INTERNATIONAL ENERGY AGENCY
Energy conservation in buildings and community systems programme

Source Book for Residential Hybrid Ventilation Development

W.F. DE GIDS (TNO)

Contributed Report 09

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Document AIVC-CR09
Year of publication: 2007

Foreword by the AIVC

This report has been produced in the framework of the EU RESHYVENT project (Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables).

The purpose of this Source Book is to review reference data from all work packages in the Reshyvent project for the development and application of residential hybrid ventilation systems. It is concerned primarily with basic data and information for industrial parties who are involved in the development of components for residential demand controlled hybrid ventilation or complete systems for it.

This source book intends to help and guide industry during the pre phase of the development process with information in the field of demand controlled hybrid ventilation.

RESHYVENT
Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables

Contract No: ENK6-CT2001-00533

Report:

Source book for Residential Hybrid Ventilation Development

RESHYVENT report No: RESHYVENT-WP8-D8.1
RESHYVENT work package: WP 8 Specifications and terms of reference

Status: Report for public use

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Foreword

This report is a kind of compilation of all relevant data from the Reshyvent project work packages meant for industry developing hybrid ventilation systems. It is an official EU report as a result of the EU project Reshyvent. It covers the condensed content of all Work packages. It guides people to the real sources in case the condensed information in this Source book is insufficient for the reader. All relevant Work package reports can be found in the references. The Reshyvent CD covers all report from the Reshyvent project.

The editor

Willem de Gids

Content

1. Introduction

1.1 Scope

The purpose of this Source Book is to review reference data from all work packages in the Reshyvent project [1] for the development and application of residential hybrid ventilation systems. It is concerned primarily with basic data and information for industrial parties who are involved in the development of components for residential demand controlled hybrid ventilation or complete systems for it. It is the intention of the author to help and guide industry with indispensable information in the field of demand controlled hybrid ventilation during the pre phase of the development process.

1.2 Target audience

This Source Book is aimed primarily to ***design engineers*** concerned with the development of either components or complete demand controlled hybrid ventilation systems. All people interested in hybrid ventilation such as:

- Architects
- Policy makers
- Building contractors
- Consulting Engineers
- Installers

might find useful information and data.

1.3 Guiding the reader

Each chapter tries to cover a topic on its own and can be read without reference to other chapters. However to understand some relations it is inevitable to read some parts in other chapters.

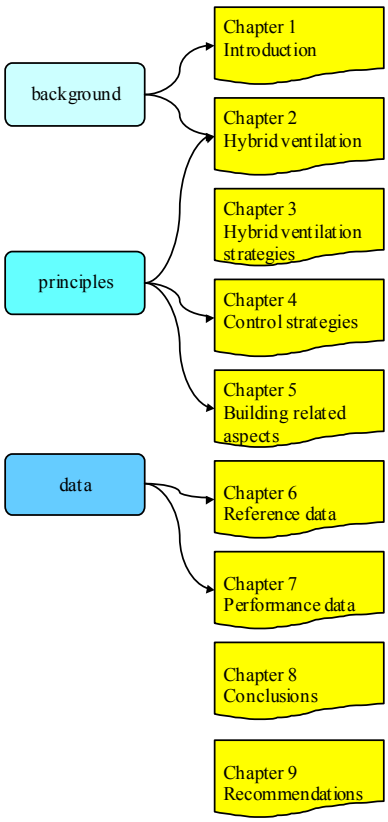
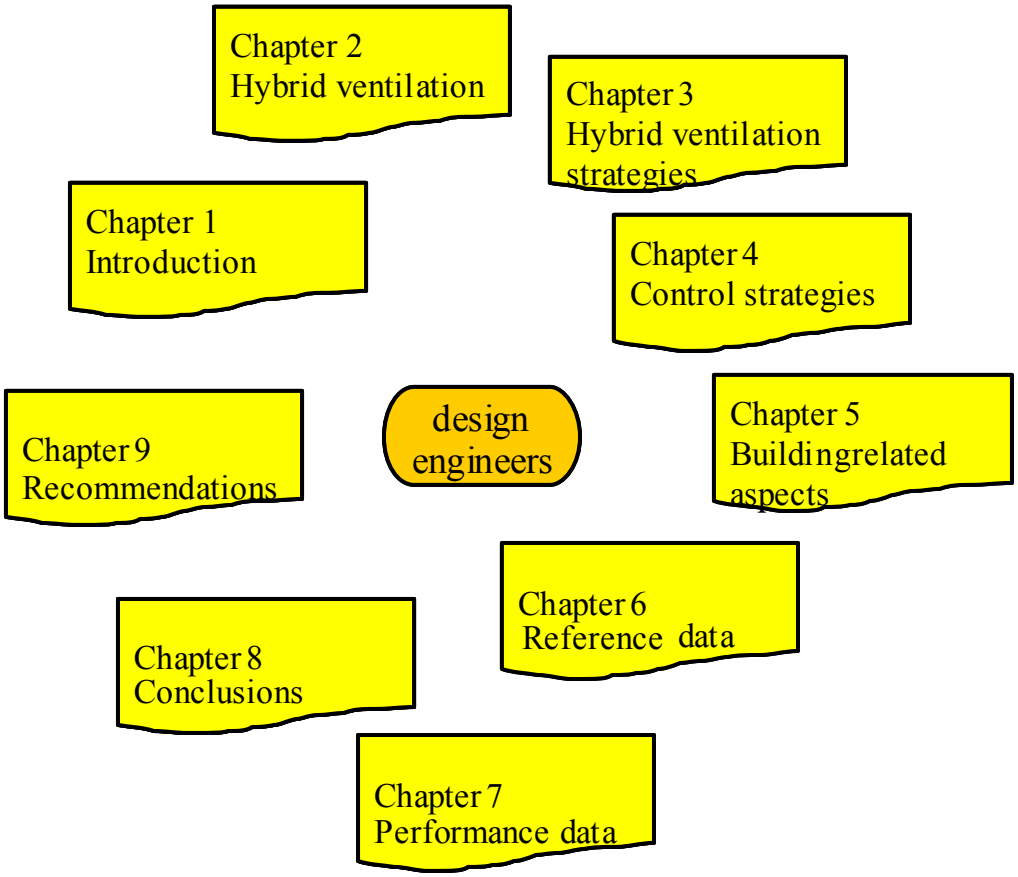
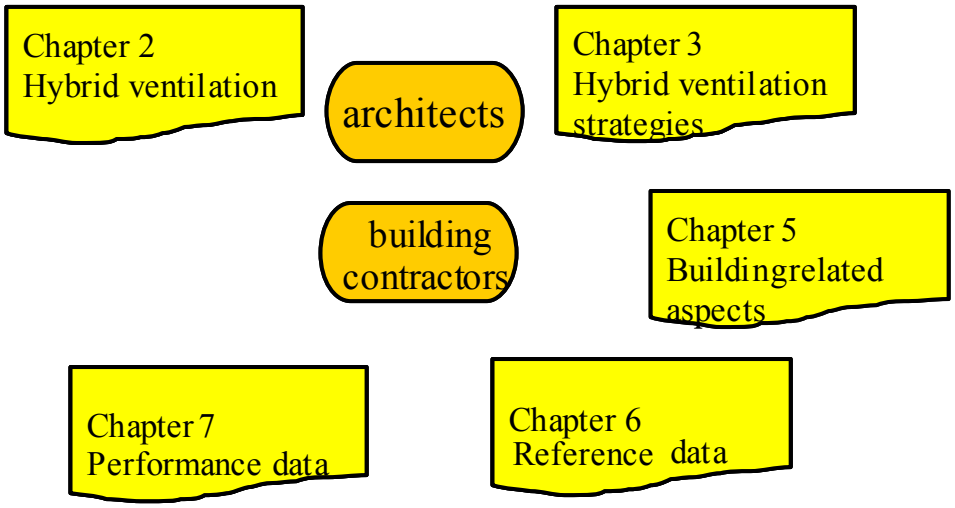


Figure 1 Guidance to the reader

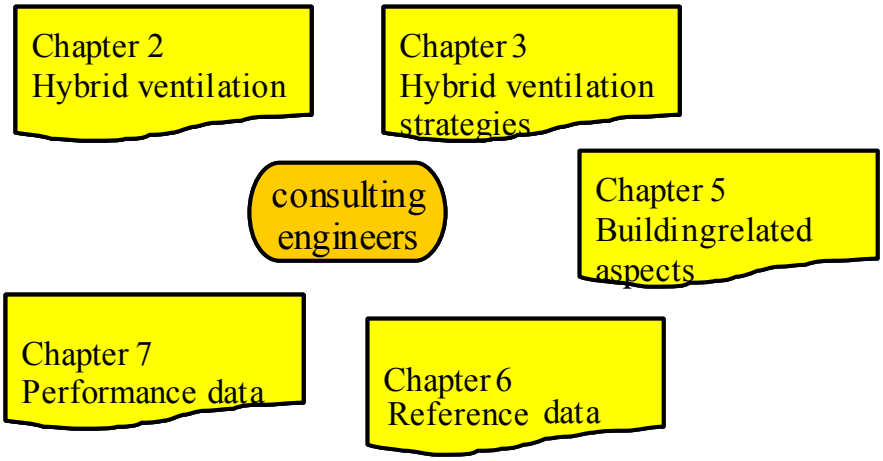
Design engineers



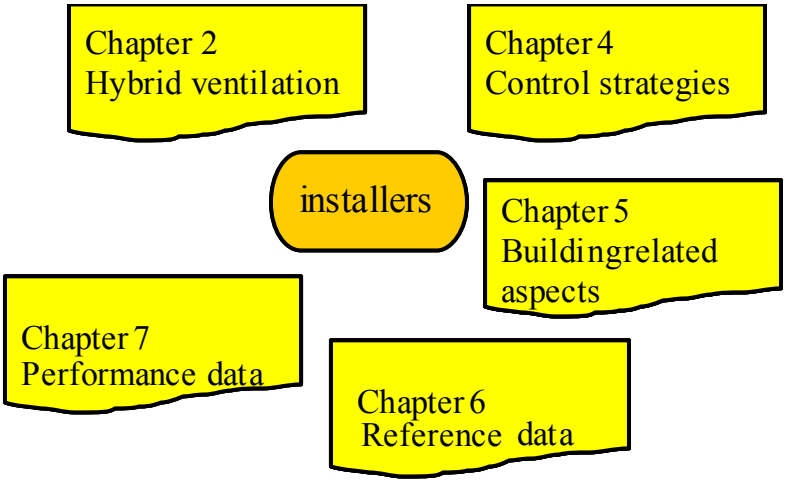
Architect and Building Contractors



Consulting Engineers



Installers



Policy makers

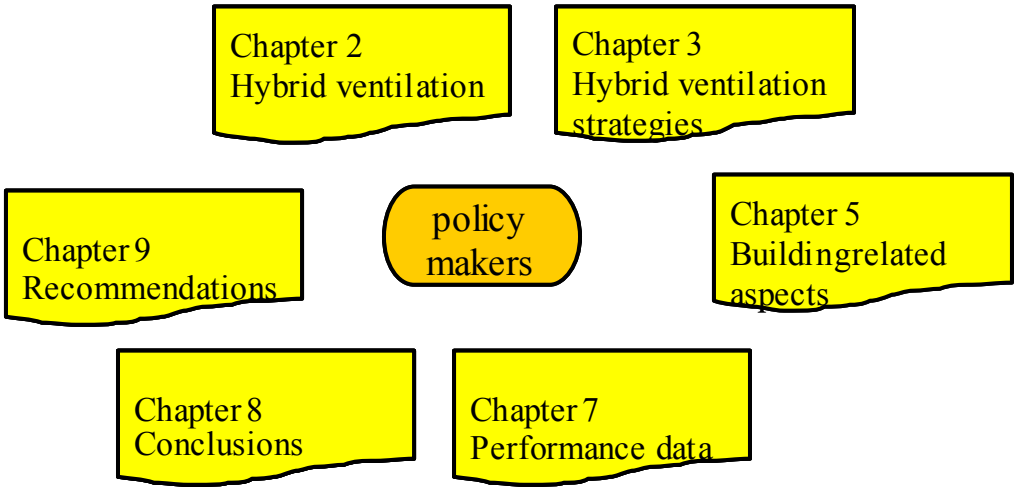


Figure 2 Important chapters for the different type of audience

2. Hybrid Ventilation

2.1 Why ventilation

Ventilation is a need for all living creatures in any enclosed environment. For breathing, people and animals need oxygen. But ventilation is much more than that. It also removes pollutants submitted to the indoor air by people and animals themselves (so called bio effluents) at the same time removing emissions from building materials, furniture and household activities, such as wash drying, cleaning etc.
Ventilation also has some consequences, for instance:

- energy use
  - due to heating or cooling the outside air
  - for transporting the air through the building and ventilation system
- comfort
  - mostly in terms of draft, due to air supply of outside air,
  - temperature problems may occur, due to a lack of heating and cooling capacity

Ventilation should always be at a level that the health risk is negligible at the same time creating a draft free and comfortable environment.

2.2 What is hybrid ventilation

Ventilation needs a driving force, they might be natural or mechanical. The natural driving force is caused by wind and buoyancy, the mechanical driving force is normally an electrical driven fan.
Due to developments over the last years the advanced mechanical and natural ventilation systems are approaching each other.

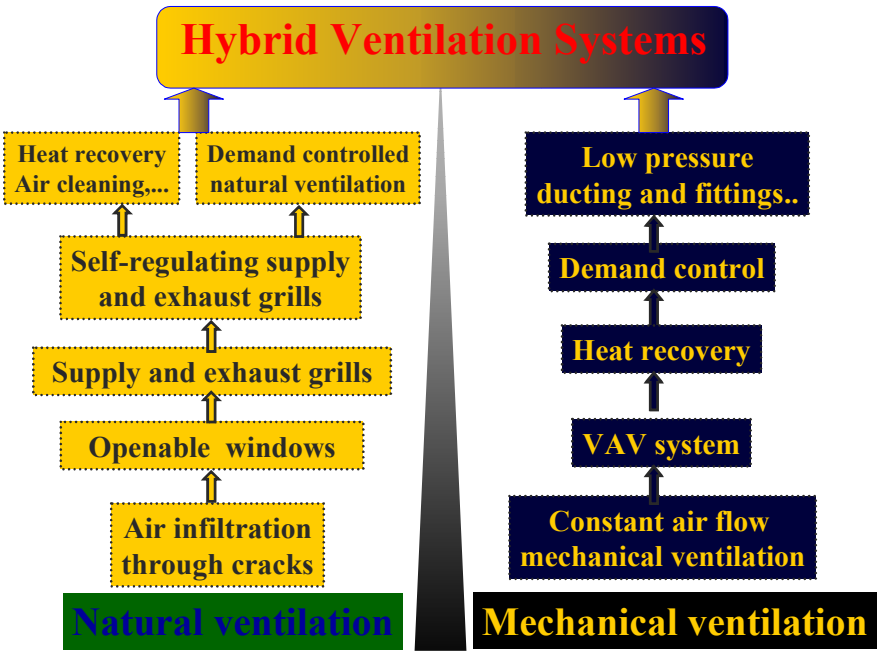


Figure 3 Recent developments in ventilation systems

According to the IEA project HybVent [2] the definition of hybrid ventilation system is:

"Hybrid ventilation systems can be described as systems providing a comfortable internal environment using different features of both natural ventilation and mechanical systems at different times of the day or season of the year. It is a ventilation system where mechanical and natural forces are combined in a two-mode system. The main difference between conventional ventilation systems and hybrid systems is the fact that the latter are intelligent systems with control systems that automatically can switch between natural and mechanical mode in order to minimise energy consumption and maintain a satisfactory indoor environment. "

So it is a two mode ventilation system. The two modes refer to natural and mechanical driving forces.

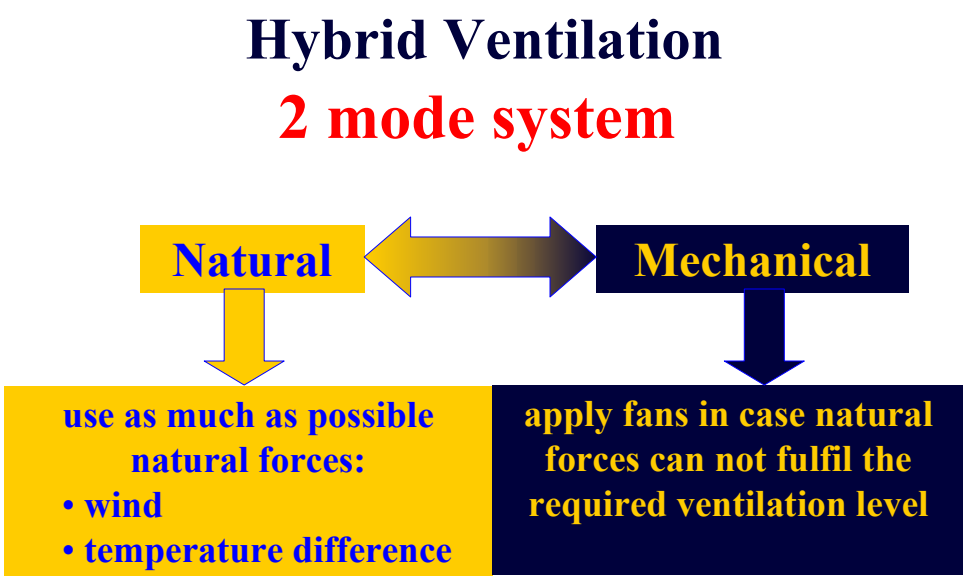


Figure 4 Schematic picture of hybrid ventilation

The basic philosophy is to maintain a satisfactory indoor environment by alternating between and combining these two modes to avoid the cost, the energy penalty and the consequential environmental effects of year-round air conditioning. The operating mode varies according to the season and within individual days, thus the current mode reflects the external environment and takes maximum advantage of ambient conditions at any point in time.

According to Wouters [3] three hybrid ventilation concepts can be described:

- alternate use of natural and mechanical ventilation
- fan assisted natural ventilation
- stack and wind supported mechanical ventilation

All buildings with hybrid systems up till now are not what might be called the optimum solution. There is a knowledge gap especially on dimensioning and control of hybrid ventilation systems.
Research questions that were studied in HybVent and Reshyvent are:

- what ventilation strategy should be chosen to optimise the energy efficiency, indoor air quality and the thermal comfort;
- what control strategy is the most appropriate,
- what control parameters should be used under the different climate conditions and demanded flow rates,
- how to size or dimension the ventilation systems for both natural and mechanical modes, including components of the system such as openings, ducts, fans, internal overflows, heat exchangers etcetera.

2.3 Why hybrid ventilation

The main difference between conventional ventilation systems and hybrid systems is the fact that the latter are intelligent systems with control systems that automatically can switch between natural and mechanical mode in order to minimise the transport energy consumption. Minimising transport energy can be achieved by:

- better efficiency of fans
- lower resistances in the ductwork, including fittings, control valves and air terminals

But not only the transport energy should be minimised also the heating and cooling energy. So demand control is a necessity.
Hybrid ventilation requires a complete other view on the dimensioning and control of ventilation systems.

2.4 Demand Control

Transport energy is normally much lower than the energy need for heating and cooling the air. Therefore there is also a need for adjusting the air flows to the demands in the building. This will lead to controls, which try to maintain the exact required airflow rates. The heart of a hybrid ventilation system is a sensor-based control. The ventilation system will direct respond to the demands resulting in optimal energy consumption. Control algorithms have been developed also in the Reshyvent project. Nevertheless this area is still under development.

2.5 Markets

2.5.1 General

The ventilation systems in the existing building stock differ very much from country to country due to differences in building codes, traditions, user preferences and climate etc. In northern Europe most new dwellings are

equipped with mechanical ventilation systems (more and more with heat recovery), while southern countries often rely on window airing. In many countries with mechanical ventilation the building code has required and sometimes still requires this system. Other market driving forces are related to indoor air quality, health, comfort, climate and energy issues. In countries with a predominance of mechanical ventilation systems the older buildings still often have natural or passive stack ventilation. There is not yet a real European ventilation market. The market for ventilation systems can until now considered mostly as national market.

An overview of all kind off market aspect can be found in Blomsterberg [4]

2.5.2 Barriers

Hybrid ventilation is a relative new concept for designers, architects, building constructors, consulting engineers and installers of ventilation systems. Therefore the application of hybrid ventilation might not be there first choice. Above that there are other barriers that may play a role;

- relative small national markets
- relative high initial cost
- lack of knowledge and information about hybrid ventilation
- mental barriers
- the design interaction that is needed between the different groups during the design process
- the way the different groups are paid for the design of a ventilation system
- the size and room space for the system is slightly larger
- also in the standards and legislation of most countries there are likely barriers, through the single fact that the systems are not recognized

2.5.3 Opportunities

The opportunities that can be achieved by demand controlled hybrid ventilation are several;

- relative low running cost for transport energy
- relative low running cost for energy conditioning the ventilation air
- considerable energy saving
- a good environment both in terms of indoor air quality and comfort
- an easy to use ventilation system for inhabitants
- a reliable ventilation system that needs almost no interaction from the inhabitants
- a ventilation system that might be more suitable for persons with health problems
- relative low maintenance
- a reduction in mechanical equipment in the house
- possibilities for passive or night cooling

2.6 Limitations of hybrid ventilation

Hybrid ventilation is not applicable is all situations. It has its restrictions too. Due to the fact that during a substantial part of the time there will be natural ventilation, the stability of the flows is not the same as with mechanical ventilation. This may result in pressure fluctuations and even flow direction changes. In case these aspects play an important role in the design of the ventilation system for a room, for instance in a clean room, an operating theatre in a hospital, a laboratory etc. full mechanical ventilation might be the only solution.

3. Hybrid ventilation strategies

3.1 What is a hybrid ventilation strategy

A hybrid ventilation strategy consists of a combination of the four different aspects:

- Hybrid ventilation mode
- Building airflow strategy
- Room air flow strategy
- Pre heating or cooling approach

As ventilation modes the rough classification of Wouters might be good one;

- Fan assisted natural
- Stack and wind assisted mechanical
- Alternate use of mechanical and natural

For building air flow the distinction can be made between;

- Cascade air flow
- Room supply and exhaust

For room air flow the different strategies are;

- Mixing ventilation
- Displacement ventilation
- Local displacement.

Also pre heating or cooling of the supply is part of the hybrid ventilation strategy, some examples;

- heat recovery
- ground heat exchangers
- greenhouses

Which strategy will be chosen is very much depending on the choice of the architect and the designer of the hybrid ventilation system.

3.2 Description and explanation of different aspects

3.2.1 Hybrid mode

3.2.1.1 Alternate use of mechanical and natural ventilation

The first example given is a dwelling in which a balanced ventilation system is installed and above that natural ventilation provisions are installed in all occupied zones.

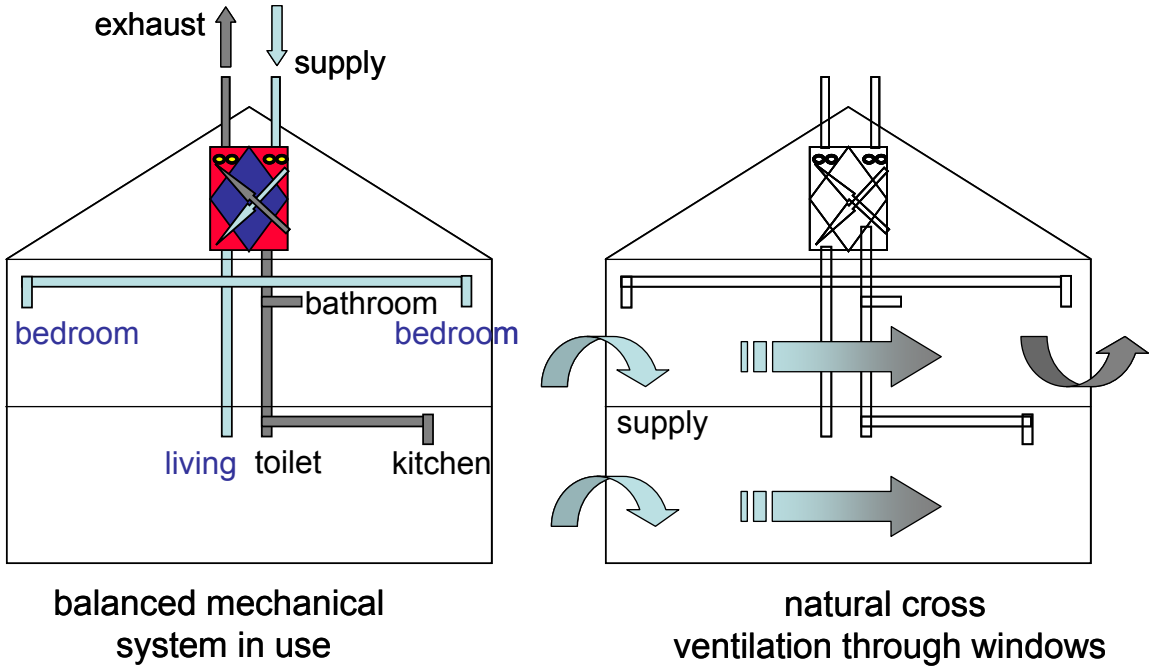


Figure 5 An example of the alternate mode application of hybrid ventilation

In case the outside weather conditions allow natural ventilation the mechanical system is shut down. In extreme weather conditions either to cold or to warm the natural system will be shut down and the mechanical system will take over. Some indication for occupants in which case the mechanical or natural mode should based on the number of occupants, their activity and the weather are helpful.

3.2.1.2 Fan assisted natural ventilation

An example of a hybrid ventilation concept. The system works under most weather conditions with natural forces. But in case the wind and buoyancy forces do not fulfil the required ventilation level, the special developed fan starts to run. The air enters through inlets in the façade Through a concrete duct with a so calles shunt duct the air will be extracted from the WC, Bathroom and kitchen in the individual apartment. A fan can support the flow through the system.

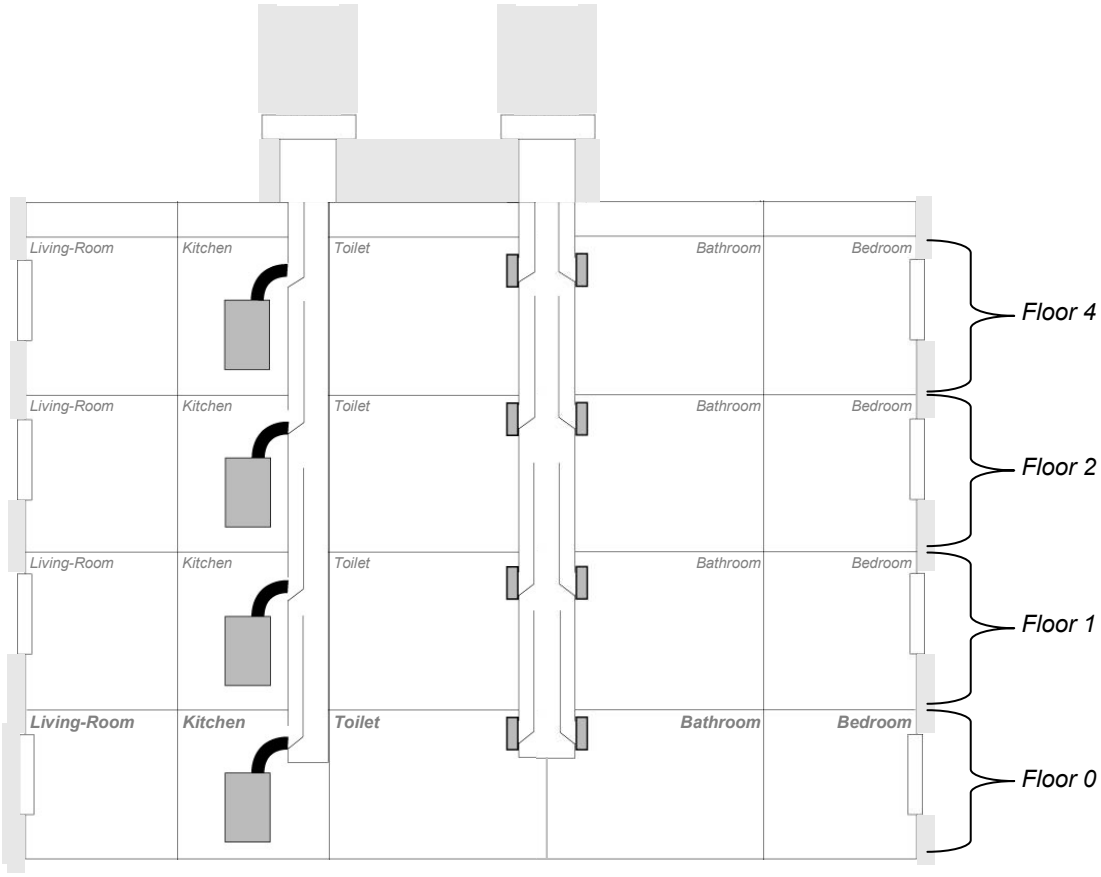


Figure 6 An apartment building with a typical example of fan assisted natural hybrid ventilation system

3.2.1.3 Stack and wind supported mechanical ventilation

This system is a mechanical balanced system with heat recovery. Due to the relative high pressures of this system a lot of the time mechanical fans are needed to run the system. The fan energy in this hybrid system is minimised due to wind and stack effect. Moreover during some periods of the year the system is running without mechanical forces. The system has a low resistance heat recovery system that also works under circumstances of natural driving forces. The system is also applied in dwellings. It is a typical mechanical ventilation design but low pressure distribution was taken in account to make the available natural sources a relevant part of the driving forces. The buildings in which the system is applied are just ordinary buildings without any specific hybrid ventilation item in the building fabric. The application of this system is almost unlimited, bust cost and investment plays a decisive role.

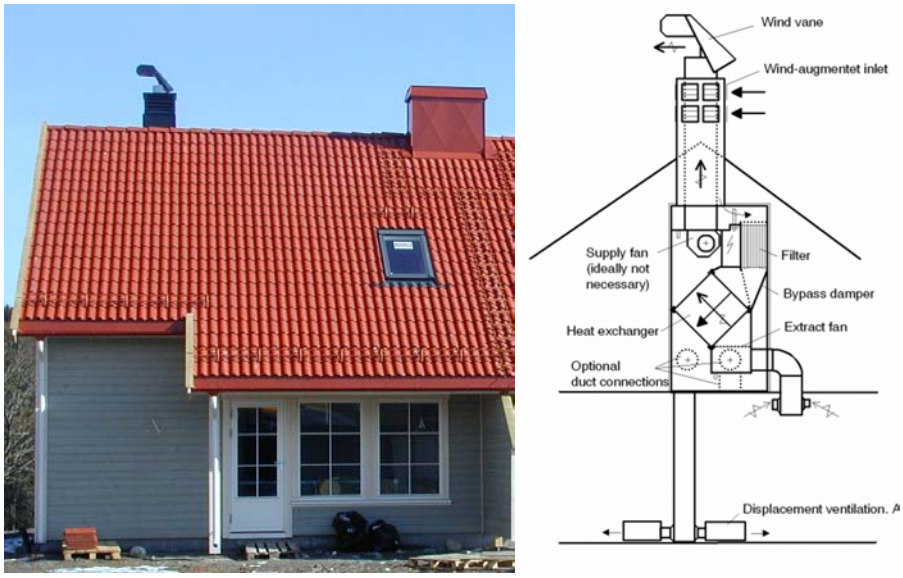


Figure 7 A typical mechanical system with support of natural forces

3.2.2 Building Airflow

3.2.2.1 Cascade air flow

With cascade airflow is meant the airflow from living room and bedrooms through an overflow in the internal walls in most cases gaps under the internal doors to the so called wet room, bathroom, kitchen and toilet, where the extraction either natural or mechanical takes place. In residential buildings this strategy is quite common.

3.2.2.2 Room supply and exhaust

Each room has its own direct supply from outside and its direct exhaust to outside. Overflow of air is not considered. This strategy is common in office type building but not in residential buildings.

3.2.3 Room Airflow

3.2.3.1 Mixing ventilation

Under mixing ventilation the situation is meant where apart from the direct local effect of supply and extract on the room air flow the air is almost perfectly mixed . The result of it is a more or less homogeneous concentration of pollutants in the room.

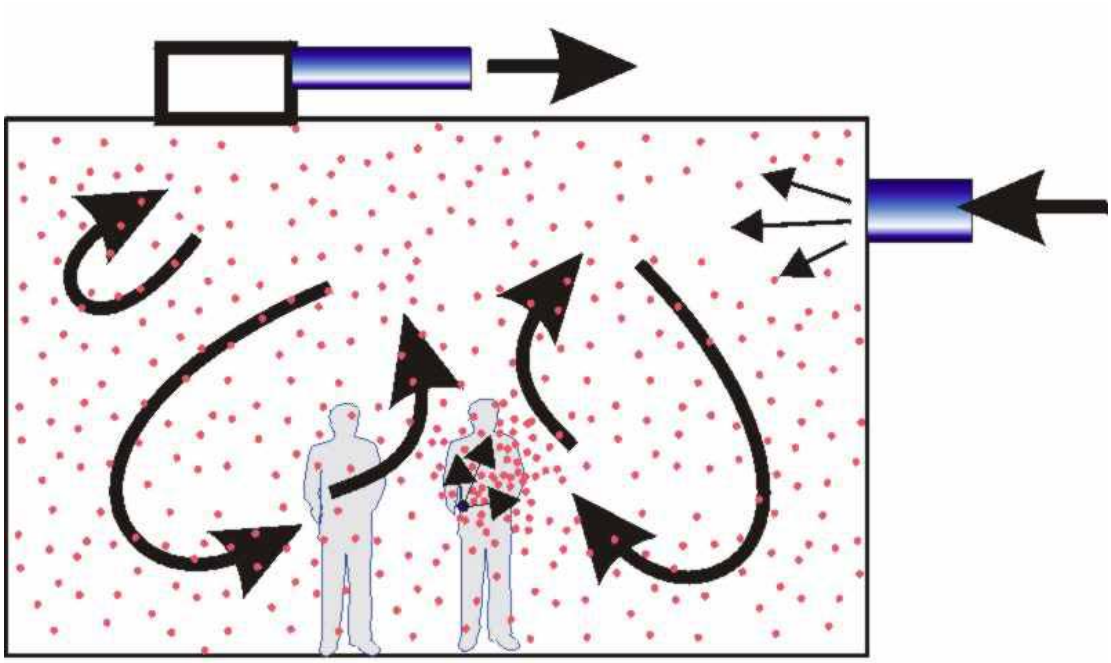


Figure 8 An example of mixing ventilation in a room

3.2.3.2 Displacement ventilation

Full displacement is very uncommon in residential buildings. It is typically applied in clean rooms and operating theatres The piston type flow through the room minimise the exposure to pollutants to a very localised area, while the clean or fresh outside air is supplied to the right place. The possible contamination with a pollutant from the room is minimised.

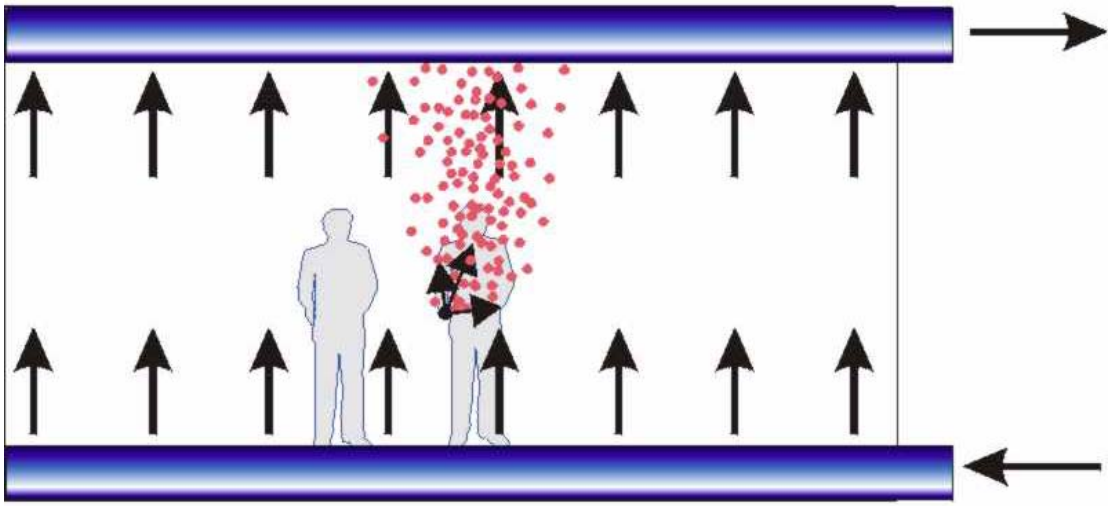


Figure 9 An example of full displacement ventilation in a room

3.2.3.3 Local displacement

For local displacement the goal is to keep a certain area in the room as clean or fresh as possible. Local displacement is applied in offices, schools, hospital and laboratories but as far is known very rarely applied in residential buildings. The application nevertheless in residential building is for hybrid ventilation a good alternative.

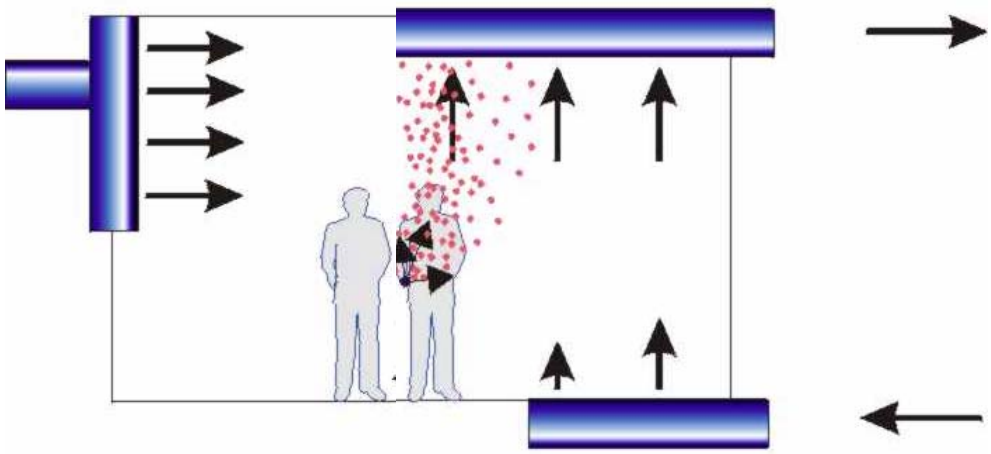


Figure 9 An example of local displacement ventilation in a room

3.2.4 Pre heating or cooling

3.2.4.1 Heat recovery

Heat recovery can be done by air-to-air heat exchangers, but also through heat pumps with heat recovery from the extract air. The disadvantage of the air-to-air heat exchangers is mainly the relative high-pressure loss. An application in hybrid system is given in figure 7.

3.2.4.2 Ground heat exchangers

The advantage of ground heat exchangers is normally the relative low-pressure loss. The impact on the building design and the suitability of the soil is absolutely dominant, both in terms of possibility and cost. The main risk is condensation in the ground duct which might cause micro biological problems in the building. Until now no negative effects of microbiological growth in these ground ducts is reported.

3.2.4.3.Greenhouses

A easy to design option for a residential building is a greenhouse or double façade where the incoming air is pre heated with the heat loos from the building envelope. This option has relative low-pressure losses and is relatively cheap with regard to the other options of pre conditioning. It has however a large effect on the esthetical aspect of the building.

4. Control strategies for hybrid ventilation

4.1 General

Control is a key item in hybrid systems. The control has to take care of the optimum switch from natural to mechanical mode, so monitoring the driving forces and the required flow rate. The required flow rate may be monitored in very different ways.
Control strategies are characterized by their time or special effect. Spatial control and temporal control can be distinguished.

4.2.1 Spatial control

The spatial strategy is closely related to the system design and has to be considered at early design phase. The following can be considered.
Outdoor air enters in habitable rooms such as living and bedrooms and is extracted in so called wet rooms (kitchen, bathroom and toilet) with the following aims:
• to limit the overall air change rate which is favourable to energy impact and should not be a problem as occupant presence is shorter in wet rooms than in inhabitable rooms
• to limit, to a certain extent the dispersion of short term pollutants produced in so called wet rooms to habitable rooms
Nevertheless, this strategy has the drawback of increasing the air change rate in habitable rooms to unnecessary level when high levels of extract air flow is required in a given the wet rooms. In this case, a direct part of outdoor air entering the wet room could be more efficient. Another point part of the system design is the direct extraction of spot pollution in service rooms

4.2.2 Temporal control

The temporal strategy can be related on one hand to presence of occupant and the pollutant emission due to metabolism and/or activities, and on the other hand by climatic conditions. It is closely linked to demand controlled ventilation and require in general an associated control system.
Flows can be controlled by:
• Presence:
- movement sensors
- clocks
- combination with light switch

• Metabolism:
- CO_2
- Water vapour
- Odours

• Activities
    - Cooking
    - Bath and shower (water vapour)
    - Cleaning
• Climatic conditions
    - outdoor temperature
    - indoor temperature
    - wind speed
    - wind direction

The control strategy can be based in general on CO_2, humidity and temperature or a mix of these control parameters.

To summarize the questions for control will always be:

- What to control ?
    - For instance IAQ
- Where to control ?
    - For instance habitable rooms
- When to control ?
    - For instance only during occupation
- How to control ?
    - CO_2 sensoring

From the answers of these question one might start to develop a control strategy.

4.2 Types of control

The control systems have to ensure that the appropriate actions are taken to maintain the controlled variables to a value defined by a set point.
HVAC control and building automation is in general quite straight forward. Although heating and air-conditioning make use nowadays of more and more complex control loops, ventilation systems still require relatively standard control loops namely:

- Open loop control
- Close loop control

4.2.1 Open loop control

In this case the action according to the output signal of the controller does not modify the value of the measured parameter:

- climatic data : outdoor temperature and humidity, wind speed
- indoor events : windows opening, switch on/off

This kind of control is robust if and only if it is well defined at the design phase and provided that sizing and implementation of the system is properly done following design guidelines. It highly influenced by the design and sizing of the complete system. It can hardly take into account unpredicted perturbations.

4.2.2 Close loop control

In this case the action according to the output signal of the controller will have a direct impact on the value of the measured parameter: The controller requires a set-point for the variable to be controlled.
The close loop control can use either feedback control or feed forward control with compensation.
In the case of the closed loop control, the stability is a major issue. The control strategy should ensure what kind of information is obtained from the controlled system. The quality of the return signal is very important.
For example, if a command is sent to a motorized damper, what kind of information is sent back to the controller:

- no direct information
- an “electronic” value of the position of the damper, that is the actuator acknowledges
- receipt of a command but does not confirm that the damper has taken the desired position
- the actual measurement of the position of the damper

Following the type of feedback, there is a possibility to include a reset position of actuators after a regular interval of time.

More detailed information about control can be found in [6] .

4.3 Occupant interaction

The control strategy will have an impact on the comfort of the occupant and this will obviously lead to some direct or indirect interactions between the system and the occupant.
The definition of a "standard occupant" does not exist. Although it is possible to agree on what is clearly uncomfortable for the occupant, it is difficult to define exactly his priorities. These will vary from one occupant to another one and can vary in time for the same occupant. For example some can be really interested in energy savings, and some prefer a better indoor climate even if it requires energy and is more costly.
Therefore, it is important for any control strategy to be accepted by the occupant that the latter should have the possibility to adapt the system behavior to his will according to his feeling.
Besides research has shown that occupants are more willing to accept a wider comfort band if have control over a local area.
Note that the occupant will react to a need (a specific condition) but not on the disappearance of that condition. For example if an occupant detects tobacco smoke he puts the "supplementary airflow" on but is not likely going to return "normal flow" when smoke disappears.
On the opposite, the occupant is not directly sensible to many points (risks of condensation in building fabrics for example), or unable to predicted the impact of an action (for example, whether increasing ventilation at night will improve the comfort next day during summer period)

Another point is that the control must easily understandable for the user, and that it should feel directly or indirectly the impact (for example a moderately noisy high speed in a kitchen may be not a bad design).
Following the above considerations, the control strategy should include the following criteria:

- It must allow for manual override.
- In the automatic mode, it should give access to the user to modify some set point.
- Once in the manual mode, it should provide rules to switch back to automatic mode
- Auto-learning capabilities might improve the functioning of the control strategy

More detailed information about occupant interaction with control can be found [7].

5. Building related aspects

5.1 Building design

5.1.1 New buildings

There are many parties involved in the building design process (investors, architects, civil engineers, building system specialists, etc.). The final outcome of the building design process is usually a matter of negotiations. Many problems can be avoided when hybrid ventilation is implemented in the early stage of building design. The best situation is when a designer of a hybrid ventilation system is, from the beginning, involved in the discussions between an investor and an architect. If this is not possible then the hybrid ventilation system designer should review the first building layout, which comes out from that discussion, and prepare a layout of a hybrid ventilation system with suggested changes in the building design. Some changes of a floor plan can still be possible and different parts of a ventilation system can be integrated into the building constructions. Horizontal ductwork can be integrated in ceilings or a lowered ceiling can be design to create space for a ductwork, a shaft for a vertical duct can be prepared, a roof shape can be modified to provide more space for the hybrid ventilation system components in an attic, a domestic water heater can be replaced by air-to-water heat pump for heat recovery, etc.

5.1.2 Existing buildings

More difficult situation is in case of refurbishments, were the layout of the dwelling is given from the beginning. Even in these situations hybrid ventilation can be implemented quite effectively. Similar to the new buildings it is important to begin with implementing of the hybrid ventilation system in the early stage of refurbishment. It will not probably be possible to integrate horizontal ductwork into the building constructions and so lower ceiling may be necessary in some parts of a dwelling. If a dwelling was fitted with a passive stack or exhaust fan ventilation system before refurbishment it should not be difficult to install a vertical duck. Air inlets can easily be integrated into the windows, which are quite often replaced during refurbishments.

5.2 Building integration

5.2.1 Floor plan

A floor plan of a dwelling is not usually a barrier for implementation of hybrid ventilation. There are, however, some aspects, which should be kept in mind when implementing a hybrid ventilation system.

The hybrid ventilation systems require a very low pressure drop of a ductwork. The total lengths of the horizontal ductwork should be as short as possible, with a minimal number of bends. The ductwork is usually a part of the exhaust side of a hybrid ventilation system. The exhaust air is extracted from “wet” zones as kitchens, bathrooms, toilets (if these are separate from bathrooms), stores, etc. The “wet” zones should be located close to each other, so as the lengths of horizontal ducts was short.
A floor plan may have some consequences also on the air supply side of a hybrid ventilation system. Fresh (outside) air is usually supplied through the openings in the outside walls (facades). These opening (air supply grills) are located in habitable areas of the dwelling like living room, bedrooms, study room, etc. The flow direction in a dwelling is from the point of air supply to the point of exhaust-air extraction. Some areas of the dwelling are not ventilated directly by fresh air, but by means of cascade ventilation. It is desirable that all habitable rooms are ventilated directly by fresh air and cascade ventilation is used only for other areas like “wet” zones, corridors, stairways, etc.

5.2.2 Space for ducting

A hybrid ventilation system as a low-pressure system requires ducting with bigger cross section areas. There may sometimes be a problem how to accommodate such ducking in a construction of a dwelling. The points of extraction are usually close to each other in apartment buildings. The horizontal ducts are quite short and easy to accommodate. Installation of vertical ducts in shafts can be a problem if several vertical ducts should be placed in one shaft. The space for horizontal ductwork can be a problem in detached dwellings where extraction points can be far from each other. It is easier to install the horizontal ductwork in wood-frame constructions, but only in case that the ducts are parallel with beams.

5.2.3 Roof shape

A roof shape might have an impact to the hybrid ventilation system. Roof slope and position of the roof outlet may influence the pressure on the roof outlet. For traditional mechanical systems this effect is normally negligible. For hybrid ventilation systems however this can be very important. The exhaust that should work as long as possible on natural driving forces should take the maximum benefit of wind and buoyancy. Therefore the position on the roof ridge as high as possible through the roof construction is preferable.

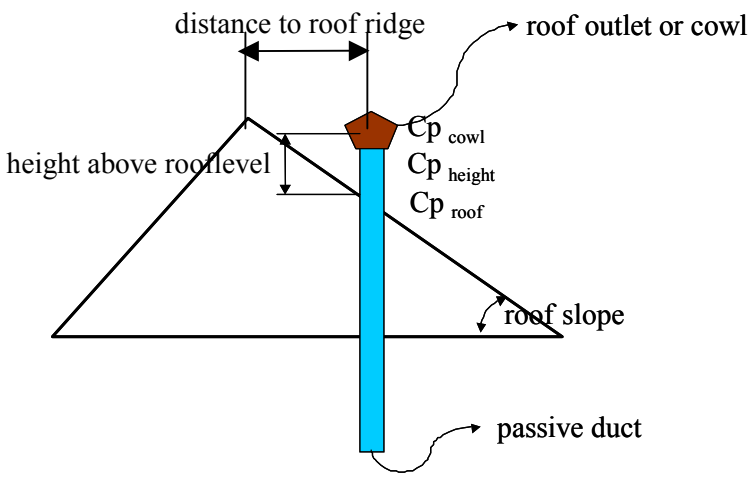


Figure 10 Roof outlet position

In case this aspect is neglected natural exhaust might act as supply due to wind pressure on the roof outlet. This phenomenon is called back drafting and might cause serious problems;

- dispersion of odors from kitchen and toilet through the dwelling
- draught and comfort problems in bathrooms
- spread of bacteria from the toilet

Furthermore an advantage of an uninhabited attic might be that a very suitable place to put in some parts of the hybrid ventilation system (e.g. a fan or heat recovery) will be available.

5.3 Urban aspects

The hybrid ventilation, as well as, the natural ventilation concept is very dependent on the outdoor climate and the microclimate around the buildings. The urban environment has a major impact on natural and thus on hybrid ventilation especially in the Southern regions during the cooling period of the year. Therefore, it is essential that a number of urban parameters should be taken into consideration in the design procedure of a hybrid ventilation system.
The most important parameters are listed below:

- geometry characteristics of the canyon (height, width, density, etc.)
- layout of the building
- temperature distribution inside and outside the canyon
- humidity of the external air
- wind velocity inside and outside the canyon
- wind pressure on the facades of building
- solar/daylight access
- pollutants concentration of the external air
- external noise

Micrometeorological effects of canyon geometry primarily control the climate in urban canyons rather than meso-scale forces controlling boundary layer climatic systems. Significant components of the street canyon microclimate are their characteristic wind induced flow patterns. The dynamic characteristics of the air circulation in a street canyon reflect the near field geometry whereas, depending on the canyon aspect ratio and the local roof circulation, different canyon vortex patterns develop. Three types of airflow regimes are observed as a function of the building (L/H) and canyon (H/W) geometry. (Figure 11).
When the buildings are well apart, (H/W>0.05), their flow fields do not interact. At closer spacing (Figure 11a), the wakes are disturbed and the flow regime is known as "Isolated Roughness Flow".
When the height and spacing of the array combine to disturb the bolster and cavity eddies, the regime changes to one referred to as wake interference flow (Figure 11b). This is characterized by secondary flows in the canyon space where the downward flow of the cavity eddy is reinforced by deflection down the windward face of the next building downstream.
At even greater H/W and density, a stable circulatory vortex is established in the canyon because of the transfer of momentum across a shear layer of roof height, and transition to a “skimming” flow regime occurs where the bulk of the flow does not enter the canyon. Because high H/W ratios are very common in cities, skimming airflow regime has attracted considerable attention.

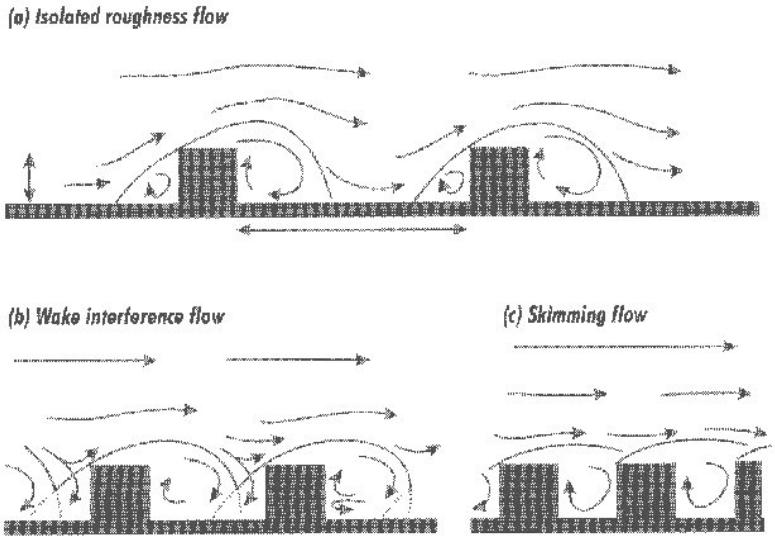


Figure 11. The flow regime associated with air flow over building arrays of increasing H/W

Transition between these three regimes occurs at critical combinations of H/W and L/H. In literature proposed threshold lines separating the different flow regimes as a function of the building (L/H) and canyon (H/W) geometry can be found. The proposed threshold lines are given in Figure 12.

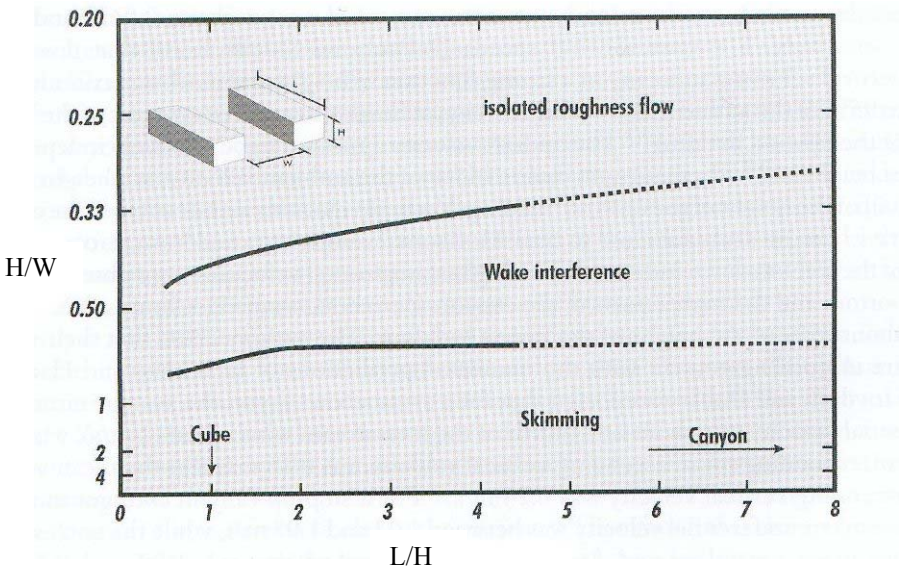


Figure 12**.** Threshold lines dividing flow into three regimes as functions of the building (L/H) and canyon (H/W) geometry. (Source : Oke T.R, (1988).

More detailed information about occupant interaction with control can be found [8].

5.4 Interaction with other systems

5.4.1 Heating system

In some hybrid ventilation concepts outdoor air is supplied into the rooms without pre-heating. That has to be taken into account when a space heating system is designed. A ventilation heat loss associated with the supply of cold outdoor air can change quite quickly (more quickly than transmission heat loss). Therefore, a space heating system has to promptly respond to the changes in the ventilation heat loss in order to avoid fluctuations of indoor temperature, which could cause the discomfort of the occupants. The impact the air supply without preheating will be more significant in the buildings with no or very small thermal mass. There are certain aspects that should be kept in mind when designing a space heating system. When a radiator heating system is used then the radiators should be located below the air supply openings (air inlets). In some hybrid ventilation concepts air supply openings can be located behind the radiators. Floor heating, which has a long response time, can be problematic when used together with the air supply without pre-heating. Warm air heating, even though not very common in Europe, can also be used with hybrid ventilation. Warm air heating requires a ductwork for the supply of warm air into the rooms. If no preheating of fresh air is used then the warm air supply outlets of the heating system should be positioned below the air supply openings. There are several configurations of the warm air heating. There can be a return air duct in every room where the warm air supply is or just a couple of return air ducts in the dwelling and the return air grills enabling the cascade flow. The configuration of warm air heating system has to

be taken into account when designing a hybrid ventilation system. It is generally more difficult to design a hybrid ventilation system in case of warm air heating. The main problem is the control of airflow inside a dwelling since the ventilation and heating system can interfere with each other.

5.4.2 Heat recovery

A heat pump heat recovery is the most common way of heat recovery used with the ventilation systems involving natural supply and mechanical exhaust. The heat pump heat recovery can be quite efficient, because under some conditions temperature of air leaving a heat pump can be lower than outdoor air temperature. A recovered heat can be used either for space heating or for domestic hot water. A payback time of the heat pump heat recovery used with a demand controlled ventilation in mild and moderate climates is usually not favorable. It is because the heat pumps are still quite expensive, and the demand control minimizes ventilation flow rates so much that the heat pump can efficiently run only a few hours a day.

5.5 Noise

There are two groups of noise problems in hybrid ventilation. The first group involves the problems related to the noise coming into the dwelling from outside through the air supply openings. The second group involves the problems related to the noise inside a dwelling caused or transferred by a ventilation system. The outdoor noise can be a problem especially in urban environments. Different shapes of air path in the inlets can be used to reduce the noise transfer from outside to inside. The noise absorbing materials can also be employed in the inlet design. A fan is the main source of noise in the ventilation system. It is because relatively small axial fans with high speeds are used. The noise of a fan can be the most enjoying in a passive/night cooling mode when a fan runs at the highest speed. The transfer of noise from a fan to the surrounding can be reduced by placing a fan into a sound proof casing and/or locating it in an unoccupied space (for example an attic). The problems with the noise transferred from room to room by means of a ductwork are more difficult to avoid due to relatively large duct diameters and low-pressure resistance. Fortunately, the ductwork connects the rooms that are not permanently occupied (kitchen, bathroom, toilet, store, etc.) and so these problems are not as crucial as the noise of a fan or the noise coming in from the outside.

5.6 Application of Solar power (photo voltaic cells)

5.6.1 Background

When dealing with renewable energy sources the electricity consumption of the components, which are to be supplied by renewable energy, has to be evaluated in detail in order to determine the feasibility of integrating renewable energy solutions. The major part of the electricity demand of a ventilation system is for the fans. However, controls, sensors, actuators, electrostatic filters, heat recovery with rotating wheels or pump driven water circuit will also contribute to the electricity use of the ventilation system. The two major renewable sources, which can be used to generate electricity are, solar power (PhotoVoltaic, PV) technology and wind technologies. At present various initiatives have been developed and tried for the use of small wind engines for the built environment. These small wind engines are however not accepted and proven yet, primarily because they are not fit for physical integration into a build environment, however also technical constraints, such as vibrations and weight are yet to be solved. Due to these constraints it has been chosen only to analyse the possibilities for "local" (stand-alone, autonomous, de-central, off-grid) generation of electricity by means of PV solar power, as this solution has the possibility to be fully integrated into components and the building.

When dealing with stand-alone PV the following thresholds and target values has been identified:

- Thresholds are space (required area for solar module/-cell integration or installation), energy consumption, orientation (preferably south) and location.
- Target values may be defined as compensation of the extra costs for an advanced ventilation system for the electricity produced for the ventilation system by applying PV. In some cases applying PV may reduce installation costs (e.g. cabling).

5.6.2 Exterior placement of PV panels

Provided that the power consumption is within the economic and technical boundaries of PV solar application, roof mounted PV solar powered fans can generally be applied. For wall/façade mounted devices as inlet grilles, even when power consumption is reasonable, there will still be substantial barriers for the application of PV solar, mainly due to shading or unfavourable orientation angles and tilts.

5.6.3 Interior placements of PV panels

Controls, sensors and actuators are in principle fit for stand-alone power supply. It would give these devices the flexibility of mounting them in the best position.

However, the lay out of the internal wiring in houses/buildings may reduce this flexibility if wireless technologies are not used. Integration of PV can reduce cabling to and from the components, but it must be analysed that adequate light intensity is available for the PV cells. This means positioning near windows is favourable, which is not necessarily the best position for the component.

5.6.4 General approach

In order to consider the application of PV solar select only low consumption DC devices or find/develop low consumption DC alternatives for AC devices. For each of the devices the electricity consumption profile must be defined or estimated. Based on this the PV solar system requirement can be calculated and physical feasibility (space, orientation and location) and economic feasibility (initial and avoided costs) of PV solar can be determined. For economic comparison of Wh costs of (off-grid) PV solar with Wh costs of connection to the commercial grid the Wh costs of use of the commercial grid for the electricity consumption of the ventilation system and Wh costs based on the life cycle costs of the PV installation should be calculated. For environmental reasons and “image” a slight increase of initial costs may be accepted for the PV solar solution compared to the standard grid connected option. However, often it is difficult to assess an acceptable difference on the basis of image, therefore some countries offer subsidies to help to bridge the gap.

5.6.5 Summary

PV solar is under very specific and favourable conditions a commercially viable power supply option for electricity consuming devices in hybrid ventilation systems. In the future new PV solar cell technology with much higher conversion percentages, greater availability of DC appliances and availability of appliances with very low power consumption will increase the potential for use of PV solar power in hybrid ventilation systems. The above indicates both the permanent constraints for the application of PV solar as well as the areas of improvement to enable the application of PV solar power in hybrid ventilation systems. The feasibility/potential of the use of PV solar systems is dependent on the energy consumption and the energy consumption pattern of the fan(s) and auxiliary components during the day, the week and the year. The availability of fans and auxiliary devices with DC (Direct Current) operation rather than AC (Alternate Current) operation is an important criterion for the economic and trouble-free application of PV.

More information can be found in [9].

5.7 Commissioning and maintenance

Commissioning of hybrid systems is just a bit more extensive than commissioning a traditional system. The air flow are measurements requires as

well as more time because of the larger variation over time with these systems but also some higher accurate measurement equipment because all components work at considerable lower pressures.

Like other ventilation systems hybrid systems must be regularly cleaned and maintained.
This is for hybrid systems even more important because the system is working at low pressures.
Weekly cleaning of the surfaces of air inlets in the façade and other air terminal devices by the household self is concerned as normal cleaning activity.

Component	**Type of maintenance**	**Frequency**
ATD	Cleaning	Once a week
ductwork	Cleaning	Once a year
Fan	Cleaning	Once a year
Fan	Checking functioning	Once a year
control	Checking functioning	Twice a year
roof outlet	control on corrosion	Once a year
sensors	Checking functioning	3 times a year

6. Reference Data

6.1 Background

Building performance assessment is the wider scope in which assessment of ventilation systems play a key role. The main aim for the assessment will be harmonized European assessment methods for various performances. The challenge is to strive for a assessment method that is suitable for innovative ventilation systems such as demand controlled hybrid ventilation systems. The assessment method is unclear because of the time depending performances of hybrid systems.
CEN , EOTA and other EU projects have activities to solve this problem of assessment of innovative systems. Also Work package 4 Standards and regulations has spent part of their work on demand controlled hybrid ventilation systems.

6.2 Standards and regulations

Some more information about the assessment of hybrid ventilation in standards and regulation is important for almost everyone to consider. [5]

Often standards and regulations are to a large extent written on the basis of the experiences with existing systems. This may create barriers for innovative systems. Moreover, still a large number of standards and regulations are written in descriptive terms instead of performance based terms :

→ In the **descriptive approach** for indoor air quality control, one avoids to a large extent the need to specify the boundary conditions and the '*real objectives*' to be achieved. By assuming certain default values, it is then often possible to come to requirements which are less complex and easier to be understood by most designers and installers, e.g. air flow rates in $dm^3/s.m^2$.

→ In a ***performance oriented standard*** for indoor air quality control, one will express the required 'real objectives'. This can be done by defining for a series of pollutants (CO, TVOC, CO_2, NO_X, dust,…) e.g. the maximum concentrations, the acceptable dose,… and the boundary conditions for which the requirements must be met. In principle, such approach is preferable but practice shows that its implementation is often not evident.

As far as standards and regulations are concerned, it is not always evident to show the compliance of new and innovative systems with the regulations and/or the benefits of these innovative systems when compared with the more classical systems.
Within the European context, the Energy Performance Directive (= European legislation) and the national implementation of this directive (by imposing national regulations) is probably the most critical regulation : it offers in principle the possibility to quantify the advantages of hybrid ventilation but it is far from evident

to come to correct assessment procedures for innovative technologies, i.e. hybrid ventilation.

The assessment of thermal comfort in summer and in particular the impact of night ventilation strategies is at present not well covered in CEN standards.
On national level, it is clear that hybrid ventilation systems must comply with the requirements in the standards and regulations dealing with minimum ventilation provisions. It might require specific studies to show compliance of certain types of hybrid ventilation systems.
The principle of equivalence is very important for assessing innovative systems :

- To show compliance with minimum ventilation requirements (if not directly meeting the requirements in the standards or regulations)
- To show the equivalent energy performance of probably ALL hybrid ventilation systems (unless default values are included in the standards or regulations)

In order to have correct market conditions, it is necessary to set up :

- A coherent and transparent scientific and technical assessment scheme for assessing innovative systems;
- An appropriate formal and legal framework for attestation of the performances of these innovative systems.

Given the complexity of certain systems and the increased international trade, it seems preferably to develop such assessment schemes through international collaboration whereby of course specific national inputs are allowed and, moreover, surely required during the coming years given the major differences in the present national regulatory approaches.

More information can be found in [5].

6.3 Performance assessment methodology

There are several criteria to be tested on reference cases under identical boundary conditions. Target values for all aspect are a necessity. A more global assessment method might be for instance ranking, indexing or labelling of systems. Absolute information on the performance are in that case missing.
A important question for the assessment methodology is, should any assessment method be valid for all systems and all building types or for a specific systems and a specific building type in a specific climate.
As mentioned earlier criteria and target should be available. They are in most cases in some form available at national level but not on European or world level. Criteria to be defined such, that they can be handled in the planning phase, for instance to solve some problems with simulation models. Checking in the real building later by measurements.

6.4 Parameters for performance assessment

Design parameters as used for the performance assessment can be distinguished in:

- Performance criteria and target values
- Design constraints, boundary conditions and assumptions
- Building and ventilation system design variables

Parameters can be defined on building, system and component level.

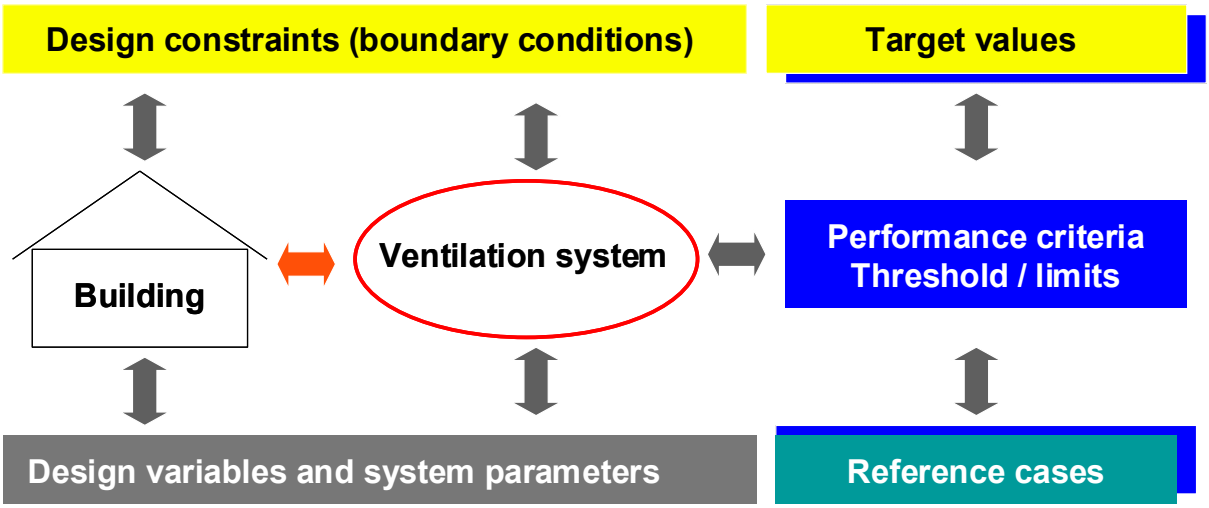


Figure 13 Design parameters differentiated into performance criteria, target values, design constraints and ventilation system design variables and parameters.

6.5 Simulation tools

The most appropriate approach for the assessment of hybrid ventilation systems seems to be a combined heat – airflow model. Examples are TRANSFLOW and ESP R. Both models combine heat transfer and ventilation in a manner that allow studying the interaction between airflow and room temperatures. Multi zone modelling (for instance COMIS) alone might also be of help. The year around performance however is lacking the right temperatures in the different rooms.

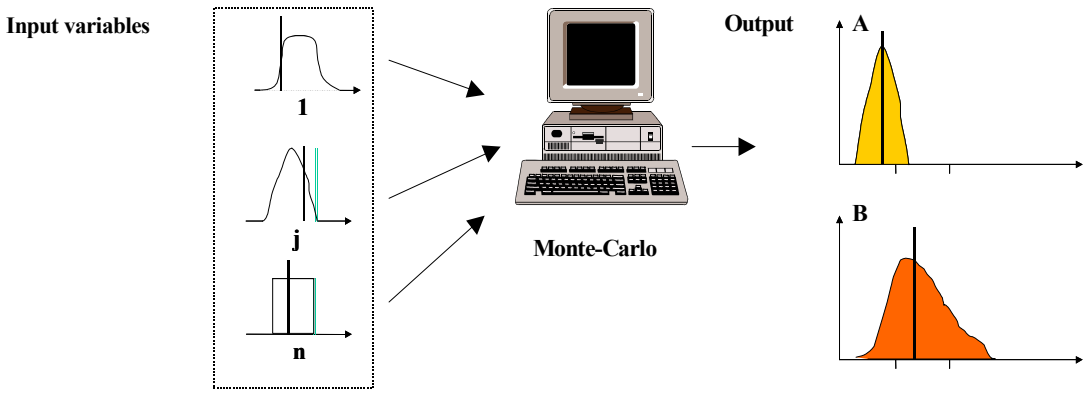


Figure 14 A schematic presentation of the probabilistic approach

Deterministic modelling is possible in case two systems will be compared and the input parameters are valid for both systems. For time depending variables a better approach will be the so-called probabilistic approach. In this approach a number of input parameters are simulated as distributions, where a random choice will be made according to the Monte Carlo method. Also the output of the model delivers in that case a distribution.

More information can be found in [10].

6.6 Reference data for weather

6.6.1 General

Reference data for weather is a key item to evaluate the airflow as well as the energy consumption of ventilation systems. Depending on the complexity of the demand control the required meteorological data might differ from region to region. The most complex systems at this moment require:

- Outside temperature
- Vapour pressure
- Wind speed
- Wind direction
- Solar gains

The problem with this data can be the time averaging. For the year around performance of ventilation and energy consumption hourly values are needed. It is impossible to give in this report a complete overview of hourly data representative for the whole of Europe. This data can be found in EUROMET [11]

6.6.2 Wind data

Wind data is very important for the evaluation of hybrid ventilation systems. It is an important driving force. However using wind data from a meteo-station to the onside of a building is not a straightforward procedure. The relation with a local wind speed is quite complex.

Advanced Method:

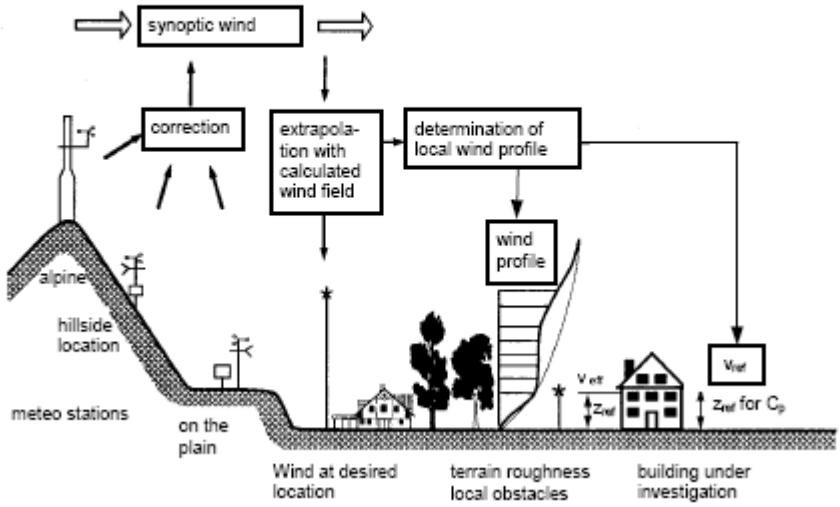


Figure 15 Transfer of wind speed data from a meteo location to building location in complex topography.

More information on the use of meteo data can be found in [12].

6.7 Reference data for driving forces

Wind pressures are a major driving force for natural and hybrid ventilation systems. However, in the dimensioning process, the determination of actual wind pressures on the facades of a building, especially in the built environment, is still very limited. Application of meteo station wind data and of standard data about pressure distribution on buildings may lead to very large errors in the estimation of system performance. Thus, any performance prediction of such a system is very limited in general. As a consequence, severe barriers for a more widespread application of such systems may result.

The reason for these large uncertainties is due to the very complex nature of wind and of wind pressure distributions on the building facade. Much research work already has covered this issue, however, no reliable design procedure has been established so far.

Some examples of Cp data are given here.

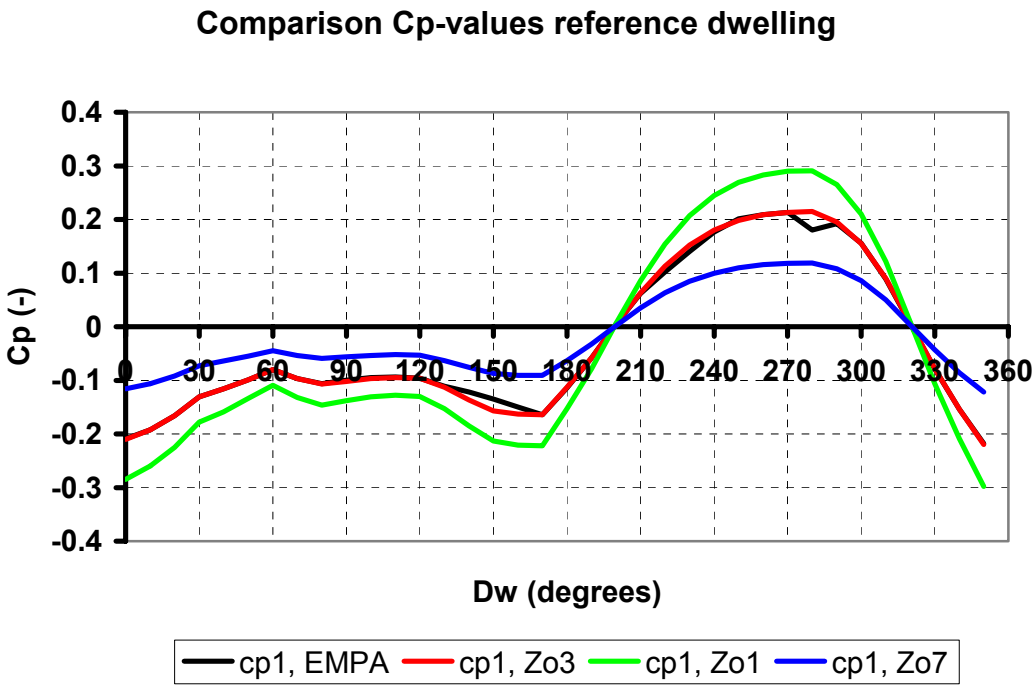


Figure 15 An example of the comparison of Cp values simulated and produced by a pressure model.

A typical pressure distribution result of a multi zone ventilation model is presented in figure 16. For two levels of air tightness (n50 of about 3 and 1) the distributive pressure difference across different facades is given. The observation can be made that the pressure are almost always in the range of –10 Pa to +10 Pa. Although this case is just one of many cases but the observation that the pressure are relatively low is important for hybrid ventilation design.

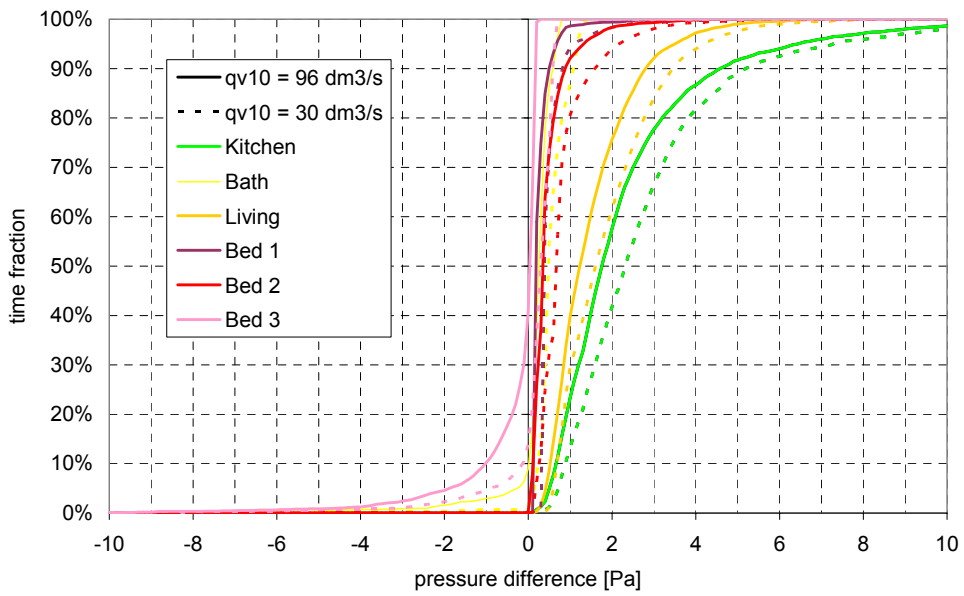


Figure 16 Impact of the building leakage on the pressure difference across façade.

More information on the use of meteo data can be found in [13].

6.8 Use of ventilation provisions

The use of ventilation provisions is dominant for the performance of a system in real life. There are big differences in the use of ventilation provisions.
Important variables for the use of ventilation provisions are:

- Weather
  - Wind
  - Temperature
  - Rain
  - Sunshine
- Building type
  - Apartments
  - Single family housing
- Type of family
  - Number of persons
  - Number of children
  - Age
- Attitude
  - Energy conscious
  - Spender
- Type of ventilation system
  - Natural
  - Mechanical
  - Hybrid

An example of the use of natural ventilation supplies in the façade is presented in figure 17.

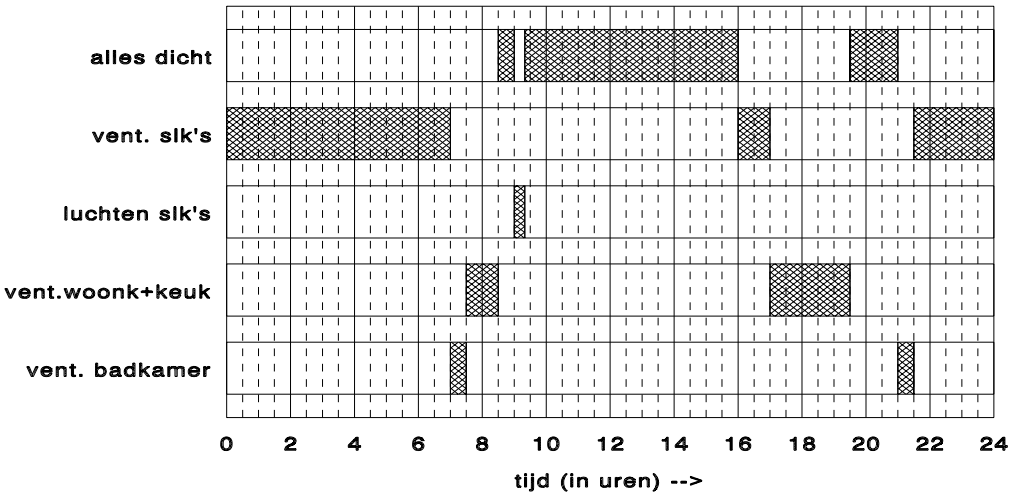


Figure 17 The time certain provision are open during the day

Also the use of mechanical exhaust systems is important. A typical use is presented in figure 18.

Ventilation pattern	level mechanical exhaust	exhaust flow (dm^3/s)		
		kitchen	bathroom	toilet
All supplies closed	low position (during 2 h/day)	10,5	7	3,5
	high position	21	14	7
ventilating bedroom's airing bedroom's	middle position (20 h/day)	15,5	10,5	5,5
ventilating living plus kitchen ventilating bathroom	high position (2 h/day)	21	14	7

Figure 18 The time mechanical exhaust is in a certain position during the day

6.9 Occupation Schemes

For the right assessment of systems also the distribution of persons in the dwelling over the different rooms is necessary information. A typical use is presented in figure 19.

	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom	Kitchen	Living
0 – 7 h	2 persons	1 person	1 person	-	-	-
7 – 8 h	2 persons	-	-	2 persons	-	-
8 – 9 h	-	-	-	1 person	1 person	-
9 – 12 h	-	-	-	-	-	2 persons
12 – 13 h	-	-	-	-	2 persons	-
13 – 18 h	-	-	-	-	-	2 persons
18 – 19 h	-	-	-	-	-	4 persons
19 – 20 h	-	-	-	1 person	3 persons	-
20 – 21 h	-	-	-	-	-	4 persons
21 – 22 h	-	1 person	1 person	-	-	2 persons
22 – 23 h	-	1 person	1 person	1 person	-	1 person
23 – 24 h	-	1 person	1 person	-	-	2 persons

Figure 19 Distribution of people over the differerent rooms of the dwelling during the day

6.10 User instruction

User instructions are not a very common item for ventilation systems. The very rarely exist. The more complex the systems are the more detailed the instruction should be. Natural supply openings without a kind of automatic control, such as pressure or humidity control, will fail in maintaining a good indoor environment in case there are not used in the right way. The advantage of demand controlled hybrid ventilation is however that it is less dependent of the active use of the system or components by the inhabitants.

6.11 Reference data for Photo Voltaic cells

6.11.1 During design

From a technical point of view PV technology is relatively simple. However, there are still some crucial steps that must be taken in both the design and installation stage. In the design stage there are a number of parameters, which needs to be considered. The below table illustrates the design parameters which are necessary to consider when applying PV.

Main Item	**Sub Issues**	**Example**
Geography	Latitude	50° North (Brussels)
	Longitude	5° East
	Orientation	195° - 15° from south
	Tilt angle	90° - Vertical
Load profile	Input voltage range	6-12 Volt DC
	Power needed	2-6 Watts
	Time of consumption	6 Hours
	Period of consumption	Daily during summer, weekends in spring / autumn, none during winter.
	Consumption pattern	6-9 AM, 1-4 PM
Shadowing	Shadows occur	Yes / No
	Time of shadowing	Winter between 8-12 AM
Available area	PV	L_{max} = 900 mm, L_{min} = 400 mm
	Battery	H_{max} = 100 mm, L_{min} = 20 mm, W_{max} = 25 mm
	Control device	H_{max} = 100 mm, L_{min} = 80 mm, W_{max} = 50 mm
Wiring	Distance between battery and consumption	2 m
	Distance between PV location and battery	0,5 m
	Distance between PV location and controller	0,5 m
Weather conditions	Average ambient temperature	Summer +22°C, Winter 2°C
	High / Low ambient temperature	-25°C to +42°C
	IP class needed for battery	IP 23
	IP class needed for controller	IP 65
Feasibility	Cost of kWh	0,13 Euro / kWh

	Price to power the component (AC transformer, cabling and installation cost, battery cost)	14 Euro
	Electrical maintenance cost	5 Euro per year
Integration	Possibility to integrate PV	Yes, front of inlet – 0,36 m^2
	Possibility to integrate battery	Yes, inside inlet – 20 cm^3
	Possibility to integrate controller	No
	Design requirements	"Black PV module look"

Design parameters for evaluation and integration of PV in a ventilation system.

6.11.2 How to optimise the energy output

Installing the PV cells in a perfect location and orientation optimises the energy output from a PV system. The geographic location is important for the environmental conditions (weather related) and for the insolation. The orientation is important for eventual reductions in the output as a result of (partially) shading, not optimal orientation (south for northern latitudes) and not optimal tilt angle.

For an optimal PV solar output the following is required:

- South orientation: This is not always possible. East and west orientations may be considered. North orientation should be discouraged.
- An optimal tilt angle: This is almost never possible, as a wall/façade is stationary (vertical), even a sloped roof may have an unfavourable slope.
- Free horizon: Especially when apartment/office buildings are opposing each other along streets this is not possible. Moreover, in a built environment the chance of a 100% free horizon is limited.
- No shading: In a built environment this may be hard to achieve.

6.11.3 Photo Voltaic cell types

While conventional mono-crystalline cells have an efficiency of 13-17% and poly-crystalline about 12-15%, relatively high efficiencies (about 20%) are achieved by using new mono-crystalline cells with embedded contacts and a grooved surface area. Amorphous silicon is the least efficient of the commercial silicon based products. Its efficiency is in the 8-10% range when new. Instability of the material though lowers the efficiency to a stabilised efficiency of about 4-7% after a few months exposure to sunlight, another disadvantage of the amorphous cell is that it requires twice as much surface to generate the same energy as crystalline.

The table below gives the technologies (anno 2004):

Technology	Commercial efficiency (%)	Commercial size (m^2)	Yield per m^2 (Wp / m^2)	Price pr. Wp (Euro / Wp)
Monocrystalline	13-17	0,5-1,5	160	3.000 – 4.20
Polycrystalline	12-15	0,5-1,5	150	2.80 – 4.00
Amorphous	4-8	0,2-0,8	40	1.80 – 2.50

6.11.4 Battery types

For the applications requiring energy at night or during periods of low sunlight, a storage medium must be used to ensure the autonomy of the system. The usual storage equipment used with stand-alone systems is rechargeable batteries.

The table below sums up the technologies (anno 2004):

Technology	Commercial size (cm^3)	Voltage level (Volt)	Rated power (Ah)	Ambient temperature (°C)	Price pr. Wh (Euro / Wh)
Lead Acid – Open	120 – 25.000	2 – 12	6 – 2.000	-20 to +50	0,05 – 0,40
Lead Acid – Closed	120 – 50.000	2 – 12	6 – 2.000	-20 to +50	0,10 – 1,00
NiCd	5 – 50	1,2 – 9,0	0,36 – 2,4	-20 to +50	1,00 – 2,00
Lithium – Ion	10 – 30	3,7 – 9,0	3,7 – 7,4	-20 to +50	2,75 – 3,25

6.11.5 Size of the PV panels and battery

The energy consumption load from the component and the geographical position, orientation and possible shading determines the required PV size. For example a fan system in De Bilt (NL) will in the winter season require twice the solar surface of the same fan in Nice (FR). Therefore also the battery capacity of the solar power system in De Bilt (NL) will be twice the size of the same system in Nice (FR). The feasibility of a PV system is therefore better in Southern Europe than in Northern Europe.

More information can be found in [9].

7. Performance data

7.1 Systems developed in the Industrial Consortia

7.1.1 Introduction

There have been 4 Industrial consortia active in the Reshyvent project.
The different industrial consortia were all focussing on a certain climate.
Furthermore each consortia had its priorities and target for the development.

Consortia structure

	B	NL	SE	NO	
Climate	**Mild**	**Moderate**	**Cold**	**Severe**	
Building type	**Dwelling**	**Apart.**	**Apart.**	**-**	
Renewables	**Solar**	**Wind optimisation**		**Low exergy**	
Summer comfort	**Crucial**	**Limited**	**No**	**No**	
Demonstration	**Strong**	**Limited**	**Limited**	**Strong**	
Supply-exhaust	**I - C**	**I-C**	**C-C**	**C-C**	
Winter Comfort	**I - C**	**I-C**	**I**	**C**	

I = important
C = crucial

Figure 20 the targets and application fields of the industrial consortia.

To give the reader a inside in the performance mostly focussed on the components there are two extensive description of the systems IC1 and IC2 presented in this chapter.

7.1.2 IC1 Cold climate

7.1.2.1 General philosophy and assumptions

The task was to develop a concept for demand controlled hybrid ventilation for apartments in a cold climate. The concept is to some extent based on the experience of a Swedish technical procurement for demand controlled ventilation

for new apartment buildings. Today's mechanical ventilation systems in Scandinavia often have the following characteristics:

- Actual air flow rates deviate from design values due to deficiencies in system design, adjustment and uncontrolled influence of users (Sandberg 1994, Månsson 1998)
- The use of bathrooms have changed, increased moisture load due to increased shower frequencies and installation of washing machines with associated risks of moisture and mould problems (Gaunt 1985).
- Mechanical ventilation in apartment buildings usually has an almost constant ventilation over time. Thus it is independent of variations in loads such as moisture, odours, cooking fumes, number of persons present, which results in excessive use of energy. There is a considerable energy savings potential in using demand controlled ventilation (Månsson 1992, Blomsterberg 2002).
- Today's ventilation systems are often associated with draught problems (Engvall 1992, Andersson 1993). This is especially true for well insulated buildings, where the outdoor air enters behind the radiator.
- Ventilation systems fulfilling design air flow rates often create noise problems (Andersson 1993, Blomsterberg 1995).
- Some ventilation systems include the possibility of increasing the air flow in the kitchen when cooking. The odour capturing ability of fume hoods/fans are often not satisfactory and very often result in complaints concerning cooking odours according to questionnaires (Engvall 1992, Blomsterberg 1995).

A new type of ventilation system is needed, which can solve all or most of the above mentioned problems and which at the same time can reduce the energy use for ventilation (energy for operation and space heating). The most promising system to achieve these goals is demand controlled hybrid ventilation. Such a system should also include features such as individual control of heating and individual metering of energy use.

The first step in improving the performance of ventilation systems based on exhaust fan ventilation and at the same time lowering the energy use is adding demand control. This first step was taken for apartments in an ongoing Swedish technical procurement.

An important part of the work consisted of the development of performance specifications for the concept. Applying performance specifications to ventilation systems provide a more flexible and less rigid approach to ventilation system design and operation whereby targets are set which must be met in order that the ventilation system performs as required. This approach also facilitates the implementation of innovative systems.

Performance specifications can be applied to a wide range of criteria that influence the overall performance of a ventilation system and at three different levels:

- building (energy use, maintenance cost, IAQ, noise levels)
- system (energy use, maintenance, IAQ, ventilation rate, noise levels, draft, air/operative temperature, thermal comfort, humidity)
- and component.

In practice the performance of ventilation components influence the overall performance of the ventilation system, which in turn influence the overall performance of the building and its occupants. Ventilation systems are significant consumers of energy and therefore it is important that ventilation systems are energy efficient.

Performance specifications must meet certain criteria in order to be successful in implementation: measurable in order to enable verification and checking against set targets, predictable in order to enable design, technically “sound”, relevant to the criteria in question, resulting in reasonable life cycle cost, and defensible during possible litigation.

The ventilation concept was to be designed such that the user has the possibility to control the ventilation within the apartment. Nonetheless, the air flow shall automatically increase as needed, to the degree that the minimum environmental and health requirements are met.

The ventilation system shall be designed such that the varying airflow needs at different operational levels can be met e.g. forced ventilation in the kitchen and bathroom and minimum flow in an empty apartment etc. The ventilation system within the apartment shall be designed with regard to internal loads such as humidity, temperature and carbon dioxide. One desired feature is control of the airflow for each room (living room, bedrooms, kitchen, wet rooms) within each apartment. However, the exhaust air flow for the apartment may only fall below the normal ventilation rate (usually 0.35 l/s(m² of floor area)) in the case of empty apartments (requirement to meet the current Swedish Building Code).

The ventilation system shall be designed as an open solution; i.e. one that can be integrated with other systems and components from various manufacturers and that allows subsequent adaptations. The ventilation system shall be prepared for individual metering and customer billing. One desired feature is that the technical solutions are prepared for future integration with real property’s technical systems and IT-systems for users; e.g. time scheduling, internal messages, locking and security systems.

7.1.2.2 Climatic conditions

The climate can be described as cold and representative weather is considered to be the weather of Stockholm, which can be obtained directly from the Energy-Plus home page. The table 7-1 and figure 7-1 and figure 7-2 show a brief analyse of the weather data file, as one can see the wind velocity is predominately from North direction and with a wind speed between 2 and 4 m/s and the maximal and minimal outdoor dry bulb temperature, throughout all heating season, is 27 ºC and -17 ºC, respectively

	ºC	Date of occurrence
$T_{máx}$	27.0	24 June_14:00
$T_{mín}$	-17.0	27 January_03:00

Table 7-1 Range of outdoor dry bulb temperature

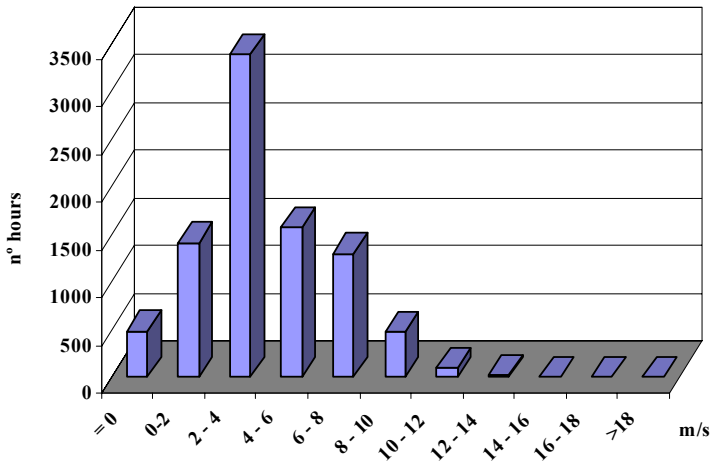


Figure 7-1 - Frequency of different wind speed for all year

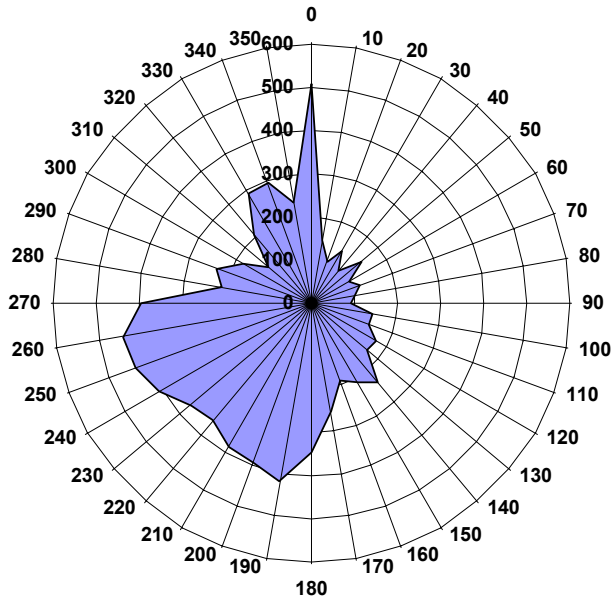


Figure 7-2 - Frequency of wind directions during all year

(0º for wind from North, 90 from East, 180 from South and 270 from West)

According to the Energy Plus weather data, in figure 7-3 is showed the monthly average of the ground temperature for three different depths (0.5, 2 and 4m).

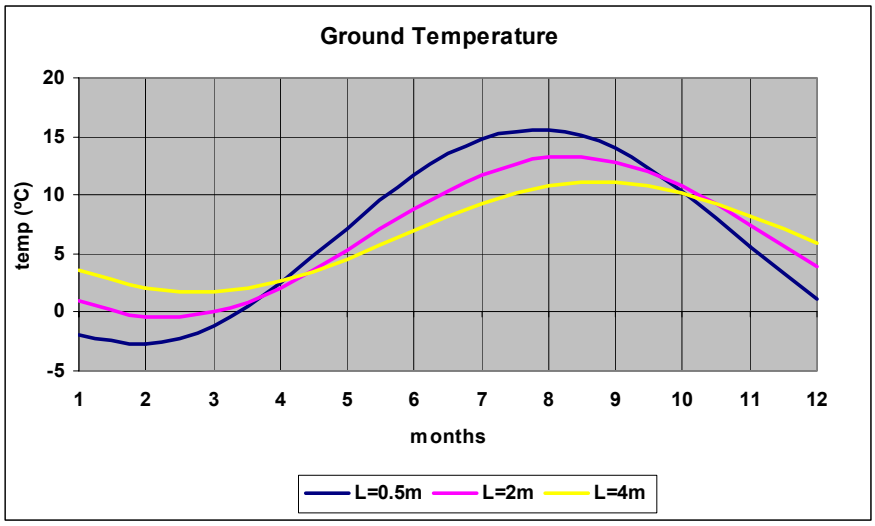


Figure 7-3 - Ground temperature evolution throughout the year

The heating energy demand is obtained when the heating system must be switched on only on those days when the daily averaged heat gains using a conventional utilization factor do not balance the averaged heat losses. On days with the heating system switched off, the room temperature might fall temporary below the set point. The definition according to A27-V2 is:

1. calculate for each day the average outdoor temperature on the period of 15 days before and 15 days after;
2. start in summer;
3. stop when this averaged daily temperature is equal to 13 ºC. This is the starting day of the heating season, which is defined as Monday;
4. restart the calculation of daily average temperature until spring;
5. stop when it is equal to 13 ºC. This is the last day of the heating season, whatever day it is.

The conventional heating period begins in the September 2nd that has an average outdoor temperature below 13 ºC and ends in June 8th when the same parameter exceeds 13ºC, which means about six months for heating.

7.1.2.3 Design constraints

The performance specifications below refer to the occupied zone.
- Outdoor air filtrated by filter class EU 5
- CO_2 < 1000 ppm (12 hour average) (less stringent the Reshyvent requirement of CO_2 > 1050 ppm max 500 kppmhours and CO_2 > 1750 ppm max 100 kppmhours) - RH < 70 % within 8 hours (bathroom)
- Supply air to living room pre-heated to 5 °C – 30 °C by special convector which minimizes back draft, wind effects and night ventilation
- Indoor temperature 19 °C – 23 °C
- Air velocity < 0.15 m/s (winter) and < 0.25 m/s (summer)
- Outdoor air flow normal operation 0.35 l/(sm^2), the ventilation rate to be based on the number of persons living in the apartment, which means that there are cases when the flow rate will be below 0.35 l/(sm^2)

- Outdoor air flow empty apartment 0.10 l/(sm^2)
- Lowered night ventilation in living room
- Air change common areas ……..
- Air change efficiency > 40 %
- Cooker hood odour capturing ability > 75 % (should requirement 90 %)
- Thermal comfort (% of room PD < 15 %; outdoor temperature = 0 °C) 85 – 95 %
- Pressure difference indoor - outdoor < 15 Pa
- Sound pressure level from HVAC - class B: 26 dBA for rooms and 35 dBA for kitchen (Reshyvent 35 dBA)- Sound pressure level from outside - class B: 26 dBA for rooms and 35 dBA for kitchen (Reshyvent 35 dBA)

Energy efficiency

- SFP exhaust system < 0.5 kW/(m^3/s)
- SFP balanced system < 1.0 kW/(m^3/s)
- SFP balanced system with heat recovery < 1.5 kW/(m^3/s)

System stability

- Ventilation system must tolerate window opening
- Demand controlled ventilation must not cause lasting changes in indoor air temperature
- Air flow stability 25 – 50 % (good)

System flexibility

- Open solution - allowing mixing of systems and components from different manufacturersOperation and maintenance
- Individual metering of heating and electricity
- Accessibility for adjustment, cleaning, service
- Measurability of air flows
- EMC directive
- Instructions and user friendliness

7.1.2.4 Control

The air flow is controlled according to the number of persons living in the apartment. If no one is at home the air flow is lowered to a basic level. If the relative humidity exceeds a pre-determined level in the bathrooms the air flow is always forced. The cooker hood air flow can be manually raised.

7.1.2.5 Air inlets

Ventilation slots are located in the living room (supply convector) and bedroom facades (behind the radiators), below the windows:

The air supply through the façade is provided with supply convector in the living room (figure 7-4) or supply radiators in the bedrooms.

Figure 7-4 – Pre-conditioned supply air convector

The purpose of this device is to do a pre-heating of the supply air to 18 ºC.
Some of the characteristics are:

- Varying heating power ~ air flow;
- Frost protection;
- Z-duct for sound attenuation;
- Night position – external impulse;
- PI-controlled heating (figure 7-5).

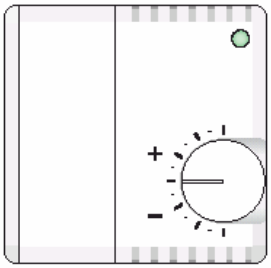


Figure 7-5 - PI - controlled supply air convector
Delivered heat influenced by air flow in convector as well as in supply radiator.

Performances

The characteristics of the air inlets are as follows:

$Q_{living\ room} = 7.35\ \Delta p^{0.6}$ l/s, with simple filter

$Q_{bedroom} = 2.2\ \Delta p^{0.7}$ l/s, with simple filter and two persons in the bedroom

According to these ventilation slots pressure/air flow relation, the figure above shows the resulting curves.

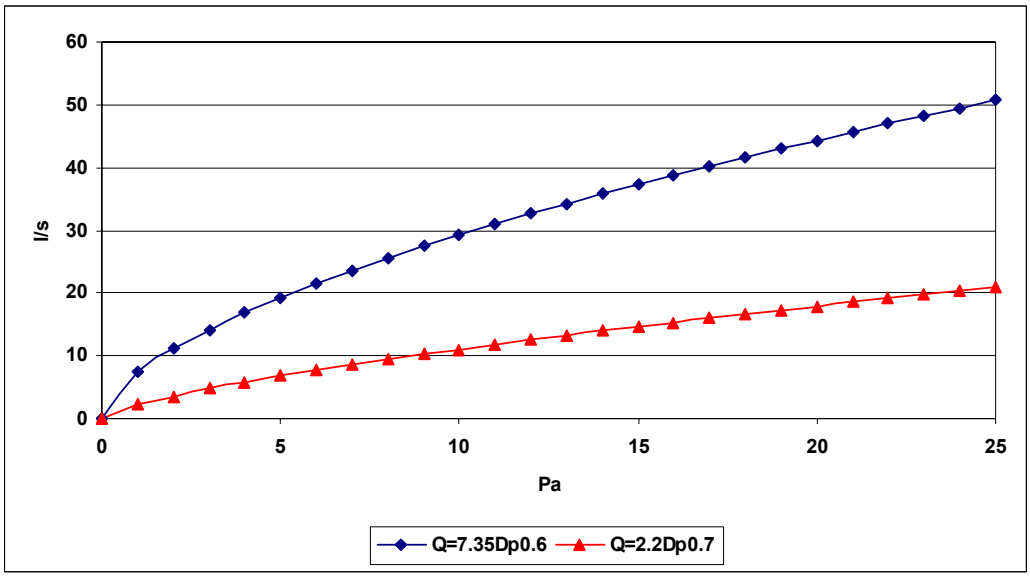


Figure 7-6 - IC1 ventilation slots

There are no wind and back dampers.

7.1.2.5 Extraction

From each apartment there are two extraction points (kitchen and bathroom) connected to only one fan located in the attic.

The main extract duct is vertical and it connects the kitchen's extract device to the exhaust fan. A horizontal duct branch is used to link the exhaust grilles from the bathroom to the main duct.
The fan is a self regulated constant volume flow EC fan.

Performances

The flow and pressure drop in the system are:

- Normal flow (3 person) 30 l/s @ 60Pa
- Maximum flow (cocking) 42 l/s @ 90 Pa
- Minimum flow (empty apartment) 8 l/s @ 6 Pa

The figures above were obtained from the file W1G200-HH41-XQ luft 4072.xls, where we can find the detailed characteristics of the fan.

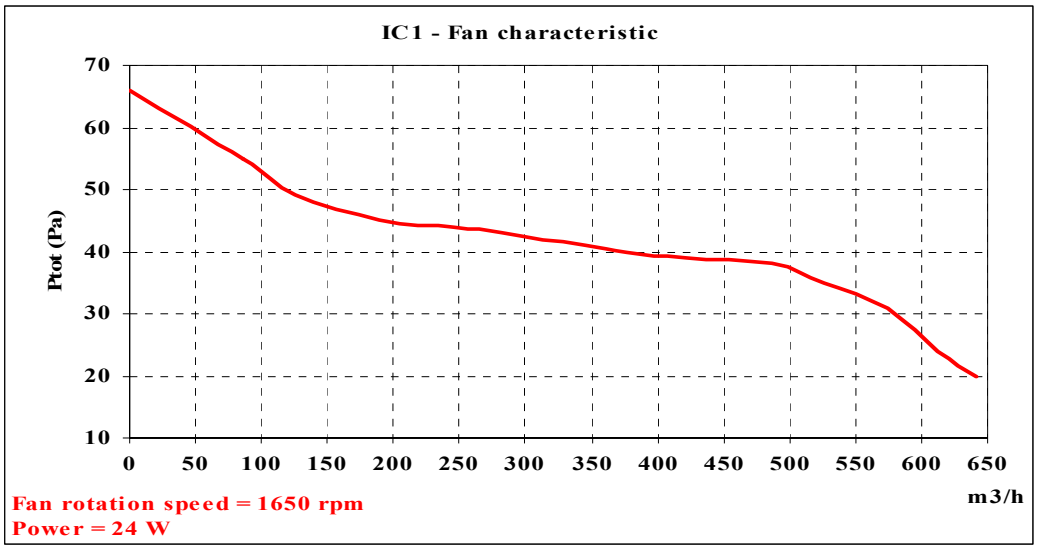


Figure 7-7 - Fan characteristic

The different exhaust air flows are achieved through the fan speed reduction.

In the bathroom there is a extraction valve connected to the extraction system. We know that this device as a working point of 25 l/s @ 10 Pa. Based on this and according to the following equation we assumed the characteristic showed in figure 7-8.

$$\Delta p = k\dot{Q}^2$$

Where, for the referred device, k is 0.016.

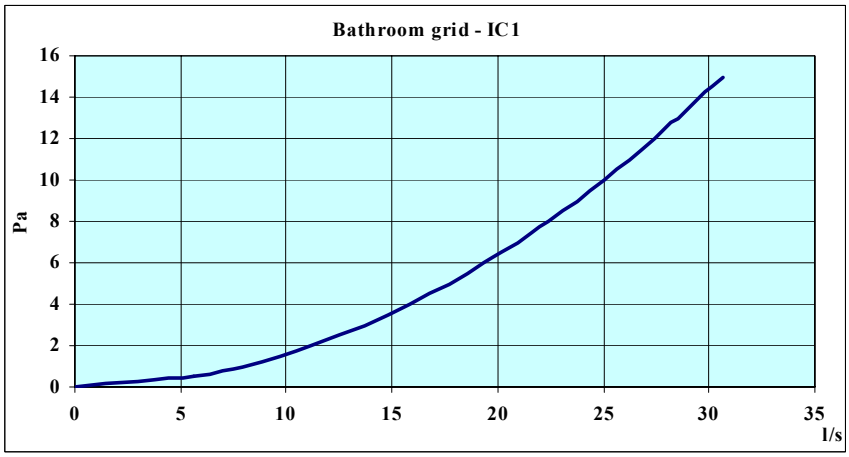


Figure 7-8 - Bathroom exhaust device characteristic

For the kitchen cooker hood, we assumed a working point with 17 l/s @ 13 Pa, resulting the characteristic of figure 7-9.

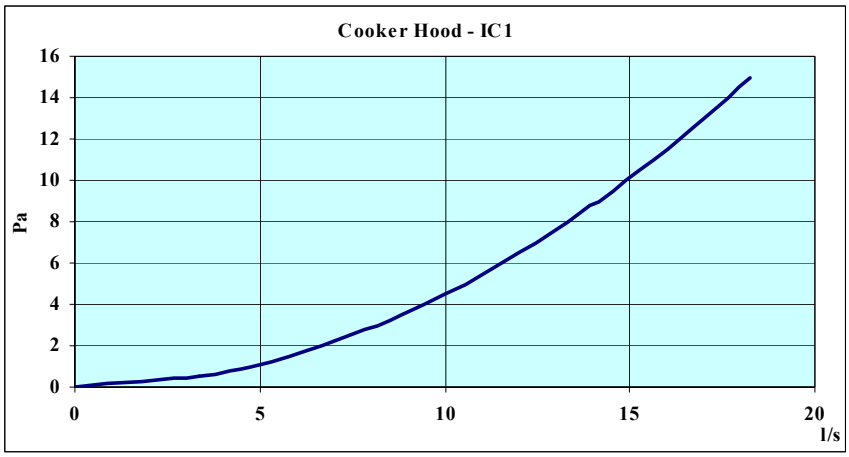


Figure 7-9 – Kitchen cooker hood characteristic

7.1.2.6 Ducting

The ductwork basically consists of round sheet metal ducts. From each apartment there is a vertical duct with a diameter of 200 mm in the shaft next to the kitchen. Vertical ducts start in the apartments and end up in the attic. Horizontal ducts from bathroom to kitchen are basically diameter 160 mm. All the fans are located in the attic (see figure 7-10 and figure 7-11 for details).

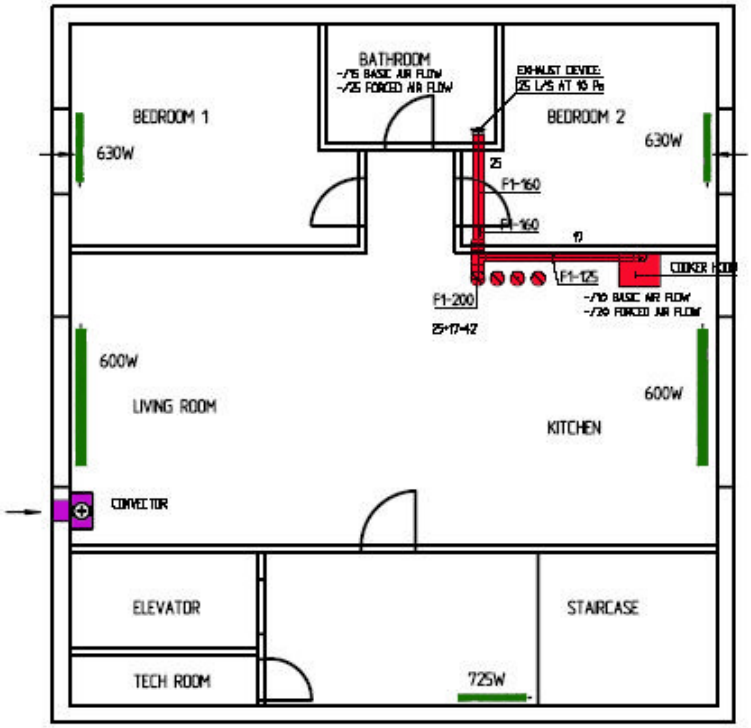


Figure 7-10 - Exhaust and heating system (ground floor)

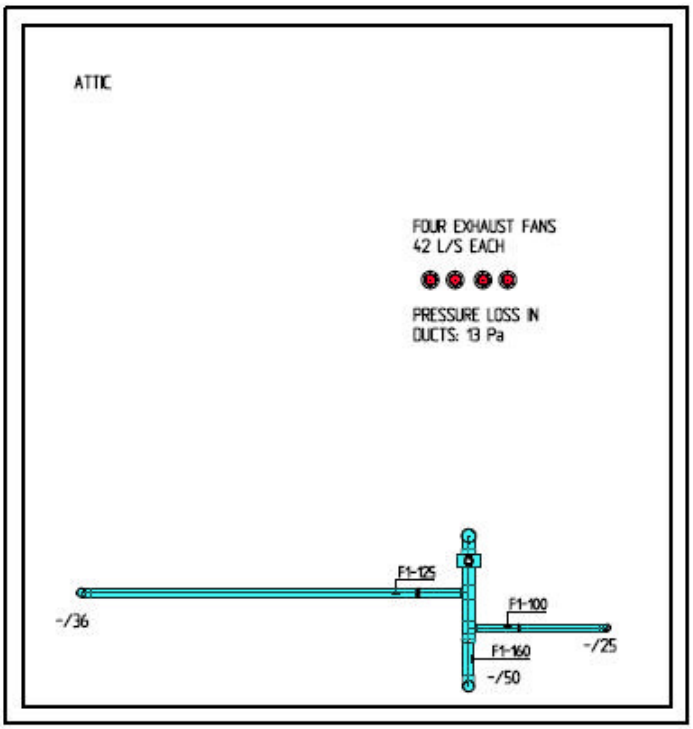


Figure 7-11 - Exhaust system (attic)

7.1.2.7 Control

The control system can be summarized as follows:

- passive stack assisted exhaust fan, one self regulated constant volume flow EC fan per apartment
- pre-adjusted normal ventilation as a function of number of persons
- cooker hood – manually forced ventilation with timer
- lowered ventilation when no one at home, manual or automatic control
- lowered ventilation at night in living room, manual or automatic control
- relative humidity controlled ventilation in bathroom i.e. preventing lowered ventilation if high humidity level and no one at home
- high efficiency cooker hood with indicator for dirty filter
- seasonal adjustment of ventilation rates
- the radiators are controlled as function of outdoor and indoor temperature
- a thermostat controls the supply air temperature from the supply convector

Parameters taken into account:

- relative humidity (in bathroom)
- time (night mode for 8 hours)
- presence (manually activated)
- cooking fumes (manually activated)
- outdoor temperature
- number of occupants
- exhaust air flow (constant regulation according to controlled set points)
- inlet air flow (manually set for one or two persons, automatically according to night/day mode, see time control)

Performance data

- Demand adaptation of ventilating air flows: 17 – 40 l/s according to number of occupants.
- Automated increased air flow when low heating demand: outdoor air temperature/control signal with two set points. Within the temperature interval low – high the signal is increased linearly.
- The no one at home air flow rate: 8 l/s (appr. 0.1 l/s,m2).
- The constant airflow at each set point: +/- 10% (fan with built in control function)
- The accuracy when using only passive stack: 5 – 10 l/s (fan motor turned off)
- Forced air flow rate: 40 l/s (humidity indication in the bathroom and/or manually controlled kitchen valve)
- Humidity control: hygrostat in bathroom
- Night air flow: -30 % of set air flow + closing damper in supply air convector, resulting in increased air flow in bedroom.
- Activation/control of night mode: Manual activation of 8 hours night mode.
- Being considered: Automatic activation of night mode: typically 23.00 – 07.00
- Outdoor air temperature compensation: fan with built in control function allows for low duct pressure drops and still control accurate air flow.
- The space heating system is designed for: 60/40 °C.
- Flat temperature control: PI regulator within the interval 19 – 23 °C
- Bedroom temperature control: thermostat control accepting lower temperatures.
- Control of the space heating system of the building: the outdoor air temperature adding to this an overall system feedback by recording measured indoor air temperatures in the individual apartments i.e. the flow temperature curve is lowered when the indoor temperature increases.
- Overall control system: logging hourly values of air temperature and exhaust air flow in each apartment.
- Calculation of the heat loss from each apartment as a share of the total heating energy supplied to the building.
- Option: data logging of hot water to each apartment.

7.1.2.8 Other important components

Air-to-air heat recovery can added to the common areas such as staircase, basement i.e. preheating the supply air to the common areas by the exhaust air from the apartments.

The supply air can be filtered in the supply convector.

7.1.2.9 Integration aspects with the building and habitation

The ductwork needs more space than e.g. the ductwork of a conventional mechanical exhaust only ventilation system due to increased duct dimensions. However the horizontal ductwork is shorter which might on the other hand be a limiting factor as to possible floor plan layout. The desire to have absolutely vertical shafts might also influence the layout.

7.1.2.10 General information

The investment cost (including material and installation, but excluding taxes) for a traditional ventilation system for a new building is 1 800 Euro (16 000 SEK) for an apartment with 2 bedrooms, a living room, a kitchen and a bathroom. The floor area is 80 m^2. The traditional ventilation system is a mechanical exhaust fan ventilation system ventilating 8 apartments. The outdoor air enters through Z-ducts behind the radiators in the façade. The IC1 system is expected to be 50 % to 100 % more expensive. The higher price includes individual climate control and energy metering. In the future with more stringent energy requirements it is likely that balanced ventilation systems with heat recovery will be the main competitor to demand controlled hybrid ventilation. The investment cost today of such a system is 4 100 Euro (37 000 SEK) i.e. higher than the IC1 system.

The IC1 system is however likely to become cheaper the more units are being produced (see table 9.1). The expensive parts of the system are the supply convector, the EC fan, the control panel and the programming. The supply convector does not contribute to any major energy savings, apart from the fact that if there is no supply convector the occupants might perceive draught and raise the indoor temperature. The supply convector must be made more production friendly. The other expensive components are likely to be cheaper once they are produced in bigger numbers, but of course requiring some product development.

Number or apartments	40	300	300	1 200	10 000
Supply convector	652	598	598	435	326
Z-duct	185	152	152	136	130
EC fan	435	380	380	359	217
Control panel	543	435	435	380	272
Hygrostat	65	65	65	65	43
Room control	163	163			
Cables	272	250	174	163	130
Program, configuration etc.	543	326	326	326	76
Miscellaneous	715	592	533	466	299
Sum	3 573	2 962	2 663	2 330	1 495

Table 9.1 Investment costs, in Euro, for the IC1 system.

The target investment cost for IC1 should be lower than the balanced system with heat recovery and preferably close to the investment cost of a mechanical exhaust fan ventilation system without heat recovery as long as this is the main competitor.

The straight payback period taking into account the complete IC1 system and comparing with mechanical exhaust ventilation without heat recovery is appr. 4 years for the energy savings.

A comparison of hybrid ventilation with mechanical and natural / passive stack ventilation for a number of different aspects was done by the IC1 team and the hybrid ventilation system used as a reference was the IC1 concept.

For aspects categorised as system/components issues the IC1 concept is rated higher than the existing ventilation systems in the area of reliability, user friendliness of the system, operation and service, but rated lower in the area of maintenance and technical life span. The aspects with high relevance/priority according to the expert group is reliability, user friendliness and operation and service, and maintenance. As to aspects categorised as design issues the IC1 concept rated on the same level as mechanical exhaust ventilation and both systems are rated higher than balanced mechanical and natural ventilation. However for the aspect with high relevance such as influence on the design the IC1 concept is rated lower.

The overall performance is rated somewhat higher for the IC1 concept than for the existing ventilation systems. For the aspects with high relevance/priority the IC1 concept is rated better for risk of draft i.e. less risk of draft. For generation of internal noise by ventilation systems it is better than mechanical ventilation, but not as good as for natural ventilation.

Central controllability of the IC1 concept is rated better than natural ventilation but worse than mechanical ventilation. However user controllability is best for the IC1 concept. Both aspects were considered important by the expert group.

The expected energy savings are 50% of ventilation heat losses for an apartment, kWh/år:1. Basic adjustment saves on average 9 l/s , 1.200
Varies with family size from 0 – 18 l/s. 8 h/day.
2. Night position (-20%) saves on average 4,2 l/s 180
during 8 h , raises the quality in bedrooms3. No one at home position (8 l/s during 8 h): 560
Saves 0.02 Euro/h at an outdoor temperature of 0 °Cr.
For the big family the savings is 0.04 Euro/h during winter
Other savings which not are accounted for above are: Individual metering, fan electricity, indoor temperature compensation of forward temperature are not included.

Below follows an estimation of energy savings for an existing building equipped with IC1:

Total measured for 72 apartments	890	MWh
of which dhw	201	
Reshyvent savings	140	
Individual metering heating 10 %	55	
Heating control 10 %	49	
Individual metering dhw 15 %	30	
Total savings	274	
per apartment	3,8	MWh/apt
Payback assuming 1750 Euro	8 years	

additional cost and 0.06 Euro/kWh

7.1.3 IC2 Moderate climate

7.1.3.1 Introduction

Figure 0-1 gives an overview of the system. A single-family house is shown, with the living room and the kitchen at the ground floor and the bathroom and the bedrooms at the first floor. To reduce the flow resistance the exhaust is lined up under the roof outlet.
The ventilation flow is demand controlled. For the living room and the bedrooms CO_2 sensors are foreseen. Also other sensors to detect the presence of persons like infrared (IR) can be used. A central control unit receives information from these sensors and gives set points to the self-regulating inlets and vents and, if necessary, starts and controls the fan. The nominal total flow rate is 56 dm^3/s. However the maximum flow rate is foreseen at 100 dm^3/s, which can be used during cooking, showering and for passive cooling.

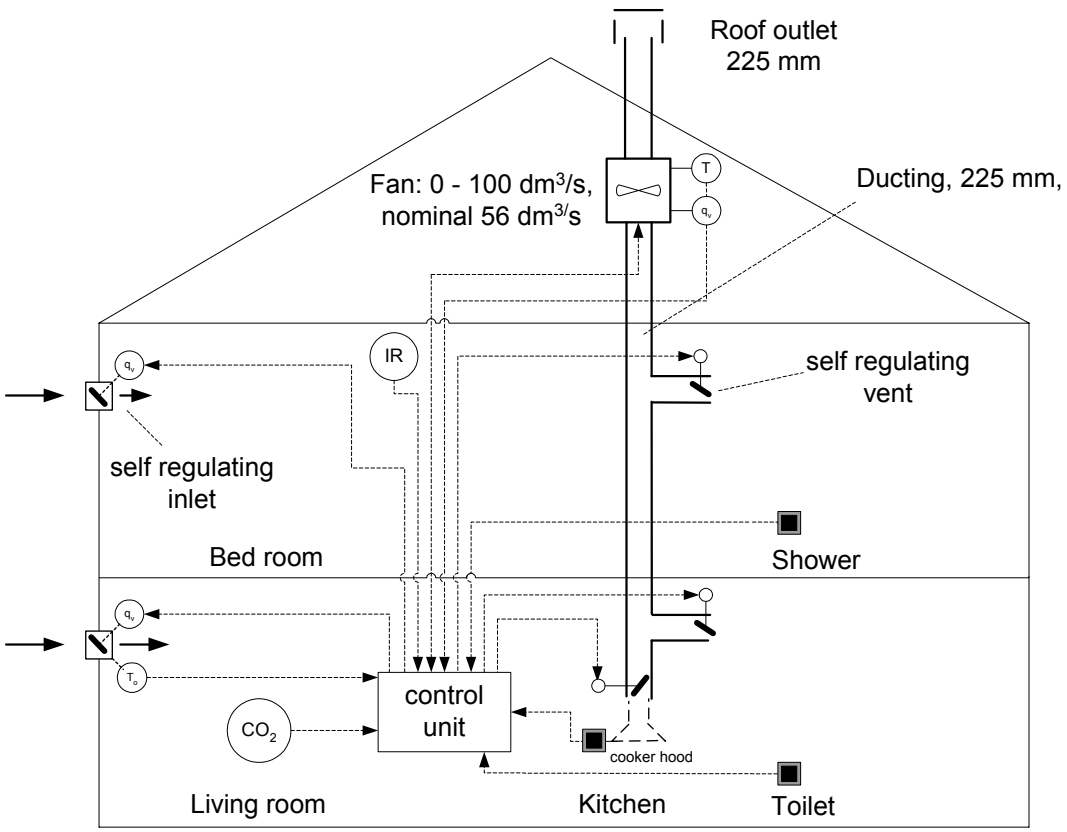
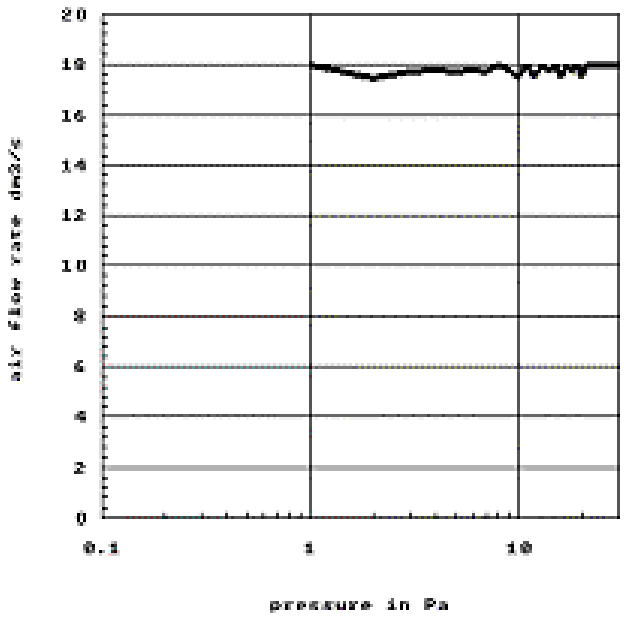


Figure 0 1: demand controlled hybrid ventilation system in family house.

7.1.3.2 Supply

The supply inlets comply with the following requirements:

- Self-regulating inlets;
- Placement in window frame;
- Draught correction (comfort);
- Allow for (separate) cooker hood, compensation of supply during use of hood by control unit;
- Possibility for passive cooling (through ventilation) through extra fixed inlet with larger geometric aperture;
- Building leakage compensation on inlets.



7.1.3.3 Distribution

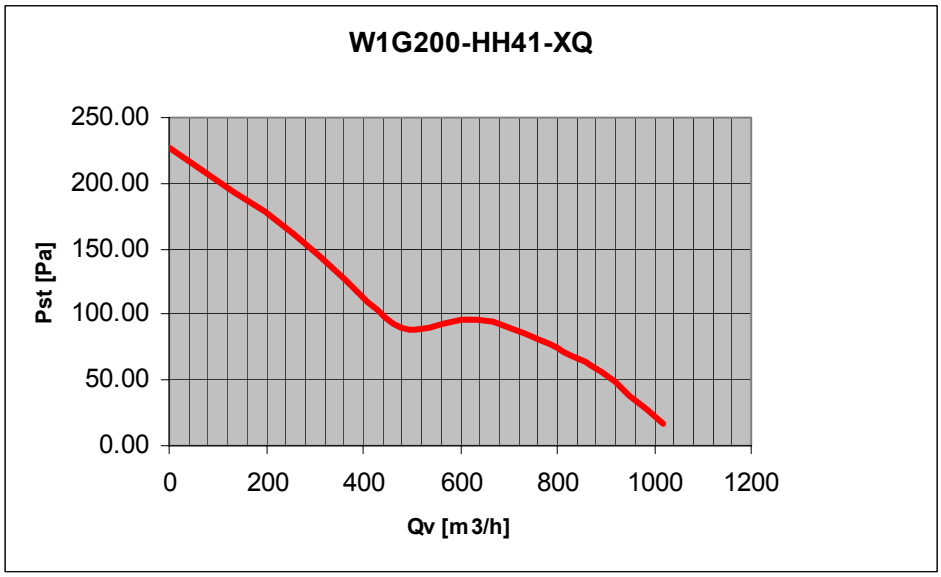
The distribution components will comply with the following requirements:

- Pressure drop over ducting @ 56 dm^3/s maximum 2 Pa;
- Ducting round maximum 180 mm;
- Improved coupling fittings;
- Limited noise propagation (cross transmission of noise) especially with regard to fan;
- Special fittings for apartments with individual units on central exhaust;
- Development self-regulating vents at approximate 5 Pa pressure difference with controllable flow rate.

7.1.3.4 Fan

The fan complies with the following requirements:

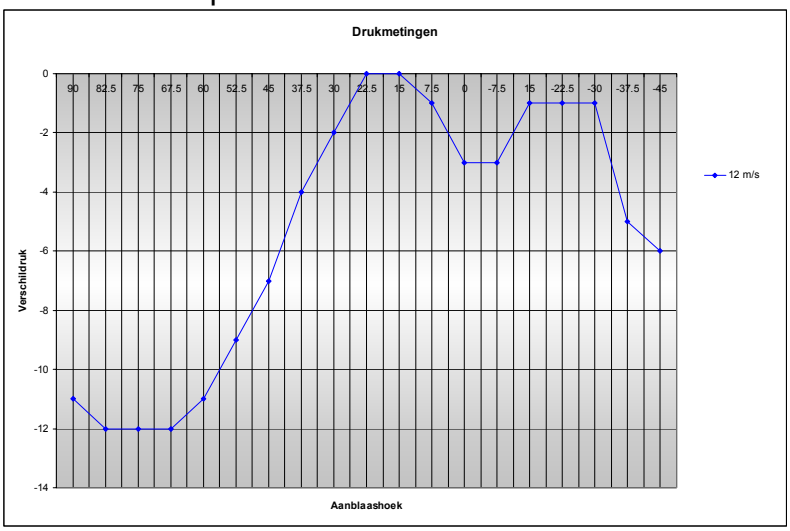
- Energy consumption fan: 1 – 2 W @ 56 dm^3/s and 10 Pa (nominal flow);
  20 W @ 100 dm^3/s and 40 Pa (excess for cooker hood, shower or limited passive cooling);
- DC power supply and controls, max. 1 - 2 W energy consumption;
- Low speed fan, max. 800 rpm;
- Low noise generation;
- Limited noise propagation especially with regard to large size ducting;
- Flow controlled.



7.1.3.5 Roof outlet

The roof outlet will comply with the following requirements:

- Optimized for wind conditions;
- Max. static pressure 1Pa;
- Condense water drain or provisions to prevent the formation of condense water;
- Rainproof.



7.1.3.6 Control

The controls comply with the following requirements:

- Demand control;
- Limited investment costs;
- Minimum energy consumption, 1 - 2 W continue.
- Temperature control (passive cooling), outside temperature through self regulating inlets and inside temperature through sensor at fan system;
- Possibility for overruling system by inhabitant;
- User-friendly interface for control by inhabitant.
- Minimum wiring, e.g. sensor position near inlet;
- Indoor Air Quality controllable at several levels of CO_2 concentration.

8. Conclusions

- The development of demand controlled hybrid systems has just started. It will still need many years before this type of system will be available as a standard product on the market.

- The main barriers for the application of hybrid ventilation systems will be initial cost, suitable assessment methods and current legislation and standards.

- Since there is an important interaction between hybrid ventilation systems and the building design, the future market will be mainly in newly built residential buildings. In retrofitting buildings it might be possible to apply hybrid ventilation systems, but this will be rarely the case

- Since cost is one of the important barriers the future market will be mainly in the top segment of the residential building market. In more expensive housing one might consider to apply hybrid ventilation systems.

- The remaining research questions are still:

    - how to develop low pressure components such as heat recovery units
    - where is the optimum of the sizing in relation to the time the fan has to run to fulfil the required flow rate
    - what is the best control strategy
    - what kind of sensors are accurate and reliable

- The assessment methods to prove the performance for as well components as for the whole ventilation system are still under development. There is neither guidance nor an accepted approach in the European Union for assessment of innovative ventilation systems.

- The best approach industry might follow seems, to demonstrate:

    - The year around performance in terms of IAQ
    - The year around performance in terms of energy

  With the help of a combined heat- and airflow model, using a kind of probabilistic approach for the input parameters. Compare the results with results of a standard system

- The sensor technology is quickly developing. Cheaper, more accurate and reliable sensors will probably on the market in the next 3 to 5 years.

- The most important part which should be cheaper is the control system and especial the sensors.

9. Recommendations

- Price reduction is one of the most important items for a wider application of hybrid ventilation systems. This is a challenge for industry.

- Improvement of control is still advisable both in terms of sensor technique and improved algorithm.

- More education on hybrid ventilation is required at all levels and for a wide range of professions.

- User interaction of hybrid ventilation systems and user instructions can be improved.

- There is a need for a European guideline for the assessment of hybrid ventilation systems. A big challenge for CEN and the European Union.

- The application of the principle of equivalence in all national building regulations will be a good start for stimulating the application of innovative systems

- Architects and consulting engineers should take in their pre-design considerations hybrid ventilation as an option to evaluate

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