is designed to guarantee a minimum amount of air change for health, comfort and building protection. For most, the drafts from consciously applied openings below or inside doors and windows are just a nuisance.

The lack of awareness on the necessity of ventilation with the general public was clearly demonstrated in the 1980s and 1990s when several authorities induced people to close all these drafty 'holes' for reasons of energy saving but without stressing the need to take appropriate measures to still guarantee a proper air change. The resulting bad indoor climates at least prompted the authorities to take a more serious look at 'ventilation', spurring the introduction of heat recovery solutions very often at the level of mandatory building regulations.

The awareness of ventilation, the user-habits and the policy in the field of 'ventilation' varies very much from the North to the South of the European Union.

The above attitude applies very much to the middle of Europe, with countries like the Netherlands, Germany, the UK and the Northern part of France, where heat recovery products have been on offer for the last 15 years and have become mandatory in building regulations for new buildings over the last decade. But with the slump in the construction industry, market penetration is growing only very slowly and ownership of heat recovery systems (HRS) in the residential area is estimated at 1-2%.

In larger commercial buildings, where heat recovery units are an addition to the modular air-handling units, the market penetration of heat recovery is growing very rapidly, but still the overall penetration per m² gross floor area may not be more than 5-10%.

For instance, a 2003 Belgian survey of office buildings, relatively 'easy' to tackle with central ventilation, showed that only about 50% of the buildings had a balanced mechanical ventilation. Less than 20% had an exhaust or supply ventilation and 31% had no mechanical ventilation at all.

In the year 2000, the Finance minister of the German district ('Land') of Baden-Würtemberg (approx. 10 mln. inhabitants) reported that 35% of its university buildings and only 15% of its other 6000 public administration buildings had HVAC-installations. In other words, 65% of university building and 85% of public administration buildings had no centralized ventilation at all. Remarkably, the Green Party that prompted the Finance minister to release these figures was only concerned over the electricity costs of the fans and did not mention the much more important issue of abating the ventilation heating losses at all.

In 2009, German air-handling-unit manufacturers reported that around 40% of total units sold (50% of balanced units) featured heat recovery units, whereas in 2005 it was only 23%. Still, with new construction being slow and the potential for retrofitting existing buildings being low, this still doesn't amount to much. In total it is estimated that market penetration in mid Europe is around 10%.

In Scandinavia, heat recovery ventilation was made (semi-) mandatory for new buildings – residential and non-residential—already in the early 1980s and the market penetration in the building stock is relatively high, i.e. estimated at over 50% of the commercial and multi-family buildings. Still, Sweden and Finland constitute only 3% of the EU building stock.

In Southern-Europe, heat recovery ventilation is practically unknown in multi-family buildings, unless in the alpine areas. For commercial buildings it may be used as a means to cut down on the cooling (air-conditioning) costs in summer, but exact numbers are not known.

Barriers

The major barriers for making heat recovery ventilation more attractive are

1. The capital investment is still the main barrier. A 2009 Taylor Wessing report confirms that this is true for any investment in 'sustainability' for non-residential buildings and heat recovery ventilation is no exception. The Taylor Wessing report mentions the "vicious circle of blame". This is a self-perpetuating cycle, when:
   a) end users claim that not enough sustainable buildings are available;

b) designers and constructors say that developers don't ask for sustainable buildings;
c) developers assert investors won't pay for them; and
d) investors claim they would respond, if only there was demand from end users.

2. Lack of awareness on both health and energy aspects of ventilation. Few people are aware that one-third or even half of their space heating bill is due to 'ventilation'. Still fewer people are aware that the ventilation heating energy losses can be tackled with heat recovery systems.

3. Lack of knowledge. Even if all decision-makers were aware of the need for sufficient ventilation and the ventilation energy saving potential, it is very difficult to find advisors and installers that are well-informed and properly trained. This does not only concern small electrical installers being unfamiliar with heat recovery ventilation. For many of big installation firms dealing with larger commercial buildings, ventilation mainly considered as is part of air-conditioning, i.e. cooling and air heating. Design calculations and lay-outs that provide best price/quality for 'ventilation only' are therefore rare. This is especially true for retrofitting existing buildings where there are significant opportunities for heat recovery ventilation linked with renovation of the facades or even simple retrofitting with the latest decentralized heat recovery ventilation products.

4. Asymmetric economical information. Consumers are not able to consider the cost-efficiency of the use of heat recovery ventilation and the full life-cycle costs. The purchase price is well visible and is considerably higher for heat recovery ventilation. On the other hand, information on running costs/cost savings is not explicit and can be obtained only with difficulties.

5. Split responsibilities and budgets. Especially in multi-family buildings and commercial buildings the builders, installers and users of ventilation systems are not the same entities and do not have the same budgetary priorities. Builders and developers want to cut down on building costs. Because the ventilation systems is one of the last items to be installed/purchased and usually a low-interest product with future buyers/users of the building, it is a perfect item for cost saving. Buyers of the building and building authorities increasingly value low energy buildings, but commercially it is often more attractive to boost some sort of 'high visibility' renewable installation (solar, heat pump) than highlighting a heat recovery ventilation system. The users of the buildings have to pay the energy bill, but very often have no say (and expertise) in how the buildings' installations should be improved.

6. The 'packaging' with air-conditioning. For many decision makers on the equipment in buildings, centralised ventilation is still very much linked to air-conditioning, i.e. space cooling. And given a fixed budget, the price of an installation with heat recovery may become prohibitively high. In many instances, space cooling is seen as a big bonus (e.g. 4-star hotels) or even a necessity (labour conditions). On the other hand, heat recovery ventilation –given the lack of awareness-- is just an inconspicuous part of the building installation to help the building meet the minimum energy performance requirements. Few manufacturers of air-handling-units see heat recovery ventilation as a separate product in its own right, as a minimum necessity for every building, cooled or not. For instance, Kaup mentions that despite the fact that the German energy saving act EnEV makes heat recovery ventilation one of the cheapest options to meet the overall requirements, still 60% of AHU's is sold without heat recovery.

7. The 'sick building' syndrome. Especially because of older air-conditioning systems with a significant degree of re-circulation and dust built-up in the venting ducts, many centralized ducted systems still have a bad reputation of spreading germs from co-workers and bacteria. If, as is often the case, the heat recovery ventilation is combined with a fair amount of

recirculation heating or cooling air, also the commercial success of heat recovery ventilation may suffer.

8. Polluted ductworks. Heat recovery ventilation requires balanced mechanical ventilation. And balanced mechanical ventilation means that there are supply side ducts that may become polluted with dust and fungi on the long run. There is no risk of spreading germs from co-workers, but polluted ductwork has led to several health problems especially in the residential sector (e.g. in Amersfoort). The problem can almost always be traced back to a faulty installation (see paragraph on ‘Barriers, Lack of knowledge’) but it is giving balanced ventilation a bad name. This problem is aggravated by the fact that –in case of a faulty installation-- cleaning of the supply ducts is very difficult. Currently there is ductwork that is easier to clean, the filters are better and there are alternative (decentralized, not ducted) heat recovery ventilation solutions. However, awareness amongst the general public is low.

9. Noise. Another problem, again mostly due to faulty installation work, is the noise which is transmitted from the central unit to living rooms and bath rooms. Solutions are the use of adequate noise dampers in the ductwork; lower noise production by the central unit, etc. but especially in the residential sector a part of the population will be sensitive to any type of extra noise.

Drivers

1. The main drivers for heat recovery ventilation are national building regulations and specifically minimum energy performance requirements for (new or renovated) buildings. This is certainly the case in Sweden and Finland, but also the holistic approach in the Benelux, Germany, the UK and France makes heat recovery ventilation economically one of the best options to meet regulatory demands. However, as mentioned under ‘barriers’ the regulations relate only to new buildings and are successful in only half of the cases. In Southern and Eastern Europe the regulations for heat recovery are inexistent or (e.g. Italy) show significant loopholes.

2. Regulations on health and labour conditions play an important role, not so much in promoting heat recovery ventilation but at least in promoting mechanical ventilation systems to stay below the maximum pollutant levels (including CO_2). And in some cases the demand on ambient temperature necessitates air cooling, i.e. the need of balanced mechanical ventilation systems, even in areas and instances like the Netherlands and Belgium where indoor temperatures would exceed the maximum temperature limits only 4-5 days a year. But there is no denying that once a balanced centralized air handling unit is installed, the step towards heat recovery is a simple and relatively cheap upgrade.

3. Sufferers of respiratory health problems. As mentioned in the previous paragraph, the general public and the professional builders are not the main drivers (see barriers), with the exception of some special interest groups like sufferers from asthma, hay fever and other respiratory health problems. These special interest groups do not have an interest in heat recovery as such, but they require high standards of air purification/filtering which are difficult to achieve without balanced mechanical ventilation units. The heat recovery comes in only as an extra. With the on-going rise of number of sufferers from respiratory health problems it also becomes more and more likely that in any multi-family building or commercial building they are amongst the inhabitants/ co-workers.

4. Another special interest that is driving balanced mechanical ventilation are health concerns of school-children. Schools represent a special ventilation problem because of the high density of people in a classroom requiring a high air flow rate. In these sorts of situations, exhaust ventilation systems (air coming in through openings in the façade and extracted by a central fans) lead to uncomfortable drafts, which in turn induces personnel and pupils to close the façade-openings as much as possible. As a result the actual ventilation is insufficient, the CO_2-

levels increase (far) above the maximum allowed and children start to suffer from headaches and other health problems, concentration loss and other symptoms of CO_2 intoxication. The solution is heat recovery balanced mechanical ventilation, which deals both with the comfort problem (because incoming air is preheated by outlet air) and the ventilation requirement.

5. Homes for the elderly and handicapped represent a significant interest group that is very susceptible to cold drafts. Heat recovery ventilation provides pre-heated incoming air and is therefore a good solution to the problem.

6. Early adopters, not captured under any of the previous groups, which undertake to have heat recovery ventilation installed for energy saving, for economical and/or environmental reasons are a driver for market take-up.

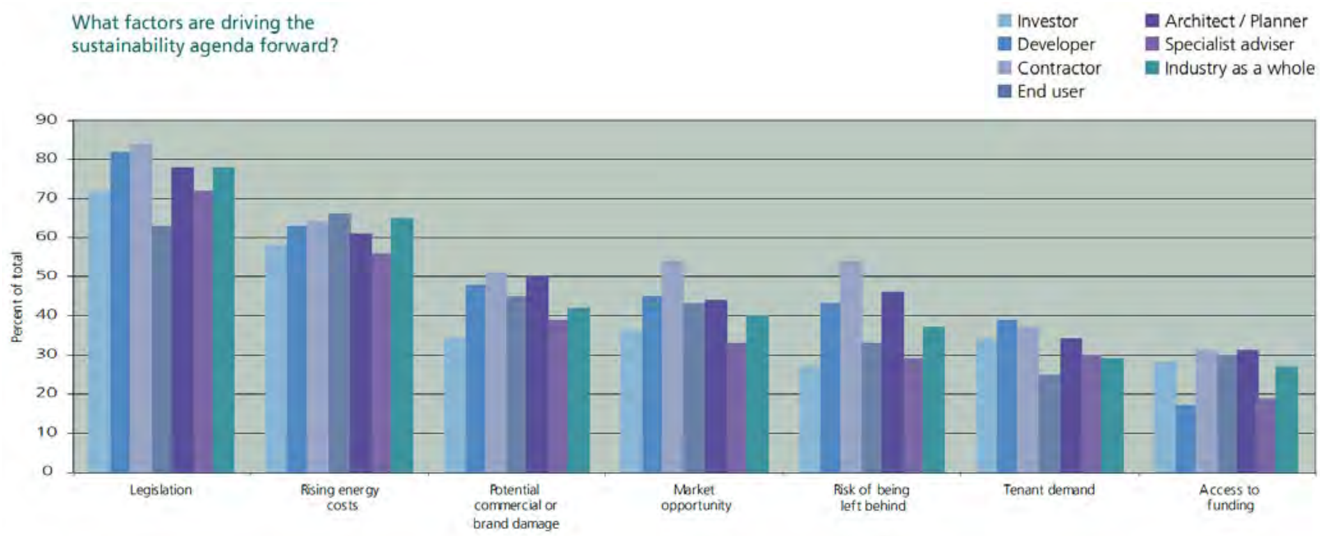

Figure 3 - 3. ***The major driver is legislation*****. From: Taylor-Wessing, "Behind the green façade", 2009. Survey amongst 800 professionals in the UK construction industry of non-residential buildings.**

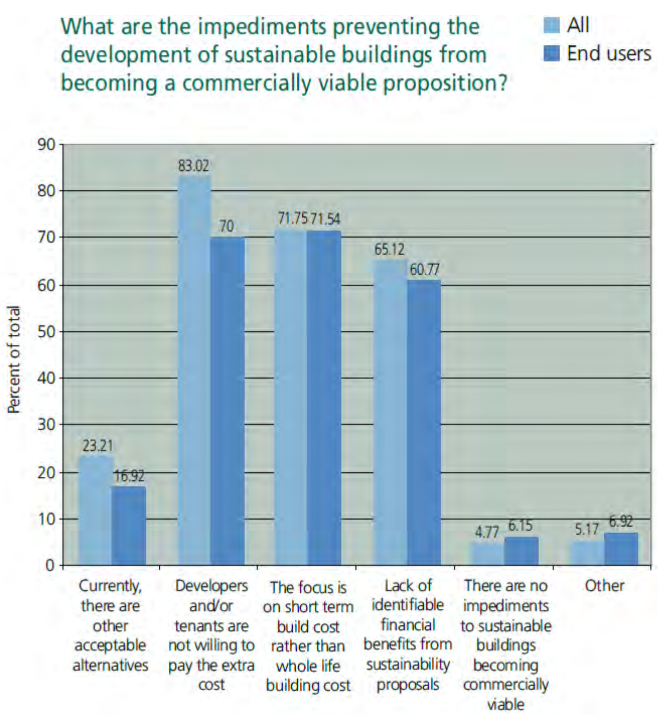

Figure 3 - 4. ***The main barrier is (investment) costs***

From: Taylor-Wessing, "Behind the green façade", 2009. Survey amongst 800 professionals in the UK construction industry of non-residential buildings.

The report also quotes the "vicious circle of blame". That is a self-perpetuating cycle, when:
a) end users claim that not enough sustainable buildings are available;
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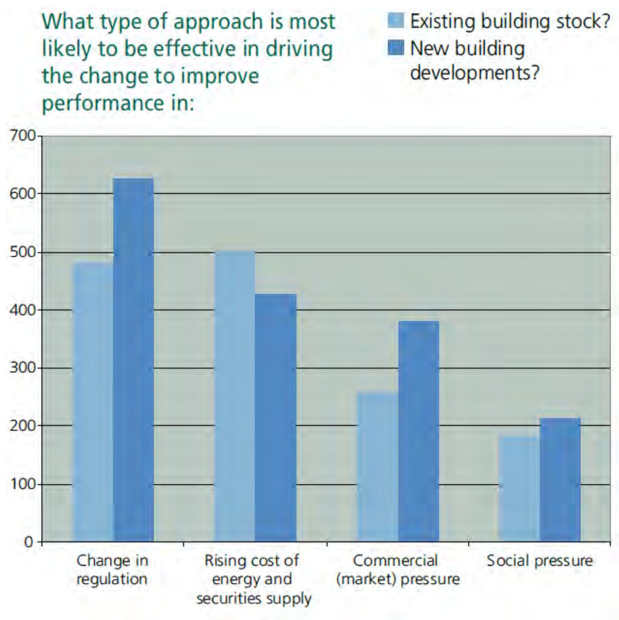

Figure 3 - 5. ***For existing building stock, rising energy costs may be the major driver.***

From: Taylor-Wessing, "Behind the green façade", 2009.

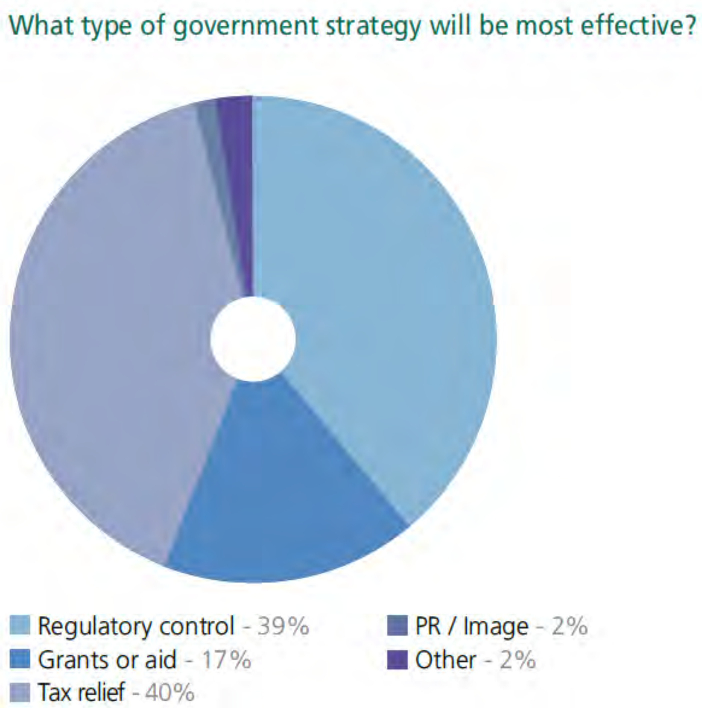

Figure 3 - 6. ***Government regulatory control and tax relief believed to be most effective***

From: Taylor-Wessing, "Behind the green façade", 2009.

2.2 Ventilation estimates by general parameters

2.2.1 Introduction

If, as is the case with ventilation systems, little quantitative data is available, it is customary –before trying to assess the status per sector—to make some dome estimates that at least will indicate an order of magnitude that can be expected. This 'top-down' approach is very useful to avoid that the more detailed estimates from a 'bottom-up' approach in the Chapters 3.1 to 3.4 gets out of hand.

To make these estimates a number of general parameters are used, for which a 'best case' and 'worst case' estimate is attempted:

- By number of persons that need ventilation
- By number of buildings and some general building parameters
- By type of building and specific floor area or volume.
- By estimating ventilation and infiltration losses as a fraction of the total heat loss of a building

2.2.2 By number of persons that need ventilation

For an IDA-3 level indoor air quality EN 13779 and EN 15215 recommend ventilation of 4 litres per second per person (4 l/s/p). Adding 25-30 % for infiltration/ventilation of the building, this results in approximately 20 m^3/h.

In 2009 the EU-27 had a workforce of 248 mln. people. Taking into account unemployment and a number of part-time workers, it is estimated that the full-time equivalent (40h/week) of 200 mln. workers remains. Of these, there will be an estimated 20% working outdoors or at home, which brings the total to 160 mln. people working indoors.

On the other hand, also the outdoor workers will have some need for indoor space (at least meeting rooms) and of course there is a considerable amount of people that –voluntarily or not—spends part or all of its day in the non-residential sector: school-children and students (93 mln.), prisoners (0,6 mln.), people in homes for the elderly and handicapped, people in hospital (0,2 mln.), hotels (10 mln. beds) and people using transportation buildings (train, subway stations, airport terminals, etc.).

Therefore, an overall estimate of 250 mln. people in the non-residential buildings seems like a fair estimate. At 40h/week, 48 weeks (plus some overtime) each will use a non-residential building for at least 2000 hours per year. If they get exactly a ventilation & infiltration rate of 20 m^3/h during these hours, the total annual ventilation requirement is 2000 h x 250 mln. people x 20 m^3/h = 10.000.000 mln. m^3 = 10 x 10^{12} m^3. This is the 'best case'.

The much more realistic 'worst case' is that the workplace is often heated when they are not there. For instance, for an air-handling unit it is not unusual to ventilate 6 days a week with half of the time at half capacity and another half at full capacity (i.e. this means 18 full-time hours per day). During 52 weeks this makes a total of ca. 5600 hours per year. A large part of the people will be working with suboptimal ventilation (natural ventilation), so their hourly air-flow will be not 1,05 but is estimated modestly at 15% more: 23 m^3/h. The total annual ventilation requirement in non-residential buildings is thus 5600 h x 250 mln. people x 23 m^3/h = 32.200.000 mln. m^3= 32 x 10^{12} m^3.

This is a –fairly realistic—worst case estimate. The conclusion is that the annual ventilation air moving through EU non-residential buildings should be between 10 and 32 x 10 Tm³ (T=Tera= 10^{12}).

Note that this is an annual figure. Only during the heating season (5000 h/yr, 57% of the year) the displaced air was heated by a space heating system.

For the ventilation of multi-family dwellings the same method was followed.

The EU-27 has close to 500 mln. inhabitants. In the best case –at 20 m³/h/p and 8000 h/year[1]— would require 80 Tm³ of fresh air per year. At work or school they would get already 10 Tm³, which means that 70 Tm³ of ventilation takes place at home. Around 220 mln. people (44%) of people are living in multi-family dwellings, which means that around 31 Tm³ of fresh air per year is needed for multi-family buildings.

In the worst case, the EU residential sector would need 8760h x 500 mln. people x 23 m³/h = 100.740.000 mln. m³ = 100 Tm³ of fresh air per year. This would come on top of the worst case non-residential ventilation of 32 Tm³. So the total is 132 Tm³ per year.

People in multi-family buildings would take up 44% of 100 Tm³, i.e. 44 Tm³. Together with the worst-case non-residential ventilation this means 76 Tm³ are in the scope of the underlying Lot 6 report. And an almost equal share of 66 Tm³ would be in the scope of DG ENER Lot 10.

2.2.3 By type of building and specific floor area or volume.

Statistics of new building permits for several countries (DE, NO, FR, SV, UK), show at least the subdivision in building type that was used on the application: Offices, shops, schools, etc.. Especially in the non-residential sector this can be helpful to determine whether the detailed data are roughly correct.

On the other hand, the building permit statistics should also be used with care because e.g. 'offices' can be found in most any non-residential sector and the building permits may relate to extensions or renovations and not a complete building.

The diagrams below show an estimate of 4,74 mln. heated buildings in the tertiary sector and 2,67 mln. heated buildings in the primary and secondary sector. For multi-family buildings (see Chapter 3.1) the estimate is 12,7 mln. heated buildings. In total around 20,11 mln. buildings are possibly in the scope of measures for Lot 6.

[1] Assumed 10% outdoors or in transit

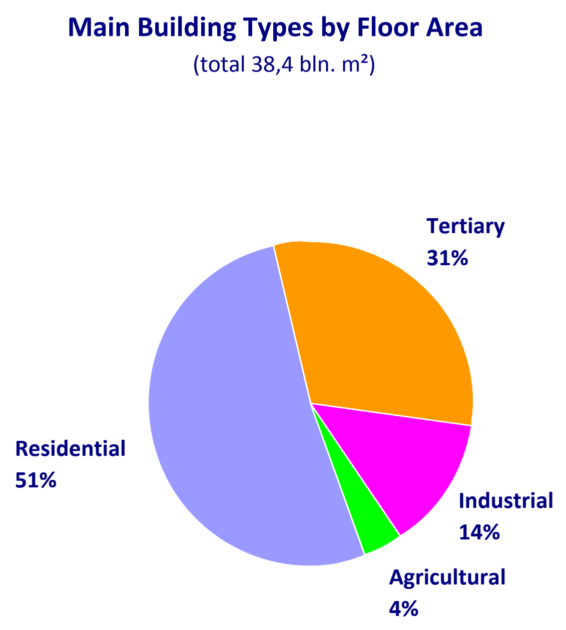

Figure 3 - 7. Main building types by floor area

Simplified approach: One- or two dwelling units, 110 m²/dwelling, Multi-family 65 m²/dwelling+125 m²/shop, tertiary 2.500 m²/building, Industrial 2.500 m²/building, agricultural greenhouses 5.800 m²/building.

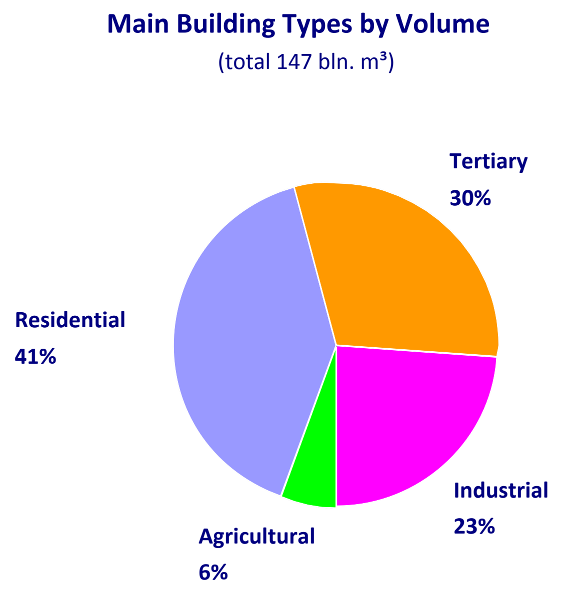

Figure 3 - 8. Main building types by volume

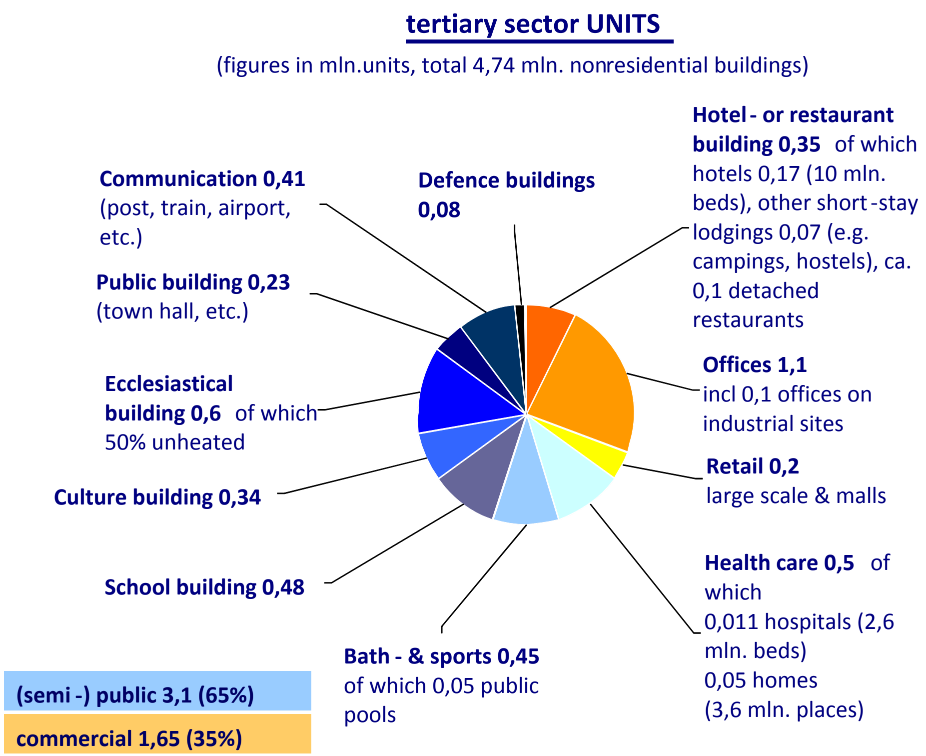

Figure 3 - 9. No. of tertiary sector buildings (VHK, summary of DG TREN, Lot 1, 2007, Task 3 report)

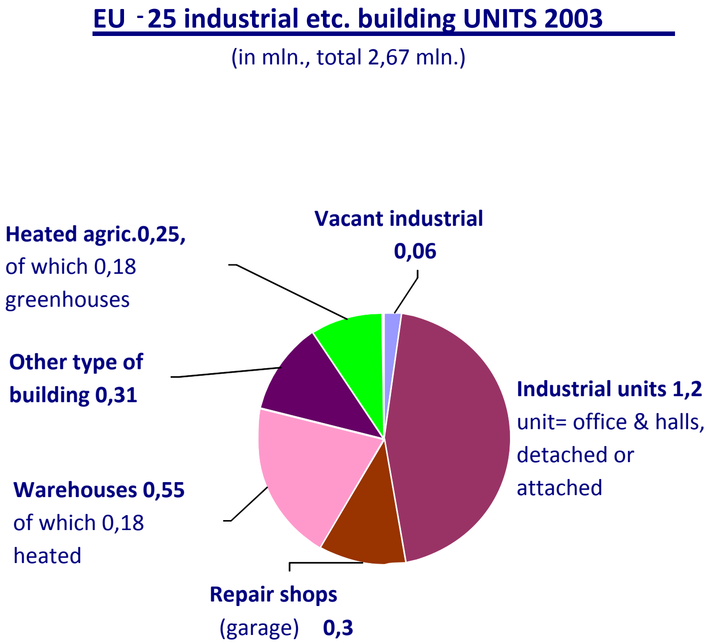

Figure 3 - 10. No. of industrial sector buildings (VHK, summary of DG TREN, Lot 1, 2007, Task 3 report)

2.2.4 By estimating ventilation losses as a fraction of the total heat loss

Ventilation and infiltration losses are around one-third (<1995) to half of the total heat losses (transmission + ventilation). On average they should represent around 35% of the total and this is also the suggestion of e.g. the ECCP statistics.

With data from the preparatory study for boilers (DG ENER, Lot 1) the total heat requirement of buildings can be calculated. That started from a total of 110 bln. m³ of heated volume at an average temperature of 18 °C.

The average European heating season is around 7 months (ca. 5.000 hours), during which time the average outdoor temperature is on average 6,5 °C. In other words, there is a temperature difference between indoor and outdoor temperature of 11,5 °C. Around 2,5 °C out of this temperature difference is supplied by solar gains (sun coming through windows) and internal heat production of appliances and people. This leaves 9 °C to be supplied by an active heating system.

Lot 1 sets the average insulation value (U-value) of an average building is set at 1,2 W/K.m² and the average AV ratio is estimated at 0,5 m²/m³. For the average ventilation & infiltration rate Lot 1 assumes 0,75 m³/m³ (0,6 ventilation + 0,15 infiltration). The specific heat of air is 0,33 W/m³.K. The heating season is 5.000 hrs. per year. The total heat load can thus be estimated as follows:

$5.000h * 9K * 110 \text{ bln. } m^3 * \{ 0,75 \, m^3/m^3 * 0,33 \, W/m^3.K + 0,5 \, m^2/m^3 * 1,2 \, W/K.m^2 \} = 4,19 \times 10^{15} \, Wh$

This means that the net heat load is 4.195 TWh with the proportion 1:2 between ventilation and transmission losses. The ventilation of heated buildings during the heating season would thus be 5.000 x 110 bln. x 0,75 m³/m³= 412.500 bln. m³ (550 Tm³). The ventilation during the whole year (8.760 h) would then be 723 Tm³.

This is more than **a factor 5 higher** than the worst case that was estimated on the basis of the personal ventilation requirements. A small part can be explained by the ventilation need of heated goods. But for sure it means that

a) a considerable amount of over-ventilation is taking place, and

b) it is vital to make the estimate of the building volume more robust, before drawing any final conclusions on the huge suspected saving potential is done.

With respect to the latter: In Europe most of space heating is done by a central heating boiler and the total systems efficiency, including all losses, is not more than 60% (2005) to 65% (2009).

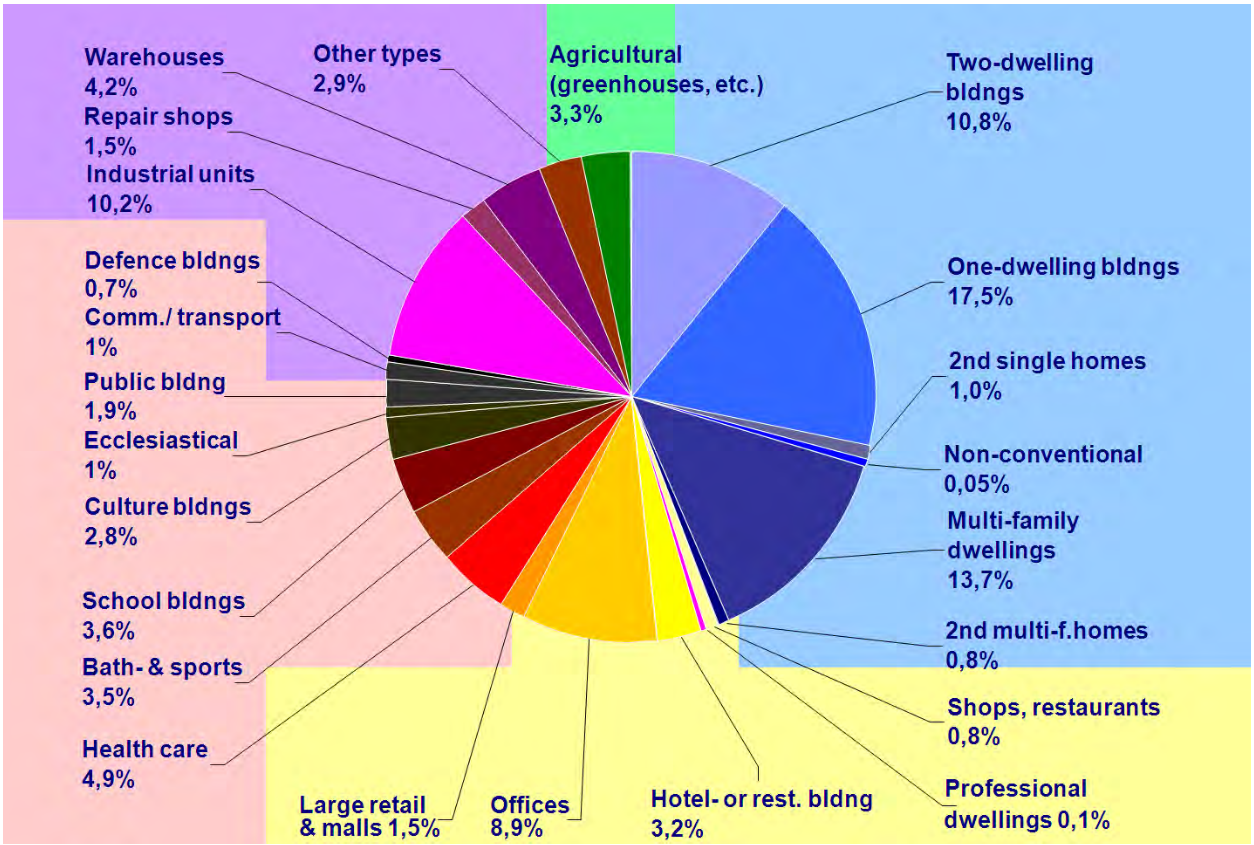

Figure 3 - 11. Split-up of 110 bln. m³ heated volume equivalent at 18°C indoor temperature in the EU (VHK, summary of DG TREN, Lot 1, 2007, Task 3 report)

2.2.5 Examples

For Finland and Belgium sources were found that indicated the share of natural ventilation in certain sectors. These are only two countries out of 27 and the Belgian data only refers to the office sector, but it is information that can serve as a confirmation of a more systematic data search.

In that sense, the Finnish data are rather surprising. Finland is generally seen as one of the frontrunners in heat recovery ventilation and at least a decade ahead of the rest of Europe in this respect. However, the market penetration data shows that even in Finland (estimated 2002-2003) the share of HR ventilation was as low as 5% in existing individual housing and for new houses 25%. It was negligible in existing multi-family buildings and new buildings the share is 2%. Only in existing non-residential buildings the share was 30% and for new buildings of this type 70%.

Another interesting figure from this table relates to the 5-10% share of buildings with natural ventilation. For 2010 this is deemed unavoidable, even for new buildings. It is assumed that this is due to infra-structural problems.

Table 3- 2. Data for the Finnish ventilation market (Statistics Finland, VTT Building Technology databases, ca. 2003)

		Maximum potential deployment by 2010	Current deployment level (% of stock)
Residential new built	**single-family housing**		
	natural ventilation	5%	35%
	mechanical: exhaust	95%	40%
	mechanical: balanced HR		25%
	multifamily housing		
	natural ventilation		10%
	mechanical: exhaust	100%	88%
	mechanical: balanced HR		2%
Residential existing	**single-family housing**		
	natural ventilation	75-80%	85%
	mechanical: exhaust	20-25%	10%
	mechanical: balanced HR		5%
	multifamily housing		
	natural ventilation	30%	40%
	mechanical: exhaust	70%	60%
	mechanical: balanced HR		-
Non-residential new built	natural ventilation	5%	5%
	mechanical: exhaust	95%	25%
	mechanical: balanced HR		70%
Non-residential existing stock	natural ventilation	5-10%	15%
	mechanical: exhaust	90-95%	55%
	mechanical: balanced HR		30%

In Belgium there has been a survey in 2003 on ventilation in office buildings (Kantoor 2003). The result was, that 31% used natural ventilation, 19% had either a supply of exhaust system and 50% had a balanced ventilation system of which an unknown share with heat recovery. This is surprising, because it is easily assumed that if there is one type of building where it is easy to realize balanced ventilation it is office buildings. And yet, only in half the cases balanced ventilation (probably in combination with air cooling) was realized.

In France the following penetration data were given.

Ventilation systems in residential buildings stock (source: AIR .H, 2007)

	Multifamily buildings (13.1 millions dwellings)	One-family houses (17.3 millions)	Total dwellings stock (30.4 millions)
No ventilation system	9 %	14 %	12 %
Room by room ventilation	34 %	36 %	35 %
Overall ventilation	57 %	50 %	53 %
Overall natural	*17.6 %*	*22 %*	*20 %*
Overall mechanical	*39.5 %*	*28 %*	*33 %*

Market share for new residential buildings 2000-2004 (source: AIR .H, 2007)

	Multifamily buildings (653 000 dwellings)	One-family houses (1.04 millions)
No ventilation system		1 %
Room by room natural		4 %
Room by room mechanical		3 %
Overall natural	3 %	1 %
Overall mechanical	98 %	91 %
Exhaust only without demand control of air flow rates	*53 %*	*54 %*
Exhaust only with demand control of air flow rates	*44 %*	*36 %*
Balanced systems	*1 %*	*2 %*

Ventilation systems in commercial buildings stock (source: AIR .H, 2007)

	Offices	Shops	Education buildings	Health care buildings	Leisure buildings	Hotels	Total
Stock (thousands square meters)	3 026	3 732	1 747	1 700	1 666	821	12 692
No ventilation system	50 %	40 %	60 %		10 %	5 %	34 %
Overall natural						9 %	1 %
Room by room mechanical	10 %	10 %		15 %	20 %		10 %
Overall mechanical	20 %		39 %	50 %		85 %	22 %
Exhaust only without demand control of air flow rates	*9 %*		*20 %*	*25 %*		*75 %*	*13 %*
Exhaust only with demand control of air flow rates	*1 %*						*0.2 %*
Balanced systems	*10 %*		*19 %*	*25 %*		*10 %*	*9 %*
Air handling unit	20 %	50 %	1 %	35 %	70 %	1 %	34 %

Table 3- 3 *.* Ventilation market France (source AIR. H. 2007, in F. Durier, 'Trends in the French building ventilation market and drivers for change', AIVC, VIP 19, May 2008).

3 Subtask 3.2 User requirements for the use phase

3.1 Ventilation in multi-family residential sector

The diagrams below give an overview of the most important characteristics. They were calculated from data in the DG ENER Lot 1 preparatory study. The reference year for the data in the diagrams is 2005 and the scope is EU-25. For the EU-27 a multiplier 1,06 will be used at a later stage. Note that there may be small deviations between the figures in the diagrams, due to definition problems.

The analysis for the EU-25 (2005) gives the following results:

106 mln. multi-family dwellings (44% of the residential sector), of which ca. 80% (84 mln.) are occupied, used permanently and equipped with a heating system (see fig. 16);

12,8 mln. multi-family buildings with a total floor area of ca. 9,1 bln. m², including dwellings at 65 m²/unit and a multiplier 1,25 for entrance, stairs, elevators, service area, indoor parking in a part of city apartments;

At an average floor height of 3 m (high share of older buildings), the built volume will be around 28 bln. m³, of this it is assumed that only the permanently occupied dwellings (heated and ventilated) are in the scope, representing 5,5 bln. m² and 16,4 bln. m³;

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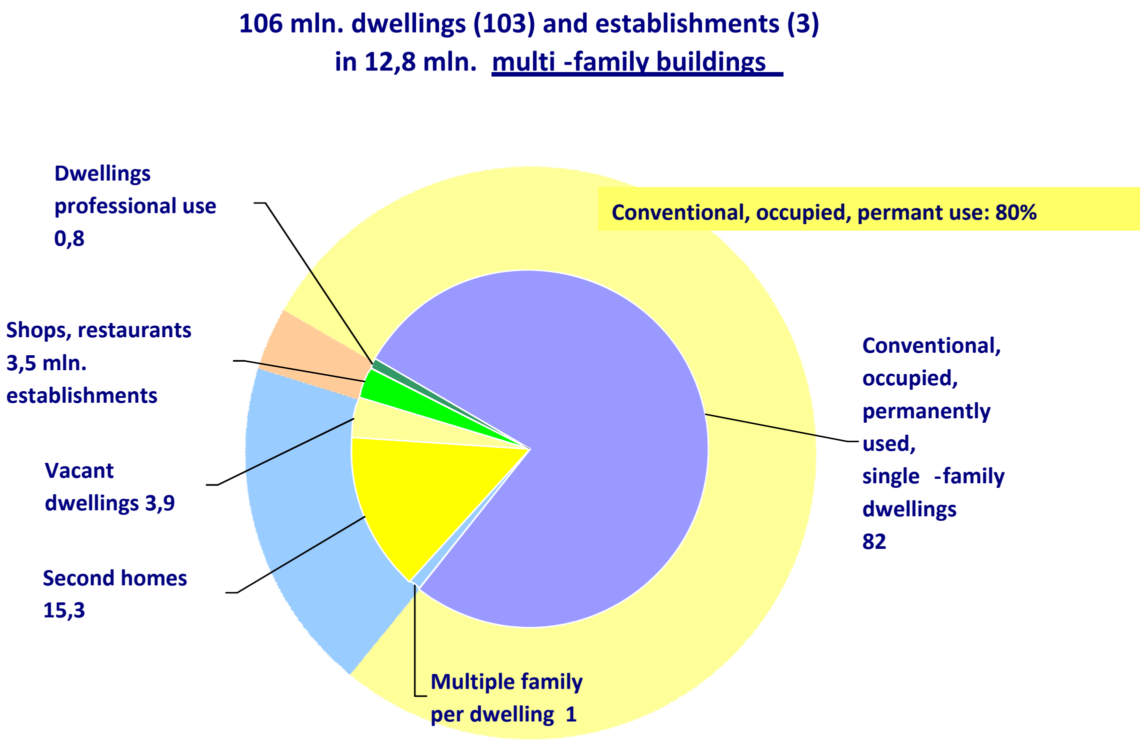

Figure 3 - 12. No. of dwellings in multi-family dwellings

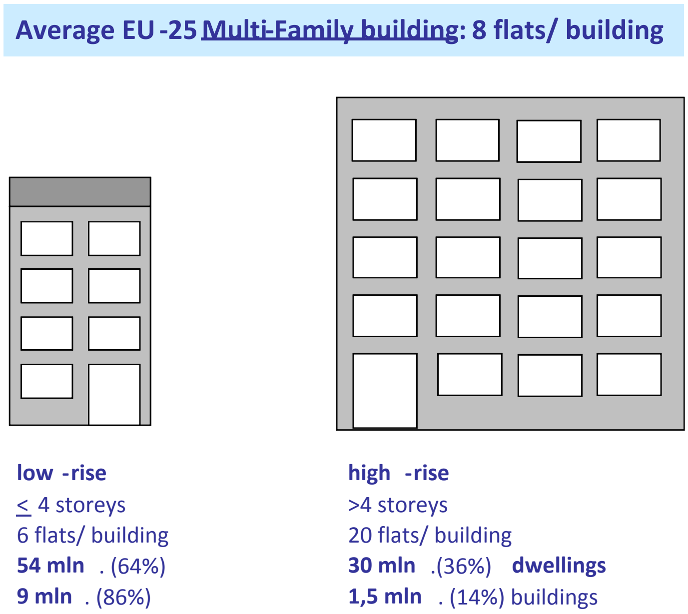

Figure 3 - 13. Share of low- and high rise buildings EU-25

64% of low-rise apartments (54 mln.; 10,5 bln. m³) are in 9 mln. buildings with 4 layers or less, i.e. typically city apartments with side-walls attached to a neighbouring apartment. The AV ratio of the building will be 0,55 m²/m³. Per dwelling the ground- and top apartments will have a significantly higher AV-ratio (ca. 0,7) and the mid-apartments a lower AV-ratio (ca. 0,3).

70% of these low-rise apartments use natural ventilation (37,8 mln. dwellings; 7,35 bln. m³), 28% are using central mechanical exhaust ventilation (15,1 mln; 3 bln. m³) and 2% luxury apartments (1,1 mln.; 0,2 bln. m³) with a balanced mechanical ventilation system, possibly with cooling. Of this latter group half may have heat recovery (1%, 0,1 bln. m³).

36% of apartments (30 mln. dwelling; 5,9 bln. m³) are in 1,4 mln. buildings with 5 layers or more, i.e. typically peripheral flats. The AV ratio of the building will be 0,65 m²/m³. Per dwelling the corner, ground- and top apartments will have a significantly higher AV-ratio (ca. 0,7) and the mid-apartments a lower AV-ratio (ca. 0,3).

50% of these high-rise apartments use natural ventilation, with passive stacks for the wet rooms (15 mln.; 2,9 bln. m³) and 48% are using central mechanical exhaust ventilation, largely from retrofitting the passive stacks (14,4 mln.; 2,9 bln. m³). Again 2% luxury apartments (0,6 mln; 0,1 bln. m³) may have a balanced mechanical ventilation system, possibly with cooling. Of this latter group half may have heat recovery (0,3 mln.; 0,05 bln. m³).

To translate the above data into numbers of active installed ventilation equipment it is assumed that exhaust systems for the low-rise apartment buildings work vertically in a stack of 4 apartments with two exhaust openings (1 kitchen, 1 bathroom) per apartment. In practice this means 1 exhaust fan for every 2 dwellings. For balanced systems it means 1 balanced ventilation unit per 4 dwellings. For the high-rise buildings the stack is twice as high.

In total 52,8 mln. apartments are using natural ventilation, possibly (say 10%, 5 mln. units) with the help of a simple local extraction fan. The apartments with mechanical exhaust systems will use around 11 mln. rooftop/boxed fans, i.e. 7,6 mln. for low-rise and 3,6 mln. (with twice the average capacity) for high-rise buildings. Finally, around 0,35 mln. balanced ventilation units (AHU or CHRV) will be installed in multi-family buildings. Note that these are the products that are permanently operational. If the total number of apartments is considered the numbers should be increased by 33%.

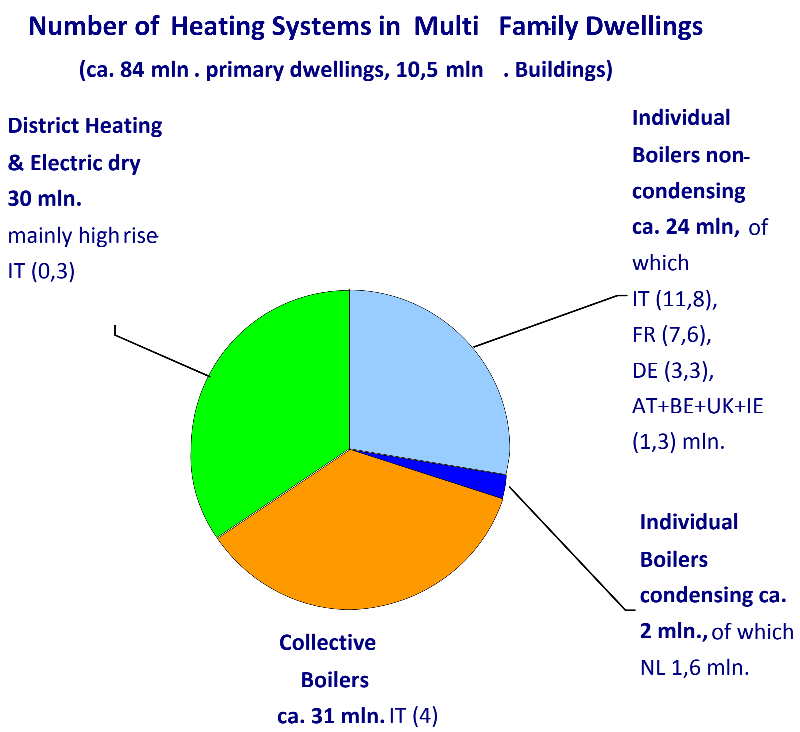

Figure 3 - 14. No. of heating systems in multi-family dwellings (VHK, summary of DG TREN, Lot 1, 2007, Task 3 report)

3.2 Ventilation in (semi-) public sector buildings

3.2.1 Introduction

One of the sectors that should be a frontrunner in energy saving is the public sector. However, in the case of ventilation, let alone well controlled heat recovery ventilation, the government appears to be lagging behind. It is estimated that EU-wide only about 35% of schools (in terms of gross floor area) uses some sort of central mechanical ventilation. For other government buildings the market penetration is estimated to be no more than 15%. Overall market penetration of centralized ventilation in this sector is estimated at 20%. The other 80% uses natural ventilation (infiltration, windows).

Of this 20%, no more than 20-25% is believed to employ heat recovery modules. So the overall market penetration of 'good' ventilation practice is estimated at around 5%. In theory this means that there is a theoretical saving potential of 15% by retrofitting existing installations and around 65% through new installations. How much of this theoretical potential can be achieved in practice will depend –apart from appropriate measures and policies—on the technical limitations of the local infra-structure.

To express the current ventilation losses and future savings in terms of energy is no easy task. Data availability on buildings for public administration, education, health care another community services is very poor, amongst others because the activities are very heterogeneous, fall under the responsibility of different departments in the various member states. Only about 40% of the buildings can be classified as typical "offices". All the rest are police stations, prisons, schools, archives, army camps, etc..

For those reasons desk research very often had to resort to national statistics and anecdotal sources, making the task 3 research for this sector much more labour-intensive and error-prone than for other sectors.

The following paragraphs describe how the estimates were made. Unless indicated differently in the text, an hourly air exchange of 1,2 m^3/m^3 is assumed. This reflects the high share of natural ventilation and infiltration.

The paragraphs are structured in accordance with typical government departments. The most important departments –health care, education, justice, home office & municipalities—are discussed in detail. The NACE subdivision, given in the table below for section L , was considered not to be very helpful as it often describes only the regulatory and policy part of the activities and not the executive side.

Table 3- 4 .NACE rev. 1.1. L - Public administration and defence; compulsory social security

75.110	General (Over-all) public service activities
75.120	Regulation of the activities of agencies that provide health care, education, cultural services and other social services excluding social security
75.130	Regulation of and contribution to more efficient operation of business
75.140	Ancillary service activities for the government as a whole
75.210	Foreign affairs
75.220	Defence activities
75.230	Public order and safety activities
75.24	Public security, law and order activities
75.25	Fire service activities
75.300	Compulsory social security activities

3.2.2 Health care

The table below shows the number of health activities and the estimated ventilation losses in mln. m³/h.

Table 3- 5. VHK Business & public sector statistics, section N - Health and social work (2005, EU-25, © VHK 2007-2010)

Code	Description	Number	*Totals*	mln. m³/h @18°C
85.111	Hospital primary health activities	5.949		
85.112	Hospitals for specialized somatic health activities	2.732		
85.113	Hospitals for specialized psychiatric health activities	833		
85.114	Rehabilitation centres	13		
85.115	Other specialized health activities	2.250		
			11.777	**993**
85.121	Medical practices, at hospitals	161.804		
85.122	Medical practices, not at hospitals	139.813		
85.123	Somatic polyclinics	506.534		
85.124	Psychiatric healing centre	19.333		
85.125	Adult psychiatric polyclinic	10		
85.127	Children's and adolescents psychiatric polyclinic	11.314		
			838.808	**815**
85.130	Dental practices	156.840		
			156.840	**189**
85.141	Medical laboratories etc.	13.535		
85.142	Ambulance transports and ambulance health activities	6.045		
85.143	Medical nursing homes	45.341		
85.144	Other health establishments n.e.c.	272.001		

85.145	Organ collection centres and banks	6		
			336.928	**2.028**
85.200	Veterinary clinics	45.754		
			45.754	**55**
85.311	Service homes and homes for the aged	6.128		
85.312	Homes for disabled persons	5.807		
85.313	Homes for children and young people	13.776		
85.315	Homes for adult substance misusers	2.786		
85.316	Hostels etc.	489		
85.322	Child day-care establishments	15.927		
85.323	Social work establishments for children and young people	1.533		
85.324	Welfare and counselling centres	10.097		
85.325	Humanitarian relief organisations	1.439		
85.327	Day-care establishments for the aged	3.836		
85.328	Day-care establishments for disabled persons	9.297		
85.329	Day-care establishments for adult substance misusers	1.998		
			73.112	**1.320**
	TOTAL		**1.463.219**	**5.400**

The total is set at 5.400 mln. m³/h, not only due to the actual heated floor area, but also influenced by certain specific activities like laboratories, operating theatre and treatment areas that require up to 10 times the usual ventilation fold. These special activities are outside the scope of the study but their effect on ventilation was taken into account here.

In the EU-27 (2006) there are 200.000 curative beds in hospitals (406,3 per 100.000 inhabitants) and 29.700 psychiatric care beds (60,4 per 100.000 inhabitants).[2]

3.2.3 Education

The table below shows the number of schools and institutions of vocational training, pertaining to NACE section M [code 80].

The numbers on universities require some extra explanation. In the EU there are approximately 550 larger universities with an average 170.000 m² gross floor area and 774.000 m³ volume officially named universities[3]. The rest are institutes of Higher Education or comparable institutes (including

[2] Eurostat Yearbook 2009.

[3] The Finance Minister of Baden-Württemberg (Drucksache 12 / 4784, 20. 01. 2000, Stromsparen in Landesgebäuden durch Modernisierung der Lüftungsanlagen …) mentions 1,9 mln. m² for 1060 university buildings and 0,7 mln. m² for 340 university hospital buildings. Of this total of 2,6 mln. m² it is estimated that 910.00 m² (35%) has an air-conditioning or ventilation provision (Raum Luft Technische RLT Anlage). This is equivalent to around 530 buildings with an estimated 4 'RLT-Anlagen' per building. Overall electricity consumption was estimated at 38 GWh (taken as 0,53 x 72 GWh). In total around 15% of these installations were renovated in the last 5 years. The German district ('Land') Baden-Württemberg has 11 universities, so on average this is 172.000 m² per university. District inhabitants total ca. 10,8 mln., which is ca. 2% of EU-27. Other anecdotal evidence: Rotterdam Erasmus university 180.000 m² (20.000 students of law, economics, medicine). Gent university real estate 771 buildings and 750.000 m² total. Leiden University has 70 buildings with 222.000 m² floor area. Extreme cases are universities specialized in law, economics with much less m² per student and there are

around 250 small universities), assumed to have a gross floor area of around 20.000 m² and 90.000 m³ volume.

Table 3- 6 . VHK Business & public sector statistics, section M - Health and social work (2005, EU-27, © VHK 2007-2010)

Code	Description	Number	*Totals*	mln. m³/h @18°C
80.101	Pre-primary school education	39.999		
80.102	Compulsory comprehensive school education and pre-school class	8.682		
80.103	Special school primary education	192		
			48.873	1100
80.211	General secondary education	1.063		
80.212	General secondary education	12.418		
80.221-80.223	General secondary education and technical and vocational secondary education	19.979		
			33.460	1150
80.301	University (ca. 500-600) and university college higher education (ca. 10.500)	11.235		
80.303	Military higher education	1.389		
80.309	Other higher education	557		
			13.181	1415
80.410	Driving schools	40.153		
80.421	Municipal adult education	917		
80.422	Labour market training	2.724		
80.423	Folk high schools	458		
80.424	Adult education associations	2.190		
80.425	Staff training	73.021		
80.426	Municipal culture schools	229		
80.427	Educational service	98.176		
80.429	Other education	50.660		
			268.527	310
	TOTAL		***364.042***	***3.960***

In the EU-27 (2006) there were 93,9 mln. people enrolled in school (excluding pre-school), of which 28,5 mln. in primary school (ISCED 1), 22,9 mln. in lower secondary school (ISCED 2), 23,6 mln. in upper secondary and post-secondary non-tertiary school (ISCED 3 and 4) and 18,8 mln. in tertiary education (ISCED 5 and 6).[4]

Minimum gross floor area building standards per pupil/student (derived from NL and checked against anecdotal evidence form other EU countries) are 3,5-4 m² for primary schools, 7-8 m² for secondary schools and on average 9 m² for university. For ISCED levels 4 to 6, the ratio depends highly on the direction, e.g. as low as 5 m² per law-student and up to 40 m² per engineering student.

On the other hand, anecdotal evidence suggests that the floor area per pupil may also be as high as 17-20 m² for primary schools[5] and 40 m² for tertiary (technical) education.

technical universities with much more than average m² per student. E.g. Delft technical university has around 450.000 m² gross floor area (12.000 students).

[4] Eurostat Yearbook 2009.

[5] Example Germany: model 'Passiv' school: 8700 m², 40.347 m³ for 400 primary school and 100-125 kindergarten, 50 staff. Heat recovery ventilation at a rate of 21.700 m³/h.

Average floor height is assumed to be 4,5 m. The total heated floor area is 880 km² and the volume is **3.960 mln. m³**.

Apart from the institutions mentioned in section M, Ministry of Education has extra costs for subjects dealing with research and culture, e.g.

- national research laboratories (3,6 mln. m² floor area, but at high ventilation fold estimated at **50 mln.** m³/h at 18°C), mainly classified under section K (code 73).
- core central ministry, classified under NACE section O (code 75), accounting for 4 mln. m² or **16 mln. m³**.
- national museums, classified under NACE section O (code 92.520) and not taken into account here
- university clinics, classified under 'Health care', NACE section N (code 85.111) and not taken into account here.

In total, educational activities account for around 900 mln. m² heated floor area and the equivalent of **4.000 mln. m³** heated volume.

3.2.4 Justice

The **EU Justice departments** occupy a relatively large heated gross floor area. It is estimated that they occupy around 75-80 mln. m², which equals ca. **350-370 mln. m³** of heated volume. The estimated split-up of this figure is as follows:

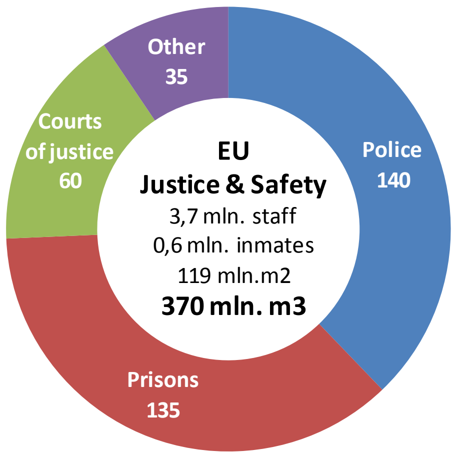

Figure 3 - 35. Justice dept., heated building volume by application

Eurostat reports that in 2006 the EU-27 **police**-force consists of 1,7 mln. police officers[6]. From national statistics it is estimated that the police force is supported by around 1 mln. technical and administrative staff and trainees.[7] In most countries police efforts are split between justice and defence department, but for the sake of clarity the 0,25-0,3 mln. paramilitary forces working as

[6] Eurostat 2009, crim_plce

[7] Ministry of the Interior NL, Kerngegevens personeel Overheid en Onderwijs 2008, The Hague 2009. Police officers 35.972 (equals Eurostat data), support staff 20.042, trainees 6.232. Total 62.246 police staff.

border police, coast guard and customs guards are classified as 'police' and have to be added to the 1,7 mln. staff reported by Eurostat. Statistics on heated gross floor area of buildings are scarce, but from anecdotal evidence a figure of 10 m² per person is estimated.[8] At around 3 mln. personnel this brings the total heated floor area to approximately 30 mln. m² and a volume of around **110 mln. m³**. An archetype police station (small city) has around 800-1000 m² heated floor area. Building sizes ranges from <100 m² (small village) to >25.000 m² (regional head office or larger city).

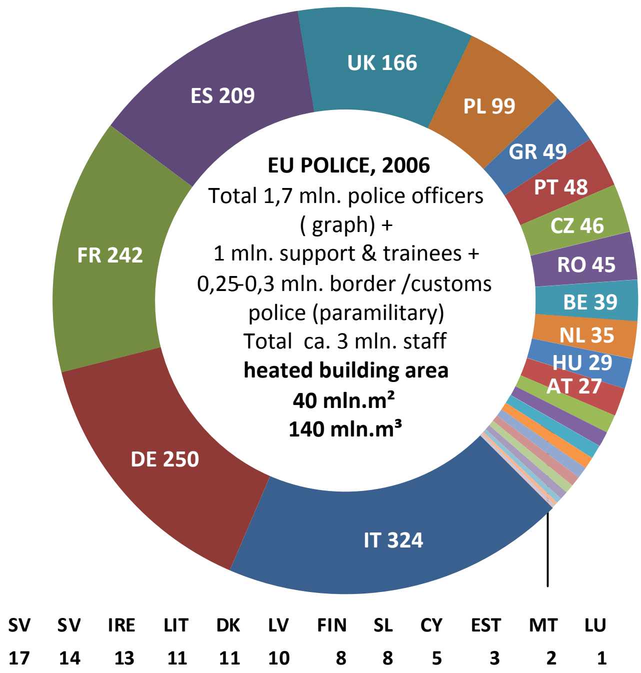

Figure 3 - 46. EU no. of police officers, by country

Courts of justice are the working place of around 50-60.000 judges and 120-150.000 other staff[9]. Gross floor area can be derived directly from central government statistics and will be around 15 mln. m², which results in around **60 mln. m³.** [10]

The EU-27 has around 0,6 mln. **prisoners**[11] and 0,28 mln. direct prison personnel.[12] Gross floor area per EU prisoner is around 70 m² for smaller prisons (<500 inmates) [13], 56 m² for medium sized prisons (500-1000 inmates) and 36 m² for large prisons (>1000)[14]. At 56 m² per inmate the prison floor area is 33,6 mln. m² and at a floor height of 4 m the total volume is **135 mln. m³**.

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[8] Netherlands has 15% state police (military police (6800 staff), national police force KLPD (5000 staff)) and 85% regional police. State police (RGD 2009) takes up 85.959 m² (ca. 5400 officers).

[9] NL: 800 public defenders in NL (source: Chairman of the NL 'College van procureurs-generaal', Harm Brouwer, 22.11.2009, programme Buitenhof). EU=NLx30→ 24.000. Note that in some countries the denominations 'judge' and 'public defender' may be used differently.

[10] RGD Jaarverslag 2009: Courts of Justice NL 2009: 535.551 m² for ca. 4000 staff (ibid. 10) . In 2000 there were around 1700 judges in the Netherlands.

[11] Eurostat 2009, crim_prsn

[12] CBS, Netherlands: 17.600 prisoners (2005), 9.447 direct prison personnel (on a total of 17.558 full time personnel for all types of penitentiary institutions).

[13] Typical for NL: RGD Jaarverslag mention s 1.265.460 m² for penitentiary institutions

[14] Nawal Al-Hosany, Energy Management and Façade Design in Prison Buildings in Hot Climates: The Case Of Abu Dhabi, Research Paper, 2000.

Other personnel on the Justice department budgets involves general management and policy (100.000 staff[15]), immigration service (100.000 staff), state bailiffs service (25.000 staff), national forensics labs[16] (20.000 staff, 9 mln. m³), ICT and other support (15.000). [17] The ventilation need is estimated at around **30 mln. m³**.

3.2.5 Defence

The EU Defence departments employs around 2,1 mln. active military staff [18] (2004), with around 15% (300.000) civilian support staff. The number of reservists varies widely per country, but they are not estimated to take up heated floor area (training facilities partitioned to active military staff). Para-military forces are not included under this heading, but included under the heading 'police'. Total headcount of employees under the heading 'Defence' is thus estimated at 2,4 mln. For the heated gross floor area only anecdotal were found, but is estimated at around 15 m² per person.[19] This results in 40 mln. m² floor area and an estimated **140 mln. m³** of heated volume. [20] Note that this is 0,15% of the EU total, i.e. considerably less than the 0,7% estimated in the diagram.

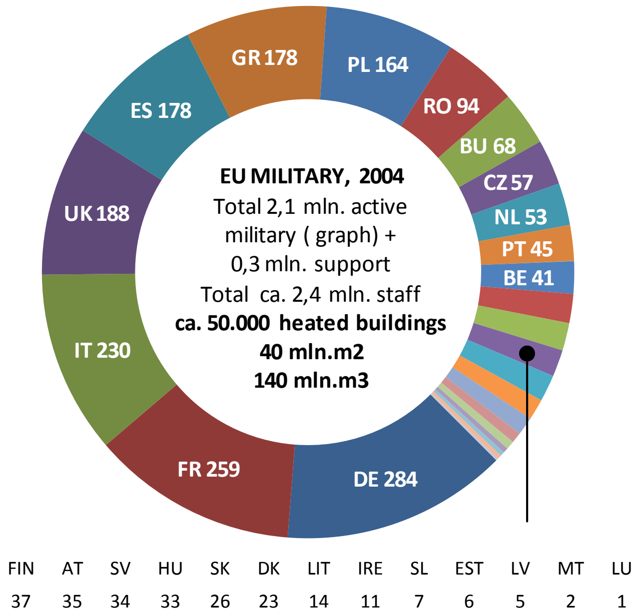


Figure 3 - 57. Defence dept., EU military personell by country

3.2.6 Home office and municipalities

[15] RGD: Core departments 625.206 m² for 13 departments → ca. 50.000 m² per department.
[16] NFI, the Dutch Forensics Lab, employs 350 staff (+200 at central level), 28.000 m², volume ca. 100.000 m³, but very high ventilation need at 300.000 m³/h (3 m³/h).
[17] NL: Immigration 3392, bailiffs ('deurwaarders') 880, forensics 580, ICT and Justis 389.
[18] Active military staff: Wikipedia.nl. Ratio civilians/military taken from ibid. 11.
[19] Netherlands (53.150 military) occupies 47 army bases (Wikipedia). Gross floor area of buildings is around 25.000-40.000 m². Part of this will be unheated. Estimated is 15.000 m² of heated floor area for around 1000 personnel.
[20] Netherlands (professional army only): 67.000 personnel, 85.496 m² gross floor area. In countries with drafted personnel specific floor area is believed to be factor 2 higher.

The core department of the Home Office (a.k.a. 'Ministry of Internal Affairs) is estimated to account for around 4 mln. m² (**16 mln. m³**). But more importantly, the Home Office in many countries has the prime responsibility for the regional and local government, i.e. the 'municipalities'.

In the EU around 6 mln. civil servants are working at regional and municipal level. Apart from the regulatory and policy activities, these jobs include municipal personnel for waste collection, public transport (often privatized), museums, libraries, archives, municipal health services (e.g. ambulances etc.), secretarial services and administration. At an average of 20 m² per employee (80 m³/employee) this results in an extra 480 mln. m³, bringing the total to **500 mln. m³**. Below two sectors, fire & rescue services and the waste collection and disposal are highlighted.

Fire & rescue services are mentioned as a separate NACE group, but statistics on the EU-27 fire & rescue services are relatively poor. The EU-27 has probably around a few million registered fire fighters, but only around 130-150.000 of those are professionals. The others are pure volunteers and on 'Retained Duty Service' ("on-call"). Numbers and organizations differ between countries, based on national customs and geography.[21] The buildings of the fire brigades are mainly unheated garages and do not contribute to the heated gross floor area. The estimate in the table is based primarily on a number of 150.000 professional firemen and a heated gross floor area of 20 m²/employee. This gives 3 mln. m² heated floor area and –at a floor height of 4,5 m, around 13,5 mln. m³ of heated volume. In order also to take into account the heating of training and meeting facilities of the voluntary brigades this latter figure was rounded to **20 mln. m³**.

Another activity that is often part municipal and part private is the waste disposal. The table below gives an overview.

Table 3- 7. VHK Business & public sector statistics, section O - Other community activities (2005, EU-27, © VHK 2007-2010)

Code	Description	Number	*Totals*	mln. m³/h @18°C
90.001	Sewage collection and -treatment	38.787		
90.021	Collection and sorting of non-hazardous waste	86.261		
90.022	Plants for composting and anaerobic digestion of non-hazardous waste	2.783		
90.023	Depots for non-hazardous waste	6.758		
90.024	Handling and interim storage of hazardous waste	9.938		
90.025	Treatment plants and final depots of hazardous waste	5.963		
90.026	Other refuse disposal plants	27.366		
90.030	Street cleaning and other sanitation establ.	185.685		
total			363.540	148

It is estimated that around 0,7 mln. workers are engaged in NACE code 90. NACE code 90.030 (street cleaning activities) was not taken into account for the calculation of the ventilation requirement. In recent years private companies have started to become the major employer in this activity.

[21] A country like Austria boosts as much as 312.897 registered firemen, but out of the 4.894 fire brigades only 6 are professional, 333 are private company fire brigades and as much as 4.555 voluntary brigades. On the other side of the spectrum the Netherlands reports 500 fire brigades and 27.000 firemen, of which as much as 4500 are professionals and 22.500 are volunteers. In Germany, the Feuerwehr is organized in 33.000 locations with around 1,3 million firemen. The UK and Belgium organize their Fire & Rescue Services at regional level. E.g. Wales reports 151 Fire and Rescue stations and 1978 firemen, of which most volunteers. The Flanders (BE) professional association reports 12.000 members, of which 25% professionals and 75% volunteers.

3.2.7 Other public buildings

The Finance department involves around 1 mln. tax office & customs staff and 100-200.000 central staff. Total gross floor area is estimated at 30 mln. m², resulting in **110 mln. m³**.

The ministry of Transport, co-ordinates building and maintenance of highways, bridges, waterways, etc. usually by hiring 3rd parties, but also by state agencies (**40 mln. m³** extra).

Foreign Affairs runs embassies and consulates (**24 mln. m³** extra). The Ministry of Social Affairs has extra personnel in the form of around 600.000 staff for the Social Service[22] (**35 mln. m³** extra)

International organizations are estimated to employ around 0,1 mln. people. Given the need for meeting space, the average floor area per employee is estimated at 44 m². At a floor height of 4 m this results in about **18 mln. m³**.

On top of the above, each department occupies around 4 mln. m² (16 mln. m³). For e.g. the PM office this is the only item on the balance.

3.2.8 Public sector summary

The total ventilation of public sector, health care and education buildings is estimated at 11.100 m³/m³.h. The diagram below gives the breakdown of this figure.

The ventilation and infiltration during the heating season (5000 h) is 55.500 bln. m³. The ventilation heating energy loss, at an indoor-outdoor temperature difference of 9 degrees, is

55,5 x 1012 x 9K x 0,33 Wh/m³.K = 165 TWh

where 0,33 Wh/m³.K is the specific heat capacity of air.

At a heating system efficiency average of 60% this results in a fuel consumption (primary energy, Gross Calorific Value of fuel) of 275 TWh or 993 PJ per year. Assuming natural gas to be the predominant heating fuel type this amounts to carbon emissions of 57 Mt CO_2 equivalent per year.

Assuming that

- 0,25 m³/m³.h of infiltration losses will be inevitable (20%),
- of the existing installations (20% of total) only 70% can be upgraded (missing 5%),
- of the buildings without centralized ventilation around 25% cannot be equipped with centralized ventilation for reasons of infrastructure (missing 25%),

the practical saving potential is estimated at around 50% of 57 Mt CO_2 equivalent, or rather around 28 Mt CO_2 equivalent per year. In terms of energy this equals 135 TWh or close to 490 PJ per year.

This does not take into account the effect on the cooling energy in summer, which may add some 30-50% to the potential depending on the location.

[22] Kerngegevens: Zelfstandig Bestuursorgaan for Dutch Ministry of Social Affairs: 19.899 staff (2008)

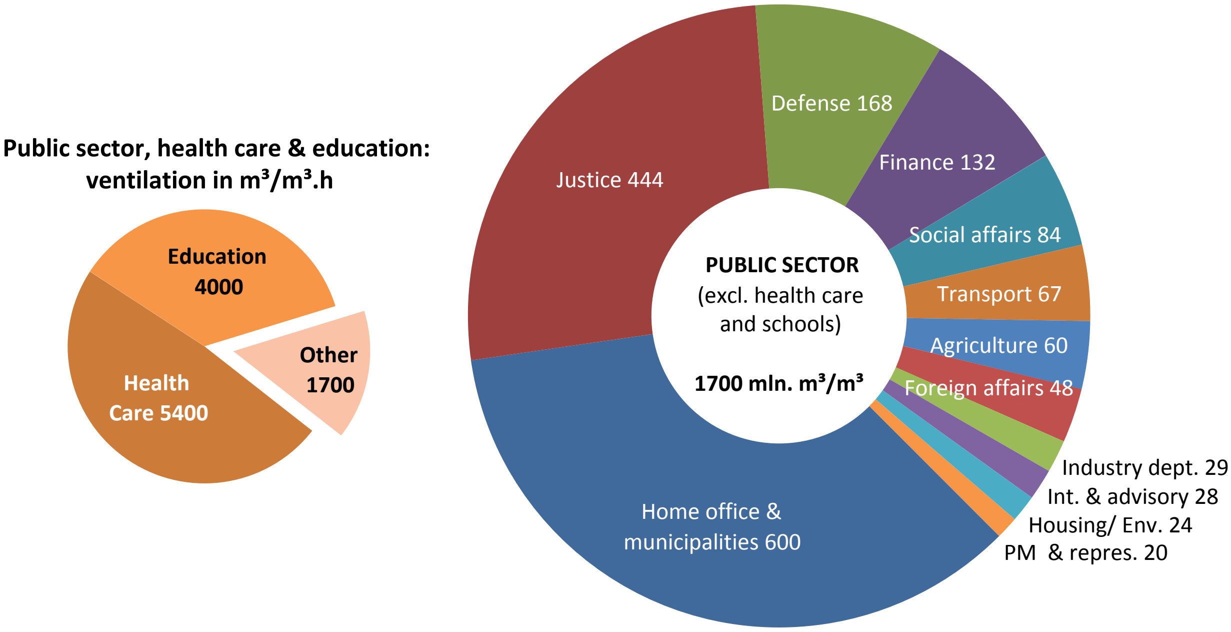


Figure 3 - 68. Public sector summary, heated building volume by department

3.2.9 Social, culture and entertainment, sports activities [NACE O]

Overview

Section O of the NACE statistics contains an overview of organizations in social, communication, entertainment and sports activities. Both national and Eurostat statistics on this section are notoriously unreliable: Definitions are not well defined, several activities are mixed between private and public and a great number of organizations are working with volunteers and overall the registration practice is poor.

Nevertheless, VHK has pulled together the best available statistics and additional information in order to give an estimate of building stock and volume. The tables are taken from the VHK Business & Public Sector Statistics project.

Political and religious organizations

Table 3- 8. Political and religious organisations, NACE section O (code 91) - Other community activities (EU 2005, © VHK 2007-2010)

91.111	Business organizations	34.167		
91.112	Employers organizations	3.579		
91.120	Professional organizations	4.194		
91.200	Trade unions	6.296		
91.310	Religious congregations (11.265, figure=churches)	200.000		
91.320	Activities of political organizations	131.295		
total			190.795	1.136

Even though the statistics offices register only a limited number of 11.000 'religious congregations', the church statistics show that there are around 150-200.000 ecclesiastical buildings (churches)[23]. There are no exact data on size, but it is estimated that an average church will have a volume of at least around 20.000 m³ (e.g. 35 x 70 x 8 m). Their total volume will be at least some 4000 mln. m³. Even if they are heated to a temperature well below 18 °C and only at times of mass, weddings, etc., it is estimated that the hourly air change amounts to **1.000 mln. m³/h** during the time that the heating is on. To this the heating of convents has to be added. In total the ventilation losses will amount to around 1% of the EU-27 total.

<u>Entertainment and news</u>

Table 3- 9. Entertainment & news, NACE section O (code 92.1-92.4) - Other community activities (EU 2005, © VHK 2007-2010)

92.110	Video and movie production for televisions	12.410		
921B	Institutional and promotional movie production	23.251		
921C	Production of movies for the movie theatre	25.451		
921D	Technical service for the movie theatre and television	11.051		
92.121	Motion picture distribution	1.687		
92.122	Video distribution	3.730		
92.130	Motion picture projection	5.585		
			83.165	899
92.201	Production of radio programs	9.861		
92.202	Production of television programs	9.861		
92.203	Editing of general channels	266		
92.204	Editing of thematic channels	2.079		
92.205	Distribution of program clusters for radio and television	965		
			23.032	476
92.310	Performing artists and producers of artistic and literary works	391.691		
92.320	Theatre and concert hall co etc.	16.069		
92.330	Fairs and amusement parks	11.067		
92.341	Dancing and other entertainment establ.	7.802		
92.342	Dancing and other entertainment establ.	7.989		
92.343	Dancing and other entertainment establ.	4.296		
92.344	Dancing and other entertainment establ.	10.642		
			449.556	1.594
92.400	News agencies	37.355		
			37.355	84
	TOTAL 92.1-92.4		**593.108**	**3.053**

Note that the publishers and printers of books, magazines and newspapers are not included here, because it is represented by NACE section D (manufacturing), code 22.

Furthermore, note that 'dancing and other entertainment establishments' are listed under NACE 92.341, but that discotheques are listed as a retail activity.

Finally, it should be noted that the NACE classification places 'Personal services' such as hairdressers, funeral homes in the underlying section O, whereas this study classifies them in the

[23] NL: around 2500 catholic churches, 450 mosques, 3-4000 protestant churches.

Other cultural/ educational activities

Museums and libraries were already mentioned as part of the public sector activities, but in fact many of these activities are also private or semi-public, at best co-financed by the public sector at national, regional or municipal level. For that reason, the table below on NACE section 92.5 at least provides some further insight.

Table 3- 10. Libraries, museums and zoo's, NACE section O (code 92.5) - Other community activities (EU 2005, © VHK 2007-2010)

92.510	Library and archives activities	6.227		
92.520	museums activities and preservation of historical sites and buildings	7.422		
92.530	Botanical and zoological gardens and nature reserves	2.261		
	TOTAL 92.5		**15.910**	**263**

Sports facilities

Table 3- 11. Sports and related activities, NACE section O (code 92.6-92.7) - Other community activities (EU 2005, © VHK 2007-2010)

92.611	Ski facilities	1.764		
92.612	Golf courses	8.134		
92.613	Motor racing tracks	2.295		
92.614	Horse race tracks	3.197		
92.615	Arenas, stadiums and other sports facilities	14.688		
92.621	Sportsmen and sports clubs	32.284		
92.622	Horse racing stables	112.042		
92.623	Sports schools, boat clubs, etc.	14.927		
92.624	Sports events organizers	13.118		
92.625	Sports activities administrators	835		
			203.286	868
92.710	Gambling and betting companies (incl. lotteries)	17.506		
92.721	Riding schools and stables	56.374		
92.729	Various other recreational establishments	129.844		
			203.724	778
	TOTAL 92.6-92.7		**407.010**	**1.646**

The estimate of **1.646 mln. m³** heated volume in the VHK Business & public sector statistics, based on official statistics appears to focus on sports activities where a considerable amount of money is involved, but hardly on municipal facilities for non-profit sports clubs. From the buildings and heating perspective this is incorrect.

The number of indoor swimming pools is 1 per 50.000 inhabitants in Western Europe, 1 per 300.000 inhabitants in Eastern Europe. Overall in the EU-27 this means around 5.000 indoor swimming pools, with a surface of at least 12.250 m³ (25 x 35 x 10 m), up to 37.500 m³ (50 x 50 x 15). At an average 20.000 m³ per pool this means 100 mln. m³. But the average temperature is high, as is the ventilation effort. Around **200 mln. m³/h** is estimated.

The EU has at least 500 larger indoor sports arena's with an average capacity of 9.000 seats. (15.000 m³ x 20 m= 300.000 m³). Indoor speed-skating halls (400 m tracks) are small in numbers but large in volume: There are an estimated 20 in the EU. At around 0,25 mln. m³ per hall this results in 5 mln. m³. In total the volume of the larger indoor sports arena's is estimated at **155 mln. m³**.

Finally, it is estimated that around 150.000 public (municipal) indoor sports courts (at 30 x 15 x 8m= 3.600 m³ per court) outside of the ones in schools. This results in a heated volume of **540 mln. m³.** [24]

In total, excluding the facilities in educational institutions, the ventilation need in sports facilities is estimated at **2.541 mln. m³**. Note that this is considerably less than the 3,2 % (3.520 mln. m³) estimated in figure 3.18.

[24] Example Ahoy (tennis): 30.000 m² x 20 = 600.000 m³ x 30 → 18 mln. m³.

3.3 Service sector

3.3.1 Introduction

The table below gives the Eurostat overview of added value and employment in the service sector (excluding financial institutions). With an added value of close to € 3.000 bln. the sector represents around 28% of EU-27 GDP and 35% of employment in the active workforce.

Table 3- 12. EU-27 Service sector 2005 (source Eurostat, SBS)

	Value added		Employment	
	EUR billion		x1000	
Services (G to I and K) TOTAL	2.991,3	100,0%	76.133,0	100,0%
Distributive trades (G)	1.022,4	34,2%	30.963,9	40,7%
Sale, maintenance/repair of motor vehicles (G50)	150,9	5,0%	4.106,7	5,4%
Wholesale/commission trade, exc. for motor (-cycles) (G51)	479,7	16,0%	9.732,4	12,8%
Retail trade (exc. motor vehicles), repair of personal goods (G52)	391,8	13,1%	17.124,8	22,5%
Hotels and restaurants (H)	167,8	5,6%	8.845,9	11,6%
Transport and communications (I)	629,9	21,1%	11.823,7	15,5%
Land transport, transport via pipelines (I60)	180,0	6,0%	5.500,0	7,2%
Water transport (I61)	25,0	0,8%	213,5	0,3%
Air transport (I62)	27,2	0,9%	400,0	0,5%
Supporting transport activities, travel agencies (I63)	147,9	4,9%	2.612,1	3,4%
Post and telecommunications (I64)	250,9	8,4%	3.075,2	4,0%
Real estate, renting & business activities (K)	1.171,2	39,2%	24.499,5	32,2%
Real estate activities (K70)	248,0	8,3%	2.690,0	3,5%
Renting of machinery, and of pers. & househ. goods (K71)	75,0	2,5%	600,0	0,8%
Computer and related activities (K72)	170,0	5,7%	2.700,0	3,5%
Research and development (K73)	21,8	0,7%	400,0	0,5%
Other business activities (K74)	655,5	21,9%	18.102,4	23,8%

3.3.2 Distributive trade and personal services

The diagrams below are an extract from the VHK Business & Public Sector Statistics project.

The diagrams show the number of companies and the estimated hourly ventilation rate for the retail sector [NACE section H, code 52], personal services [NACE section O, code 93], wholesale [NACE section H, code 51] and the trade in motor vehicles [NACE section H, code 50].

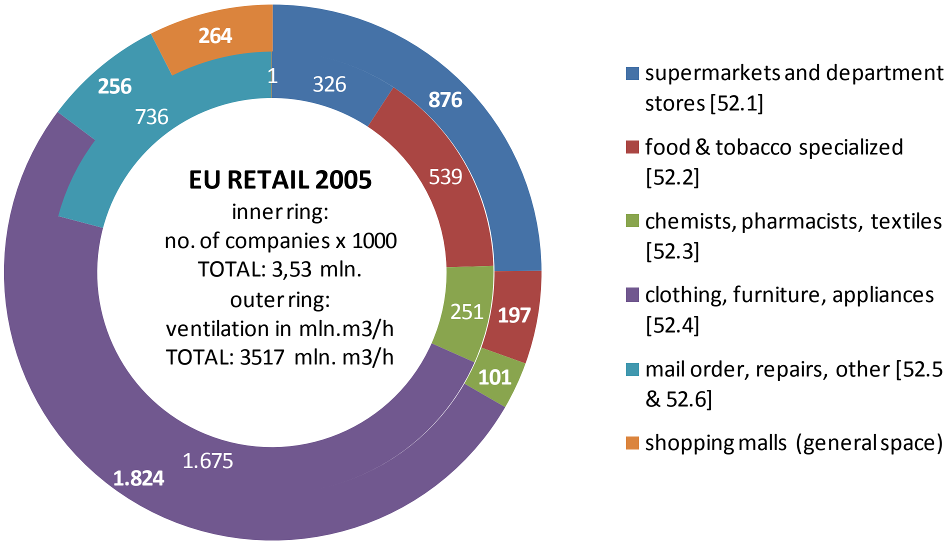


Figure 3 - 79. EU Retail 2005, no. of companies and accumulated ventilation rate (in mln. m³) by type.

Table 3- 13. VHK Business & public sector statistics, section O. Personal Services (2005, © VHK 2007-2010), EU-27)

Code	Description	Number	*Totals*	mln. m³/h @18°C
93.011	Laundries and drycleaning establ. for businesses and instit.	3.805		
93.012	Laundries and drycleaning establ. for households	62.595		
93.021	Hairdressers	353.193		
93.022	Beauty parlours	158.709		
93.023	Care for the defunct	20.794		
93.030	Undertakers etc.	16.599		
93.041	Physical well-being establishments - hot baths and spas	10.708		
93.042	Other physical well-being establishments	72.302		
93.050	Other service establishments n.e.c.	146.058		
total			844.762	466

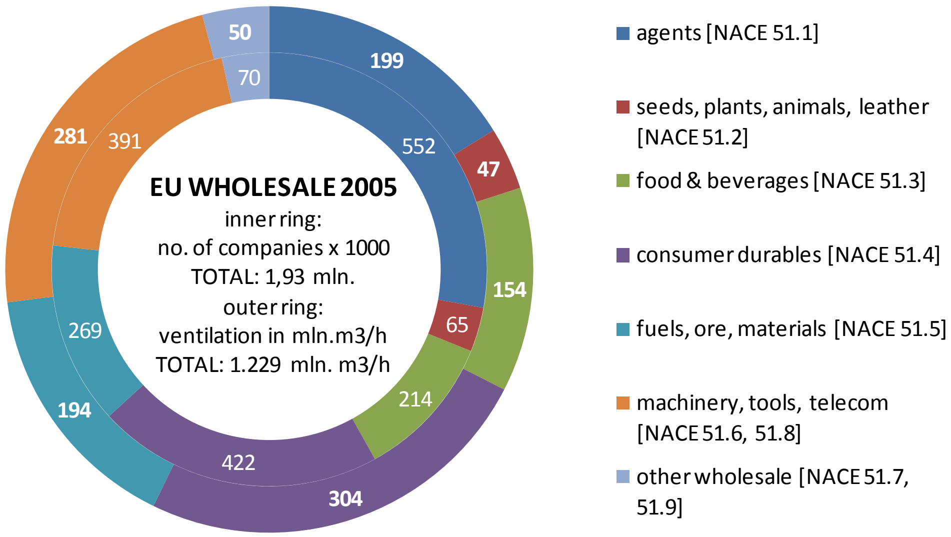


Figure 3 - 208. EU Wholesale 2005, no. of companies and accumulated ventilation rate (in mln. m³) by type.

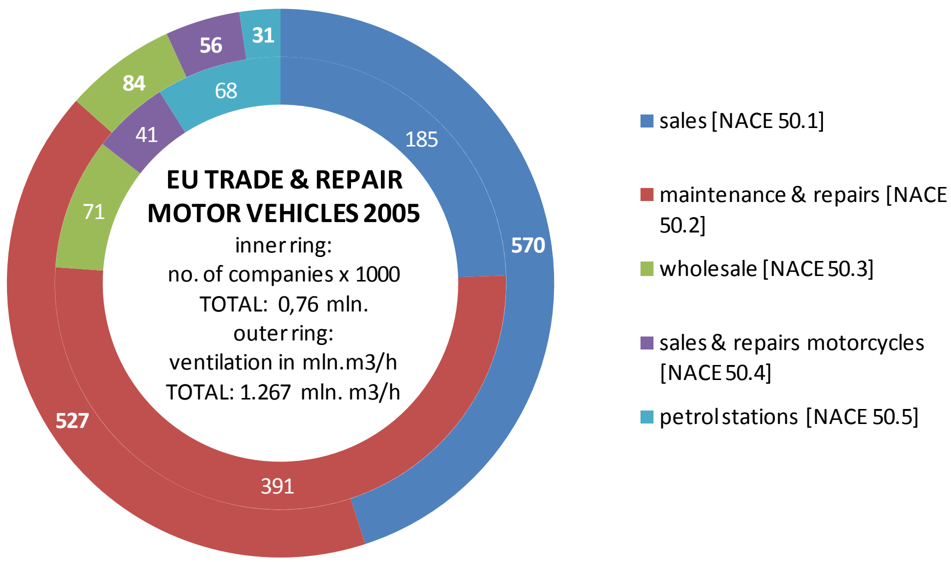


Figure 3 - 29. EU Trade & Repair Motor vehicles 2005, no. of companies and accumulated ventilation rate (in mln. m³) by type.

It is estimated that retail and personal services (total 4,37 mln. companies) account for a ventilation need of around 4.000 mln. m³/h@18°C. of heated floor space.

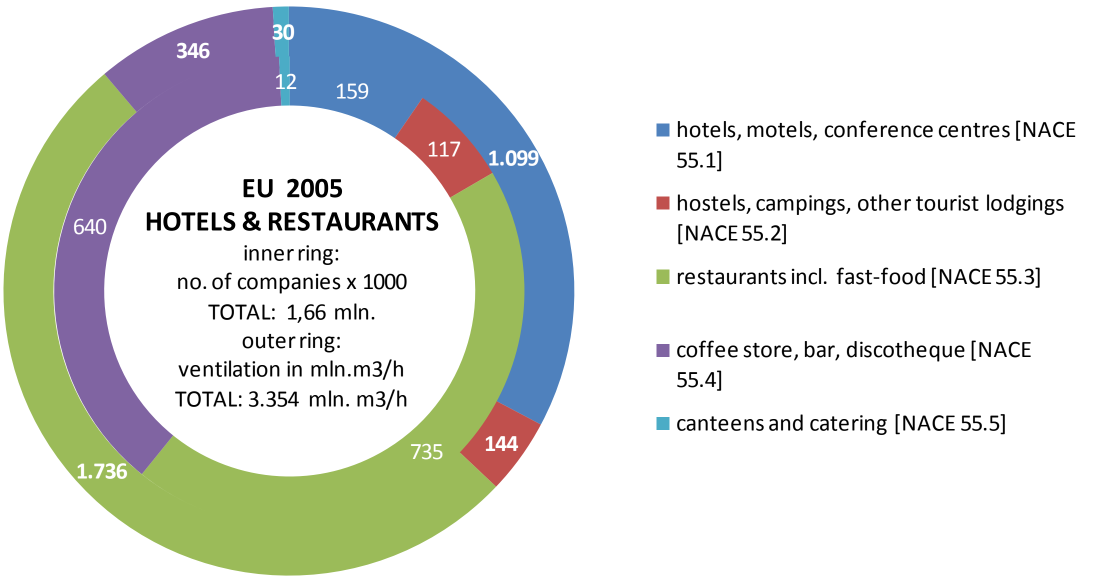
There is a trend towards more (indoor) shopping malls in the EU. In 2005, the Retail Consulting Group, already predicted 150 m²/1.000 inhabitants. Today, this may be around 200 m²/1.000 inhabitants. At a typical size of 100.000 m² per mall this means 2 large malls per mln. inhabitants or rather around 1.000 large shopping malls in Europe. This represents the equivalent of 100 mln. m². Every mall holds around 100-150 retail outlets, already taken into account above and representing one third of the volume, but it still means that 66 mln. m² (**264 mln. m³**) is unaccounted for, which has to be added to the above total.

This brings the retail total to around **4.264 mln. m³.** Including wholesale and trade in motor vehicles the total becomes **6.760 m³.** This is 6,1% of total, which is much more than the estimated 4% in figure 1.

3.3.3 Hotels & Restaurants

Eurostat (2006) reports for the EU-27 a capacity of in total 25 mln. beds/places, subdivided between 11 mln. hotel beds, 9 mln. places on tourist camp-sites, 2,5 mln. holiday dwellings and 2,2 other collective accommodations.

The count of the number of enterprises and an estimate of the floor area is given in the graph below



3.3.4

Figure 3 - 22. EU Hotels, Bars and Restaurants 2005, no. of companies and accumulated ventilation rate (in mln. m³) by type.

3.3.5 Business services, real estate and rental companies

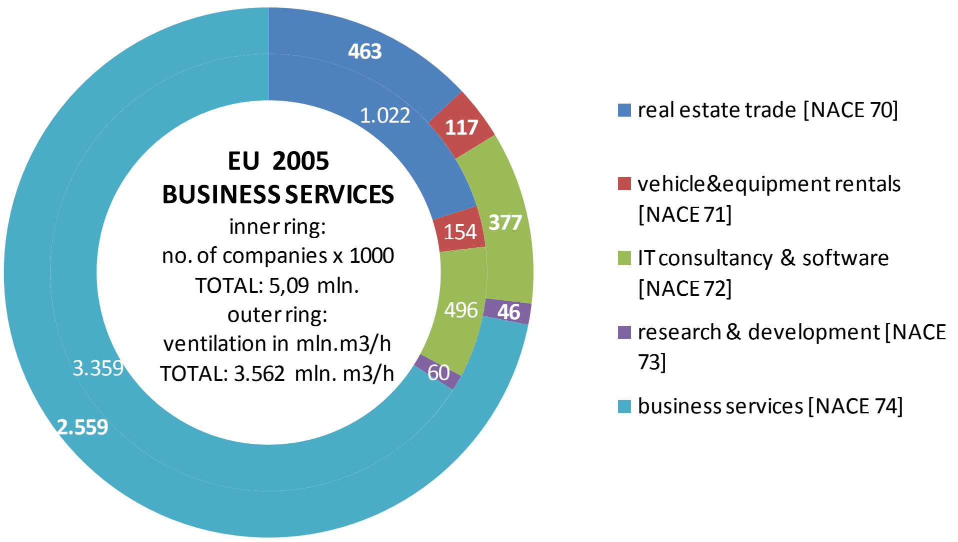


Figure 3 - 23. EU Business Services 2005, no. of companies and accumulated ventilation rate (in mln. m³) by type.

EU-27 Business services: Number of Companies (total 3,359 mln.)

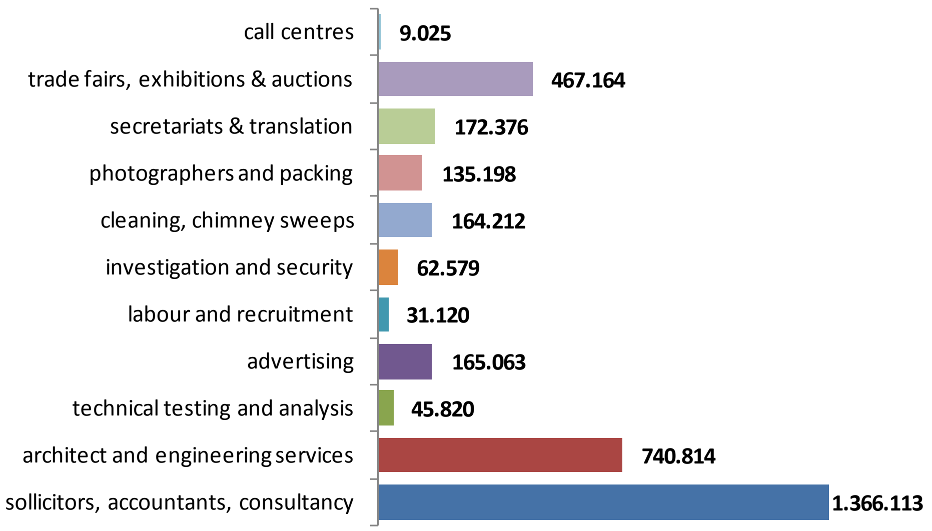


Figure 3 - 24. EU Business Services 2005, no. of companies split-up by type.

Trade Fairs

In terms of the size of the buildings, the trade fair exhibition halls are an interesting subsection at NEC 5-digit level. Germany alone boosts 2,7 mln. m² of trade fair exhibition hall floor area. In total EU-27 is estimated to have ca. 10 mln. m² of trade fair exhibition area. At a ceiling height of 8 m this comes down to ca. **80 mln. m³**. Largest 5 fairs in EU: Hannover, Milano Fiera, Frankfurt, Cologne, Dusseldorf.[25]

3.3.6 Transportation and communication

Transportation

It is estimated that the EU has around 10.000 manned train stations, i.e. featuring at least one heated area. The size of the heated area may range from a one-man ticket counter to the arrivals & departures hall of an international high speed rail station. As a first guess, the heated area is estimated at 200 m², including the company head-offices. This brings the total to 2 mln. m² and around **8 mln. m³**.

There are around 25 large cities in the EU that feature a subway-network. Per network, around 100 underground stations are estimated, which require ventilation. In total, these 2.500 underground stations will have a floor area of 2,5 mln. m² and a total ventilated volume of **5 mln. m³**.

The CIA World Factbook reports 3.376 airfields in the EU (2009), of which 1.981 with a paved runway and presumably some heated area. Of the latter it is estimated that around 200-300 airports host commercial flights, of which again around 30 large airports. Estimating the latter at 200.000 m² (2 mln. m³, excluding shops) a piece, 250 other commercial airports at 2.000 m² (10.000 m³) and 1.600 small airports at 200 m² (1000 m³) per unit, the total is around **64 mln. m³**.

For harbour buildings (port authorities, waiting hall ferry's etc.) , in as much as they are not already taken into account under the heading 'wholesale', it is difficult to make an accurate estimate. A figure of **3 mln. m³** is given.

For the whole transport sector, excluding the building area already taken into account under other headings (retail, petrol stations, motels, restaurants, etc.), the total is estimated at around **80 mln. m³**, considerably less than 1% of total mentioned in figure 3.21.

Communication

Statistics on post offices are extremely volatile, given the trends of privatisation, internet and mix of mail services with other activities (banking, shops). A very rough estimate is that typical mail activities of larger mail-offices can be partitioned to around **20 mln. m³** gross floor area in the EU. [26]

Computer and telephone data centres (a.k.a. 'server farms') accounted for 61,4 TWh of electricity consumption in the US in 2006.[27] At the same time, the energy use in the EU-27 was lagging some 20% behind[28], but it is assumed that today the EU-27 will have the same 10-11 mln. servers installed

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[25] AUMA report 2009. Note that in Belgium, the Brussels Exhibition Park (114.000 m² hall area) is the largest. In NL this is Jaarbeurs (100.000 m²).

[26] Basis of estimate: NL still has 250 'larger' mainl-offices. EU=30xNL. At 1000 m²/building for specific mail-linked activities this gives 7,5 mln. m² (20 mln. m³). Note that NL has around 1.850 mail-offices mixed with shops (headcount is under 'retail').

[27] Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431 U.S. Environmental Protection Agency ENERGY STAR Program, August 2, 2007.

[28] ECN, Data hotels, report 2008 with data 2007 on the Netherlands (average EU internet density): 1,6 TWh. EU=30xNl → 48 TWh. Of this 22% went into HVAC

as the US and will also be spending some 60 TWh/a on data centres. Of this, 22% (13,2 TWh/a) is attributed to air-conditioning and ventilation. In principle, this type of air-conditioning and cooling is **outside the scope** of the study, because it concerns process-cooling and not comfort cooling (no people). But the figure is important enough to mention here, because it can explain 1-2% of total HVAC stock of chillers or AHU's. At an ICT heat dissipation of 1 kW/m² floor area, 45 TWh/a ICT electricity use, 8.000 h operation, a ceiling height of 3,5 m, the data centres represent around 6 mln. m² of gross floor area and 20 mln. m³, but the cooling performance is of course much higher than for comfort cooling.

Note that the ventilation of tunnels and parking garages[29], as well as the ventilation and conditioning of motor vehicles, trains, ships and aircraft are **outside the scope** of the underlying study.

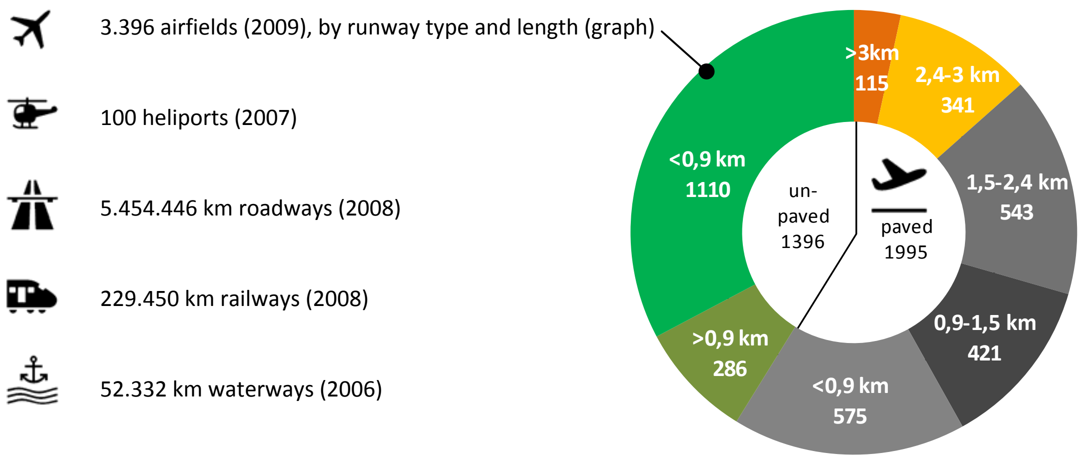

Figure 3 - 105. EU Transport key figures

3.3.7 Financial institutions

Belga (2007) reports an average density of 1 EU bank branch office per 2.230 inhabitants. At 500 mln. inhabitants this means 220.000 bank branch offices in the EU. At an estimated average of 200 m² (800 m³) per office (including ATM area, including head-office) this comes down to a heated volume of **180 mln. m³.**

[29] For the sake of estimating the total ventilation market it is mentioned here that the EU-27 has 5860 km of tunnels (CIA World Factbook data 1.1. 2009), including railroad (ca. 23%), subway(28%), road tunnels (49% of safety regulated km capacity). Regulated tunnels (>300 m) are on average ca. 1,2 km/tunnel long and account for ¾ of the total km. This means around 3660 tunnels with sufficient ventilation capacity to evacuate toxic fumes. Typical fan-values found are 2 supply fans (90 m³/s) and 2 exhaust fans (70 m³/s) per tunnel, amounting to a total of capacity of 320 m³/s or 1,15 mln. m³/h per tunnel. Assumed fans work at 50% part load, i.e. around 0,6 mln. m³/h. Total EU: 2,2 bln. m³/h → 19272 bln. m³/a (to check! extremely high!). Indoor parking garages also under investigation; also there the ventilation rate is high.

3.4 Ventilation in primary and secondary sector

3.4.1 Introduction

Although primary and secondary sector are outside the strict scope of the study they are relevant to complete the statistical overview of the number of ventilation units installed in the EU. The diagrams are extracts from the VHK Business & Public Sector Statistics project.

As regards the total volume of the buildings involved, the underlying study will rely on the estimates made in the preparatory study on boilers (DG ENER – Lot 1).

3.4.2 Primary sector

The DG ENER Lot 1 preparatory study concludes that the primary sector accounted for 3,3% of the total heated building volume (at 18 °C). This volume of 3,6 bln. m³ relates primarily to greenhouses [mainly NACE 01.120] and farming of swine and poultry [NACE 01.230- 01.250].

This does not take into account unheated buildings with mechanical ventilation. Furthermore, it should be noted that the ventilation of deep mines, very few mines but characterized by high air exchange rates, in NACE codes 10-14 is considered as process ventilation and therefore excluded from the scope (see Annex I, Exemptions).

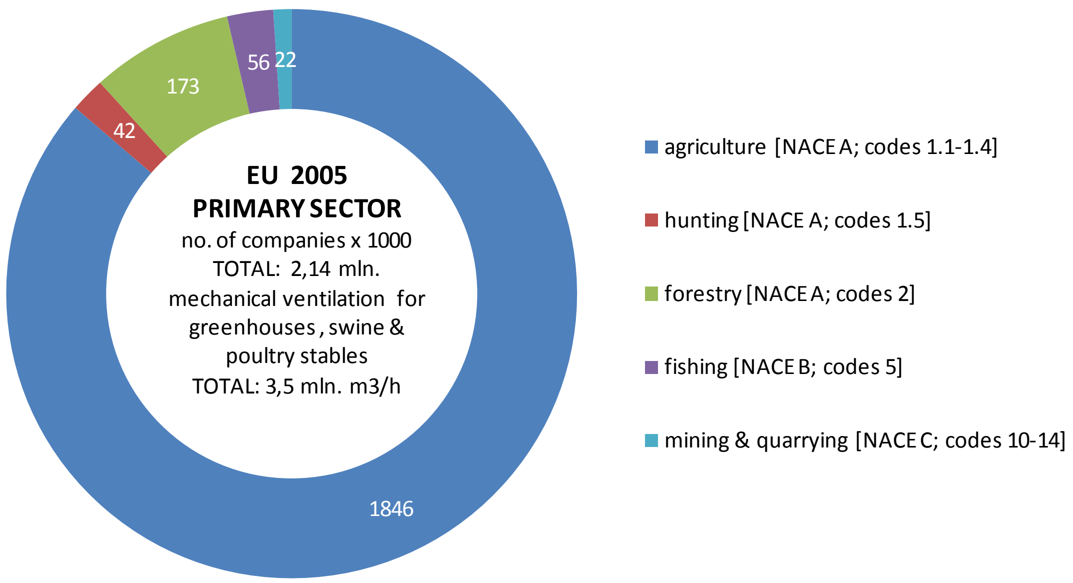

Figure 3 - 116. EU Primary sector 2005, no. of companies by type and accumulated ventilation rate (in mln. m³) .

Table 3- 14. Agriculture (NACE 1.1 - 1.4) no. of companies

Code	Description	Number
A - Agriculture, hunting and forestry		
01.110	Growing of cereals and other crops n.e.c.	650.415
01.120	Growing of vegetables, horticultural specialties and nursery products	267.276
01.130	Growing of fruit, nuts, beverage and spice crops	154.464
01.210	Farming of cattle, dairy farming	62.816
01.220	Farming of sheep, goats, horses, donkeys and mules	39.042
01.230	Farming of swine	55.531
01.240	Farming of poultry	93.613
01.250	Other farming of animals	44.886
01.300	Growing of crops combined with farming of animals (mixed farming)	86.980
01.410	Agricultural service activities; landscape gardening	318.381
01.420	Animal husbandry service activities, except veterinary activities	72.296
Total NACE 1.1 - 1.4		**1.845.700**

3.4.3 Secondary sector

The secondary sector comprises Manufacturing (NACE section D), Energy (NACE section E), Construction (NACE section F). As an illustration only the company count in the manufacturing industry is given.

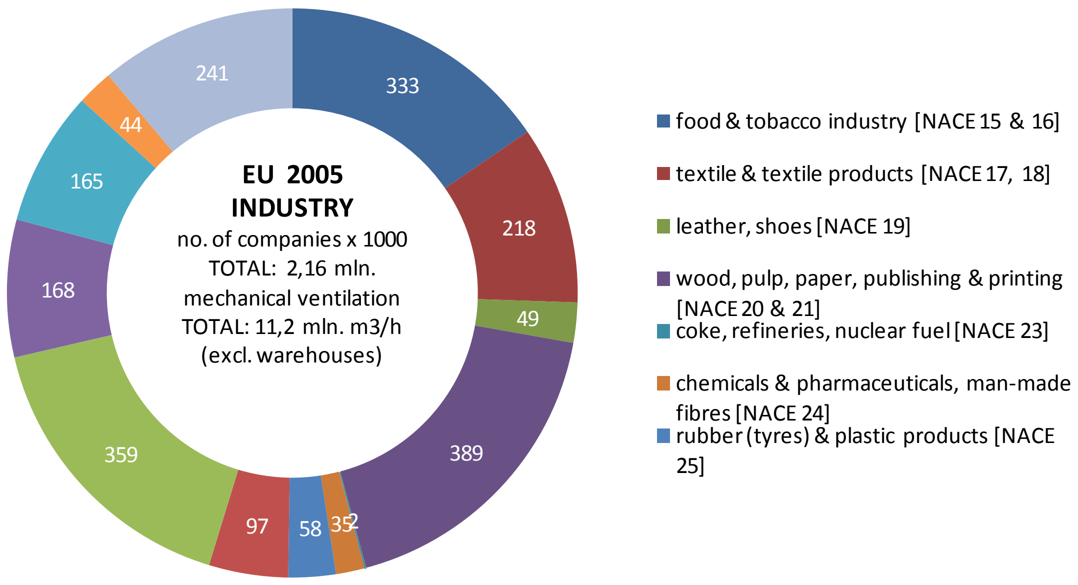

Figure 3 - 127. EU Secondary sector 2005, no. of companies by type and accumulated ventilation rate (in mln. m³)

Table 3- 15. EU-27 Manufacturing industry 2005, NACE Section D (Eurostat, 2009)

	Value added		Employment	
	EUR billion	%	x1000	%
Manufacturing (NACE Section D)	**1.629,9**	**100,0%**	**34.644**	**99,8%**
Food products; beverages and tobacco (DA)	199,1	12,2%	4.700	13,6%
Textiles and textile products (DB)	53,3	3,3%	2.614	7,5%
Leather and leather products (DC)	11,4	0,7%	564	1,6%
Wood and wood products (DD)	35,1	2,2%	1.280	3,7%
Pulp, paper and paper products; publishing and printing (DE)	134,7	8,3%	2.562	7,4%
Coke, refined petroleum products and nuclear fuel (DF)	38,5	2,4%	170	0,5%
Chemicals, chemical products and man-made fibres (DG)	178,5	10,9%	1.888	5,5%
Rubber and plastic products (DH)	76,1	4,7%	1.700	4,9%
Other non-metallic mineral products (DI)	73,5	4,5%	1.596	4,6%
Basic metals and fabricated metal products (DJ)	221,9	13,6%	5.045	14,6%
Machinery and equipment n.e.c. (DK)	178,4	10,9%	3.636	10,5%
Electrical and optical equipment (DL)	189,8	11,6%	3.664	10,6%
Transport equipment (DM)	181,9	11,2%	3.152	9,1%
Manufacturing n.e.c. (DN)	57,7	3,5%	1.988	5,7%

The DG ENER Lot 1 preparatory study concludes that the industrial units accounted for 10,2% of the total heated building volume (at 18 °C). NACE sectors E and F will make up the largest part of the 'other' category, which accounts for 2,9% . The total volume is thus ca. 14,4 bln. m³. This excludes the warehouses, which are seen as a separate category.

3.4.4 Warehouses

The DG ENER Lot 1 preparatory study treats (heated) 'Warehouses' as a separate category, accounting for 4,2% of the total EU heated building volume (at 18 °C). The total volume is thus ca. 4,6% bln. m³. This excludes mechanical (exhaust) ventilation of unheated warehouses.

3.5 Total ventilation demand, summary

The table below summarizes the findings as regards the TOTAL ventilation requirement of heated buildings. The estimate of 68 bln. m³ is within 10% of the estimate of DG ENER Lot 1 as regards the heated building volume.

Table 3- 16. Total ventilation requirement multi-family and non-residential (heated buildings), in mln. m³/h

	TOTAL	natural ventilation	exhaust or supply	balanced ventilation	balanced + heat recovery
Low-rise multi-family dwellings	10.500	7.400	2.900	100	100
High-rise multi-family dwellings	5.900	2.950	2.850	50	50
	16.400	**10.350**	**5.750**	**150**	**150**
		63%	*35%*	*1%*	*1%*
Health care	5.400	1.620	718	2.143	919
Education	4.000	2.400	2.100	100	200
Public administration	1.700	1.275	81	241	103
Political and religious activities	1.130	1.074	57	0	0
Social, cultural, sports activities	2.540	762	338	1.008	432
	14.770	**7.131**	**3.294**	**3.492**	**1.654**
		48%	*22%*	*24%*	*11%*
Retail (incl. 260 for malls)	4.260	1.278	567	1.691	725
Wholesale (excl. warehouses)	1.230	492	140	418	179
Trade motor vehicles	1.270	508	145	432	185
Hotels and restaurants	3.350	670	509	1.520	651
Business services	3.560	1.424	406	1.211	519
Transportation & communication	100	40	11	34	15
Financial institutions	180	54	24	71	31
	13.950	**4.466**	**1.802**	**5.377**	**2.305**
		32%	*13%*	*39%*	*17%*
Industrial buildings (heated)	14.400	11.500	2.100	600	200
Warehouses (heated)	4.600	3.680	690	161	69
Agriculture (heated)	3.600	2.700	600	0	300
	22.600	**18.850**	**1.700**	**1.225**	**825**
		83%	*8%*	*5%*	*4%*
Total	**67.720**	**40.797**	**12.546**	**10.245**	**4.933**
in % of total		*60%*	*19%*	*15%*	*7%*

For the share of mechanical ventilation the most optimistic (highest) penetration was assumed in case there were no concrete data (see fig. 3-28). This gives a very conservative estimate of the energy saving potential, but at least it avoids pointless disputes over market penetration data where none are available.

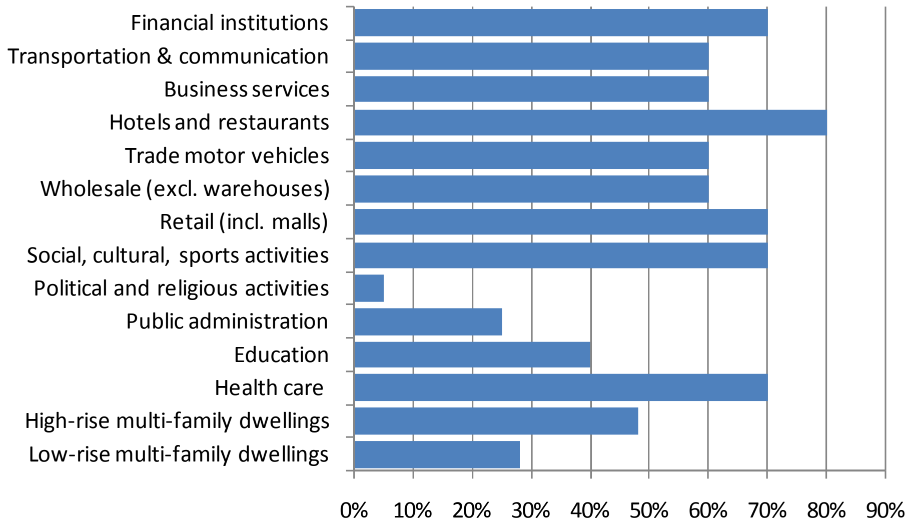

Figure 3 -28. Assumed market penetration of mechanical ventilation per sector

Taking the example of multi-family buildings it is estimated that some 30% has to be added for the ventilation of unheated parts of the buildings (staircase, entrance, service area, corridors, etc.). This will be a bit less for the tertiary sector and substantially more for industry buildings. All in all, this would bring the total ventilation to 88 bln. m³ (20 bln. m³ extra). If this ventilation is mechanical (assumed 40%), then it is estimated that it will be simple rooftop fans (exhaust). This means that around 8 bln. m³/h are to be added to the capacity of the rooftop/boxed fans, bring the total of this category to around 20-25 bln. m³/h.

Linking these categories to the number of units estimated to be on stock in chapter 2.1 we find the following

In multi-family dwellings and non-residential buildings **<u>rooftop/boxed fans</u>** represent a total capacity of 20 bln. m³/h. At on average 820 m³/h per unit a conservative estimate results in 24 mln. units installed in the EU-27. This is 44% of the total calculated stock of 55 mln. units (see Chapter 2.1). This means that a stock of around 30 mln. should be in individual dwellings or in some miscellaneous applications.

The AHU's in multi-family dwellings and non-residential buildings represent a total capacity of 15,2 bln. m³/h. This is based on the assumption that the capacity corresponds with the air exchange requirements according to building standards. The task 2 report finds a stock of 3,1 mln. units and a total capacity of 25,5 bln. m³/h (see Chapter 2.1). The 1,67 factor difference between the two numbers can be the result of inaccurate estimates, but in reality it can easily be explained by the fact that most installations are designed for operation at 60% part load (at which the pressure still must be sufficient) and a certain amount of duct leakage (at least 10% leakage, but increasing the fan-load by 33%).

Of the AHU stock of 15,2 bln. m³ operational capacity it is estimated that a little less than one-third are heat recovery units. This means that for the 10 bln. balanced units without heat recovery there is a significant energy saving potential by a relatively simple retrofit. But it should also be remembered that for 30% of balanced units that have separate locations it might be a little more expensive.[30]

Finally, the high share of natural ventilation, especially in the public sector, promises that there is a substantial potential for energy saving.

[30] Beck, dissertation, 2000.

4 Subtask 3.3 End-of-life behaviour

4.1 Miscellaneous

4.1.1 End-of-life and other LCA-inputs

The following information was received through the Lot 6 information request:

Carrier

Taking the example of a Carrier air-cooled chiller, its composition is the following:

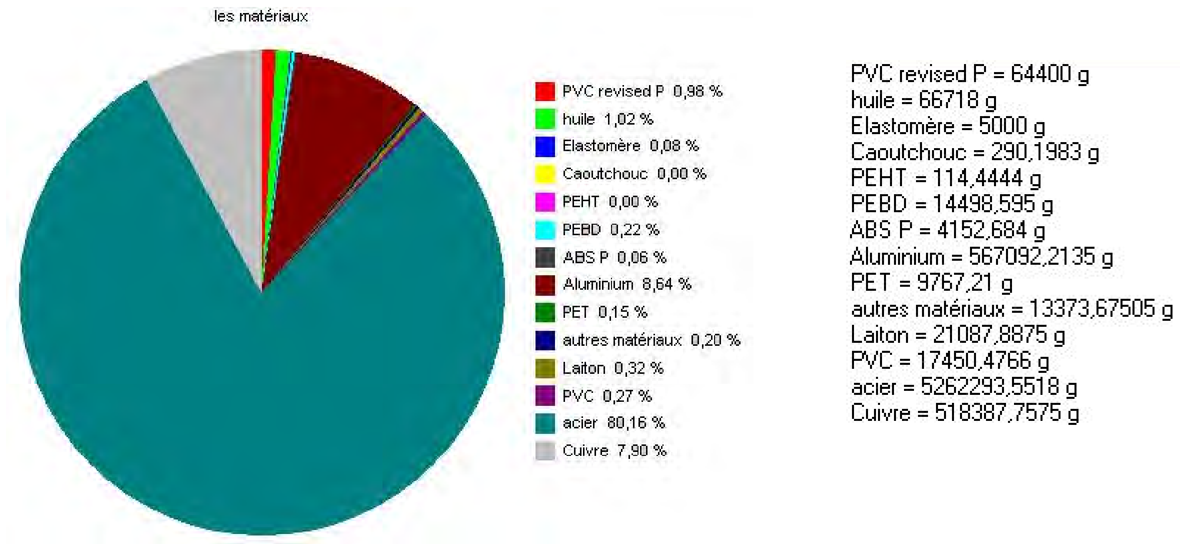

Figure 3 - 29. Bill-of-Materials air-cooled chiller (source: Carrier, 2010)

At the end of lifetime, the chillers are all dismantled; lots of components are recycled for their materials.

- Compressors: as a majority of steel and iron - **Materials recycling**
- Cooler is composed of steel and copper - **Materials recycling**
- Coils standards: tubes (copper) and fin (aluminium) strongly fixed together – **Crushing.**
- Coils MCHX, 100% Aluminium - **Materials recycling.**
- Oil separators : a majority of steel - **Materials recycling**
- Box ventilators: electric motor (**Components recycling)**, frame is **recycled** and not fans (PVC P with glass fibre).
- All the frame, panels and sound enclosure are in steel - **Materials recycling**
- Piping’s are composed of cooper or steel - **Materials recycling**

- Subset economiser: mix of steel and copper strongly fix – **Crushing.**
- Electric & Regulation box: Only steel box is **recycled,** all electronic components are **crushed.**
- Oil, valves and insulation are not recycled.

"Regarding information about the ecological impact of the production facilities, this topic is covered within the UTC group with clear reduction targets (for energy use, greenhouse gas emissions, water and waste) based on metrics that are considered in absolute terms and not as a percentage of the production. The baseline that has been considered is 2006 figures and reduction targets (i.e. – X%) have been defined to be reached in 2010. For instance, if water usage in 2006 was 100 and the reduction target is -20%, it is expected from the facility that the water usage will be 80 in 2010.

The information about targets and the action plan that is in place to achieve these is communicated to the workers and these are informed about the impact that they can have on these metrics. This contributed to generation of new ideas such as the reduction of the air pressure in the compressed air network. A reduction of 1 bar corresponds to a 7% reduction on the electrical consumption of the air compressors. In Montluel, the pressure has been decreased by 2 bars without any sensible impact of the efficiency of the tooling using the compressed air.

CO_2 emissions of the factories are also evaluated and targets for reduction are set. In Montluel, an environmental policy has been developed that focused on both the quantity and the quality of energy used. This led to the development of a sourcing contract with GDF Suez for electricity supplied at 100% by renewable energy sources (hydraulic electricity in this case). This 100% coverage is certified by TÜV-Noard. With this agreement, Carrier Montluel became the first industrial site in France to use green electricity and to have no CO_2 emissions linked to electricity."

4.1.2 Control settings

'Controls', i.e. the combination of central processor, sensors and actuators that regulate the airflow to the ventilated space(s), can be wholly or partially incorporated in the ventilation units put on the market and are therefore within the scope of the study. At the same time, it is acknowledged that often 'controls' are also at least in part supplied by external specialists (not the supplier of the ventilation unit) and thus an appropriate solution has to be found. Technical analysis of control solutions is subject of Task 4 (analysis base cases) and 5 (design options).

Task 3 deals with user behavioural aspects of those controls that require human intervention. This relates to the installer setting up the installation initially or the user discipline in setting manual (not automatic) controls.

There is no statistical information on these aspects.

Anecdotal data suggests that certainly not all installers set up the installation correctly, even if the hardware would allow –e.g. through dip-switches, an adjustment screw or software adjustments-- to regulate the flow rate in function of the installation pressure drop and the ventilation requirements. As with heating systems the priority of the installer appears to be instant customer satisfaction, i.e. an installation that works at a flow rate that under no circumstance gives complaints. This means that the upper limit to the ventilation rate is given by noise or cold drafts and the lower limit is given by odours or dampness felt by the occupants. As a rule-of-thumb this means that the installer sets the air flow at the design flow rate, i.e. at around 70% of the maximum flow at 0 Pa which is usually also 70% of the maximum pressure at 0 m^3/h, without actually taking into account the real system pressure drop or the ventilation requirement. There are no hard data, but experts[31] estimate that installers that do not regulate the fan speed of a 'fixed speed' fan installation miss out on around 33% saving, i.e. a (adjusted to the installation) fixed speed fan has a control factor 1 versus an (unregulated) "on/off" single speed fan with a control factor 1,33 due to over-sizing.

For Task 4 it will be assumed that the practice of unregulated single speed fans will occur in 50% of single speed fans, a solution usually found with exhaust ventilation in apartment buildings or older non-residential buildings. Hence, the aggregated control factor for single speed systems is assumed to be 1,16.

The normal situation for exhaust systems will be a 3-speed AC motor where the user (concierge or similar) has the option to manually regulate the system to the need, i.e. at least at a lower position or off at night and in the weekends. However, the likelihood that this will actually happen with a manual system is estimated at not more than 30%; already the fact that the occupants do not want to spend € 100 (or less) on a timer-device that would automatically realize this behaviour is a sign that it is perceived as a low priority.

For Task 4 it will be assumed that manual 3-speed systems will operate full-time at mid- to high position. The aggregated control factor is estimated at 0,9, i.e. at 90% of the design air flow rate[32].

More sophisticated Building Automation systems for AHU's, the use of local (per room) gas/humidity/occupancy sensors and actuators, etc. are believed to be still relatively rare (<20% of cases) but statistical data is lacking.

Technical details on control solutions will be elaborated in Task 4 to 6 (Technical Analysis, Best Not yet Available Technology BNAT). Classification of control types was given in the Task 1 report.

4.1.3 Climate & heat recovery

AL-KO THERM Gmbh

"For the study it is very important to consider the different climate zones of whole Europe. Energy efficiency of air handling units is mainly effected by the efficiency of air transport and energy recovery. The benefit of energy recovery depends on the climate data in different regions. It is easy to understand, that the efficiency of heat recovery is different in Scandinavia or Portugal. In our working group in the Eurovent certification company we did a lot of calculations concerning the relationship of energy recovery and different climate zones in Europe."

The following table is taken from the draft Working Document on Room Air-Conditioners DG ENER Lot 10 and the latest draft Working Documents on Boilers DG TREN Lot 1.

[31] E.g. Hartmann, ITG, Dresden.
[32] For comparison: an automatic timer-program the control factor is estimated at 0,75.

Table 3- 17 . ***– bin number j, outdoor temperature Tj in °C and number of hours per bin hj corresponding to the reference heating seasons “warmer”, “average”, “colder”***

COOLING SEASON		
j	**Tj**	**hj**
#	**°C**	**hrs**
1	17	205
2	18	227
3	19	225
4	20	225
5	21	216
6	22	215
7	23	218
8	24	197
9	25	178
10	26	158
11	27	137
12	28	109
13	29	88
14	30	63
15	31	39
16	32	31
17	33	24
18	34	17
19	35	13
20	36	9
21	37	4
22	38	3
23	39	1
24	40	0
total		2602

HEATING SEASONS		Warmer (W)	Average (A)	Colder (C)
j	**T_j**	**hj W**	**hjA**	**hjC**
#	**°C**	**hrs**	**hrs**	**hrs**
1 to 8	-30 to -23	0	0	0
9	-22	0	0	1
10	-21	0	0	6
11	-20	0	0	13
12	-19	0	0	17
13	-18	0	0	19
14	-17	0	0	26
15	-16	0	0	39
16	-15	0	0	41
17	-14	0	0	35
18	-13	0	0	52
19	-12	0	0	37
20	-11	0	0	41
21	-10	0	1	43
22	-9	0	25	54
23	-8	0	23	90
24	-7	0	24	125
25	-6	0	27	169
26	-5	0	68	195
27	-4	0	91	278
28	-3	0	89	306
29	-2	0	165	454
30	-1	0	173	385
31	0	0	240	490
32	1	0	280	533
33	2	3	320	380
34	3	22	357	228
35	4	63	356	261
36	5	63	303	279
37	6	175	330	229
38	7	162	326	269
39	8	259	348	233
40	9	360	335	230
41	10	428	315	243
42	11	430	215	191
43	12	503	169	146
44	13	444	151	150
45	14	384	105	97
46	15	294	74	61
	total	3590	4910	6446

4.1.4 Ductwork

Ductwork is not part of the scope of this study, but it does influence the ventilation requirement – and thus the energy requirement, because

a) leakages result in fresh air ending up in plenums and columns where they are of no use to good indoor air quality;

b) they are partly responsible for the external pressure difference that the ventilation unit has to overcome for an effective ventilation.

<u>Leakage</u>

There is anecdotal evidence that the air leakage in the ductwork can be up to 10% or more of the airflow.

Feedback from the Lot 6 stakeholder consultation, one of the manufacturers[33] states

"We propose to have a look to the tightness of the ducts. The leakage is sometime 10% and more of the airflow, resulting a 33% higher energy consumption of the fan.

My intention is to point at the problem with leak ducts and I hope you recognize the impact to the energy consumption of a ventilation system.

Please note, there is a study of the European commission.[34]., showing the situation and the consequences…. It is 10 years old, but there is no regulation.

So in 2007 more than a half of the installed ducts in Germany are not according to the valid norms."

Apart from the energy penalty of venting unnecessary space, leakage has a number of other negative side-effects, e.g. more noise, sub-optimal air distribution, entry of pollutants, reduction of heat recovery efficiency, etc..

Causes of leakage can be duct-damage during shipping and mounting, corrosion or faulty installation work (esp. at joints).

Relevant standards for the materials are EN 1507 and EN 12237, but probably more important is a thorough check at acceptance of the installation, i.e. as described in EN 12599 and EN 14134 (see Task 1 report). EUROVENT publishes guidelines 2/2 on air leakage of ducts, which give test procedures and also define 3 leakage classes (A, B, C) based on a leakage coefficient K per m² of duct surface.[35]

At national level, many Member States have standards in place.[36]

For the definition of base-cases in Task 4, a leakage rate of 10% of the air-flow (and 10% of pressure drop) is assumed for ductwork. Following the fan laws this means indeed an electricity consumption of the fans up to 33% higher than is theoretically (at zero-loss) necessary.[37]

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[33] Lindab GmbH

[34] Carrié et al. (ed.), Improving Ductwork, study in the framework of the European Commission Energy Conservation in Buildings Programme, 130 pp., AIVC / SAVE-DUCT, 1999.

[35] Carrié et al. (ed.), Improving Ductwork, study in the framework of the European Commission Energy Conservation in Buildings Programme, 130 pp., AIVC / SAVE-DUCT, 1999.

[36] Ibid. 33.

[37] Calculation: $1 – 0{,}9^3 = 0{,}271$ (27%) without motor and drive losses

Pressure drop

The friction losses and turbulence in ductwork is a significant part of the external pressure drop that the ventilation unit has to overcome. For a part it is certainly unavoidable, but also for a large part the installation designer plays an important role.

Schild[38] mentions e.g. that the lowest pressure drops can be achieved by exploiting building-integrated air transport conduits such as corridors, stair wells for air transfer, or underfloor air supply plenums [25]. However, mostly ductwork systems have become ubiquitous for other practical reasons.

The design of the duct system has a great impact on the ventilation function and fan energy. The duct path with the greatest flow resistance from the AHU to any terminal is called the '*critical path*'. This path determines the pressure drop in the whole duct network. If one changes the ductwork design along the critical path to reduce its pressure drop, the critical path may move to another terminal. The new critical path ductwork can, in turn, be modified to further reduce the system pressure drop.

Optimizing a duct system therefore involves a trial-and-error process whereby software is used to calculate the pressure drop for variations of the duct system. It is beneficial that the HVAC designer calculates pressure drop at an early stage in the project so that reasonable choices can be made about the location & size of technical rooms and the main service routes. The calculations should be updated in the detail design stage, and when later changes are made.

Figure 3.30 & Figure 3.31 show how the pressure drop in a duct network can be drastically reduced by small changes along the critical path.

Figure 3.30 is a poorly designed system. The total pressure drop of 168 Pa is determined by the pressure drop along the critical path to the 'index terminal' (fully open, with a pressure drop of 10 Pa). Over half of the total pressure drop is the result of two main branches (4-way 'X'-junctions) with poor aerodynamic form.

The total pressure can be more than halved by replacing these with 90° bends, and dimensioning the ductwork more generously using the *'⅓-Rule'* [39] (Figure 30). Fan power is more than halved as a result.

As guidelines for efficient duct design Schild mentions

- Try to minimize duct length and the number of bends, when designing the duct system.
- Use rigid-walled round ductwork, ideally with rubber gaskets. This has many advantages over rectangular ductwork, including lower pressure drop for a given weight/cost of duct, and less air leakage. Avoid extensive use of flexible ducting.

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[38] Schild, P.G, Mysen, M., Recommendations on Specific Fan Power and Fan System Efficiency, Technical Note AIVC 65, December 2009.

[39] The *⅓-Rule* for round ductwork: Duct diameter is kept constant along a duct until a branch (tee) flow rate exceeds ⅓ of the combined flow, in which case the duct dimension is reduced by 1 step downstream. The start of each duct branch is dimensioned for a given m/s or Pa/m. This duct dimensioning method gives results very similar to the static regain method. Static pressure is pretty constant along the duct, so little balancing is needed.
Straight main ducts should be sized so that the pressure drop is below 0.8 Pa/m. Bends and branches along the critical path should be chosen so that none exceeds 5 Pa loss. Moreover, the pressure drop for the index terminal should be selected to be as low as possible without compromising the needs for balancing and throw lengths. You should aim for a supply or return duct system total pressure drop of 150 to 250 Pa for large systems, and 70 Pa for dwellings.

- Use optimal components along the critical path. In particular, use bends instead of tees. If possible, use two 45° bends instead of a 90° elbow. Two 90° bends in series should have a distance of at least three times the duct diameter.
- Use ATDs with a pressure drop of ≤ 30 Pa. Low velocity supply terminals for displacement ventilation operate with lower pressure drop than high velocity jet supply terminals for mixing ventilation.
- Any balancing dampers along the critical path should be fully open. Each duct run shall have at least one take-off (branch) that has a fully open damper/ATD or no damper at all. → In the case of CAV systems, this is achieved by balancing using the proportional method [37]. → In the case of VAV systems, this is achieved with SPR control.
- Dimension main ducts for a pressure loss of ≤ 0.8 Pa/m.
- Both supply and exhaust duct systems require regular inspection and cleaning. Failure to do so leads to both poor indoor air quality and higher flow resistance.

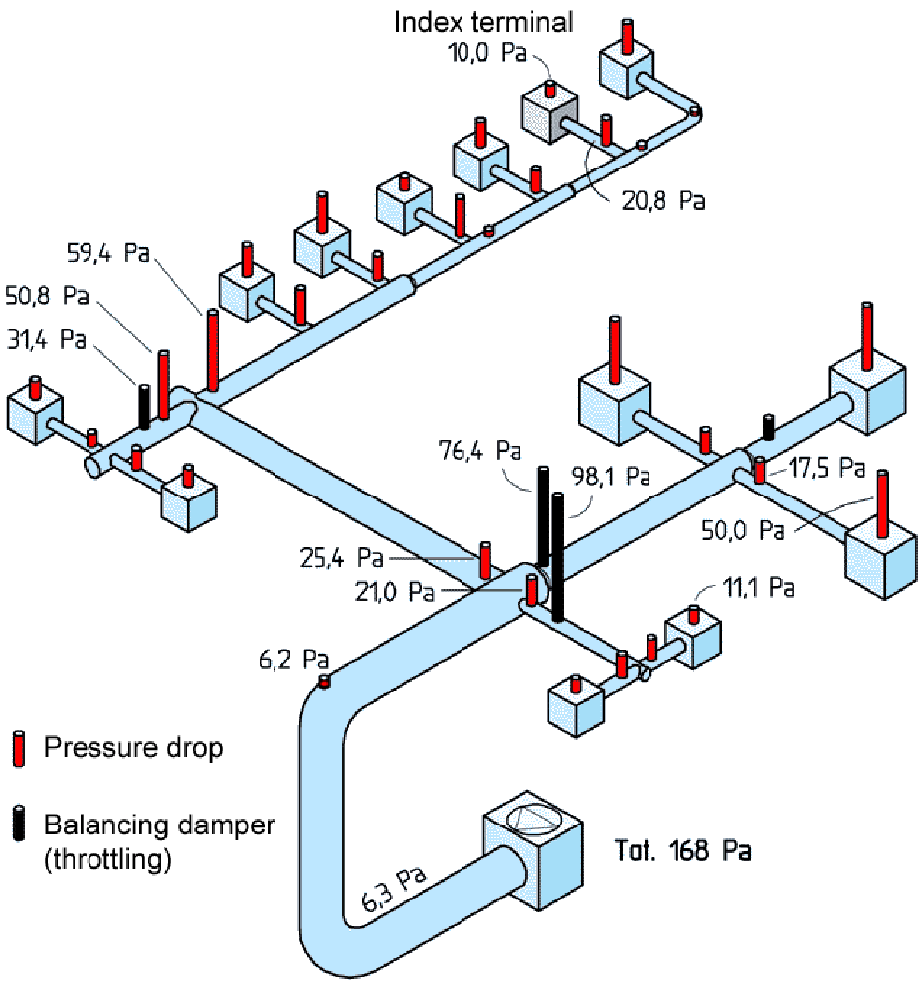


Figure 3 -30. Pressures in a poorly designed system. Required fan pressure is 168 Pa. Solution is very common. Heavy throttling of 2 dampers may necessitate extra silencers. The critical path is shown by a dashed line [source SINTEF]

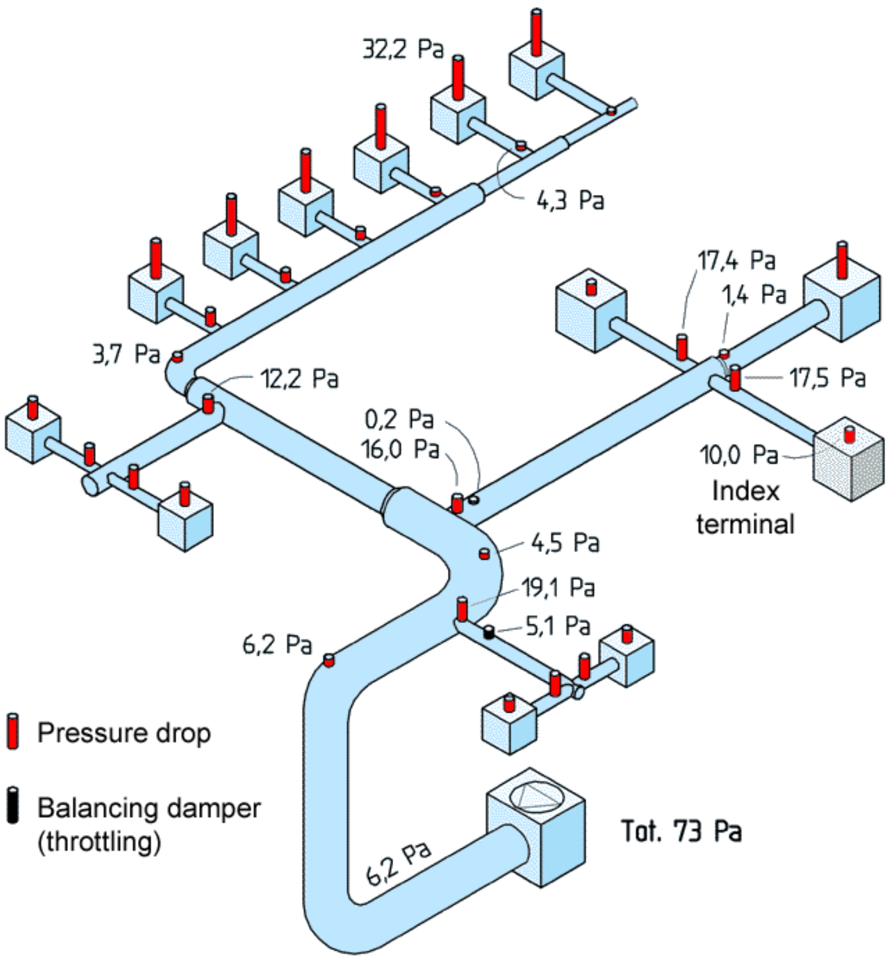


Figure 3 - 31. Optimal solution. Pressure drop is slashed from 168 Pa to 73 Pa. Observe that the pressure drop reduction measures have moved the critical path (Index ATD has Δp = 10 Pa). The amount of throttling/ balancing is reduced, which further reduces noise. The system does not need balancing dampers, simplifying commissioning and further reducing noise [source SINTEF]

For the base-cases in Task 4 it is assumed that the pressure drop of the ductwork is taken into account correctly when calculating the external design pressure drop.

For the design options in Task 5 it is relevant that the (face) air velocity is very important for the noise production.

4.1.5 Supply inlets and exhaust outlets (incl. roof stacks)

Supply inlets and exhaust outlets are again not in the product scope, but excessive pressure loss and possible short-circuiting may be having a negative impact on ventilation requirements.

Jet roof stacks (jet hoods; Figure 32) are often used as high-velocity exhaust air outlets to prevent the risk of the exhaust air mixing with fresh intake air. Jet stacks are often dimensioned with the pressure loss of over 100 Pa, which causes a significant rise in fan energy [SFP increases by +0.2 kW/(m^3/s) assuming 50% fan system efficiency]. One should rather locate the outlet at a sufficient distance from the air intake so as to render a jet stack unnecessary, without using long ducts for air inlet and outlet (e.g. guidelines in Appendix A of EN 13379). Moreover, alternative stack designs are available with low pressure loss (e.g. Figure 32, right).

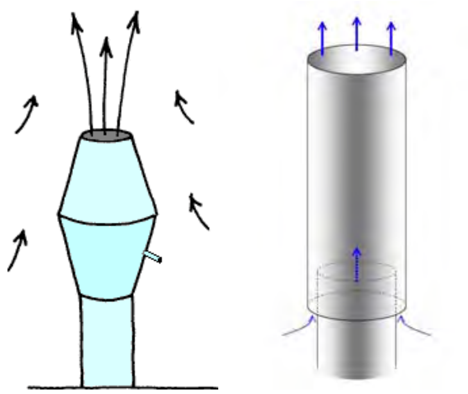


Figure 3 - 32. (Left) jet stack with high pressure loss (right) exhaust stack with low pressure loss. Both stacks have drainage for rain [Figs. SINTEF]

If use of jet stack is unavoidable, such as for laboratory ventilation, they should be selected with as little outlet velocity as possible without risk of short circuiting to air intakes.

Schild[40] recommends locating air intakes and exhausts so as to prevent short-circuiting from exhaust to inlet, while keeping the inlet & exhaust ducts as short as possible. And if high-velocity jet stacks are unavoidable, try to design to keep the pressure drop as low as possible (maximum 50 Pa).

4.1.6 Silencers (attenuators)

Silencers are not in the scope of the study, because they are delivered as a separate accessory to air handling and ventilation units. Yet, they contribute to the external pressure loss and are therefore briefly discussed here as part of the system.

The relationship between changes in air velocity and noise generation in ductwork is:

$$\Delta L_w = 10 \cdot \log\left(\frac{v_2}{v_1}\right)^6 \text{ [dB]}$$

where

ΔL_w = change in sound power level [dB]

v_1 = original air speed [m/s]

v_2 = new air speed [m/s]

This means that a 25% reduction in velocity results in approx. 7 dB less generated noise which corresponds to the noise reduction in a 0.5 meter long silencer.

In practice, this means that systems with low SFP have less problems with generated noise and thus less need for silencers in the system (cross-talk can be more problematic, however, due to easier noise propagation in wider ducts).

[40] Ibid. 36

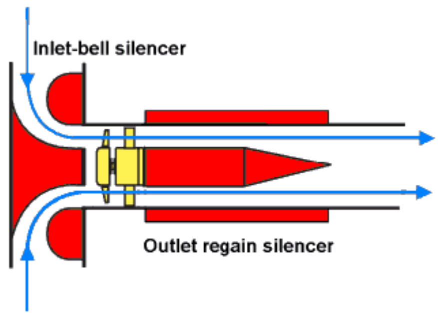
Figure 3 - 3313. (a) Rectangular silencer with baffles/splitters (b) Circular silencer without baffles [source: Lindab]

Ventilation noise should ideally be attenuated/ avoided at source. For this reason, noise reduction can either be central at the AHU (fan noise), or local in the ductwork (flow generated noise):

AHU silencers (central noise reduction)

Standard AHU silencers with internal baffles can have a pressure drop of 50 to 100 Pa (Figure 33). This is often unnecessarily energy-intensive. A better alternative is low pressure-drop silencers fitted immediately after the fan:

Inlet bell silencers and *outlet regain silencers* have optimal aerodynamic form (fig. 34). Outlet regain silencers also regain much of the fan dynamic pressure (velocity pressure) as static pressure. This reduces the system-effect pressure drop compared to AHUs without static pressure regain after the fan. For best performance, these attenuators should be custom designed for, and possibly integrated into, the AHU.



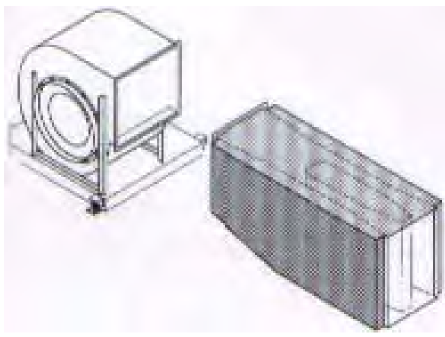


Figure 3 - 34. (a) axial fan with inlet-bell and outlet regain silencers (coloured red) [source M&I Air Systems Engineering] **(b) centrifugal fan with outlet regain silencer**

Mass-produced silencers: There are also more conventional ductwork AHU silencers with minimal inlet and outlet loss because of their shape (e.g. Figure 34b). Such silencers can be sized for a maximum pressure drop of 20 Pa.

If there are duct bends near the fan inlet or outlet, it might be appropriate to use a circular elbow silencer or rectangular bend with curved baffles or acoustic turning vanes.

Duct silencers (local noise reduction)

A duct silencer is in principle a duct component with its inside surfaces covered with sound absorbing material. The silencer should have the same internal free area as the connecting ductwork, so as to minimise flow resistance. The silencer should be accessible for inspection and cleaning. Silencers with baffles obstruct cleaning (Figure 30).

Schild gives the following recommendations for silencers:

- Calculate noise levels, ideally with the same software that is used for duct system design and pressure drop calculations. Ventilation systems with low pressure-drop have little noise.
- AHU silencers should have maximum 20 Pa pressure drop. Ideally, try to select or custom-build aerodynamically shaped AHU regain silencers that give static pressure regain after the fan.
- Select duct silencers that are as long as possible.
- The need for noise attenuation is less stringent in energy-efficient ventilation systems with a low velocity and good aerodynamic solutions.

EN 13779 mentions an average pressure drop of 50 Pa for a silencer (low 30, high 80 Pa), i.e. significantly higher than the 20 Pa recommended by Schild.

For the base-cases in Task 4 it is assumed that the pressure drop of the silencer is taken into account when calculating the design pressure drop.

For the design options in Task 5 it is relevant that the (face) air velocity is also very important for the noise production (synergy effect).

4.1.7 Air Terminal Devices

Air Terminal Devices (ATDs) may comprise diffusers, grilles, dampers or any other device that marks the entry or exit point of ventilation air in the ventilated space.

For systems that combine ventilation with cooling/heating also VAV (Variable Air Flow) or CAV (Constant Air Flow) boxes can be added to the list. The discussion of these latter devices, that currently are not part of the ventilation unit packages, will take place in the report on Air Conditioning Systems.

ATDs are not usually part of the ventilation units put on the market by one single manufacturer and therefore not in the scope of the study. In the future, this may change e.g. if and when the ventilation unit manufacturers explore further the possibility of combining central control with local active actuators (such as VAV-boxes) and local sensors. This will be discussed in Tasks 5 and 6.

For the purpose of the underlying study, the role of ATDs is limited to being just one of those many items in an installation system that may contribute to the external pressure drop.

EN 13799 mentions values of 50 Pa on average (30 low, 100 Pa high; see Task 1 report), but clearly these values apply to larger non-residential units, e.g. VAV boxes. For small ventilation systems and simple grilles values of around 10 Pa will be more to the point.

Figure 3 - 17. Diffuser (simple ceiling type)

Figure 3 - 17. Damper (motorized butterfly valve)

Figure 3 - 17. Indoor grille with connection to oval duct

Figure 3 - 17. Outdoor grille with silencer, integrated in window frame. For natural air supply in case of mechanical exhaust systems (system "C")

5 Case studies

5.1 Introduction

In preparation of Task 4, Armines has defined a number of case studies on typical buildings in the EU building stock. The cases relate to a

- *Large office buildings (type 1)*
- *Medium-sized office building (type 2)*
- *Small office building (type 3)*
- *Hospital*
- *Retirement home*
- *Hotel*
- *Shopping mall*
- *Hypermarket*

The definition entails not only dimensions and physical characteristics, necessary for the calculation of the cooling load in the air condition part of the study, but also design ventilation rates (from French building standards, but very similar to EN 13799, see Ch. 2.1, par. 2.1.2) as well as representative usage and occupancy rates.

Calculation of the cooling loads of these buildings and a discussion of the consequences for air conditioning systems takes place in the Lot 6, Task 3 report on air conditioning systems.

The underlying study concentrates on the results for ventilation. The following paragraphs give an overview of characteristics and design ventilation rates per building. The final paragraph gives an overall calculation.

5.2 Office type 1: Large office building

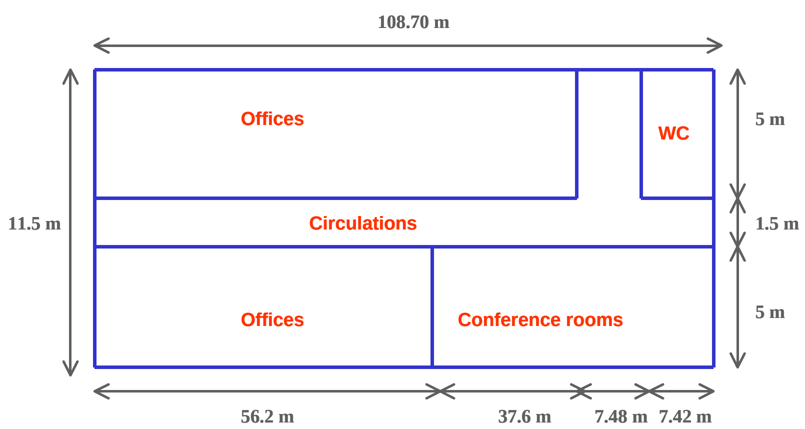


Figure 3 - 18. Overview Large office building

The large office building (type 1) has 12 floors and is being used during weekdays from 06.00h – 20.00 and is closed in the weekends. On each floor there is surface area divided in offices, conference rooms, toilets and circulation area.
The average occupation rate of the offices during working days 6.00h – 20.00h (14 hours) is 0,56 (see figure 3-41). For the conference rooms an average occupation rate of 0,5 is calculated (see figure 3-42).

Around 500 people use this office building during working hours.[41] Design air flow rate is 45.750 m^3/h, based on the accumulated maximum number of occupants in the office zone (750 pp at 25 $m^3/h/pp$), the conference rooms (900 at 30 $m^3/h/pp$) and a constant air flow for toilets (3.000 m^3/h).

An overview of these numbers is given in the table 1 below.

Figure 3 - 40. Overview data base cases office building

	Large office building	Medium office building	Small office building
Number of floors	12	4	2
Floor height (m)	3	3	2,7
Surface area of one floor *(m^2)*	1.250	1.250	396
Surface area of total building (m^2)	15.000	5.000	1.008
Volume *(m^3)*	45.000	15.000	2.721
Infiltration rate *($m^3/h/m^2$)*	1,12	1,14	1,77
Ventilation rate			
Offices (m^3/h/person)	25	25	25
Conference rooms (m^3/h/person)	30	30	30
Operating hours ('on')	14	14	14
Supply air *(m^3/h)*	18.750	5.800	1.200
Exhaust air *(m^3/h)*	18.750	5.800	1.200
AHU (supply = exhaust) *(m^3/h)*	27.000	9.300	1.530
Total air supplied or exhausted (*m^3/h*)	45.750	15.100	2.730
Avg. actual occupancy rate when 'on'			
Offices	0,56	0,56	0,56
Conference rooms	0,5	0,5	0,5
Average number people in the building	500	Between 50 and 250	<50
Design occupancy (max no. of persons)	1650	542	99
Actual peak occupancy	0,8	0,8	0,8

[41] Occupancy conference room multiplied by occupation rate + 10%

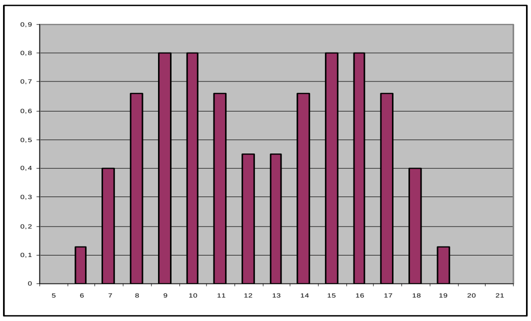


Figure 3 -41. Average occupation office type 1,2,3

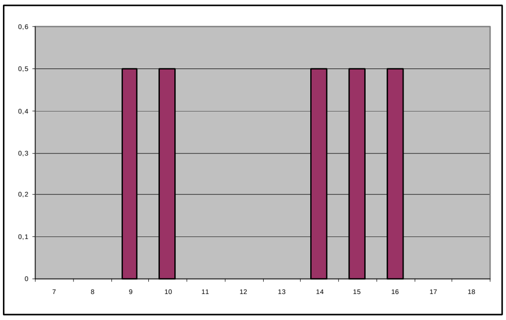


Figure 3 -42. Average occupation conference room Type 1,2,3

5.3 Office type 2: Medium-sized office building

The medium sized office building (office type 2) has 4 floors and is being used during weekdays from 06.00h – 20.00 and is closed in weekends. On each floor there is surface area divided in offices, conference rooms, toilets and circulation area.

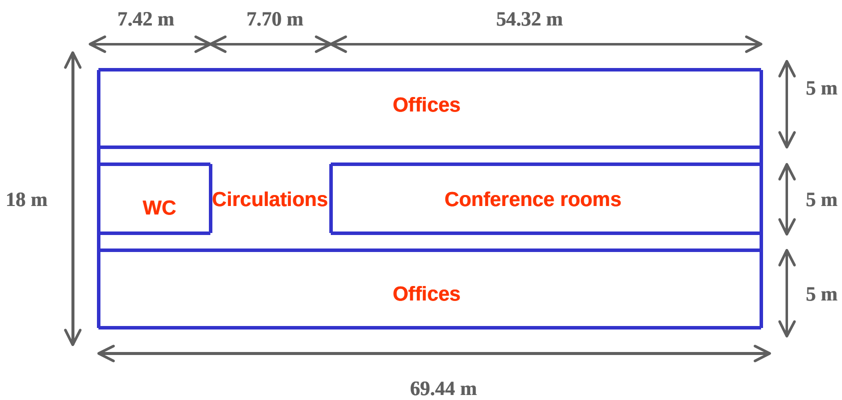


Figure 3 - 19. Overview medium sized office building

The average occupation rate of the offices during working days 6.00h – 20.00h (14 h) is 0,56 (see figure 3-41). For the conference rooms an average occupation of 0,5 is calculated (see figure 3-42).

In a medium sized office building between 50 and 250 people are present during working hours. The design air flow of the ventilation units is 15.100 m³/h, based on the accumulated maximum number of occupants in the office zone (232 pp at 25 m³/h/pp), the conference rooms (310 at 30 m³/h/pp) and a constant air flow for toilets (1.000 m³/h).

An overview of these numbers is given in Figure 3.40.

5.4 Office type 3: Small office building

The small sized office building (type 3) has 2 floors and is being used during weekdays from 06.00h – 20.00 and is closed in weekends. On each floor there is surface area divided in offices, conference rooms, toilets and circulation area.

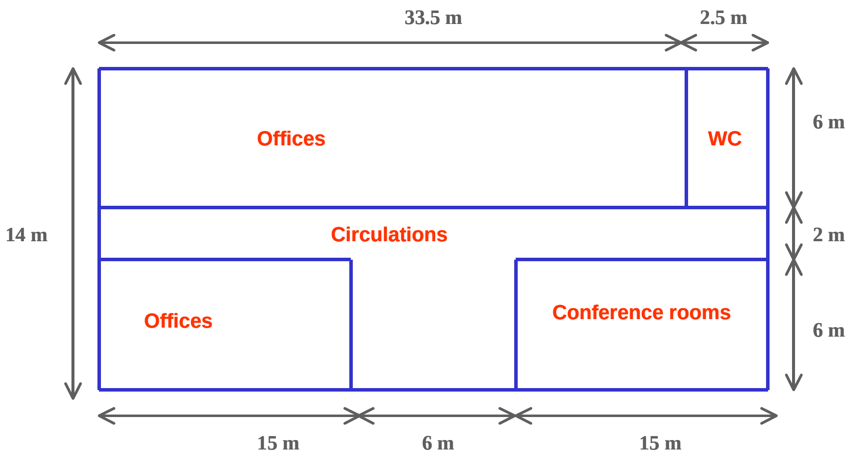


Figure 3 - 44. Overview small sized office building

The average occupation rate of the offices during working days 6.00h – 20.00h (14 hours) is 0,56 (figure 3-41). For the conference rooms an average occupation of 0,5 is calculated. (Figure 3-42)

Not more than 50 people are working in this office building.[2] Design air flow is 2.730 m³/h, based on the accumulated maximum number of occupants in the office zone (48 pp at 25 m³/h/pp), the conference rooms (51 at 30 m³/h/pp) and a constant air flow for toilets (200 m³/h).

An overview of these numbers is given in Figure 3-40.

5.5 Hospital

The hospital in the base case scenario has 5 floors and is used 24 hours a day 7 days a week. Only the operating theatres are assumed to be in use only 12 h/day and have ventilation switched off outside these hours (see also figure 3.49: occupation operations room).

On each floor the surface area is divided in:

- toilets
- offices, consultation room, emergency room
- bedrooms
- circulations
- operations room
- laboratories, restaurant, technical annexes.

An overview of the surface area is given in figure 3-45. The average occupation of the offices, consultation room, and emergency room during working hours (168 hours/week) is 0,38 (see figure

3-47). For the laboratories, restaurant, technical annexes an average occupation rate of 0,63 is calculated (14 hours operative, see figure 3-48). The operating theatre is in use 12 hours a day with an average occupation rate of 0,68 (see figure 3-49) and finally the bedrooms have a 24h occupancy rate of 0,42 (see figure 3-50). During workdays around 660 people are in the hospital working, visiting or as patient. Design ventilation requirement is 179.529 m³/h, mainly (86%) caused by laboratories and operating area. Table 3-18 gives an overview.

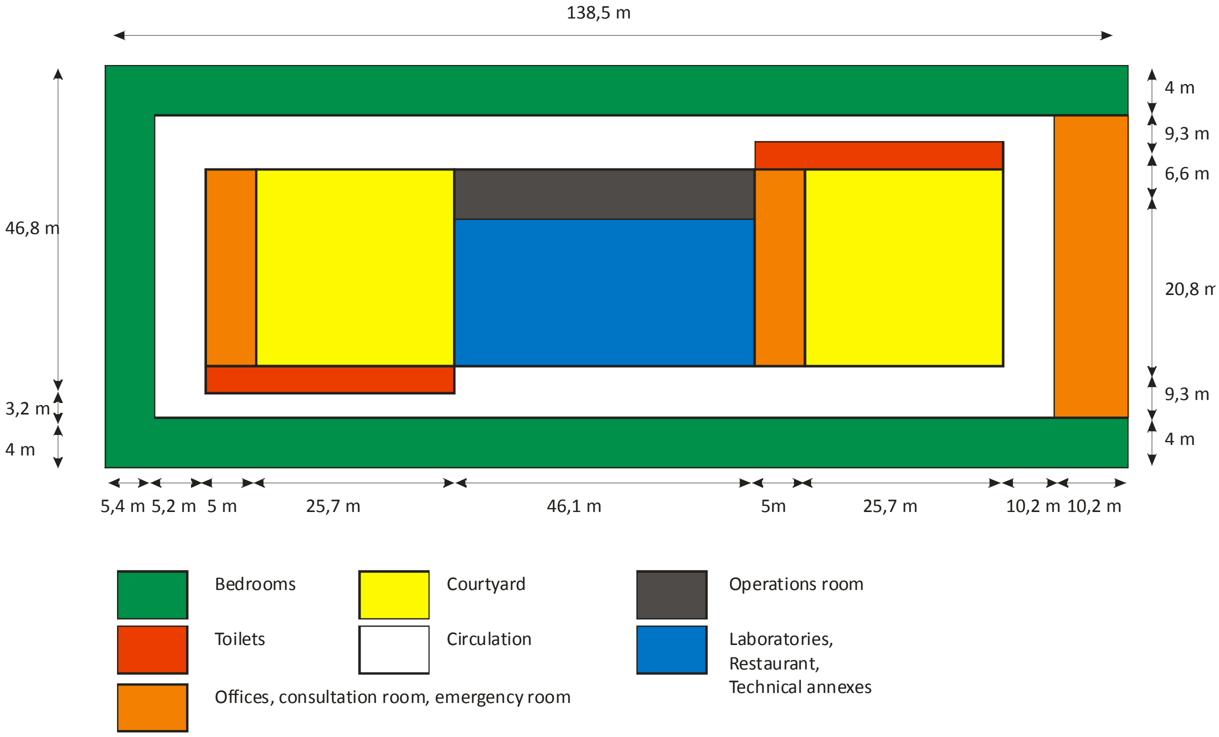


Figure 3 - 20. Plan hospital

Table 3- 18: Overview data base cases hospital

	Hospital
Number of floors	5
Floor height (m)	3
Surface area of one floor ***(m^2)***	6.069
Surface area of total building (m^2)	30.345
Volume ***(m^3)***	91.035
Infiltration rate ***($m^3/h/m^2$)***	1,20
Ventilation rate	
Offices and bedrooms (m^3/h/person)	25
Laboratories ($m^3/h/m^3$)	6
Operation rooms ($m^3/h/m^3$)	15
Operating hours	168
In study scope: design air flow ***(m^3/h)***	24.769
Out of scope (lab & OR) design air flow:	
AHU (supply = exhaust) *(m^3/h)*	154.760
Total supplied/ exhausted	179.529
Average number people in the building	660

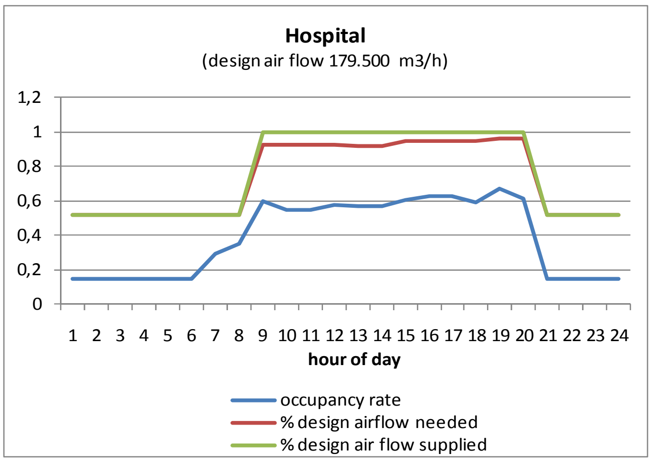


Figure 3 - 21. Hospital: occupancy rate weighted by m²; % air flow needed and % actually supplied.
Note that the lab takes up 48% during 24h. During the day, lab and operating area constitute 86% of air flow need.

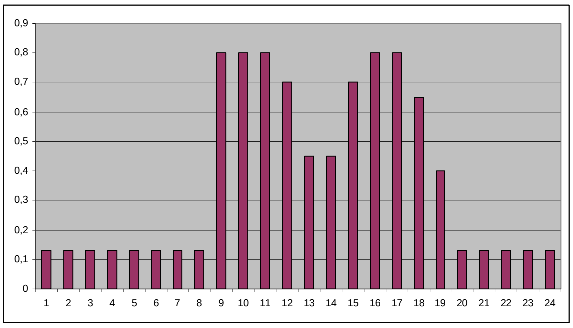


Figure 3 - 24. Occupation offices, consultation room and emergency

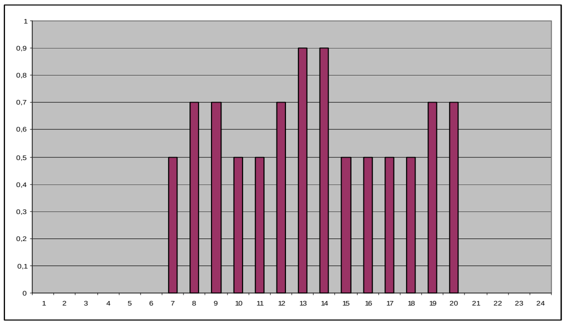


Figure 3 - 24. Occupation laboratories, restaurant, technical annexes.

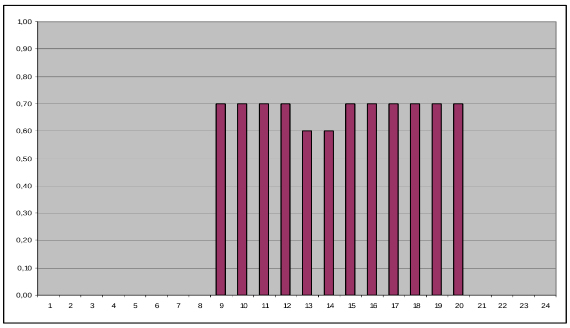


Figure 3 - 49. Occupations Operations room

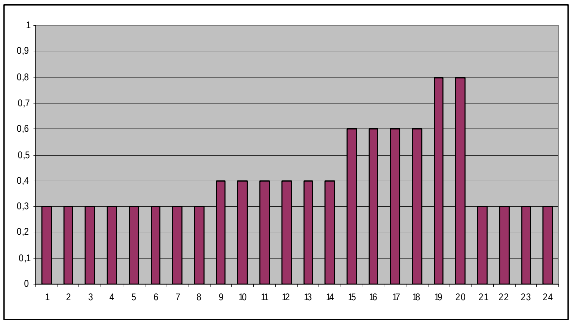


Figure 3 - 240. Occupation Bedrooms

5.6 Retirement home

The retirement home has 4 floors and is used 24 hours a day, 7 days a week. On each floor the surface area is divided in:

- bedrooms
- circulations
- technical premises
- nursing room
- common room
- restoration
- toilets.

Figure 3-51 shows the surface area.

The average occupation rate of the bedrooms (168 hours 'on' a week) is 0,59. (see figure 3-52) For the nursing room an average occupation rate of 0,45 is calculated (84 hours in use, see figure 3-53). The common room is in use 12 hours a day with an average occupation rate of 0,68 (see figure 3-54) and the restaurant's occupation rate is 0,72 (see figure 3-55). During workdays around 100 people are in the retirement home, between occupants, staff and visitors. Design air flow is 8.154 m³/h, based on accumulated maximum occupancy per zone (90 in bedrooms, 96 in common room, 48 in restaurant all at 25 m³/h) and a fixed flow of 2.304 m³/h for the nursing room during 12 h/day. Table 3-19 gives an overview.

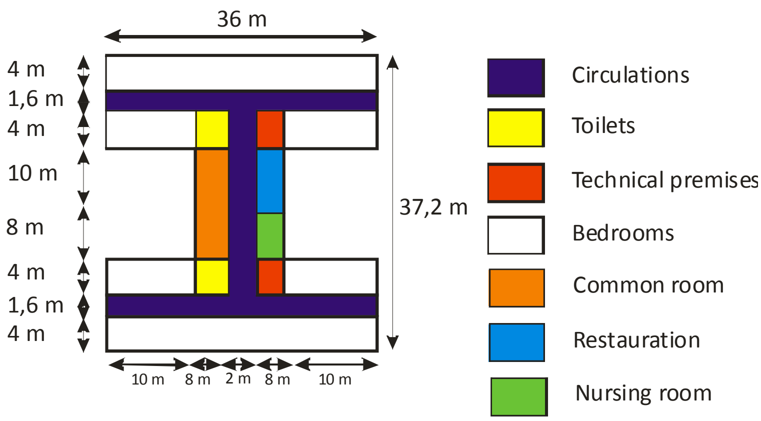


Figure 3 - 25. Overview retirement home

Table 3- 19. Overview data base cases retirement home

	Retirement home
Number of floors	4
Floor height (m)	3
Surface area of one floor *(m²)*	979,2
Surface area of total building (m²)	3.916,8
Volume (m³)	11.750,4
Infiltration rate *(m³/h/m²)*	1,2
Ventilation rate	
Offices and bedrooms (m³/h/person)	25
Nursing room (m³/h/m³)	4
Operating hours	168
Supply air *(m³/h)*	5.850
Exhaust air *(m³/h)*	5.850
AHU (supply = exhaust) *(m³/h)*	2.304
Total supplied/ exhausted (m³/h)	8.154
Average number people in the building	100

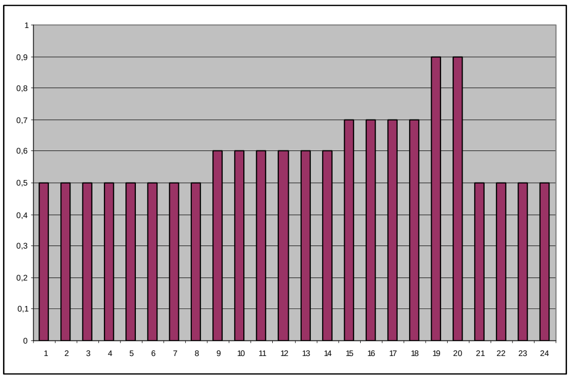


Figure 3 - 52. Occupation Bedrooms

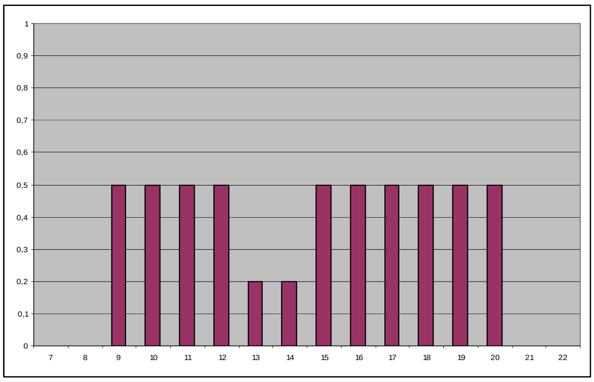


Figure 3 - 53. Occupation nursing room

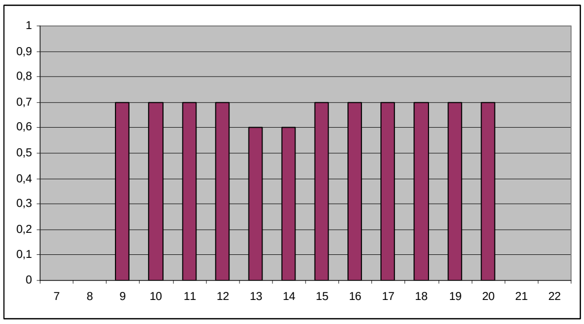


Figure 3 - 54. Occupation common room

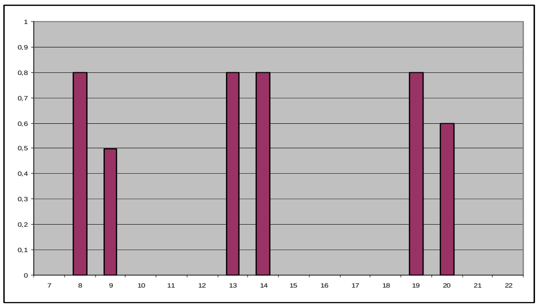


Figure 3 - 55. Occupation restaurant

5.7 Hotel

The hotel case has 4 floors, on the ground flour the restaurant, kitchen, passages, offices, hall and utilities can be found. On the 3 storeys above the bedrooms, toilets and passages can be found. The hotel is run permanently all week long (168 hours). Plans of ground- and upper floors are given in figure 3-56.

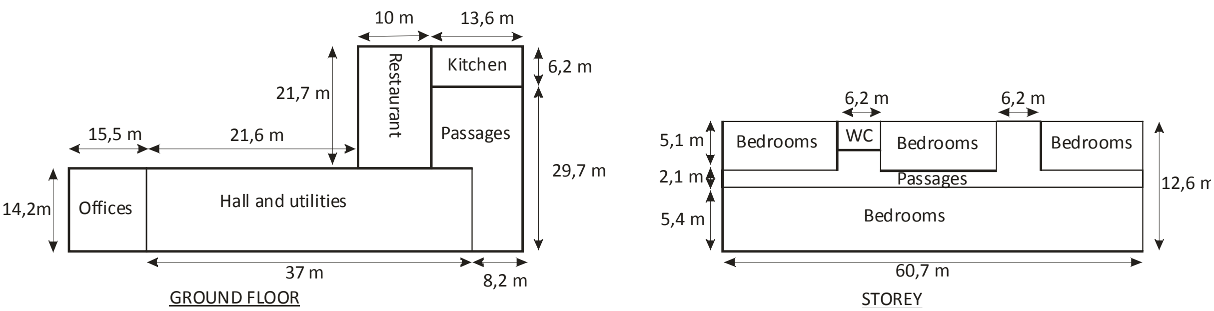


Figure 3 - 56. Overview hotel

Design air flow rate is 17.475 m³/h, based on the accumulated maximum number of occupants in the office & passage (75 pp at 25 m³/h/pp) and lobby, restaurant, kitchen (total 175 pp) and bedrooms (345 pp, in total 520 pp at 30 m³/h).

The average occupation of the offices and passages during working hours (9 hours a day) is 0,48 (see figure 3-57). For the restaurant and lobby an average occupation of 0,40 is calculated (70 hours in use during a week, see figure 3-59). The kitchen is in use 14 hours a day with an average occupation rate of 1,00 (see figure 3-60) and the occupation rate of bedrooms and passages can be seen in figures 3-58 and 3-61. The bedrooms (figure 18) are used 16 hours/day an average occupation rate of 0,30. [42] The weighted average occupancy rate (and % of design air flow rate) is thus 0,34 during

[42] The passages on the hotel-room floors are used all week with an average occupation rate of 0,75, but this is not a part of the design air flow calculation

'on' hours. The weighted 'on' time is 0,56 (13,35 h/24h), so the 24h average occupancy (and % of design air flow rate) is 0,19. Given that the ventilation system runs full time at design air flow, this means a theoretical saving potential on the air flow of 81%. Further characteristics are given in table 3-20 below.

Table 3- 20. Overview data base cases hotel

	Hotel
Number of floors	4
Floor height (m)	
Ground floor (Kitchen and Restaurant)	2.2
Ground floor (Hall and utilities, offices and passages)	3.2
Storey	2.5
Surface area of one floor *(m^2)*	2.139
Surface area of total building (m^2)	3.668
Volume *(m^3)*	9.832
Infiltration rate *($m^3/h/m^2$)*	1,2
Ventilation rate	
Offices (m^3/h/person)	25
Bedrooms and Restaurant (m^3/h/person)	30
Operating hours	168
Supply air *(m^3/h)*	17.475
Exhaust air *(m^3/h)*	17.475

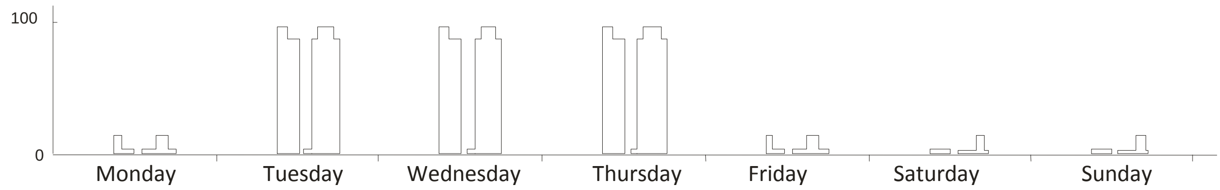


Figure 3 - 57. Occupation offices and passages

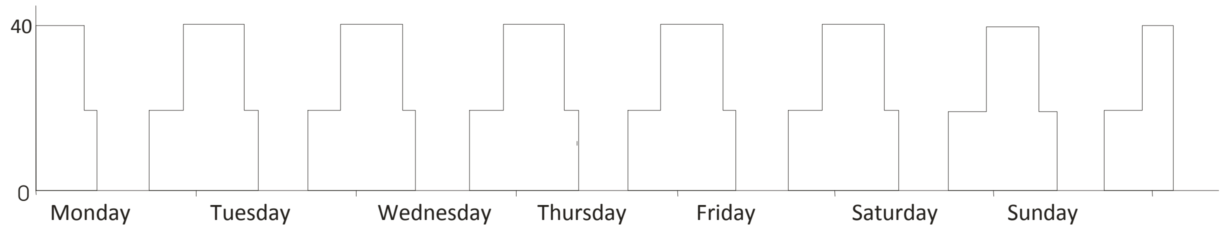


Figure 3 - 58. Occupation bedrooms

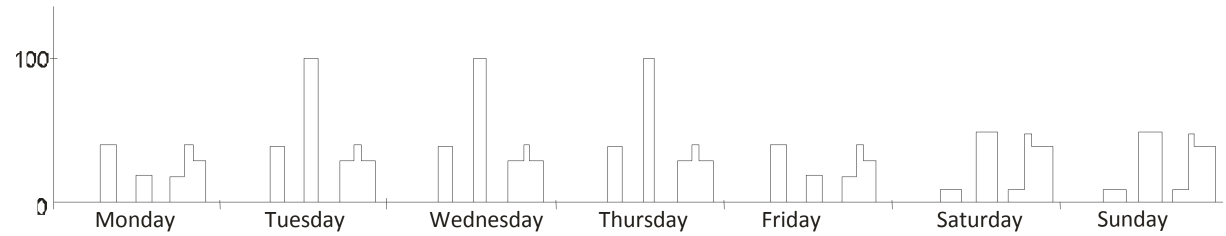


Figure 3 - 59. Occupation restaurant and lobby

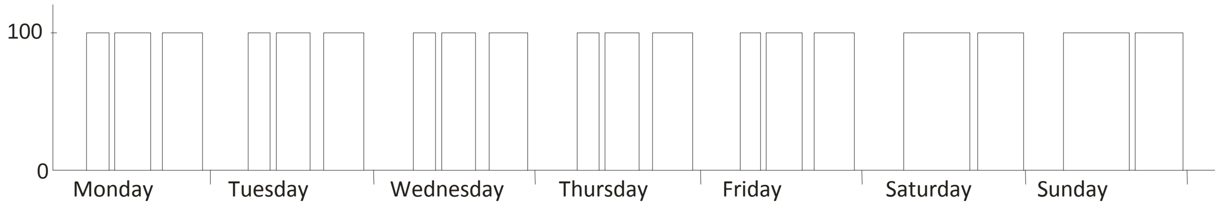


Figure 3 - 60. Occupation kitchen

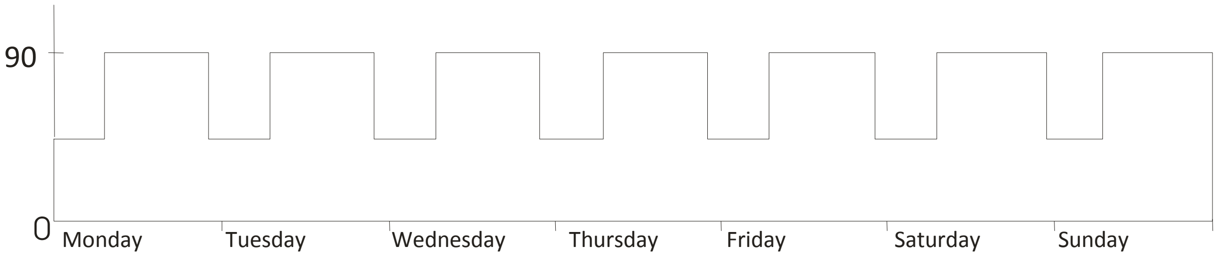


Figure 3 - 61. Occupation passages (storeys)

5.8 Shopping mall

The shopping mall has 1 floor, incorporating shops, toilets, hall, cinema and technical utility room can be found. The shopping mall is run between 10 and 14 hours. Occupation rates are shown in figures 3-63 and 3-64. The average occupation rate of the sales area, shops and hall is 0,11 during weekdays (12 hours) and 0,2 in the weekend (Saturday).
The average occupation rate of the cinema during working hours (10 hours a day) is 0,44. The design air flow rate is 146.870 m³/h, based on a maximum of 2.982 shop-occupants (at 35 m³/h), 400

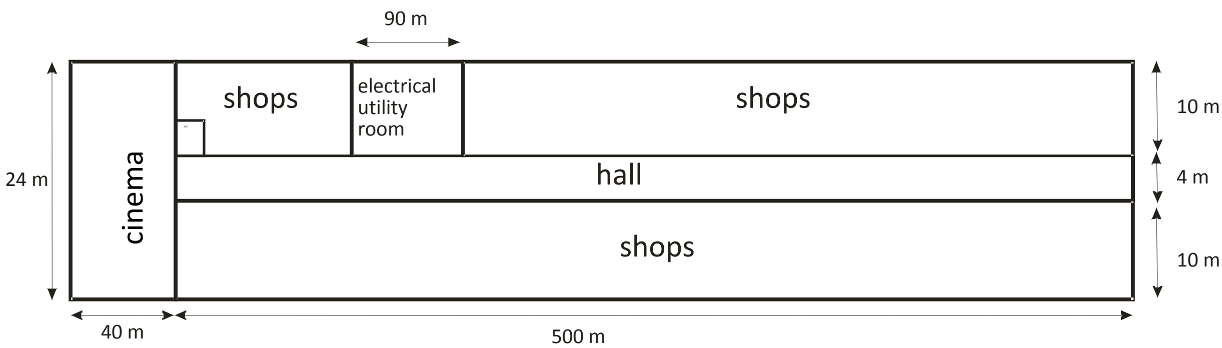


Figure 3 - 62. Overview shopping mall

people dwelling in the hall and 950 cinema-goers (at 30 m³/h). Also there is a fixed flow in the toilet area. Ventilation runs 15 h at design air flow between 9.00 (opening shops) and 24.00h (closing cinema).

An overview of these numbers is given in table 3-21 hereafter.

Table 3- 21: Overview data base cases shopping mall

	Shopping mall
Number of floors	1
Floor height (m)	7
Floor height cinema (m)	10
Surface area of one floor *(m^2)*	12.940
Volume (m^3)	93.430
Infiltration rate ($m^3/h/m^2$)	1,25
Operating hours	168
Ventilation rate	
Shops (m^3/h/person)	35
Cinema (m^3/h/person)	30
Supply air *(m^3/h)*	118.370
Exhaust air *(m^3/h)*	118.370
AHU (supply = exhaust) *(m^3/h)*	28.500
Total supplied/ exhausted	146.870

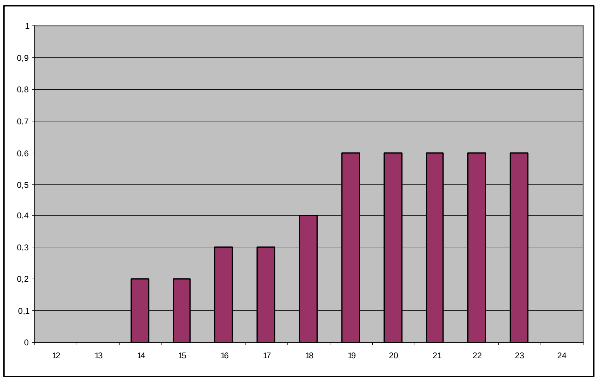


Figure 3 - 63. Occupation rate cinema

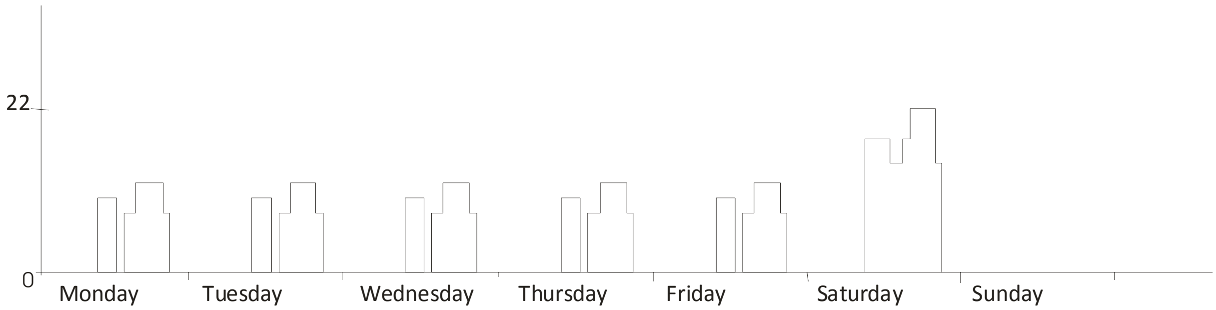


Figure 3 - 64. Occupation hypermarket and shopping malls: sales area, shops and hall

5.9 Hypermarket

The hypermarket is similar to the shopping mall and has 1 floor, on the ground flour the sales area, offices and storeroom can be found. The hypermarket is run 14 hours a day, 6 days a week, during which time the ventilation runs at full rate. Occupation data can be found in figures 3-63 and 3-66. As already discussed in the previous paragraph, shopping mall, the occupation rate in the sales area, shops and hall is 0,11 during weekday (12 hours) and in weekend (Saturday) 0,20 this is also valid for Hypermarkets and can be seen in figure 3-64.

The average occupation of the offices during working hours (14 hours a day) is 0,55. The design air flow 28.075 m^3/h is based on 900 shoppers (at 30 m^3/h) and 43 office-workers. (at 25 m^3/h).

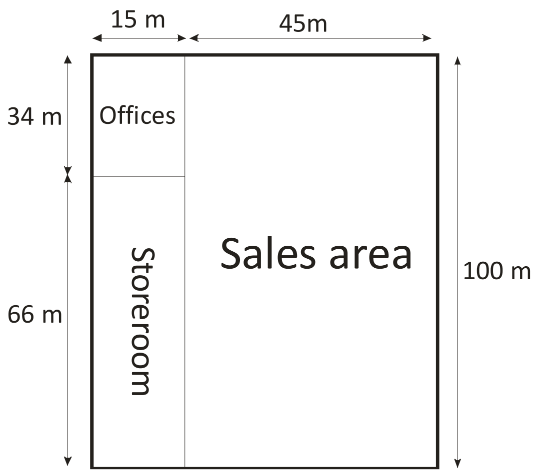


Figure 3 - 26. Overview hypermarket

Table 3- 22: Overview data base cases hypermarket

	Hypermarket
Number of floors	1
Floor height (m)	7
Surface area of one floor (m^2)	6.000
Volume (m^3)	42.000
Infiltration rate *($m^3/h/m^2$)*	1,35
Operating hours	84
Ventilation rate	
Offices (m^3/h/person)	25
Sales area (m^3/h/person)	30
Supply air *(m^3/h)*	28.075
Exhaust air *(m^3/h)*	28.075

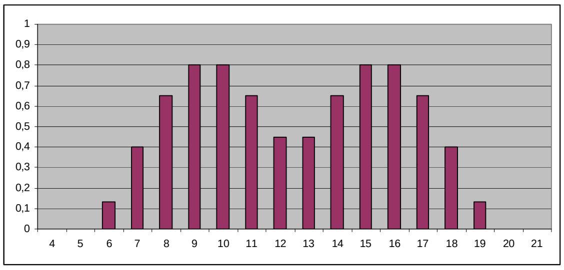


Figure 3 - 27. Occupation hypermarket offices

5.10 Overview

The following tables give a summary of the above. The first table shows the design parameters for the current situation. The second table shows the potential benefits of on-off zonal control, e.g. using occupancy sensors, and the potential benefits of zonal control with sensors (e.g. CO_2) that measure the occupancy rate.

In addition to the table it should be mentioned that in most cases the peak occupancy rate is around 80% of the design air flow rate.

Table 3- 23 . Overview ventilation design parameters of cases and current control regime

	Large office	Medium-sized office	Small office	Hospital	Retire-ment home	Hotel	Shop-ping mall	Hyper-market
GENERAL								
Floor area, in m²	15.000	5.000	1.008	30.345	3.916	3.668	12.940	6.000
Building volume, in m³	45.000	15.000	2.721	91.035	11.750	9.832	93.430	42.000
No. of floors	12	4	2	5	4	4	1	1
DESIGN								
Design: fixed air changes, in m³/h								
labs (@6 m³/h/m³)				86.300				
operation rooms (@15 m³/h/m³)				68.460				
nursing room (@4 m³/h/m³)					2.340			
Total fixed design flow, in m³/h				*154.760*	*2.340*			
Design: max. occupants per zone								
conference rooms (@30 m³/h)	900	310	51					
offices (@25 m³/h)	750	232	48	143		75		43
bedrooms, etc. (@25 m³/h)				848	90			
common room (@25 m³/h)					96			
lobby, restaurant (@30 m³/h)					48	175		
hotelrooms (@ 30 m³/h)						345		
shop, sales area (@35 m³/h)							2.982	900
cinema & hall (@ 30 m³/h)							1.350	
(labs)				*(240)*				
(operation rooms, OR)				*(152)*				
(nursing room)					*(7)*			
Total occupancy design flow, in m³/h	*45.750*	*15.100*	*2.730*	*24.775*	*5.850*	*17.475*	*144.870*	*32.575*
Total design air flow rate, in m³/h	***45.750***	***15.100***	***2.730***	***179.535***	***8.340***	***17.475***	***146.870***	***28.075***
CONTROL REGIME								
Building, fraction 'on' hours (per wk)	42%	42%	42%	100%	100%	100%	54%	50%
on/off control scope	whole building	whole building	whole building	operat. room only (12 h/d)	nursing room only (12 h/day)	not	whole building	whole building
Fraction 'on' hours with control	42%	42%	42%	81%	86%	100%	54%	50%
Average flow rate with control, m³/h	***19.063***	***6.292***	***1.138***	***145.305***	***7.170***	***17.475***	***78.680***	***14.038***

Table 3- 24. Overview of air flow reductions at zonal on/off control and zonal occupancy control

	Large office	Medium-sized office	Small office	Hospital	Retire-ment home	Hotel	Shop-ping mall	Hyper-market
ACTUAL USE, PER ZONE								
Operational hours per zone (fraction)								
conference rooms	42%	42%	42%					
offices	42%	42%	42%	100%		38%		50%
bedrooms, etc.				100%	100%			
common room					50%			
lobby, restaurant					25%	42%		
hotelrooms						67%		
shop, sales area							43%	43%
cinema & hall							42%	
(labs)				*(58%)*				
(operation rooms, OR)				*(50%)*				
(nursing room)					*(50%)*			
Weighted average 'on'	42%	42%	42%	81%	64%	56%	42%	43%
Zone on/off control, avg. flow in m³/h	***19.063***	***6.292***	***1.138***	***145.305***	***5.361***	***9.778***	***62.070***	***12.032***
Saving vs. whole building ctrl, in m³/h	***0***	***0***	***0***	***0***	***1.809***	***7.697***	***16.610***	***2.005***
Saving vs. whole building ctrl, in %	*0%*	*0%*	*0%*	*0%*	*25%*	*44%*	*21%*	*14%*
Occupancy during operational hours								
conference rooms	50%	50%	50%					
offices	56%	56%	56%	38%		48%		55%
bedrooms, etc.				42%	59%			
common room					68%			
lobby, restaurant					72%	40%		
hotelrooms						30%		
shop, sales area							13%	13%
cinema & hall							44%	
(labs)				(63%)				
(operation rooms, OR)				(68%)				
(nursing room)					(45%)			
Average weighted occupancy rate*	53%	53%	53%	41%	63%	34%	23%	15%
Avg.% design air flow (24/7, incl. on/off)	22%	22%	22%	73%	41%	19%	10%	6%
Zone demand control**, avg. flow m³/h	***10.103***	***3.335***	***603***	***130.688***	***3.378***	***3.324***	***14.276***	***1.805***
reduced vs. whole building ctrl, in m³/h	***8.959***	***2.957***	***535***	***14.617***	***3.792***	***14.151***	***64.404***	***12.233***
*reduced vs. whole building ctrl, in %****	*47%*	*47%*	*47%*	*10%*	*53%*	*81%*	*82%*	*87%*

**relates only to occupancy dependend flow rate; fixed flow rates of lab, OR and nursing room stay 'as is'*

*** intended is control with sensor that accurately measures occupancy, e.g. CO_2 sensor + fans with vsd*

****relates to reduction in annual air flow; reduction in electricity consumption is much higher because of fan laws*

List of Tables

List of figures

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ANNEX I

Special ventilation applications out-of-scope of Lot 6

OPERATING ROOMS (OR, in hospitals)

EU average 2005: 590 beds per 100.000 inhabitant→ EU27: 450 million inhabitants→ 2,7 million hospital beds.

Per bed ca. 20 m² → 54 million m² hospital surface→ 150-200 million m³. Effective 18 °C → +50% (because warmer and 24/7) ca. 300 million m³

Compare: Total health care 4,9% of 110 billion m³ @ 18°C = 5,4 billion m³

So hospitals are ca. 6% of all health care in terms of heated volume @ 18 °C→ 0,3% of total 18°C volume in EU27.

Treatment centres (OR plus services): 15% of hospital surface/volume→ 8,1 mln. M². Typically between 120 and 155 m² per OR (including pre- and post op as well as general service areas)→ 60 000 operating rooms→ total 25 mln. m³.

Ventilation requirements: OR(operating area) ventilation 20 m³/m³; Pre- and post op 10 m³/m³; other service 6 m³/m³. Average 10 m³/m³ →10 x normal ventilation → operating centres are responsible for more than half of ventilation losses of the whole hospital or rather, the OR more than doubles the heating requirements per m³ of a hospital→ hospitals at least some 12% of total health care ventilation heating requirements (instead of 6% which would be proportional to their volume and average temperature)→ all in all, not including the operating rooms Lot 6 misses out on 0,3% of ventilation losses of all buildings and around 1% in the tertiary sector.

CLEANROOMS

2002 data on clean rooms in pharmaceutical industry only (=ca. 23-25% of all clean rooms)

UK 45 000 m² (4900 staff); DE 72 000 m²; FR 65 700 m²; IT 40 000 m² →total 220.000 m². Rest of EU is much lower but estimate 180 000 m² → total 400 000 m² pharmaceutical cleanrooms → 1,6 mln. m² cleanrooms in EU27. → ca. 5-6 mln. m³. Assume ventilation fold also 10 m³/m³ → 50 mln. m³.

This is 0,04% of the total heated building volume @ 18oC of all buildings and around 0,2-0,3% of the industrial buildings.

INING

In the EU-27 there are probably only a few 100 operational deep mines that would require special ventilation provisions for mining personal working underground. Many mines are surface mines (quarrying, opencast pit) and most deep mines extract ores fully mechanized (e.g. long-walling), requiring only a minimum workforce of machine operators.

Even if these mines would require an unlikely volume of 10 000 m³ to be ventilated at 10 m³/m³ the total equivalent volume for 100 mines would not amount to more than 10 mln. m³, which is less than 0,01% of the EU27 total. Even allowing for some 500 mines this would not be more than 0,05% of EU27 total.

VENTILATION REQUIREMENTS

The ventilation requirements of clean rooms and operating theatres are completely different from those in normal dwellings. They require high ventilation folds, high filtration (HEPA, ULPA), special system lay-outs (e.g. down-flow laminar flow ceilings with overpressure system in OR), air locks, etc.. The difference with normal ventilation in terms of performance can most clearly be illustrated by the case of clean rooms, which can be classified e.g. according to the number and size of particles permitted per volume of air. “Class 100” denotes that 100 particles of size 0.5 µm at most are permitted per cubic foot of air. “Class 1000” or even “class 10,000” allow accordingly more particles of size 0.5 µm per cubic foot of air. For comparison, the ambient air outside in an urban environment contains approximately 35.000.000 particles of size 0.5 µm or larger per cubic metre. Clean rooms are known from the electronics industry (chip-manufacturing), but also widespread in all sorts of laboratories dealing with critical substances.

The case of mining ventilation is still a different one, characterised by high and critical levels of pollution. The air flow much reach sufficiently high levels to dilute and remove noxious gases (typically NOx, SO2, methane, CO_2 and CO) and particles. The source of these gases are equipment that runs on diesel engines, blasting and the orebody itself. Ventilation may be required to cool the ambient temperature in a deep hot mine. Alternatively in temperate climates it may be heated in winter time. Ventilation electricity consumption may constitute up to one third of total mining electricity consumption.

POTENTIAL MISSED BY EXCLUDING FROM THE SCOPE

Very likely, the saving potential of waste heat recovery and better controls for clean rooms, operating rooms and mining will be substantial, as they are relatively large energy consumers in their sector. However, the applications are far too critical –literally a matter of life and death—and bound by specific boundary conditions to be regulated through generic EU measures.

In the scope document, it is estimated that these –and other—special ventilation applications that are not taken into account represent around 1,7% of the total. Even though the estimates in this memo are very approximate, they confirm that this is still a fair estimate.

Sources:

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www.euracoal.be

www.euromines.org

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