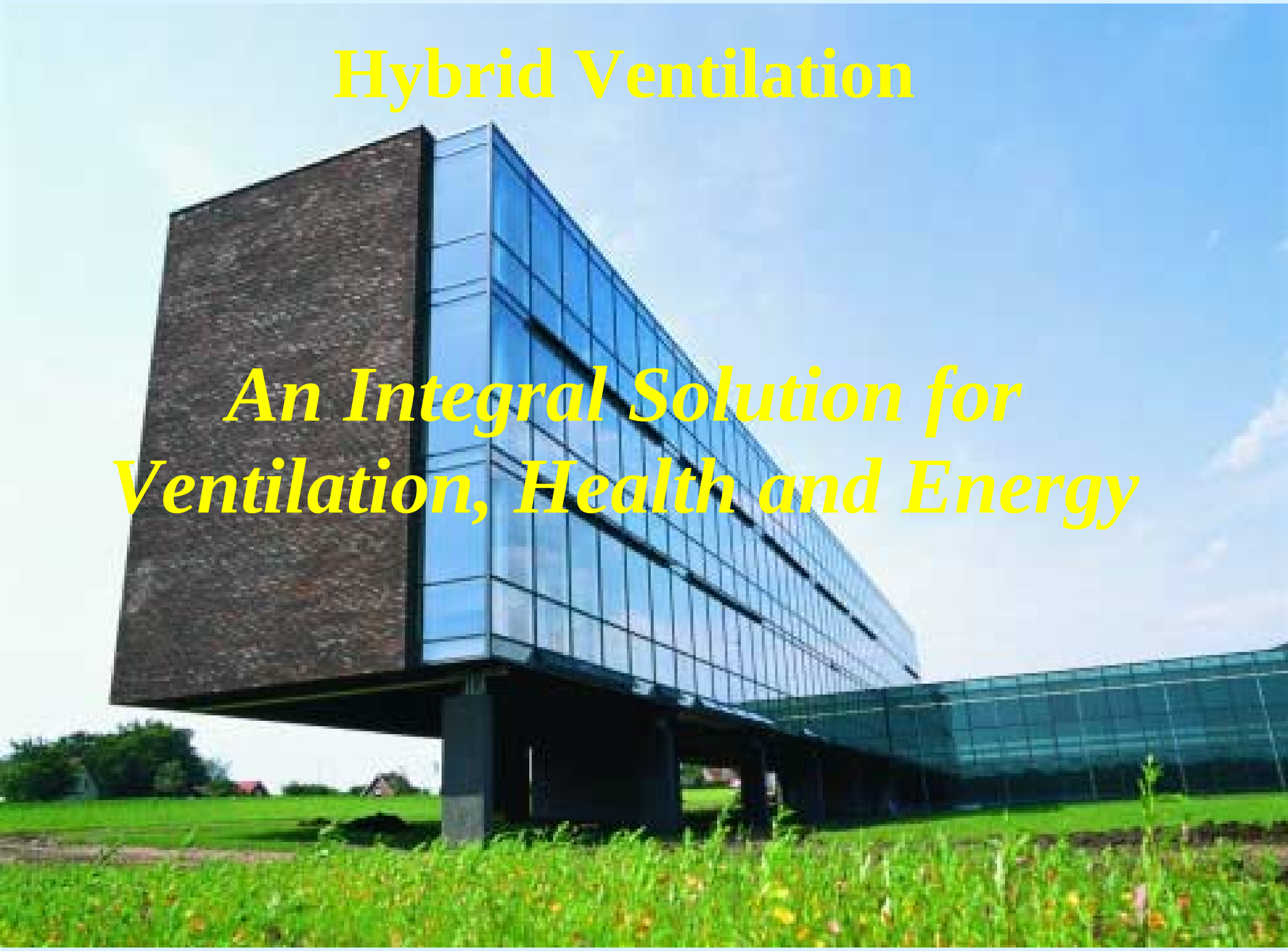
Faculty of Civil Engineering and Geoscience

Hybrid Ventilation

An Integral Solution for Ventilation, Health and Energy



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Annex35 HybVent
Hybrid Ventilation in New and Retrofitted Office Buildings

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INTRODUCTION

Inadequate ventilation is clearly reported as the most important cause of poor indoor air quality.
Investigating the impact of type of ventilation system showed that office buildings with a natural ventilation system scored remarkably better than mechanical ventilated buildings. This despite the fact that every HVAC-engineer is convinced about the quality well designed air-conditioning systems can give.
Hybrid ventilation can realise a bridge between natural ventilation and air-conditioning. The concept makes it possible to neutralise the limiting effects of natural ventilation and to avoid the negative aspects of being always dependent on a mechanical HVAC-system.

Evaluation of thermal comfort is often based on static heat-balanced models. These models are suitable for comfort judgements in HVAC-buildings.

But if there is a possibility of an own climate-modifying performance the overall satisfaction is influenced positive. The comfort zone is extended by the presence of adaptive opportunities. The lay-out of a hybrid ventilation system should be prepared for this possibility to increase the well being of people in the building.

In The Netherlands about 15% of the dwellings with natural ventilation shows humidity problems. A hybrid ventilation system can guarantee, in the wintertime and during absence, the minimum airflow to avoid these problems.

Energy saving is also a goal hybrid ventilation can fulfil.

Except the significance of the extension of the comfort zone, the reduction of transportation energy of the ventilation air is important.

The members of Annex 35 present in this symposium the first results of their work. They are grateful for every comment which brings them further.

All information about the annex is available on the Annex 35 Web-site:
http://hybvent.civil.auc.dk. This web site contains description of the annex, papers and publications, information about pilot studies and monitoring programs as well as measurement and analysis results.

I hope this may be a rewarding day for everyone.

Prof. ir. J.J.M. Cauberg,
Symposium chairman

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THE DUTCH ENERGY SAVINGS POLICY WITH RESPECT TO HEALTH EFFECTS

Martijn van Baarsen
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Abstract

This paper briefly describes the current Dutch energy savings policy with respect to the built environment, including the specific health care effects of these energy-saving measures.

The policy: climate policy implementation plan

As I'm sure you know, the European Union agreed in Kyoto to reduce greenhouse gas emissions by 8% in 2010, compared to 1990 levels. The Dutch Government has developed a range of activities designed to achieve these goals, all of which are described in the Climate Policy Implementation Plan.

Reductions will also need to be realised within the built environment sector. This reduction has been set at 3 Mton per year, to be achieved in 2010 (reductions will probably be less in the years leading up to 2010). In preparation for this, only the existing housing stock will be included. The EPA (Energy Performance Advice) is an important instrument in achieving this reduction, both for existing housing as well as existing utility building, and helps to determine which measures should be used to achieve energy savings as cheaply as possible. Implementation of the energy-saving measures recommended in the EPA can also be stimulated by the energy premium and the energy investment deduction (known as EIA).

Evaluation

The Climate Policy Implementation Plan also proposes an evaluation of the current energy performance specifications. If these specifications could be tightened up then the 3 Mton reduction goal could be achieved more easily. Energy performance specifications define the energy efficiency levels required for new utility building and housing. The energy performance level of a building is determined according to the design of the facades, roofs and ground floor, as well as the selection of the various installations.

The evaluation of these specifications will be finalised soon, so that the results can be announced at the conference in May, though the draft evaluation has now been completed. The criteria used to evaluate the current energy performance specifications are shown in the table below.

	Tightening up EPC	Cost effective-ness per ton CO_2	CO_2 reduction achieved in 2010 (in Mton)	Total environ-mental conse-quences	Increase in (living) costs	Effects on health	Effects on freedom to design
Housing	0%						
	10%						
	20%						
	30%						
Utility building	0%						
	10%						
	20%						

The table shows that both the consequences of the current energy performance specifications, as well as possible tightening up of these regulations, are being considered. In studying the consequences, the designs for houses and utility buildings are evaluated on a purely theoretical basis, although occupiers are also asked to give their practical experience of energy-efficient houses.

Attention to health issues

The latter study, mentioned above, also included the occupiers' perception of the health and comfort levels in their home, e.g. the ventilation and heating systems used, indoor air quality, temperature levels, draughts, damp, and noise nuisance.

With regard to this particular study, let's take a quick look through the keyhole. An important conclusion for the ministry is that there is no connection between the energy performance of a house and the number of health problems suffered by the occupiers. However, there is a clear connection between the complexity of the techniques used and the health complaints. Certain ventilation systems and innovative heating systems do not function well. The problems primarily concern new applied techniques, the design of the house in relation to these techniques, and the implementation of the various systems. The result is that occupiers do not know how to operate these new systems, therefore giving rise to health problems. The ministry is currently considering what can be learned from these results. The built environment sector should be doing the same.

Health and the indoor environment are not only important issues for new buildings, but also for existing homes and utility buildings. This is why we are trying to introduce health and indoor environment issues into the EPA specifications. The ministry is currently considering coupling a separate health module to the EPA regulations.

The future: policy revision?

The Implementation Plan is now almost two years old, so an interim policy evaluation is required to gain some idea of the degree to which the goals are being achieved. The aim is to have a provisional overview ready during the summer, and to send the results to the Second Chamber of the Dutch Parliament.

The Minister for VROM will not comment officially prior to publication of these results, but both the First and Second Chambers have been told informally that he is worried about meeting the goals set in the Climate Policy Implementation Plan. Should these reservations prove justified, then reserve measures from the Implementation Plan will need to be used.

The Ministry is also currently working on the fourth national environment policy plan, known as NMP4. Within this framework, CO_2 reduction targets will be set for the period up to 2030 and a preliminary selection of possible new measures will be made. This policy document is expected sometime this year.

Considering the aforementioned impetus, government policy on energy saving in the built environment is expected to be a hot item this year, during which all the various alternatives will be considered. Whether or not this does indeed lead to a tightening of the policy regulations is still open to debate: in the end the Cabinet (in consultation with the Second Chamber) will decide whether changes are necessary. After all, it is the government that governs.

HYBRID VENTILATION – STATE-OF-THE-ART REVIEW

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Introduction

Annex 35 is an International Energy Agency (IEA) task-sharing project which commenced on 1 August 1998 for a duration of four years, and in which fifteen countries participate. The objectives of Annex 35 are to promote energy- and cost-effective hybrid ventilation systems and develop control strategies and performance analysis methods for office and educational buildings.

The first goal of Annex 35 has been to provide a state-of-the-art review of hybrid ventilation. The review has included a survey of existing buildings and systems in the participating countries and a survey of building codes and standards and their impact on application of hybrid ventilation to highlight barriers to, or opportunities for implementation. The review describes the state-of-the-art in hybrid ventilation technologies, control strategies and algorithms, and analysis methods. The review has identified weaknesses and lack of knowledge in system performance, components, control strategies and design methods, and identified and prioritised research needs. It provides examples of systems installed in existing buildings, showing solutions to specific problems (fresh air supply, excess heat removal, etc.), in office buildings located in different outdoor climates. The intended audience is both the participants and the design community and the following is a short summary of the main findings and conclusions that can be found in the published report.

Expectations of Hybrid Ventilation in the Participating Countries

The 15 countries participating in Annex 35 are doing so because experts in each country believe that hybrid ventilation offers significant opportunities for improving the indoor environment and reducing energy demand. Naturally, because of climate variations and other factors, different countries have differing expectations of hybrid ventilation. Each participating country prepared a short description of their expectations of hybrid ventilation. Table 1 summarises the key issues arising from these descriptions.

Commonly cited statements were that hybrid ventilation systems are expected to:

- Offer a wider range of design options.
- Reduce noise from fans.
- Reduce electricity demand.
- Reduce energy demand.
- Reduce CO_2 emissions.
- Allow more individual control, operable windows, etc.
- Deliver satisfactory or even improved IAQ.

Country/Issue		Australia	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Holland	Italy	Japan	Norway	Sweden	UK	US
System	be a simpler and more robust system												X	X		
	be a compromise between an uncontrolled indoor environment and a mechanical system						X				X		X			
	allow the combined use of intelligent mechanical ventilation for IAQ control and a combination of natural and mechanical ventilation for summer comfort control		X													
	be especially attractive in combination with natural lighting, atriums and double façades					X							X			
	offer a wider range of design options					X				X			X	X	X	
	satisfy customers requirements					X								X		
Health and well-being	reduce noise from fans					X							X	X		
	satisfactory thermal comfort (i.e. preheating of supply air)		X			X							X			
	improve IAQ in periods with abundant natural forces		X		X											
	improve IAQ		X							X			X			
	satisfactory IAQ (filtering, etc.)					X								X		
	increased focus at demand controlled ventilation		X			X							X			
	simpler to keep clean												X			
	reduce the sick building syndrome problem	X	X										X			
	offer physiological and psychological benefits for the user							X								
	feeling of natural ventilation					X										
	increase occupants' satisfaction	X	X			X							X			
	deliver more efficient ventilation		X						X							
Cost and environment	reduce electricity demand				X	X					X		X	X		X
	eliminate mechanical cooling demand				X											
	reduce mechanical cooling demand		X										X			
	practically eliminate air conditioning demand during intermediate seasons		X						X							
	reduce demanded mechanical air conditioning operation time significantly								X							
	reduce need for mechanical air conditioning		X						X							
	reduce energy demand	X	X				X	X		X		X				
	offer competitive total heat energy demand		X										X			
	offer competitive exhaust air heat recovery					X										
	shorten investment payback period	X	X													
	reduce maintenance costs												X			
	improve occupants' productivity	X											X			
	increase property values due to improved indoor environment quality	X														
	need less maintenance					X						X	X			
	offer longer system lifetime												x			
	reduce CO_2-emissions	x					x				x	x				
Usability	allow more individual control, operable windows, etc.	x	x			x						x	x			
	be simpler to maintain					x						x	x			
	be simpler to use					x						x	x			

Table 1: Expectations of hybrid ventilation (Hybrid Ventilation systems are expected to …).

Survey of Existing Buildings

Quite a number of hybrid-ventilated buildings have already been built around the world, and more are planned or about to be built. The survey includes 22 existing buildings from ten of the countries participating in this Annex. The buildings surveyed are low to medium-rise buildings (except for the Meiji University Tower in Tokyo), located in areas with little or moderate dust and noise pollution. Further examples of high-rise hybrid-ventilated buildings, or buildings in more challenging environments, will be useful to demonstrate that innovative solutions can be found for a wide variety of applications and environments. Particular topics of interest in the survey were the overall design philosophy used to ensure good IAQ and thermal comfort, the control strategies used, and the components used.

It is clear from the descriptions of the overall design philosophy that a successful hybrid ventilation design depends on an integrated approach, in which optimal use is made of sustainable technologies such as passive solar gains, daylight and natural ventilation. In particular it requires good thermal design, and in a number of buildings thermal mass combined with intensive night ventilation (using natural forces or fan assistance) is exploited to stabilise temperatures during the day.

Some of the buildings surveyed have been successfully retrofitted with hybrid systems. Many existing office buildings either overheat in summer or use excessive amounts of energy to maintain acceptable temperatures, because of increasing internal heat gains from office equipment, low-efficiency lighting systems, high staff densities, and excessive solar gains. When refurbishment is due in these problem buildings, new air conditioning systems are installed to either replace a natural ventilation system or an existing air conditioning system. Thus retrofitting hybrid ventilation systems in existing buildings when they are due for refurbishment has the potential to greatly increase the impact of this technology on energy consumption and worker satisfaction and productivity.

Control strategies in the buildings surveyed are usually based on temperature control, with some (particularly schools) also using CO_2 control. Both manual and automatic control of openings and fans is often available. More information is needed on how well the control strategies work in practice, whether there are any reliability problems with motorised openings, and similar issues.

Some performance results are available for 15 buildings. Generally, satisfactory performance was reported: six buildings reported energy savings, seven reported comfort improvements, and two reported very good IAQ. In some cases a control strategy adjustment is required, and one building reported some noise and draught problems.

Some basic components were used in most buildings. These include fans, CO_2 and temperature sensors, manually operated and/or motorised windows or special ventilation openings, and wind towers, solar chimneys or atria for exhaust. Six buildings used underground ducts, culverts or plenums to pre-condition the supply air. The components used to solve problems presented by the particular needs of hybrid ventilation systems are of particular interest in reviewing the state of the art. The components used are summarized in table 2.

Problem	Component
IAQ control	The most common components used were local CO_2 sensors and manual and/or automatically operated windows, skylights or special openings. In the Belgian buildings, an infrared presence detection system was used to control the mechanical ventilation system.
Temperature control	Local temperature sensors were commonly used. A number of buildings used solar shading and high-efficiency lighting to control heat gains, and in the Belgian buildings lighting was controlled by luminance sensors. Seven buildings used underground ducts, culverts or plenums to precondition the supply air.
Energy conservation	In most of the buildings considerable care was taken to ensure that the building was thermally efficient. The most common measures taken were good insulation levels and use of high-performance glazing. High-efficiency heating systems, and skylights, rooflights, and reflectors to provide daylight were also used.
Ensuring low pressure drops	Low pressure drops were ensured by avoiding the use of ducts, by using large ducts or other components to transport air (e.g. corridors), by using low pressure drop dampers in extract cowls, or by terminating fitout screens below the ceiling height.
Control of air flow rate	Inlet and/or extract fans were often used to ensure a sufficient flow rate. In Denmark frequency-controlled axial fans are controlled by air velocity sensors situated in the extracts. The Netherlands building used electronic self-regulating trickle ventilators with direction-sensitive flow sensors. Many buildings used wind towers, solar chimneys or atria for exhaust, and manual and/or automatically controlled windows or other openings for air intake.
Outdoor air pollution	In Norway the intake duct was used to settle large particles. Filters were also used.
Security	In three buildings openings were designed to provide security by being either small, high-set, or designed to be burglar-proof.
Draught	In Australia screens were used to deflect air. In Norway low-velocity low level diffusers were used. In UK perimeter fans are used for winter ventilation without draughts.
Acoustic privacy	In three UK buildings the ceiling and/or light fitting design was used to control noise. Acoustically insulated or specially designed inlets were used in The Netherlands building and in Norway and Denmark sound-absorbent baffles were used to reduce fan noise.
Fire regulations	In a few buildings, under fire alarm conditions dampers, windows or doors are automatically closed or opened as required. In Norway care was taken to minimize combustible material in the intake air duct.

Table 2: Components used to solve particular hybrid ventilation needs.

Critical Barriers to Hybrid Ventilation

Hybrid ventilated buildings must comply with existing building codes and standards, where they are mandatory. A survey in twelve of the countries participating in Annex 35 describes the paragraphs in acts, codes, standards or recommendations that may have an impact, positive or negative, on hybrid ventilation systems.

Codes and standards may constitute barriers to hybrid ventilation systems in the following ways:

- Implying a high fan power demand, which is also felt to be higher than reasonable, and thus makes the difference between a hybrid and a mechanical ventilation system less significant (e.g. air flow rate requirements).
- Implying higher investment costs for hybrid ventilation than for mechanical ventilation (for example costs due to investments in special devices to prevent fire or sound propagation).
- Implying a level of safety which is felt to be higher than reasonable.
- Lack of codes and standards (almost all regulations and recommendations are made with mechanical ventilation systems in mind; the absence of regulations and recommendations made with the option of hybrid ventilation in mind can be considered to be a barrier to hybrid ventilation).

The following issues have been emphasized in the survey:

- System issues.
- Indoor air quality and thermal comfort issues - airflow rates, relative humidity and CO_2, indoor air temperatures and draught, supply air quality and filtering.
- Fire and smoke issues – compartmentation; penetration of fire separation constructions, smoke ventilation and escape routes, compensating measures.
- Acoustic issues (maximum noise level, minimum acoustic insulation, etc.).
- Energy issues (heat recovery, energy use, etc.).
- Other issues (maintenance, monitoring, safety, etc.).

In general, none of the countries surveyed have regulations that severely restrict the general use of natural or hybrid ventilation. Some paragraphs recommend or require mechanical ventilation in special cases, for example in polluted urban areas and when radon is present in the ground. Some countries have high requirements for air flow rates, which will imply a high demand for fan power. Hybrid ventilation systems rely as much as possible on natural driving forces, although in practice they may have more or less fan power installed than mechanical systems. Thus while a requirement for high air flow rates will not necessarily favour a pure mechanical system over a hybrid system, it is not in line with the HV approach.

Three countries recommend a CO_2-level less than 1000 ppm, which may require extensive use of fans. In areas with low pollution loads this may imply a higher fan power demand than necessary. In the five countries where heat recovery is required, this may imply an unnecessary high fan power demand, for example when using an underground supply air duct.

There are requirements on minimum temperatures and summer maximum temperatures, but these are mostly non-mandatory. Most countries have requirements on maximum noise levels in indoor spaces and noise generated by plant or duct systems. In addition Italy, Norway and Sweden have requirements on the acoustic insulation of façades, which may be of concern for hybrid systems since they may require façade openings.

Fire, smoke and noise regulations probably represent the most serious barriers to hybrid ventilation. Paragraphs on these issues, most of them mandatory, were found in all the countries. The more open nature of buildings with hybrid ventilation systems tends to enhance the spread of smoke and fire. Hybrid ventilation systems therefore will need careful design to meet requirements on openings, compartmentation and smoke removal. However, it should be emphasised that it is often possible to satisfy fire regulations if compensatory measures such as sprinkler systems are used.

Not all the requirements in codes and standards represent a barrier. Requirements that deal with restricting electricity use, noise generated by installations and access to ducts for cleaning may favour hybrid ventilation over mechanical ventilation systems. It is likely that almost none of the paragraphs found in the survey were written with the possibility of combining natural and mechanical ventilation in mind. The absence of such regulations and recommendations will cause uncertainty among designers and building developers, and could thus be seen as a barrier to hybrid ventilation. Notwithstanding the barriers or challenges that may exist, it is worth emphasising that none have prevented a wide variety of hybrid-ventilated buildings being built and planned.

In addition to the barriers identified in the codes and standards survey and in the AIOLOS and the NatVent projects, the following issues may represent challenges to hybrid ventilation systems.

Hybrid ventilation systems are often designed with relatively high storeys and with ducts having large cross-sectional areas. This may imply a risk for increased space demand compared with mechanical ventilation systems.

Furthermore, hybrid ventilation systems require airflow paths with large cross-sectional areas in order to keep pressure losses low. Until hybrid ventilation systems are as common as mechanical systems, components such as heat exchangers, heat recovery units, vents, etc. need to be custom-made. Furthermore, there is a lack of design tools and guidelines, and only a few designers have sufficient design competence. Thus, there is a risk for higher investment costs than in mechanical systems. Because heat recovery is less effective in hybrid ventilation systems there may be a risk of higher heating energy demand, and thus overall energy demand, than for a mechanical ventilation system.

Because of relatively low fan power installed in most hybrid ventilation systems, they are not able to respond immediately to changes in outdoor climate or in ventilation demand. Mechanical systems are designed to deliver the specified airflow rate irrespective of outdoor climate. A fear of unsatisfactory IAQ and thermal comfort may thus be the result.

The design of hybrid ventilation systems is a new discipline which requires new competencies and a different approach from engineers and architects. Those who do not have these competencies may thus feel that the task of designing a hybrid ventilated building is a significant risk – both economically and with respect to system performance. For them the easiest and often most profitable solution is a conventional mechanical system.

Barriers to natural ventilation systems have been investigated in previous projects, in particular the AIOLOS project (Allard, 1998) and the NatVent project (Aggerholm, 1998a, 1998b). Table 3 gives a broad overview of barriers identified in AIOLOS, Nat**Vent**^{TM}, and in Annex 35 to date, which may hinder the use of hybrid ventilation systems.

Type of barrier			**Source**
Design	Economy	Designers' fee depends on investment cost of ventilation components	AIOLOS
		Fear of increased costs for designers	HybVent
		Designers' fear of not succeeding	HybVent
		Fear of increased space demand	HybVent
		Fear of increased overall investment costs	HybVent
	Knowledge	Uncertainty due to lack of information, knowledge and experience about hybrid ventilation and lack of examples of documented and successful hybrid ventilated buildings	NatVent/HybVent
	Regulations, guidelines and tools	Reduced number of design options for ventilation system and increased investment costs due to fire compartmentation and noise regulations	AIOLOS/HybVent
		Uncertainty among designers due to lack of suitable design tools	AIOLOS/NatVent
		Uncertainty due to lack of suitable standards and regulations	AIOLOS
	Architecture	Fear of the impact of chimneys, towers, building envelope, etc. on the architecture and overall design	AIOLOS
	Unwillingness	Smart control devices which may overcome other barriers are not being implemented due to unwillingness among building owners or promoters	AIOLOS
Use	IAQ and thermal comfort	Fear of ventilation short-circuits	HybVent
		Risk of obstructed airflow through windows due to shading devices for solar control or privacy	AIOLOS
		Fear of unsatisfactory IAQ and thermal comfort	HybVent
		Lack of acceptance of fluctuations in indoor climate conditions (high summer temperatures, temperature variations during the day, temperature differences between floor and ceiling, etc.)	AIOLOS
		Risk of draught from ventilation openings in façade	AIOLOS
		Risk of decreased IAQ and thermal comfort because users do not know how to operate the system correctly	AIOLOS
		Risk of polluted supply air due to road traffic, industry, pollen, etc. when filtering is not used	AIOLOS
	Safety	Risk of intrusion of unwanted elements through openings, i.e. burglars, animals, insects or precipitation.	AIOLOS
		Fear of fire and smoke distribution through airflow paths	HybVent
	Noise	Fear of noise distribution through façade and between rooms within the building	AIOLOS/ HybVent
	Usability	Fear of increased user effort to maintain IAQ and thermal comfort	HybVent
	Economy	Fear of increased overall energy demand (due to less effective heat recovery)	HybVent
		Risk of increased fan power demand due to fire protection and noise distribution regulations	HybVent

Table 3: Some identified barriers to natural and hybrid ventilation.

Control Strategies for Hybrid Ventilation

The complexity of a control strategy for hybrid ventilation depends on the major purpose of the ventilation system. Where the major purpose is to guarantee appropriate indoor air quality, there is clearly a need for optimisation: air flow rates that are too low will lead to unacceptable indoor air quality, whereas air flow rates that are too high will result in unnecessary energy use. Thus advanced control strategies are very important.

Where the major purpose is to contribute to acceptable thermal comfort conditions in summer, the optimisation challenge is not so crucial (unless very strict thermal comfort conditions are specified). In this case a less advanced control strategy is possible. Moreover, one can also rely more on the occupants for control, since they can assess the thermal comfort conditions quite well. However, given the slow reaction time with respect to thermal comfort conditions, automated control may be recommended.

In a control system, control and controlled parameters must be chosen with regard to the strategy to be implemented as well as feasibility and cost. Various parameters may be measured, depending on the objectives of the control strategy. These include thermal comfort parameters to allow calculation of PMV, ET, etc, IAQ indicators such as CO_2, CO, H_2O or occupancy, and energy-related parameters to ensure that HVAC system operates efficiently.

Many control techniques have been developed over the past 50 years. They can be classified into three main types: classical; optimal and predictive control; and advanced strategies. Classical techniques are developed decades ago and implemented in most existing buildings thanks to their simple principle: On-Off, time programming or PID control. They are combined according to the control engineer's knowledge of the controlled system, and parameters (such as proportional bands for PID control, dead band for On-Off control, or planning for time programming) are tuned using simple rules of thumb. However these various techniques suffer from a number of limitations. Each technique can only control a single control parameter (e.g. temperature, humidity, pressure difference). No systematic methods have been developed for combining these techniques in an optimum way and incorporating all the criteria described above. Thus this has to be done for each new building and requires extended development times. They are very sensitive to external disturbances: variable occupancy patterns, wind or solar radiation, etc. Besides, their adaptability to system modifications, are very poor.

Developed since the early 80s, optimal and predictive control techniques are based on optimisation functions (including energy performance and/or comfort indices criteria) and account for external disturbances. They can incorporate more than one control parameter and are thus interesting techniques for the control of complex systems. However, they are based on predictions determined by on-line tuned simplified mathematical models and their performance is thus very much dependent on the accuracy of these models. This accuracy is particularly difficult to guarantee (if not impossible) for complex multizone buildings. Besides, the setting of these models being unique to each building and its equipment, such control techniques have not been developed at an industrial level due to a lack of automatic setting techniques.

Advanced strategies include the use of fuzzy logic. This makes provision for incorporating expert knowledge of the controlled system and is suitable for the management of imprecise parameters (such as comfort indices) and the incorporation of more than one control parameter. Although examples of fuzzy controller implementations have already been seen in building control, these have usually focused on simple problems, and manual parameter setting requires a long period (months). Simulation data from detailed analysis tools such as ESP, TRNSYS, or DOE2 could be efficiently used for off-line development of fuzzy control rules. Genetic Algorithms are particularly suitable for providing solutions to complex optimisation problems.

A hybrid ventilation control system must be able to control the mechanical (e.g. fans) as well as the natural ventilation components of the system (e.g. windows or other apertures, special inlets). Other components may also need to be controlled to ensure satisfactory thermal performance, for example shading devices or lighting. The occupant often constitutes the only control system of hybrid ventilation in a building, as soon as he can interact with the equipment, for example by opening a window or by switching a ceiling fan. When the occupant has control of the windows, he is also often allowed to move the shading devices (blinds, screens…). Apart from energy consumption considerations, the control strategy has to ensure optimum indoor conditions (at least indoor air quality and thermal comfort) throughout the year.

Time programming may be implemented in buildings where occupancy profiles are well known. Depending on the building, various strategies may be used: manual control of openings by occupants, forced or demand-controlled ventilation during occupancy. Time programming may also be used to control openings and/or fans for night ventilation and/or passive cooling, especially during summer periods. It also may be used for switching between a winter and a summer overall strategy.
Physical parameters measured by sensors may be used as inputs of the control system to manage both mechanical ventilation and natural ventilation, in combination with the heating/cooling system and the solar shading devices. The outdoor temperature, the indoor temperature, the wind speed and the CO_2 concentration are the typical parameters used in such strategies, in order to control the speed of a fan, the opening of a damper, the movement of a window or a roof aperture, or the use of a shading device.

The study of control strategies for hybrid ventilation is complex. Many control techniques may be applied to hybrid ventilation buildings, from On-Off control to advanced strategies based on logical programming or fuzzy logic. Very few examples exist of such hybrid ventilation controllers and there is a lack of feedback on the behavior of existing systems. The switching strategy is a key point for the overall efficiency of the system. Depending on the objective of the controller (comfort, IAQ, energy…), temperatures, pressure drops, concentrations, air speed… may be included in the control strategy of the hybrid system, possibly in a multi-criteria approach.

Analysis Methods for Hybrid Ventilation

The purpose of analysis methods is to assist, evaluate and, where possible, optimise design of hybrid ventilation of buildings. They are used to carry out one or more of the following tasks:

- To size ventilation systems for both ventilation modes.
- To evaluate flow rates for the whole building and/or through each opening.
- To predict airflow patterns in the whole building, and in each room.
- To select control and ventilation strategies.

The key difference between natural and mechanical ventilation lies in the fact that neither velocity nor flow direction at the ventilation openings are predetermined in the former system. The stack pressure is determined by the temperature difference between the indoor and outdoor air, which is in turn affected by ventilation flow rates. The wind pressure is strongly affected by the microclimate around the buildings, which is again affected by landforms, vegetation and other surrounding buildings. Natural ventilation is more unstable than mechanical ventilation and human behaviour strongly influences the ventilation.

Because hybrid systems combine natural and mechanical ventilation, they present several complex challenges to analysis tools, requiring a global approach that takes into account the outdoor environment, the indoor environment, and the mechanical system. For example, control systems developed for hybrid systems will switch between a natural ventilation mode, which may result in stratified temperatures in the space, to a mechanical mode with mixed air and no stratification. The analysis tool must be able to deal with these mode switches, and it must also be able to model the (possibly complex) control strategy itself. Furthermore, because hybrid ventilation systems are often used for temperature control as well as for IAQ control, analysis tools must be able to integrate thermal modelling with ventilation modelling.

The ideal analysis method for hybrid ventilation systems should include:

- modelling of the natural ventilation mode;
- modelling of the mechanical ventilation mode;
- modelling of the control strategy;

and be able to answer such questions like:

- if and when the natural driving forces fail to fulfil the ventilation demands;
- if and when mechanical ventilation is more energy efficient than natural ventilation.

Several methods are available that can be used to analyse air flows in mechanical or natural ventilation systems. These range from simple analytical and empirical methods, multi-zone methods, zonal methods, through to CFD methods. Each has their own area of applicability, e.g. conceptual design, preliminary design, detailed design, or system performance evaluation. There are a few tools available that integrate and model the mutual interaction of thermal conditions and natural and mechanical air flow rates. Multi-zone methods probably offer the best prospect of a balance between computational efficiency and accuracy. In fact, the existing building survey revealed that only a few buildings used any kind of design tool, much less one designed for hybrid ventilation systems.

There are several outstanding problems in modelling natural ventilation that will need to be addressed:

- Developing reliable methods for estimating wind pressure coefficients for complex buildings.
- Understanding wind-driven flows through large openings, in particular the validity of using wind-pressure coefficients obtained for solid surfaces.
- Developing better data, e.g. discharge coefficients and component flow characteristics. As new specifically-designed components become available, their performance characteristics will need to be known.

To increase confidence in the use of hybrid ventilation analysis methods, it is necessary to develop benchmark problems and solutions to enable the evaluation of these analysis tools.

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HYBRID VENTILATION CONCEPTS CLASSIFICATION AND CHALLENGES

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Abstract

Three hybrid ventilation concepts are described:

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

The concepts described comprise some newly constructed rather advanced buildings but also some existing more traditional type buildings. All buildings with hybrid systems up till now are far from what might be the optimum solution. There is a knowledge gap especially on dimensioning and control of hybrid ventilation systems. The remaining challenges and unsolved problems for hybrid ventilation are briefly described.

Introduction

Energy use by ventilation losses and fans accounts for almost 10% of total energy use in buildings. But this energy use does not result in satisfactory conditions in terms of indoor air quality and thermal comfort in many buildings. Several developments are ongoing to improve this situation.

Over the last ten years the view of architects and designers on ventilation systems have radically changed. A lot of developments have been initiated. A number of international research projects were carried out:

- IEA Annex 18 "Demand controlled ventilation".
- EU Joule Natvent "Overcoming barriers to natural ventilation".
- EU Joule TIPVent "Towards Improved Performances of mechanical Ventilation".
- EU Joule "Saveduct".
- EU Joule "Photovent".

Et ceteras.

For the near future the expectation of experts is that the most promising systems will be based on demand-controlled hybrid ventilation technologies. The impact of further development and improvement of fully mechanical or fully natural ventilation systems on energy savings and indoor air quality is reaching its limits.

Due to developments over the last ten years the advanced mechanical and natural ventilation systems are approaching each other. See figure 1.

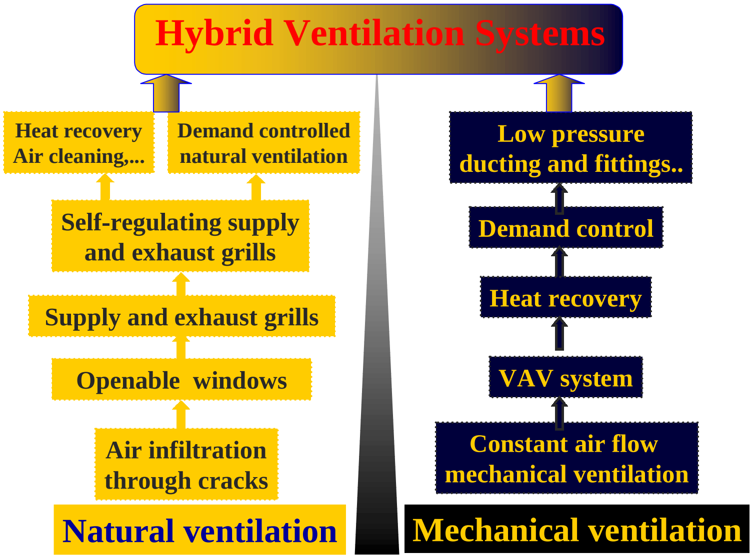

Figure 1: Recent developments in ventilation systems.

Hybrid ventilation systems

According to the Annex text of IEA Annex 35 "Hybrid Ventilation" [1] the definition of hybrid ventilation system is:
"Hybrid Ventilation is a two-mode system, which is controlled to minimise the energy consumption while maintaining acceptable indoor air quality and thermal comfort. The two modes refer to natural and mechanical driving forces".

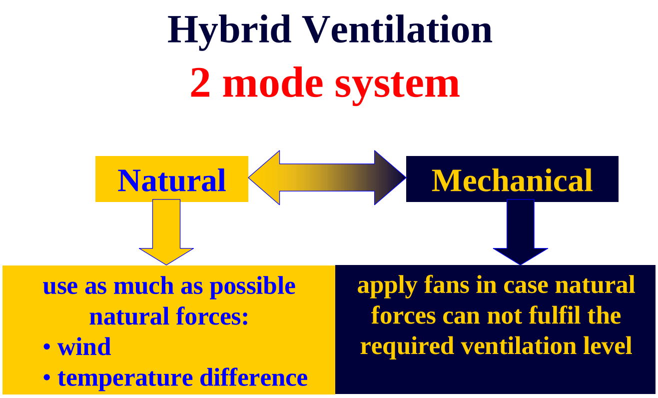

Figure 2: Schematic picture of hybrid ventilation.

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. This will lead to controls, which try to maintain the exact required airflow rates.

The driving forces must be minimised so the target is to use the minimum of electrical or mechanical energy. The heart of a hybrid ventilation system is a sensor based measurement and control strategy. The ventilation system will direct respond to the demands environmental parameters, with respect to the optimal energy consumption.
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. 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 energy consumption. It requires a complete new view on the dimensioning and control of ventilation systems.

Functions of a ventilation system

Hybrid systems should provide air for indoor air quality reasons and in addition also provide air to assist the control of temperatures hence positively effecting the thermal comfort conditions in the building. This two functions and the typical ventilation flows are given in figure 3.

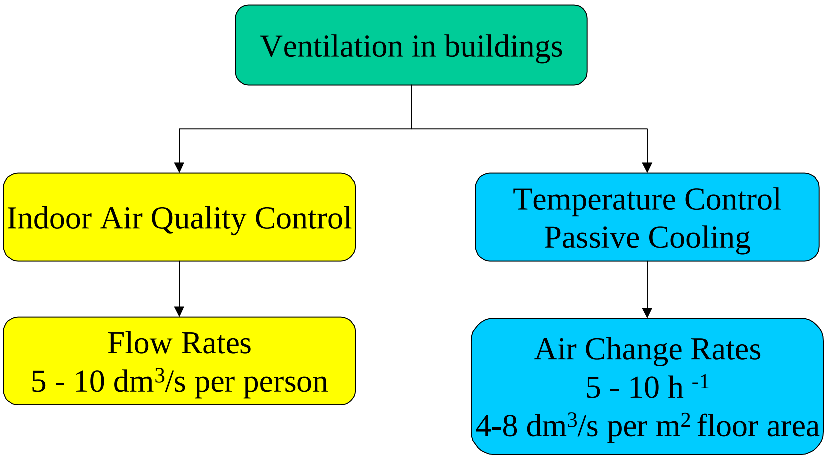

Figure 3: Functions of a ventilation system.

For indoor air quality reasons the required flow rates are normally expressed per person. The main reason for ventilation to maintain reasonable levels of indoor air quality is the fact that people are in buildings. Their bio-effluents have to be removed and diluted. In a number of cases with so called Sick Building Syndrome symptoms some people have the strategy to ventilate more because of high emissions from building and furniture materials. This is not very energy efficient. The goal must always be to keep this emissions as low as possible. The strategy therefore is source and product control not ventilation!
For the control of temperatures passive or night cooling can be very effective in moderate climates. This requires rather high flow rates, a factor of about 4 to 8 times the flow required for indoor air quality reasons.

This substantial difference leads to complete other systems for passive cooling, although the ventilation system for indoor air quality control may also be used to assist the control of temperatures during warm periods. The ventilation system for indoor air quality control will almost never be sufficient to take over the function of temperature control. It must be stressed here that for passive cooling a number of other building related items are important of which the thermal mass is the most important one.
The ventilation strategy as well as the control strategy will normally differ depending on the function of a system. For instance the ventilation strategy for indoor air quality control can be natural supply in facades combined with low pressure mechanical exhaust. In the same building the ventilation system which deals with passive cooling may be completely natural.

Examples of existing "hybrid ventilation systems"

General

The existing buildings that have a ventilation system what may be defined as attempts to hybrid ventilation are designed without the required knowledge to reach the optimum on indoor air quality, thermal comfort and energy efficiency. Nevertheless from these existing examples a certain classification was made by Wouters [3].

The classification made till now can be summarised as:

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

The concepts described comprise some newly constructed rather advanced buildings but also some existing more traditional type buildings.

Alternate use of mechanical and natural ventilation

The first example given is the Commerz Bank in Frankfurt from architect Norman Foster.


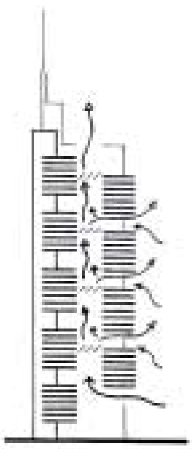

Figure 4: The Commerz Bank Frankfurt.

Commerz Bank is the tallest building in Europe. The floor area is about 70.000 m². About 2.500 employees are working in this office. Already in 1991 at the design stage the architect had the idea to try natural ventilation for this very tall building.
The idea behind the design is to give people the maximum possibility to influence their own environment.
In case the outside weather conditions allow natural ventilation the mechanical systems are 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.
Air is provided for ventilation only, with extra heating or cooling provided by standard radiators or cooled ceiling panels. A light on the control panel will indicate that the windows can be opened to ventilate the room naturally.

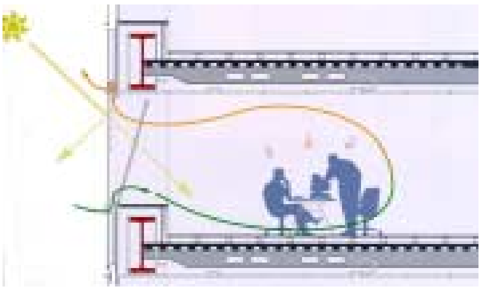
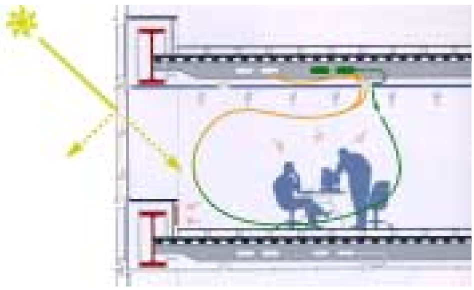

Figure 5: Natural ventilation mode. Mechanical ventilation mode.

One can imagine that this system is not the optimum of hybrid ventilation but it is a typical example of trying to minimise the energy use and give people maximum control.

Fan assisted natural ventilation

An example of a design where the total building design is effected by the hybrid ventilation concept is the Gronge school in Norway. In this school the ventilation system is designed with a so-called ground coupled preheating system. The system works under almost all weather conditions with natural forces.
The air enters the system via a tower, which is some twenty meters from the building.
Through a concrete duct the air will be preheated. A fan can support the flow through the system. In the classrooms there is a CO_2 sensor which controls the flow rate. In the cool climates the preheating may be important but in the milder and warm climates passive cooling with this system is a option to be explored.

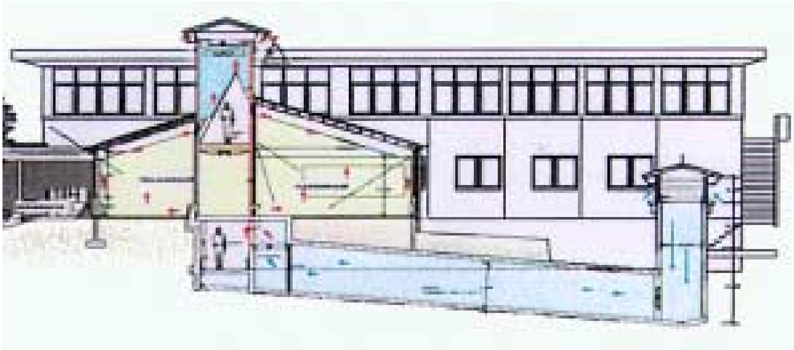

Figure 6: *Gronge school Norway a typical example of a hybrid ventilation system.*

Stack and wind supported mechanical ventilation

The system shown here is an industrial hybrid ventilation system with limited building impact. The fan energy though is limited 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.

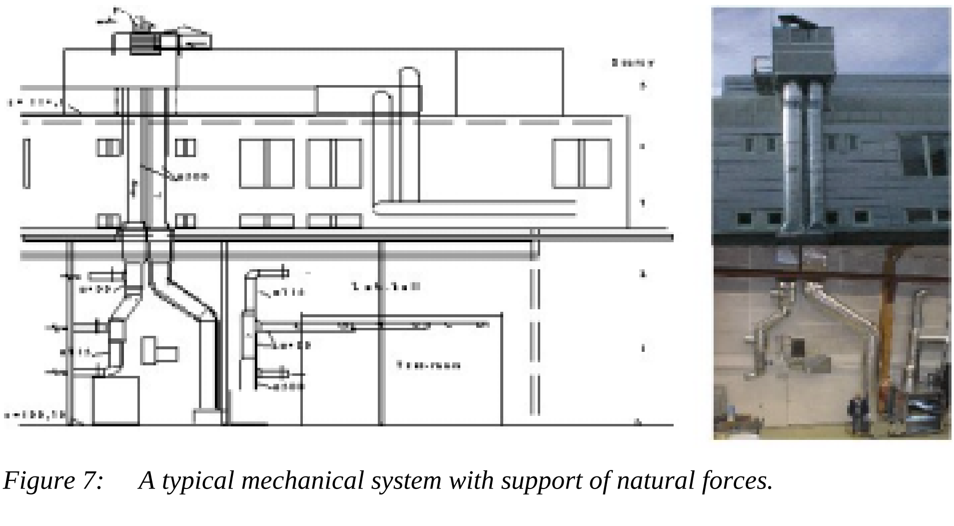

Figure 7: *A typical mechanical system with support of natural forces.*

Challenges

As every one may notice the examples given in chapter 4 have all their specific features but non of them are typically designed as optimum solutions for indoor air quality, thermal comfort and energy efficiency. All the systems have a certain goal, but the solutions are certainly not optimised.

Hybrid ventilation systems are expected to become a standard concept within a period of about 10 years. But experience and knowledge on hybrid ventilation systems is very limited. Design rules and tools are lacking. The reasons are:

- the complexity of parameters involved;
- design criteria are not well fitted for hybrid systems;
- control strategies have to be developed.

In the research projects IEA Annex 35 “Hybrid ventilation” [1] and the EU project “Reshyvent” [2] a number of open research items are described. Questions that need an answer 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;
- et ceteras.

Before all this questions are to be answered, all hybrid ventilation concepts will be far from optimal. Nevertheless we can learn a lot from examples of buildings al ready having “hybrid ventilation systems”. IEA Annex 35 and the EU project Reshyvent will give some answers to a number of questions. The building industry as well as building services, consultants and architect in the near future should start with hybrid ventilation design learning each time from solutions made by others. We need to learn from each other but at the same time develop new tools and new innovative products to find our way in the near future. Different climates as well as different building types require different solutions.

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HYBRID VENTILATION, APPLICATION OF INSTALLATION TECHNICS FROM ARCHITECTURAL PERSPECTIVE

Eric Slotboom, Kees Christiaanse Architects & Planners, The Netherlands

Abstract

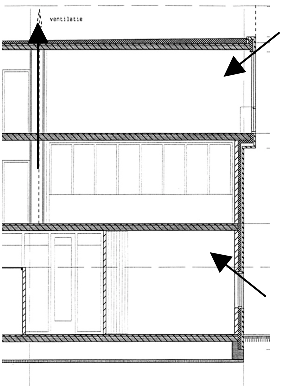
This paper describes the design process of a hybrid ventilation system in a school building "Waterland" at Leidschenveen The Netherlands. Recommendations from the architectural design process are given for further research.

A building design with hybrid ventilation

When the idea of applying hybrid ventilation was presented to us for the first time, we became interested for the wrong reasons.
We welcomed this idea because it promised to be a solution to the problem of how to achieve the required level of energy consumption for a complex of schools called Waterland at Leidschendam.
The choice of measures to be taken are derived from the so called "Energy Performance Coefficient, in short "EPC", a calculation in which all parameters important to energy consumption are included.

To meet the demands of this EPC and to minimise the consumption of energy, normally we would very simply increase the capacity of the layer of insulation material. Either by increasing the quality of the material or by adding more. But as our advisers at Cauberg-Huygen Consulting Engineers and Huygen Installation Engineers pointed out we would have to increase the thickness of the insulation a lot. The effort of adding extra insulation in order to reduce energy consumption would be in vain when the necessity to let in lots of fresh air for ventilation purposes is taken into account. All the extra insulation may not prevent the discomfort of draft from cold air and thus the necessity to heat this air.

Until a short time ago school buildings could, within the limits of the budget, be equipped with only the basic elements for heating and ventilation. Radiators for heating, windows or other devices that can be opened and closed to let through air for ventilation. That was all that could be afforded.
These basic elements are used in a preliminary school "De Pijler" in Rotterdam, which has been designed by our office only a few years ago. In figure 1 an impression of the building is given. For heating there are radiators, for ventilation we designed a system of ducts and openings in each classroom to provide natural ventilation.



Scheme

Ventilation openings

Radiator

Figure 1: Impression of preliminary school ”De Pijler” in Rotterdam.

It was simply natural ventilation and although this basic system worked, the occupants of the school made every effort to kept the system closed, because of the cold air coming in, and thus prevented any ventilation.
According to regulations for a natural ventilation situation, air has to be taken in at a minimum height of 1,8 meters above floor level. Regulating the amount of air by hand proves difficult. Heating this air by means of radiators, in a position as previously shown, is practically impossible. The result of these handicaps are that either the supply of incoming air is kept to a minimum or that by letting in enough air it becomes too cold in the room.
From this experience we knew that if the budget would allow it, we would come up with something much better.
So we welcomed the introduction of hybrid ventilation because it made it possible to use natural ventilation without the mentioned discomfort and because it gave the desired result to the EPC calculations.

In this case the application of hybrid ventilation installations was not only meant to meet abstract demands, but also to increase the quality of conditions for comfort and health beyond the level normally maintained. By guaranteeing conditions for sufficient ventilation, and simply by regulating the amount of incoming air and heating it before entering the room every aspect of comfort, health conditions and reduction of energy consumption is taken into account.
The keywords in this system are “guarantee” and “regulation”.
We will return to the significance of those words after explaining the system in the “Waterland” complex.

At first the feature that appealed to us most was the possibility of a “flexible response” to changing conditions. Flexible response means that the system reacts to changing conditions and variable use of space. It takes into account the needs of the number of occupants of the room and their level of activity.
It does so by measuring the quality of the air, CO_2, the temperature and reacting to deviations from desired conditions by opening or closing the inlet of air or/and by forcing ventilation when the natural process is not sufficient.

This flexibility is made possible by decentralization of the system, in the sense that different parts of a complex have independent operating installations.
In the case of the complex “Waterland” it means that every classroom has its own detection unit and its own ventilator. Figure 2 gives a scheme of the first and second version of the hybrid ventilation system.

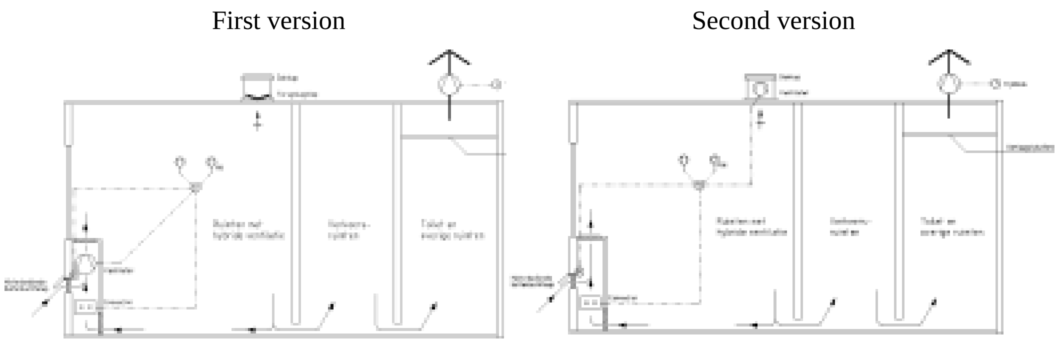


Figure 2. Scheme of ventilation system of Waterland school building.

In the process of developing the system we found out that components to create such a system are not easily available. A ventilation grill where the inlet valve can be opened and closed by remote control was practically not to be found. Regulating the opening of the inlet proved equally difficult. The consultants of Cauberg-Huygen needed to use all their influence with manufacturers to ensure production. CO_2 censors proved to be very expensive.
A combination of a ventilation grill with integrated ventilator, as first was anticipated could not to be found and explains the 2^{e} version.
It proved very difficult to find a ventilator with the right low noise level. To bring the size and capacity of the ventilator in accordance with capacity of the outlet for the natural ventilation meant extensive research.
As it turns out, the actual realisation of a basically very simple system means a very complex process.

Design consideration in relation to building services

A system of hybrid ventilation supports elements already available in a building. The building is taken as a basis to which an installation is not added as an independent element, but as an element that guarantees and regulates a system incorporated in the building.
So the installation does what we would like any installation system to do: as little as possible. The installation should help where the structure itself can not accommodate.

Regulating is most efficient when it can be performed on a decentralized basis. Every space or room has a different need, according to the activity taking place and the personal wishes of the occupants. Efficient regulation will provide the best combination of comfort and the minimum level of energy consumption.

It is the combination of the “passive” possibilities of a structure and the active support of installations that makes a system like hybrid ventilation so attractive and in fact would make any climatic installation attractive.

The aim is to integrate structural, architectural and installation elements in such a way that maximum response to variable demands is possible with a minimum of installation effort
It does not mean that an installation should be designed which consumes very little energy in the first place (although that is also good), but to determine in what way the materialisation of architectural and structural elements can help to reduce the necessity to apply installations.

It is important that architects and installation engineers both consider a structure as a machine, or at least look at the possibilities to use the structure, the materialisation of the design, as a machine.
But while doing so we should keep in mind that it is a technical analysis of an architectural design from which the concept is based on cultural/social and emotional elements.
Any architectural project, analysed from the perspective of pure optimal technical application of structure and installations, will prove to be uneconomical. Therefor the analysis should concentrate on the level of integration and synergy of different disciplines. This analysis may influence the materialisation of the design (and possibly the way the detailing take's shape?) but should not influence the concept of the design.

The ideal is to create a building that has no technical elements, no structure or installation.
At least non-recognisable, independent technical elements.

First we should establish the fact that structural and installation elements do not represent the actual function. Functions are abstractions which actually only take shape if they are translated to materials by means of which they are conveyed.
And since materialisation appeals to the senses, it means that the actual appearance of such an element is depending on the architectural significance it may have and not of its technical necessity. I do not refer to "design" of technical elements where it concerns the appearance, because "design " means the actual submittance to the appearance of technical necessities. "Design" is one of the ways to escape the dilemma of how to incorporate installation elements in a architectural design.

One way of solving the problem of integrating installations in a project, is treating them as elements that are added to the structure in order to make the structure work. In that case elements like ducts, pipes, wires etc are shown as much as possible to indicate that these elements can be as easily removed, as they seem to have been installed.
In a building that is designed for variable use and which is expected to undergo internal rearrangements a lot, that makes sense. But only in cases like that.

The problem of integrating installations in buildings is not solved but just denied by hiding the installations.
Many buildings have installations hidden behind suspended ceilings. Thus large quantities of space are consumed for which there is no architectural reason. Most of the volume thus consumed is used only for the transport of mostly air. The need to transport huge volumes is caused by the centralisation of the installation.
This may have economic reasons, meaning that a large installation is probably more efficient, maybe also because of the possibility of regaining heat, but nevertheless, the loss of space or the possible excessive use of it still is a waste. I firmly believe that this way of combining installations with a building is a result of "separate" thinking.

Thinking of a building to which a separate installation has to be added to make it work may prove highly uneconomical when the concept of integration and decentralisation is more closely looked into.

One of the great advantages of a hybrid installation system is that it may just solve this important problem. The main feature of this system is its concept of decentralisation, not only in space but also in time. It is only active where and when it is needed. Furthermore it is meant as a support. A support for a system driven by natural forces. It is actually a system that is designed to do as little as possible by means of regulating as much as possible according to the need of the occupants and only becoming active in extreme circumstances.
For a school building these are basic principles, because the use of space is not regular.
Classrooms are used only a few hours at the most without interruptions. The number of pupils vary, as does the intensity of activity. This constitutes variable demands and needs.
We know this to be the case where school buildings are concerned, but every other type of building should be examined on how it will be used, in order to be able to apply systems similar to hybrid ventilation.

I would recommend to study the following issues:

- Study the program to determine whether clusters of elements can be found that may have the same installation requirements based on the way they will be used.
- Look for possibilities in the design to use spaces for transport of air.
- Look for possibilities in the structure for transport.
- Consider possibilities of the structure to generate, contain and exchange heat or cooling.
- Consider the possibilities of the design for the application of natural ventilation.
- Try to decentralise installations in order to avoid large spaces for transport.
- Initiate manufacturing of small installation units.
- Activate manufacturers to produce integrated installations.
- (Keep in mind that for architects "design" has a different meaning, esthetics are not the central issue) .
- A careful study of the program.
  Mostly spaces are clustered for reasons of their conditioning requirements.
  A survey into the intensity of the use of spaces may proof that another clustering would be more appropriate. Intensity in use, both in time and number of people may lead to solutions like hybrid ventilation.
  It so happens that we use in the "Waterland" project traditional installation systems and hybrid ventilation for different parts of the same complex. A combination of different systems in one project may proof to be the obvious outcome of the survey of the program for an entire project.

We made several attempts to use hollow spaces in structural elements to transport air at the same time using the structural element as a way to exchange heat.
In combination with a conventional installation system it is often too mistrusted.

Perhaps combined with a system like hybrid ventilation such attempts will be considered trustworthier. The most important condition is that installation engineers are willing to support the concept of integrated systems. It means considering the possibilities of building structures to serve as a machine and not as a structure to put a machine in.

CONTROL STRATEGIES FOR HYBRID VENTILATION

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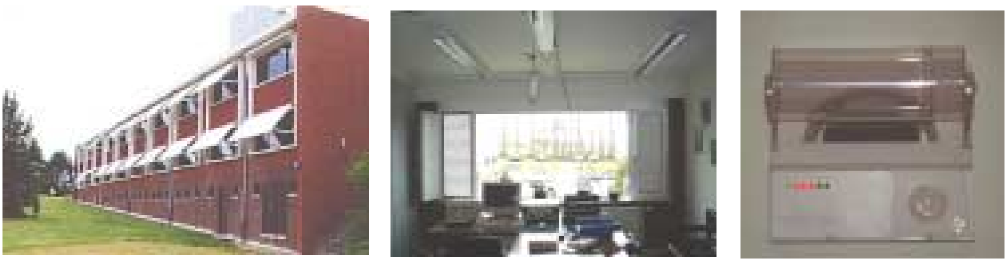
ABSTRACT

The paper presents examples of control strategies for hybrid ventilation in office and educational buildings. In hybrid ventilation there is a strong relation between the control strategy used and the actual performance of the ventilation system in relation to indoor climate, energy consumption and costs. Hybrid ventilation can cover a huge variation of systems from systems mainly based on natural ventilation with a few assisting fans to systems mainly based on mechanical ventilation where the natural ventilation for instance is mainly for night cooling. It also covers a huge variation in controls from simple user control to sophisticated central control systems. IEA Annex 35: HybVent includes a number of pilot studies of buildings with large difference in ventilation system design and controls. These controls are described and discussed in the presentation.
The focus in the presentation is on office and educational buildings situated in the northern part of Europe with low winter temperature and moderate summer temperature. To try to get a more complete picture the pilot studies in HybVent are supplemented by other examples of hybrid ventilated buildings.

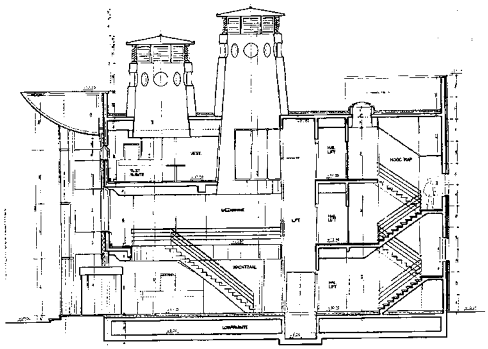
Office buildings



PROBE building, Belgium

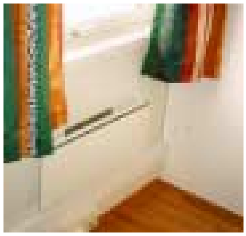
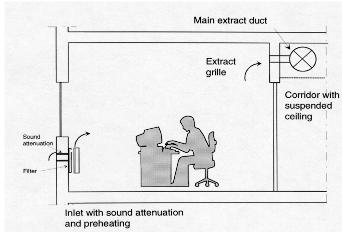
The PROBE building is a two storey, 14 m wide, 1100 m^2 office building with cellular offices for one or two persons on both side of a corridor. The building is located in an open area with no significant external air pollution or noise at the test site of the Belgian Building Research Institute. The building is constructed in 1975 and the retrofit is completed in 1997 /HybVent/, /Ducarme et.al/.
There is a balanced mechanical ventilation system with supply air to the offices and exhaust from the toilettes. The air is preheated but there is no heat recovery. The purpose of the mechanical ventilation system is to maintain an acceptable indoor air quality at winter even if the windows are kept closed during occupied hours.

For summer cooling there are large louvers in the window frames on both sides of the building. The louvers can be left open also during unoccupied hours. There are vertical external solar screens on the west side of the building and awnings on the east side to reduce the solar gains through the windows.
The mechanical supply of air to the offices are controlled by an infrared present sensor in each office. The present sensor is integrated in a unit that also includes the control damper. Two types of controls are used. One that opens the damper if people are present in the room and one that adjust the damper position relative to the activity level in the room. The unit replaces the normal supply grill. The power supply is from a normal battery build into the unit. The pressure level in the supply and exhaust ducts are controlled by a damper arrangement combined into the filter section. The fans run with constant speed. The louver and the solar shading are controlled by the individual occupants in the offices. The general lighting is controlled by lighting sensors.



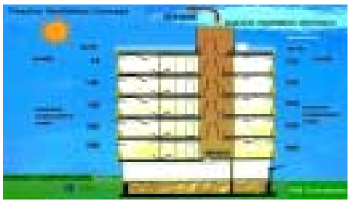
IVEG Building, Belgium

The IVEG building is a three storey, 1500 m^2 office building with cellular offices, landscape offices and meeting rooms. The building is located in a suburban area of Antwerp with some traffic noise and external air pollution. The building is completed in 1999 /HybVent/.
Like in the PROBE building there is a balanced mechanical ventilation system that supplies preheated air to the offices and exhaust air from the toilettes. In the meeting room there are both supply and exhaust of air. For summer cooling there are large louvers in the facade and two significant ventilation chimneys. The reason for having two chimneys is due to fire regulations. The building is heavy and there is a semi-open false ceiling. The windows are with vertical solar screens. A small mechanical cooling unit can reduce the supply air in the ventilation system to approx. 2 ^{o}C below the external temperature.
Like in the PROBE building the mechanical ventilation system is controlled by infrared present sensors. The fan speed is controlled to keep a constant duct pressure. The dampers in the facade louvers and in the ventilation chimneys are automatically controlled at night. At day the dampers in the facade louvers are closed, but the users can open the dampers from there PC. The general lighting is controlled by present and lighting sensors. The solar shading is automatically controlled. The control of the solar shading can be overruled by the users, if the automatic control systems allows it. The controls will be optimised in the frame of the HybVent project.

Pfizer office building, Norway

The Pfizer building is a three storey, 3070 m^2 office building with cellular offices. The building is located in suburban area of Oslo between a highway and the seashore. The building is completed in 1982 /NatVent/.
There is mechanical exhaust from all offices. Below the windows there are external air inlets with air filter and sound attenuation. The air can be preheated by the panel heater.
The speed of the exhaust fan is controlled manually. The fan is running at constant speed throughout the year, except for cold periods in the winter, when the ventilation is reduced at night. The windows can be opened by the occupants when required.


Enschede Tax Office, The Netherlands

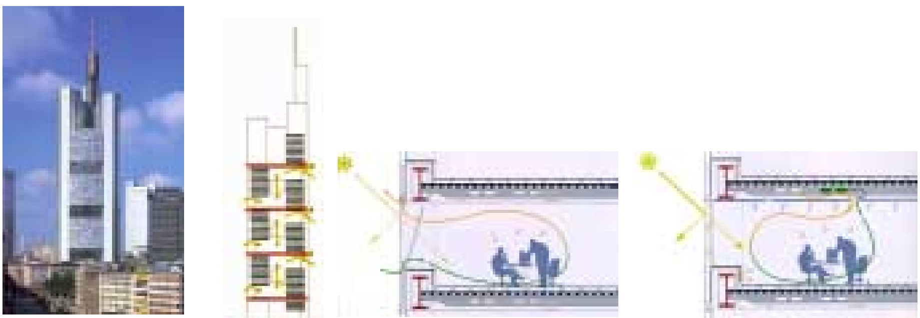
Enschede tax office is a five storey, 4300 m^2 office building with 5 m deep cellular offices. The building includes a narrow atrium going through all five storeys. The building is completed in 1996 as an extension to an existing building. It is located in the city centre with some traffic noise and external air pollution /NatVent/.
The ventilation system is a natural ventilation system with fan assistance. Air is supplied to the offices through two high positioned, manually operated, constant air flow vents in the facade. Extract air is removed from the building through small chimneys on top of the atrium. The chimneys also include a fan.
The aim is to provide maximum occupants control of the indoor climate. The vents have five positions that can be selected by the users. It is recommended to use one vent under normal circumstances and both vents for night cooling during warm summer periods. The fans in the extract chimneys are switched on if the wind speed is below 2 m/s.

B&O Headquarter, Denmark

B&O headquarter is a three storey, 1650 m^2 open landscape offices building completed in 1998. It is open between the storeys through the open stairs. The building is located in an open area outside Struer with no significant external air pollution or noise close to the production site in Struer /HybVent/.

The ventilation system is a natural ventilation system with fan assistance. The inlets are low positioned, narrow hatches (windows) in front of the floor slap. The inlet air is preheated with a ribbed pipe. The air is extracted from the top of the stairs with a fan if so needed. The large glass facade with the ventilation hatches is orientated north and there is no solar shading. On the south facade there are only some small windows. It is a partly heavy building free from false ceiling and acoustic regulations.

The ventilation is controlled by temperature and CO_2-sensors in the offices. When ventilation is needed, the hatches and the dampers in the extract hood opens. If a ventilation rate of 1.5 ach in winter and 3.0 ach in summer is not achieved by natural means the fan speed is controlled to get the defined air speed measured in the extract hood. The hatches on each floor is controlled by the temperature and CO_2-level of the floor. The opening is also adjusted to the same flow through all hatches on a floor by measuring the air inlet temperature. The ventilation is controlled by a building management system with a weather station on the roof. If the external temperature is below 0 ^oC the ventilation system is closed to protect the ribbed pipes from freezing. The ventilation system is also closed if rain or high wind speeds. The small windows on the south facade are manually controlled by the users. During night cooling all hatches, windows and dampers are opened.

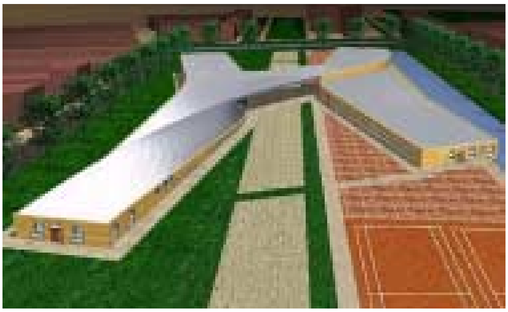


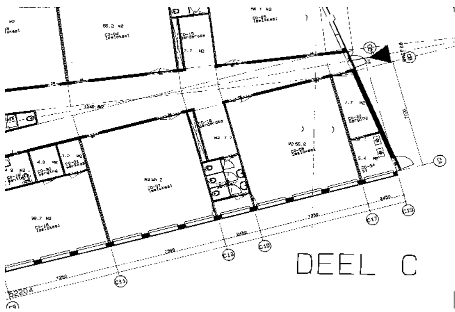
Commerz Bank Headquarters, Germany

Commerz Bank is a 53 storey, 100,000 m^2 office tower. It is constructed 1994-1997. The building is located in the city centre of Frankfurt. The middle part of the building is divided in three sections each having a central atrium that are connected to the facade at different levels /HybVent/, /Frankfurt/.

There is both a complete air-conditioning system with chilled ceilings and a natural ventilation system for all office rooms in the building. The atriums are used to improve the natural ventilation in offices not facing the exterior. A double facade with a fixed layer of single glazing is used to protect the windows at high wind speed and to improve the natural ventilation possibility of offices facing the exterior. The main aim of having two ventilation systems is to improve user satisfaction and productivity.
Each section of the building is either in air-conditioning mode or in natural ventilation mode dependent on weather conditions. At cold weather and at hot and humid weather the building is in air-conditioning mode and the windows are locked shut. The occupants are kept informed by indicator lamps. If the light is red the section is in air-conditioning mode. If the light is green the section is in natural ventilation mode and the occupant should control their own indoor climate by opening the windows. The windows can be left open in summer to cool the building over night. The ventilation is controlled by a building management system with small weather stations distributed around the building.

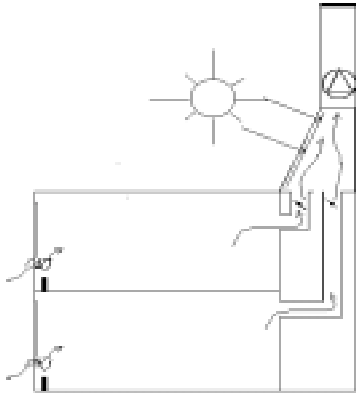
Schools





Waterland School, The Netherlands

The Waterland school is under construction. It will be a school with approx. 52 classrooms and a total of 5700 m^2. The school is located in a suburban area with low rise buildings and little external noise or air pollution.
In the classrooms the ventilation system is a natural ventilation system with fan assistance. There are two inlet grills in the facade per classroom, located just above the floor. The air is preheated by convectors behind each grill. In each classroom there is also an exhaust chimney with a low resistance axial fan.
The grills and the fan are automatically controlled by a CO_2-sensor in the class room. If CO_2>700 ppm the first inlet grill is opened. If CO_2>1000 ppm the second inlet grill is also opened. If CO_2>1300 ppm the fan is switched on. The convector is frost protected by a thermostat in the inlet grill. Night cooling is on if the external temperature is over15 ^{o}C, the room temperature is over 20 ^{o}C and there is cooling potential in the external air. The ventilation system is controlled by a lon-bus. The occupants can achieve additional ventilation by opening windows in the facade.

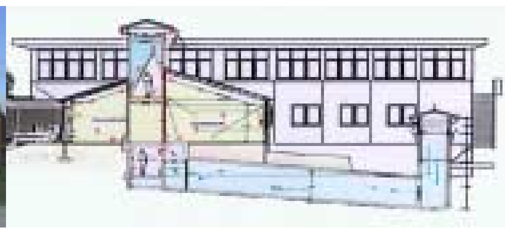
 

Tånga School, Sweden

Tånga school is a two storey, 1363 m^2 building. It is constructed in 1968 and retrofitted in 2000. The school is located in a suburban area of Falkenberg with no significant external air pollution or noise /HybVent/.

The ventilation system is a natural ventilation system with solar chimneys and fan assistance. There is a damper in the outlet from each classroom. One chimney and fan serves two classrooms, one on each floor. There is a bypass damper on the sides of the fan to reduce the pressure drop when the fan is not operating. There are four external air inlets with damper per classroom located below the windows. The supply air can be preheated by the convector.

There is a CO_2-sensor in each classroom. A red lamp in the classroom will be on if the CO_2-level is higher than 1000 ppm. There are two different control options during occupied hours, selected by the teacher: manual control of air flow and automatic control where the dampers starts to open at 1000 ppm CO_2 and are fully open at 1500 ppm. The fan is controlled in cascade with the outlet damper. Night cooling is possible if the room temperature during none occupied hours is above a set point. During night cooling the dampers are fully open. The fan starts if the temperature difference between the solar chimney and the outside is too low. The ventilation is controlled by a building management system.

Mediå School, Norway

Mediå school is a single storey, 1000 m^2 building. It is completed in 1998. The school is located in an open area in Grong north of Trondheim with no significant external noise and limited external air pollution /HybVent/.

The ventilation system is a balanced, low pressure ventilation system with both air supply and extract in the classrooms. The air is taken from an inlet tower in some distance from the building, flows through an underground duct, and is distributed via a purpose made basement corridor to low positioned supply unit in the classrooms. The air is extracted from the classrooms through a high positioned hatch into a purpose made light-well corridor and exhausted through a roof tower. The system also includes filtering, preheating of the ventilation air and heat recovery. The flow is driven by wind and stack effects supported by low pressure fans in the supply and extract, if the natural forces are insufficient.
The ventilation is controlled by a CO_2-sensor in each classroom. If the CO_2-level exceeds the set point the extract hatch is opened and adjusted by a motor. The supply fan is controlled by the pressure in the basement supply corridor to 2 Pa overpressure compared to the external. The extract fan is controlled to get 5 Pa pressure drop between the basement supply corridor and the light-well extract corridor. Both fans are frequency controlled. The summer cooling is controlled by a temperature sensor in each classroom. The ventilation is controlled by a building management system.

Hyltebjerg School, Denmark

Hyltebjerg school is a two storey extension to an existing school completed in 1998. The school is located in a suburban area of Copenhagen with no significant external air pollution or noise /VVS no. 7, 1999/.
There is a central balanced mechanical ventilation system with filter, preheating and heat recovery serving all classrooms. In each classroom on the first floor there is also motorised, high positioned ventilation windows.
The mechanical ventilation is controlled in each classroom by present sensors. When the room has been empty for 15 min. dampers in the supply and exhaust duct are closed and the light is switched off. The fan speed is controlled to keep a constant duct pressure. The ventilation windows in the classrooms on the first floor can be operated by the teacher. In the next new school designed the central mechanical ventilation system will also be switched off when the external temperature is over 12 ^{o}C if it is not strong wind or raining.

Discussion

The main challenge in the design of control systems for hybrid ventilated buildings is in each project to find the right balance between implementation costs, operation costs, energy consumption, indoor climate comfort, users satisfaction and robustness. The development of an "optimal" control solution to a specific building will depend not only on technical parameters as building type and design, ventilation system design, external noise and pollution, solar shading and internal loads but also on others like dress code, user attitude and user expectation.

On of the expected main advantages of natural ventilation systems are a higher degree of user satisfaction due to the possibility to control ones own environment by opening windows. As far as possibly this feature should be maintained in the control of a hybrid ventilation system. This can be in conflict with the possibility to guarantee a specific indoor thermal comfort, air quality or maximum CO_2-level in the rooms especially in the case of simple hybrid ventilation and control systems. Unfortunately the relationship between indoor climate and user acceptance in user controlled rooms is not well known. Recent research indicates that users are more flexible to deviation in indoor thermal climate if it is controlled by them self /de Dear et. al./.

The additional costs to install individual automatic control of the indoor climate in small cellular offices are often high compared to the related improvement of the indoor climate, energy or operation cost saving. This also goes for the ventilation system itself. In several of the example building more simple and cost effective ventilation and control systems are installed trying to balance costs and performance.

In principle it is best to control the ventilation in rooms where people are the main load by measuring the CO_2-level with a sensor. Unfortunately CO_2 sensor are quit expensive to install and maintain. This means that CO_2 sensor can normally only be used in large rooms for many people e.g. landscape offices, meeting rooms , classrooms and lecture halls. It is questionable if it is convenient to control the ventilation based only on the CO_2-level or if a minimum ventilation rate is needed to deal with other pollution sources e.g. materials and cleaning.

In some of the offices and classrooms in the example building the inlet air is intended to bee preheated by the ordinary radiator in the room without a separate control of the inlet temperature. In many offices and classrooms there are excess heat in the occupied periods most of the year. This might result in local cold draft from the inlet air when the radiator is switched off due to high room temperature.

The complexity of the control system compared to the knowledge and available time of the operation staff need to bee carefully considered. In some of the example buildings the control system is rather complex. This can lead to malfunctions.

The actual performance of the pilot study buildings in HybVent will be evaluated and reported as part of the HybVent project. Details on the actual performance of the buildings from *NatVent* can be found on the *NatVent* CD /NatVent/.

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LONG-TERM MONITORING AT BANG & OLUFSEN OFFICE BUILDING

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Abstract

This paper presents preliminary monitoring results from long-term measurements in a Danish office building with hybrid ventilation. The building is a new headquarter of the company Bang & Olufsen. The office building also serves as a pilot study building in IEA BCS Annex 35 Hybrid Ventilation. The monitoring programme was initiated in February 2000 and results from the BEMS-system are now available for one year of monitoring. The ventilation and control strategy of the building as well as operational experience of the hybrid ventilation system is presented. This paper comprises measurement results of CO_2 levels, temperatures, and energy use for assisting fans and for heating of ventilation air, as well as electricity use for appliances and space heating.

Monitoring programme

The objective of monitoring is to establish knowledge from a hybrid ventilated building with respect to thermal indoor climate and indoor air quality, ventilation capacity and energy demand and to analyse the performance of the building.
The monitoring is carried out as long-term measurements for a period of 12-15 months using the existing BEMS-system of the building for data logging. In general, data are logged every 15 minutes. The BEMS-system with all the existing sensors provides access to a large amount of data, but it also means that the data have been logged with some uncertainties corresponding to typical specifications for sensors serving control purposes in buildings. Additionally, six sensors and energy meters were installed in order to fulfil the requirements of the monitoring programme.

The monitoring programme includes only results from one wing (Building 1) out of three connected wings (Building 1-3). An overview of the measured parameters is shown in table 1.

	Measured parameters
Thermal indoor climate	Inlet air temperatures Room air temperatures Extract air temperatures
Indoor air quality	CO_2 concentrations
Ventilation capacity	Air velocity in extract cowls Degree of opening of inlets Outdoor air temperature Wind speed and wind direction Global solar radiation
Energy consumption	Heating of ventilation air by ribbed heat pipes Space heating by radiators Electricity use for assisting fans Electricity use for lighting and appliances

Table 1: Overview of measured parameters logged by the BEMS-system at Bang & Olufsen.

Building and ventilation description

Bang & Olufsen required an office building of high quality with a minimum of technical installations. The installation should also be simple and hidden.

The office layout is a combination of open plan areas and some single person offices with three similar floors with a heated gross floor area of 1520 m^2.
The ventilation principle is stack- and wind driven with fan assistance. The air distribution principle is displacement ventilation.
The north facade, which is shown in figure 1, is fully glazed with narrow windows in the horizontal divisions serving as inlet openings for the hybrid ventilation system. The south facade has a moderate window area serving as supply for daylight and has user controlled windows, which are automatically controlled during night-time for passive cooling of the building during the summer period. Air is extracted via stairwells through specially designed cowls on top of the roof, which also have integrated fans for assistance, when the natural driving forces are insufficient. The principle of hybrid ventilation is shown in figure 2.

The building is specifically designed for natural ventilation. During the design stage of the ventilation system the architects and engineers took into account both thermally generated pressures and wind induced pressures.

Figure 1: North facade of Bang & Olufsen (Building 1).

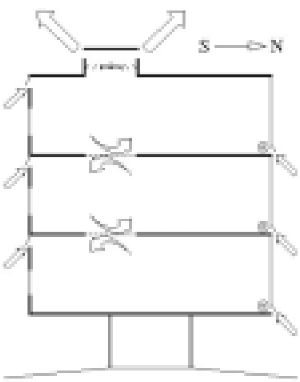

Figure 2: Principle of hybrid ventilation system (Aggerholm, 1999).

Control strategy and operating experiences

The hybrid ventilation system is automatically controlled by the CO_2 level, as an indicator of IAQ, or by the room temperature. The control system is based on centralised components divided in to local zones with sensors connected in a BEMS-system. The hybrid ventilation system gives first priority to natural driving forces and second priority to mechanical fan support.
The system is active according to a certain time schedule or a selected control mode:

- **Constant mode** based on time schedule.
- **CO_2 mode** overruled if too high room temperatures occur and also based on time schedule (daytime).
- **Night cooling mode** with fan boost based on room temperature and outdoor temperature (summer night).

Inlet temperature sensors control the ribbed heat pipes at the supply openings in order to fulfil the requirements of displacement ventilation. Besides, controlling flow in heat pipes, the position of the heat valves are used to adjust the inlet openings at the north facade according to variations in wind pressure at different positions of the facade. When outdoor temperatures are below 5°C the hybrid ventilation systems turn off and in such cases the occupants used the south facing windows for short time venting. Furthermore, the ventilation system is overruled in case of rain or strong winds, inlet openings in the north facade, fans and dampers in the extract are closed.

During the monitoring period some settings have been adjusted in order to improve the control of the building. When the monitoring programme was launched in February 2000 the set value of CO_2 was 600 ppm, a remarkably low set value, resulting in too much ventilation and in July 2000 it was therefore changed to a set value of 1000 ppm, which is more typical for office buildings. The CO_2 control is overruled by room temperature control when the room temperature exceeds a set value of 25ºC. In periods, when the ventilation system was inactive, the ribbed heat pipes in short periods have been activated to prevent cold draught or to compensate for air leakage through inlets or air movement close to the north facade.

During the first three years of operation the building staff have reported about faults on some of the inlets, some of the extract dampers and to much noise from assisting fans (Kristensen, 2001). The inlets have shown some variations in tightening of openings resulting in either air leakage or too large tensions leading to cracks in the glazing. The extract dampers have been stucked in fixed positions either open, closed, or in between in some cases this have lead to air leakage. The noise level from assisting fans has been reduced to an acceptable level by setting a maximum rotational speed of fans.

Indoor climate and energy consumption

Temperatures and CO_2 levels have been logged for a whole year. The monitoring results are shown as accumulated frequency curves in figure 3 and 4. The accumulated frequency curves gives an overview of the indoor climate in the building. During monitoring approximately 5-10% of the data for some of the parameters were lost due to internal communication problems in the BEMS-system.

Energy meters for both heating and electricity has logged energy consumption for a whole year. Measurement results are presented and compared to reference energy consumption in table 2.

	Category	Energy consumption [kWh/m^2 per year]			Index
Danish Building Code (BR-95) Maximum level	Heating			69	100
B&O facilities management Average level, building 1-3				65	94
Annex 35 monitoring, building 1 Adjusted to normal year		Ribbed heat pipes Radiators	31 93	124	177
ELO Key figures Average level	Electricity			44,3	100
B&O facilities management Average level, building 1-3				63	142
Annex 35 monitoring, building 1		Assisting fans Lighting and appliances	1 65	66	149

Table 2: Measured energy consumption from 12 months of monitoring at Bang & Olufsen and reference energy consumption based on the Danish building code, data from facilities management (Kristensen, 2001) and Danish key figures for office buildings (ELO, 1999).

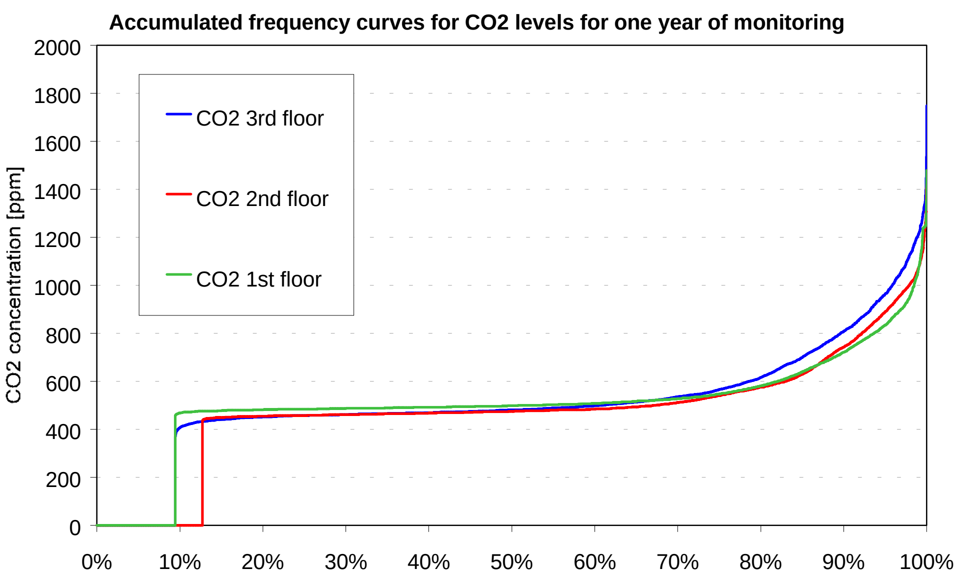

Figure 3: CO_2 levels at each office floor based on one year of monitoring. CO_2 concentrations are logged by the BEMS system.
The figure shows average values for each floor from logging with two sensors at each floor.

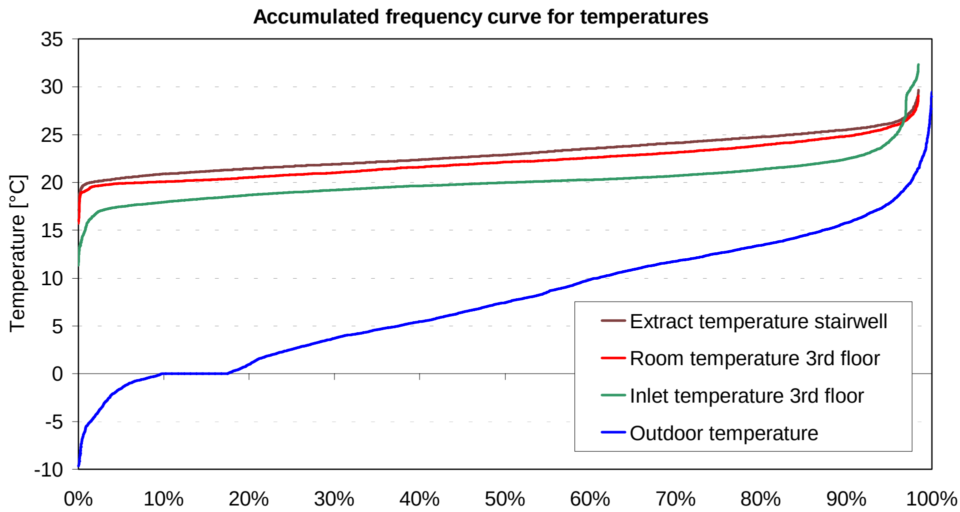

Figure 4: Average temperature levels at third floor. Temperature data are logged by the BEMS system from each temperature sensor.
Average values are shown for the third floor.

The CO_2 levels in the three office floors shown in figure 3 vary from a background level of 450 ppm to a maximum level of 1400 ppm. The occupational time is assumed to be approximately 2500 hours per year or 29% of the whole monitoring period. The CO_2 level is remarkably lower than 1000 ppm in most of the time, but the relation between occupation and CO_2 level is not fully clarified. The ventilation system has switched from CO_2 mode to a temperature mode due to high room temperature during the summer period. Furthermore, the ventilation system has been overruled and inactive in periods with outdoor temperatures below 5°C, rain or strong wind. Finally, the set value of CO_2 was changed during monitoring from 600 ppm to 1000 ppm. Further analysis of the relation between occupational hours and CO_2 levels is therefore necessary.

The temperatures measured at third floor are shown in figure 4. The maximum outdoor temperature was 29,5°C, during the monitoring period it was only moderate summer weather resulting in only very short periods were the ventilation system was running in the night cooling mode. The average inlet temperature has been below the room temperature in almost all of the monitoring period, but in less than 5% of time, the average inlet temperature was increased to 25-32°C to compensate for cold draught or air leakage close to the north facade. The maximum room temperature based on an average of six room temperature sensors on third floor was 29°C.

Table 2 shows that energy demand for heating of building 1 is remarkably larger than expected according to the Danish building code, but also that the average level for the complete three buildings, which has been registered by the facilities management, is in good agreement with the Danish Building Code. This can be related to the large heat loss transmission areas, as well as a very large glazed area in the analysed wing, compared to the two other wings of the building.

Furthermore, calculations of the relation between CO_2 level, occupation, and air change rate, when the ventilation system was inactive, indicates a rather high air change rate due to infiltration of approximately 0,5-1 ach In some shorter periods during the summer period unintended heating has been registered.

The use of electricity has been logged for assisting fans as well as for all other electricity consumption for lighting, appliances etc.. The total use of electricity for the analysed wing is in good agreement with the use registered by the facilities management. In both cases the electricity consumption is approximately 40-50% larger than the average level based on key figures for Danish office buildings. The occupational pattern and the type of office work with one computer per occupant can explain this. The electricity use for running assisting fans are very low, approximately 1,5% of the total consumption, which can be related to a very low system pressure drop for natural ventilation.

Conclusions

The hybrid ventilation system was specially designed for the Bang & Olufsen office building with a combination of many distributed components and some centralised components. The ventilation components are well known components from either manufacturer of natural or mechanical ventilation components. The amount of distributed components has resulted in time consuming fault detection and some replacements of components during the first years of operation. Noise from assisting fans were reduced by limiting the maximum rotation speed, which underlines the importance of using fans with speed control.

The control strategy is based on a combination of CO_2 and temperature control with settings to overrule in order to compensate for certain outdoor climate conditions, which leads to a complex control system.
The measured CO_2 levels are low indicating a good air quality, but also indicating periods with either too much ventilation or a large rate of infiltration, which also results in larger heating consumption than expected. The measured temperatures are typical for Danish office buildings without mechanical cooling.

Energy consumption for assisting fans are very low, which underlines that a well designed natural ventilation system can be supported by mechanical fans with only small impact on the electricity consumption.

Acknowledgement

This paper present work carried out as part of the Danish contribution to IEA BCS Annex 35 Hybrid Ventilation. The project is carried out in collaboration with Aalborg University and the Danish Building and Urban Research. The project has received funding from the Danish Ministry of Environment and Energy.

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AN OVERVIEW OF NORWEGIAN BUILDINGS WITH HYBRID VENTILATION

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Abstract

This paper gives an objective overview of existing and planned Norwegian buildings with hybrid ventilation, many of which are schools. The following features are covered:

- Background for interest in hybrid ventilation in Norway.
- Design influences related to climate, potential for energy savings, and indoor air quality (IAQ).
- Summary and categorisation of existing buildings and applied technologies.
- A case-by-case description is given together with, costs, energy consumption, and experiences.
- Future trends: Planned buildings.

Interest in hybrid ventilation in Norway

The growing interest in hybrid ventilation in Norway is mostly founded on the present concerns about poor air quality in many schools. The IAQ problems experienced in Norwegian schools are mostly due to prolonged poor maintenance or lack of ventilation. Roughly 30% of Norwegians suffer asthmatic symptoms. Experiences from naturally ventilated buildings abroad, mainly Sweden, have inspired a recent upsurge in new progressive school projects in Norway with features such as hybrid ventilation and healthy materials, many of which are mentioned in this paper.

Although there has been a growing interest in hybrid ventilation in Norway, many decision makers are still ‘sitting on the fence’ as regards choosing between specifying modern balanced ventilation or a hybrid alternative.

There are many reasons for this: (**i**) modern conventional balanced mechanical systems are also improving, (**ii**) improved knowledge about the causes of SBS (often due to lack of maintenance or moisture ingress through poorly designed air intakes) leads some people to feel that the root of the problem has little to do with which type of ventilation system but a lot to do with quality of design, installation and maintenance, and (**iii**) perceived higher risk with hybrid systems due to the prevalent lack of competence.

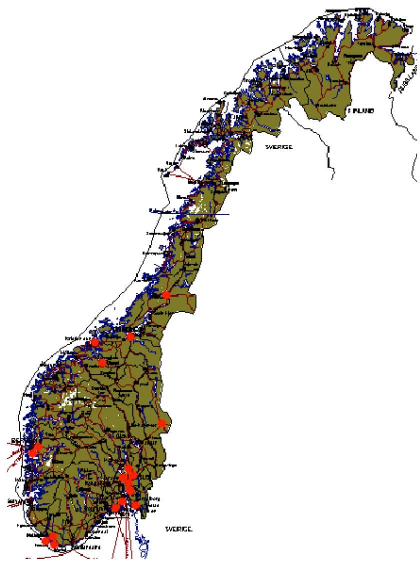


Figure 1: Locations of known hybrid ventilated buildings in Norway.

The Norwegian HVAC trade, as a whole, is gradually appropriating new skills in order to design reliable and efficient low-SFP ventilation systems, with additional features such as demand-controlled ventilation and other advanced building controls. The climatic constraints in Norway limits (but does not preclude) pure natural ventilation, so we can not expect a paradigm shift away from pure mechanical ventilation systems towards passive natural systems, but rather that the two could be expected to develop towards each other and meld sometime in the future, resulting in very low SFP mechanical systems.

Design influences

The Norwegian climate ranges from mild marine west coast (3200 degree days) to severe sub arctic (6300 degree-days). The population is concentrated in the warmer regions.
Figure 2 below shows two time distributions of natural ventilation driving force in 6 Norwegian cities during working hours, due to (a) stack-effect only, and (b) stack-effect + wind, for a 10m high building [1]. It is assumed that the wind and stack-effect act on the same air flow path. These graphs show that purely naturally-ventilated buildings in Norway must have a flow path with a pressure drop of not more than 10 Pa.

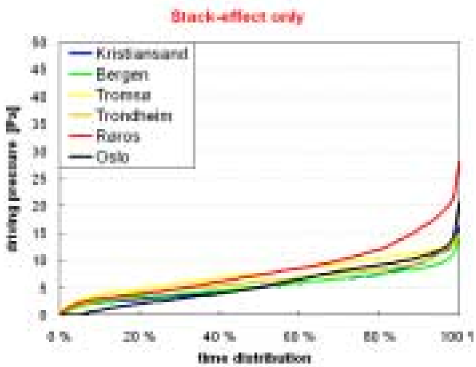


Figure 2a: Prevalent stack-effect driving forces.

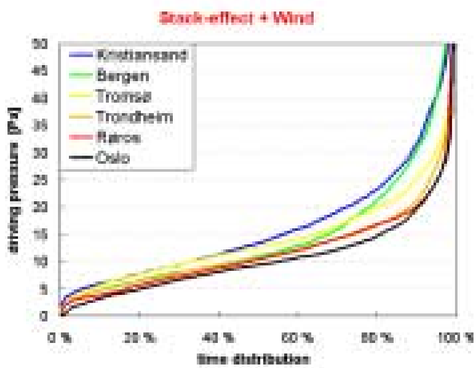


Figure 2b: Stack-effect driving forces.

Figure 3 below shows fan energy savings for different system pressure losses, as a percentage of the fan energy for a typical ventilation system with a SFP of 3.0 and 30% system efficiency. A mechanical ventilation system with a pressure loss of 100 Pa provides approx. 88% savings; if in addition the above natural driving forces are exploited optimally, then the savings increase only by a further 3%.
So you can see that the energy benefits of exploiting natural driving forces are very marginal.

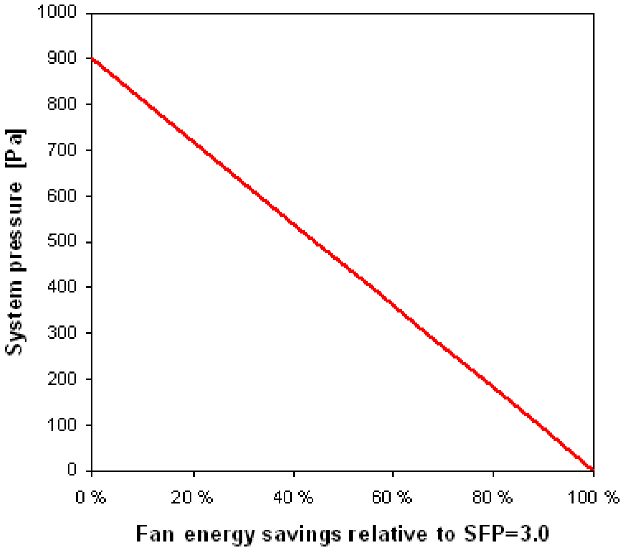
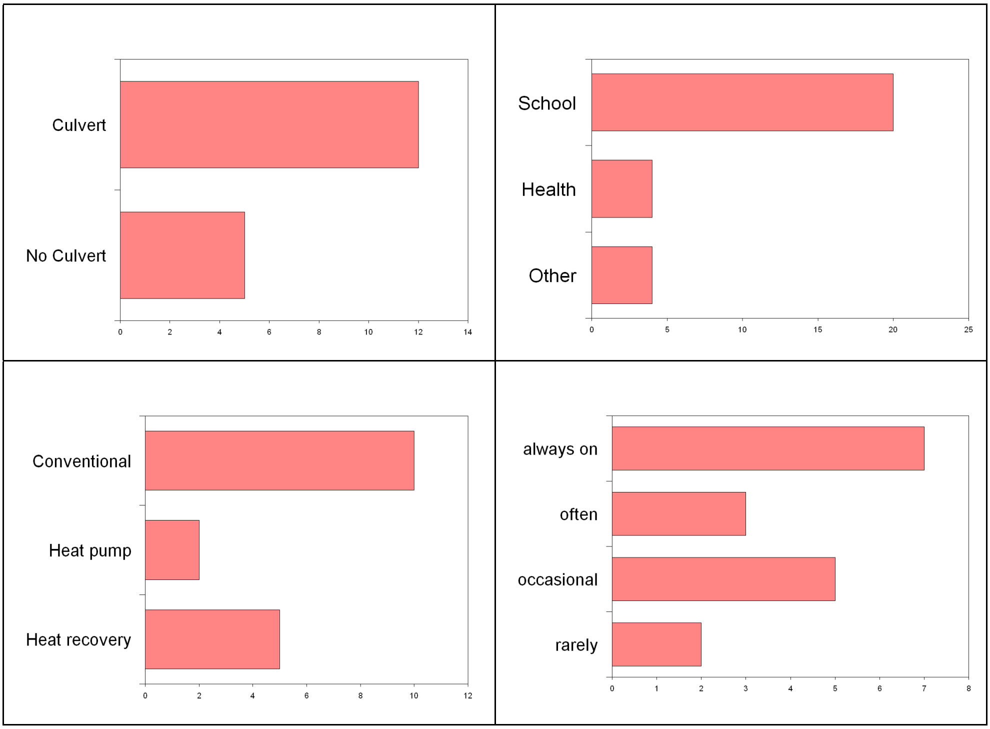


Figure 3: Fan energy savings for different system pressure losses, relative to a system with SFP=3.0.

The interest in natural and hybrid ventilation in Norway is therefore predominantly due to its perceived benefits to the quality of the indoor environment. A large number of published studies have confirmed a link between poor HVAC maintenance and cleaning routines and the prevalence of allergies and other SBS symptoms. The idea of low-maintenance HVAC systems is therefore very seductive. Some architects, notably in Sweden, have taken this philosophy a long way and specified natural ventilation systems with very few components (no filter, no preheating coil, fan only for summer overheating, only manual control of airing vents etc.) in the hope of designing a system that is easier to keep clean, and is more immune to poor maintenance. However, in Norway, a more balanced approach has generally been taken, encompassing more components and automation. Nevertheless, there is a wide spread of approaches in Norway, as you will see on the next few pages.
Another common problem in schools, which is related to poor ventilation, is overheating. This is the reason behind the rather expensive recent practice of building underground culverts for summer cooling.

Categorisation of Norwegian hybrid buildings

	HybVent house	Borhaug kindergarten	Borhaug school	Frei school	Gjerde school	Grong school	Jaer school	Klokkeråsen school	Lavollen center/cafe	Lier school	Lista hospital	Norsk film	NatVent pilot plant	Presterød school	Sammanger care cetnter	Sem school	Tredal school
Fans and hybrid mode																	
Low-pressure fans	•					•							•				
Supply fan				•	•	•	•	•	•	•	•	•	•		•	•	•
Extract fan	•	•	•			•				•			•	•			•
Fans always on when occupied	•					•						•	•	•			
Fans predominantly on		•		•	•				•	•					•		•
Fans predominantly off			•				•	•								•	
Fans contingency only (manual)											•						
Natural driving forces																	
Cross-flow ventilation																	
Stack-effect ventilation	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Wind-augmented inlet or outlet	•										•	•	•				
Wind/rain/snow protected inlet/outlet		•				•	•							•			
Air distribution																	
Displacement ventilation	•					•	•			•							
Half displacement / mixing		•		•	•			•	•		•	•			•	•	•
Mixed ventilation														•			
Building integration																	
Stacks / chimneys	•		•	•	•	•	•	•	•		•	•	•	•	•	•	•
Atria										•							
Underground ducts / labyrinth			•	•	•	•	•	•		•	•	•			•	•	•
Heavyweight stacks for supply air					•		•	•		•					•	•	
Cooling																	
Auto mechanical cooling daytime mode				•	•	•	•	•	•	•	•	•		•	•	•	•
Natural nighttime ventilation mode							•									•	
Mechanical nighttime ventilation mode						•											•
Room temp. sensors for cooling/htg		•		•	•	•	•	•	•	•	•	•		•	•	•	•
External shading						•	•										
Daylight compensation of lighting						•											
Heating																	
Heat recovery	•	•				•				•			•				•
Preheat of supply air			•			•	•			•							
Electric panel heating	•																
Low-temperature hydronic heating			•	•	•	•	•										
Electric boiler						•	•										
Oil boiler						•											
Heat pump					•										•		
District heating																	
Night-time set-back control optimiser							•										
Control of flow rate																	
Flow rate reduced slightly in winter		•	•				•	•			•						
Motorised vents						•	•			•				•		•	•
Passively controlled vents														•			
Manual control (or override)											•	•			•	•	
Speed-controlled fans	•	•		•	•	•		•	•	•	•	•	•	•	•	•	•
CO_2 demand-control						•	•			•							•
IR occupancy sensor for htg/vent																	
Control of AIQ																	
Electrostatic filter	•			•									•				
Quilt filter		•				•				•							•
Filtration effect in supply culvert						•	•	•		•							
Other energy saving features																	
BEMS				•	•	•	•					•	•	•	•	•	•
Presence-detected light switching						•	•										
Water-conserving/heat recovery of water services		•														•	



As can be seen from the top-right chart, the vast majority of hybrid ventilated buildings in Norway are educational.

Over 70% have buried intake ducts or a labyrinth/culvert in the basement to provide summer cooling.

Understandably, the Norwegian climate lends it self to exploiting the stack-effect. Only one building is located in a very windy coastal climate, so it has inlets and outlets that prevent draughts (dynamic insulation).

Hybrid ventilation buildings in Norway can be divided into the following two competing camps. Many buildings fall somewhere between the two:

Seasonally adjusted flow rate Camp

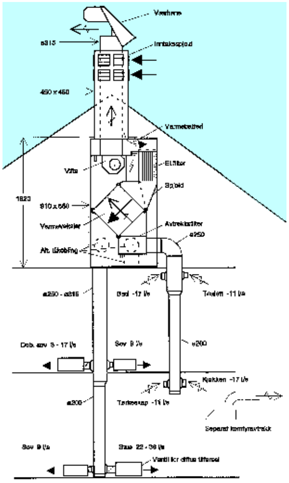
The majority of Norwegian hybrid buildings have no heat recovery or heat pump. This is partly due to the practice of 'seasonally adjusted flow rate' imported from Sweden [2], which supposedly reduces the ventilation heat loss whilst improving IAQ during winter, reducing the profitability of heat recovery or heat pumps. The idea is that reducing flow rates slightly in winter keeps relative humidity at normal levels, preventing IAQ problems related to low %RH. This idea is attractive because it results in lower building costs. Evidence for the benefits of this principle are circumstantial, and need proper further study. These buildings generally use only temperature sensors for demand-control of ventilation volume. They have lower pressure drop and can run much of the year without fan assistance.

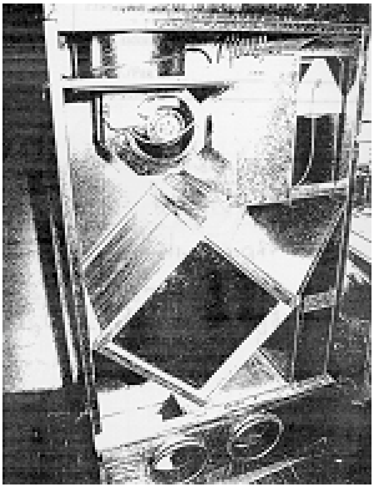
Heat recovery Camp

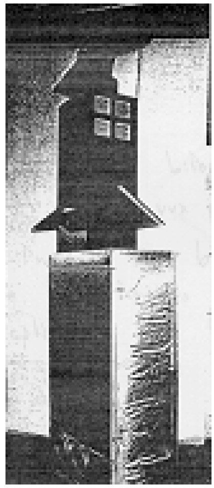
Three heat recovery systems have been demonstrated, air-to-air heat recovery, air-to-water and dynamic insulation (these last two in the same building). These systems need the ventilation fans to run continuously during occupancy, augmented by natural driving forces. These buildings all have CO_2 sensors for demand control. Due to the higher pressure drop, these buildings need continuous fan assistance.

Case examples

Hybvent House

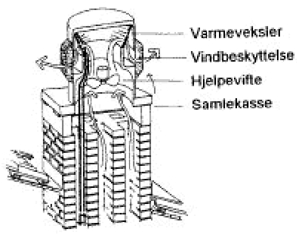






- Prototype balanced heat recovery ventilator for housing, developed by NBI in 1994, now in field tests.
- Exploits stack-effect and wind. Fan power only 30-40 W.
- Heat recovery 70-80% efficiency.
- Only short vertical ducts. Easier to clean, and low pressure (10-40 Pa) and thus very low noise levels (28 dB(A) in bedroom).
- Displacement ventilation.
- Effective electrostatic filter.
- Costs slightly more than conventional balanced residential ventilation, 5 year payback.

Borhaug Kindergarten



- Approx. 160 m² kindergarten extension, completed 1999.
- Dynamic insulation in roof.
- Windy location.
- Rooftop extract fans [4] are temperature-controlled. Fan speed reduces at lower outdoor temperatures because the stack-effect is stronger. Low flows resistance when the fan is not running. It also has integrated air-water heat recovery.
- No teething problems have been reported for this kindergarten's ventilation system. The heating system controls need to be improved – it swings between too hot and cold. Installed by unspecialized workmen.
- Children show no symptoms of poor AIQ.

Frei School

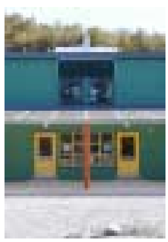
- New 2700m² school, completed autumn 1999.
- Culvert / Assistance from supply fan / Electrostatic filter / Healthy materials.
- There have been a number of teething problems. Controls were installed by an unspecialised electrician. CO_2 sensors were placed directly under supply vents (displacement) - now moved. Motor noise from the motorised clerestory vents is disturbing. The vents are draughty and let rain in. The vent controls have therefore been overridden to shut them. Vibration from the supply fan downstairs is disturbing, so the fan is now run at reduced speed. Poor air quality, spot measurement of CO_2 1400 ppm.
- There is no access to the culvert for cleaning, as it is blocked off by the electrostatic filter.

Gjerde School



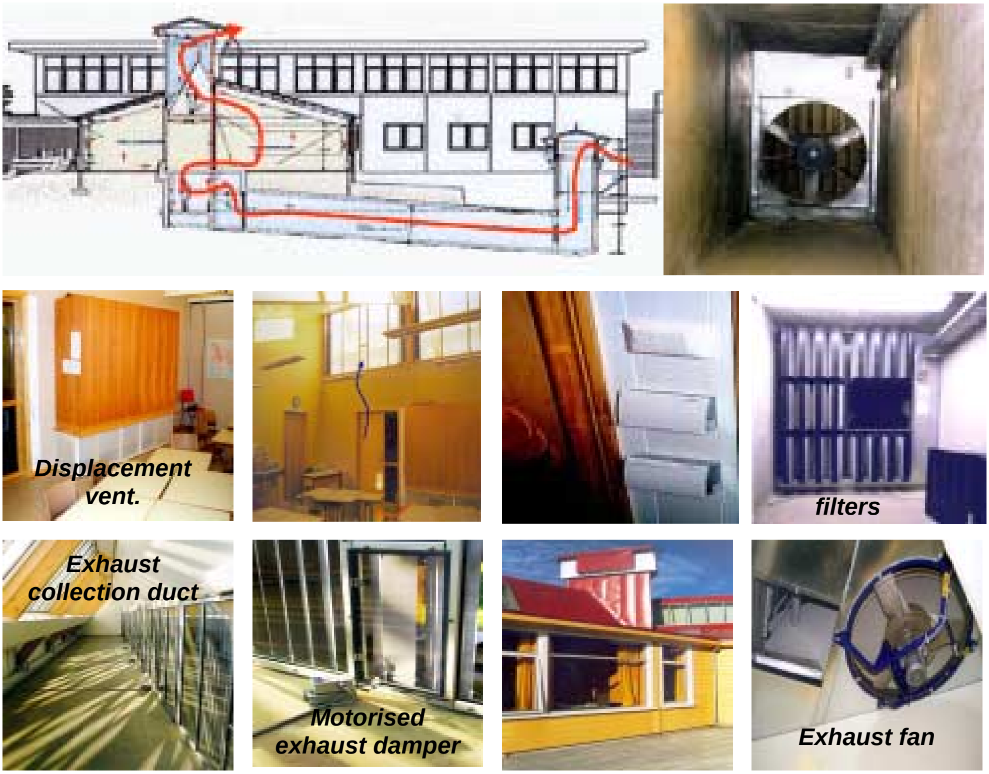




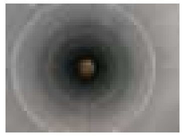

- New 2000 m² school, opened Nov. 1998.
- Culvert, supply fan-assistance, double wall used as shaft for vertical air supply (improved thermal storage for cooling), motorised clerestory window in each classroom, controlled by room temperature and CO_2 sensors. BEMS, good daylight design.
- Low-temperature hydronic heating (radiators, under-floor in changing rooms). Heat pump with 5 boreholes (150 m deep) and a shallow 400 m² loop in the ground; also electric boiler.
- This is a very successful building indeed: Low budget, and very low energy consumption.

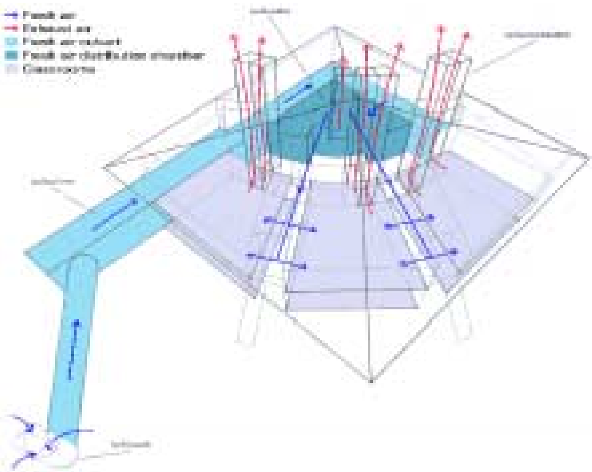
Grong School

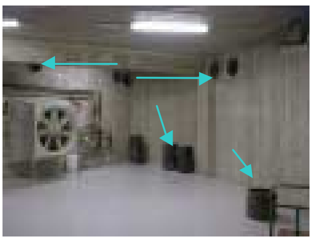


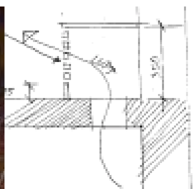
- New 1001m² school, completed 1998.
- Run-around heat recovery, 55-60% efficiency expected (25 Pa for inlet exchanger, 28 Pa for exhaust exchanger). When it is very cold outside, extra preheating using water from the water heating system.
- Supply fan runs at 70 Pa during occupancy, the extract fan about 35 Pa. Frequency controlled.
- EU7 filters (20 Pa when new) located at the end of the underground culvert, just before the heat exchanger. Larger particles precipitate to the floor in the culvert before they reach the filter.
- Demand-controlled with CO_2 and temperature sensors / BEMS.
- Displacement ventilation.
- Low energy consumption 107 kWh/m² despite some teething problems.

Jaer School



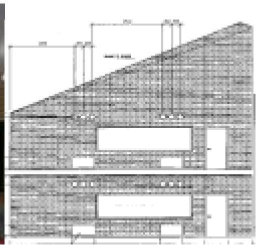




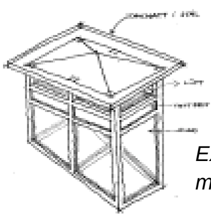


Section, integrated displ.vent.

Classroom



Section



Exhaust chimney, with motorised dampers at top

- New 800 m² school, completed autumn 1999.
- Assistance from supply fan. The system is designed with a very low pressure drop (10 Pa), so the fan is practically only needed for summer cooling, in fact it has never been needed yet since the cooling effect of natural night-time cooling is very effective, see Figures 4a and 4b below.

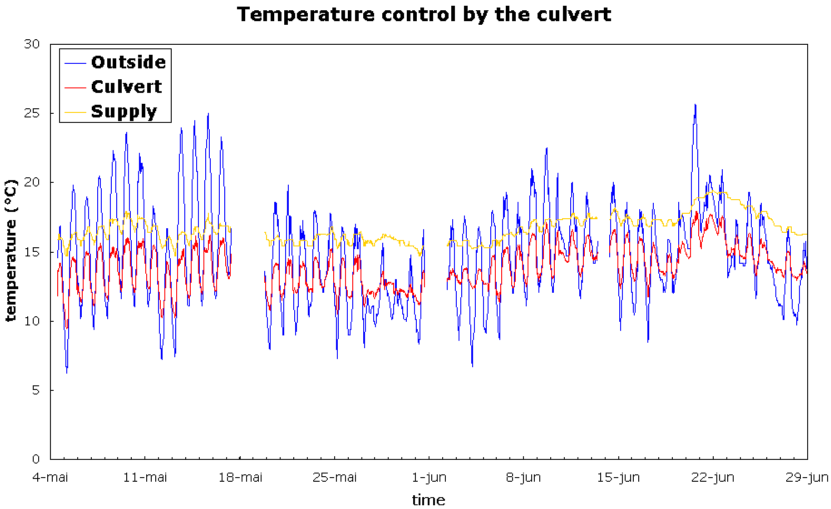


Figure 4a: The thermal performance of the culvert over a couple of months.

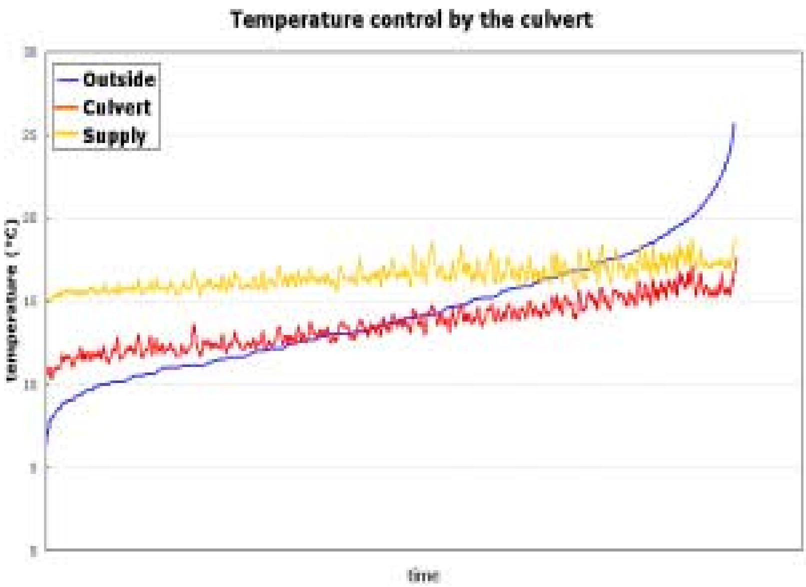


Figure 4b: Distribution curve showing the cooling effect culvert over a few months. "Culvert" is the air after it has passed through the culvert, "Supply" is the air after it has passed though the preheat battery.

- Demand controlled ventilation with CO_2 and temperature sensors / Displacement ventilation.
- There has been a number of teething problems with the controls system, many of which are now solved. To cut costs, entrepreneurs were reluctant to install standard controls features (time control, winter night-time setback, differing heating and cooling set-points, summer night ventilation, frequency control of fans). Some of these features have since been added to reduce energy consumption. Three motorised radiator valves caused overheating problems and were replaced. Due to these severe controls hiccups, heating costs were three times expected value. There was rain and snow ingress though the chimneys, so these have now been retrofitted with louvers.
- There is no filter, but the 2m² culvert has a measurable filtration effect. Figure 5 overleaf illustrates measurements with a particle counter at different locations along the culvert and inside the building during the pollen season. The effect was seen for all particle sizes, though is most marked for the larger particles. Smaller particles may be clinging together and precipitating due to the combined weight.
- The occupants are very satisfied with the air quality in the building.
- Approx. 30% more expensive than typical school buildings, mostly due to its architectural qualities. It was completed within budget. HVAC equipment costs were below average.

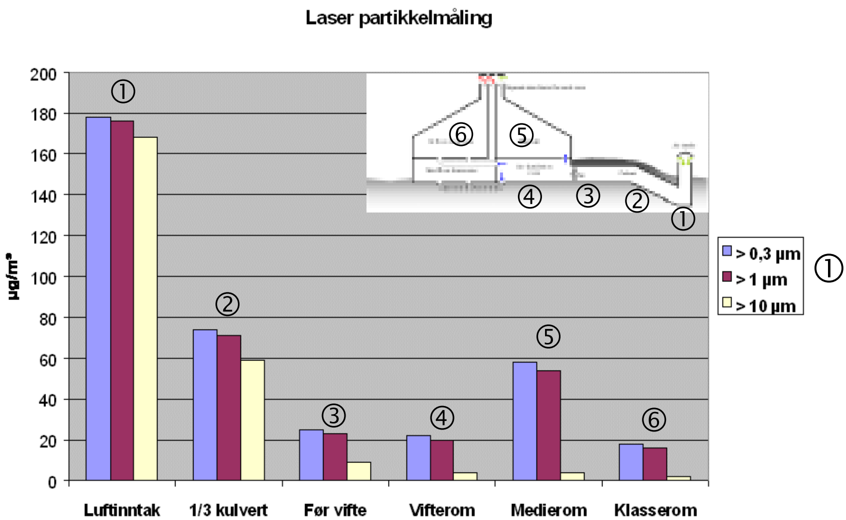
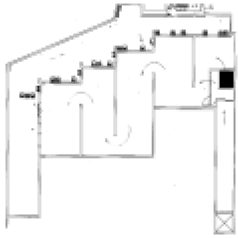


Figure 5: Gravimetric laser particle counter measurements of particles of different sizes at 6 different locations.

Klokkeråsen School



Classroom showing supply vents half way up wall, and exhaust vents at top

Culvert – horizontal preheat battery (frost/condens. Protection)

Culvert – fans and one-way bypass damper (passive, Swedish)

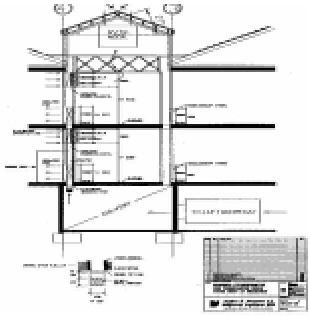
Left: Preheat coil for supply air from labyrinth basement up to each classroom

- School extension, completed Sept. 1998.
- Basement labyrinth; 3 parallel supply fans; Controlled according to Swedish "seasonally adjusted" ventilation, and demand control for each classroom with CO_2 and temperature sensors. Relative humidity never drops below 25%. No BEMS. High ceilings. Healthy materials.
- Supply air is led up though a heavyweight double wall to supply vents halfway up each classroom wall; the air falls gently to the floor, hopefully achieving draught free displacement ventilation.
- A number of teething problems with the controls have been reported; these have still not been solved.
- There was no drain in the labyrinth, one had to be retrofitted to enable washing.
- A significant amount of dust collects on the extensive pipework in the labyrinth, and is difficult to clean.

LavolLen Center/cafe

- An old farmhouse, part of an outdoor pursuits centre/cafe. Rehabilitated with supply fan for hybrid ventilation in the 1990's.

Lier School



Atrium

Classroom, showing displacement ventilation ATD, and exhaust

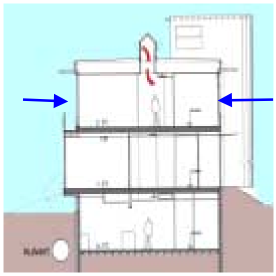
- New 4300 m² school completed autumn 1998.
- The air distribution method resembles Klokkeråsen School, though this system is more like a conventional VAV system, with heat recovery, and supply/extract fans. Culvert / The supply air is led up thought a double wall to each classroom via a device for displacement ventilation. Exhaust air is via the atrium. In summer, the exhaust fans can be switched off and vents in the atrium roof open, exploiting the stack-effect.

Lista Hospital


Front and rear views

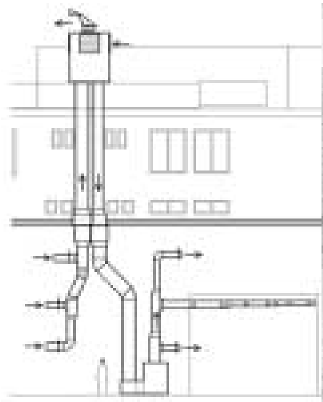
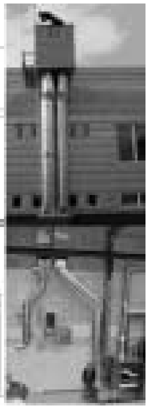
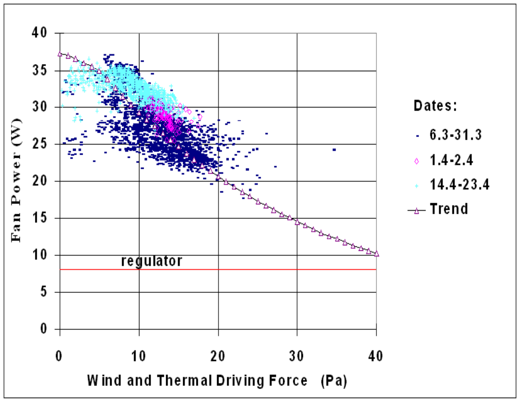
- New 320 m² psychiatric clinic opened May 2000.
- Predominantly natural ventilation. Supply fan is provided as a manual contingency for summer cooling and for smoke ventilation. It has not been needed yet, due to sufficient cooling capacity if the labyrinth.
- Labyrinth occupies the entire basement area / Air intake through a 4 m long buried pipe / Preheat battery / Air leaves though clerestory vents in the roof - a wind sensor controls which side of the clerestory the vents are opened to exploit the wind maximally.

Norsk Film

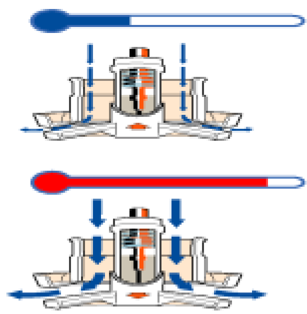

- 950 m² office building completed May 2000.
- This building has a split ventilation system. Ventilation-intensive areas in the basement and ground floor, including kitchen, canteen, and conference room, have a conventional mechanical ventilation system. Remaining areas on ground floor and top floor have air supplied from a second, lower pressure, supply system, with exhaust by stack effect up to motorised the rooflights. A wind sensor controls which side of the roof lights should be open. 35 m long buried culvert.
- All vents on the top floor can be manually overridden. As the vent arrangement in the top floor is rather complex (window-room, room-corridor and corridor-rooflights), some occupants were not sure which combination of vents they should adjust and how.

NAT VENT Demonstration System

- Demonstration plant used to ventilate the main laboratory hall at NBI, Oslo. Constructed in 1998 as part of the EU project NatVent [5].
- This prototype tackles the following hybrid design issues that are typical of urban buildings: (**i**) Filtration using electrostatic filter, (**ii**) Intake of clean air from the roof instead of polluted air from street level, (**iii**) Minimizing traffic noise, (**iv**) Ceiling-ceiling heights can be kept to a minimum since horizontal ductwork is reduced. As this was a prototype system, aesthetics were not an issue.
- Exploits stack effect optimally, also has wind-augmented intake and exhaust. 50% efficient heat recovery. Supply fan 35 Pa, exhaust fan 13 Pa. SFP=0.14 kW·s/m³.

Presterød School

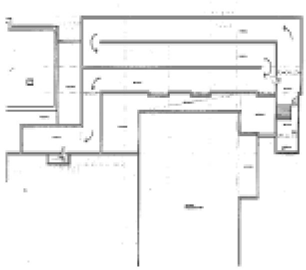
Themostatic Velco [6] supply vent under cold and hot conditions

- 4700 m² new school building, completed in January 2000.
- Supply from outer wall through high level horizontal ducts with thermostatic vents that reach to the supply temperature – the pressure drop increases in winter whilst the jet momentum is kept high, keeping the stack flow relatively constant or slightly reducing it, and at the same time ensuring good mixing and preventing downdraught. Temperature-controlled mechanical extract stack from each classroom, each with its own fan. Fan speed does not fall below 15% of design.
- No filtration, the argument is that it is a clean rural setting.
- A very large number of motorised vents (200) and rooftop fans (one for each classroom) are used.
- There have been teething problems with the BEMS. The occupants are very satisfied.

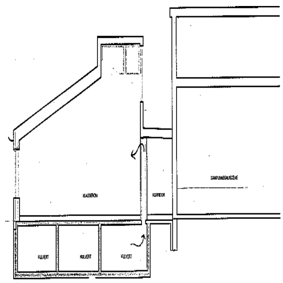
Samnanger Care Center


- New 500m² care center, completed October 2000.
- The HVAC design is very similar to that of Gjerde School mentioned earlier (culvert, heat pump, etc.), so very good performance is expected.

Sem School

plan of labyrinth in basement

cross-section showing principle of using double wall as supply shaft to classrooms

- New 700 m² school extension, completed winter 1998/99.
- The HVAC design is very similar to Klokkeråsen School mentioned earlier, the main difference being a different solution for the air intake and labyrinth, and use of clerestory windows for venting.
- Some heat is reclaimed from waste water pipes that pass through the labyrinth. However, such pipes pose a cleaning problem.
- Clerestory vents are controlled solely by a timer, not CO_2 or temperature. They are not controlled according to wind direction, consequently it can be draughty. Sensitive to wind. Flow reversals appear to occur with cold air falling down in pupils, causing discomfort.

- The ventilation system is an improvement over the old system, occupants sense fresher air.
- There have been a number of problems. Ultimately a BEMS had to be installed (EUR 50 000) to help monitor the building. The school still has its original boiler which does not have sufficient capacity.

Tredal School

- 1692m² new school building. Construction finished summer 2000.
- Heat recovery. The system has been modelled on Grong school, is expected to perform similarly, though it has a larger culvert.
- Room temperature sensors were wrongly positioned inside electrical conduit where they were influenced by wind and outdoor temperature – now moved. Some more teething problems not yet solved. Complaints that it is too warm.

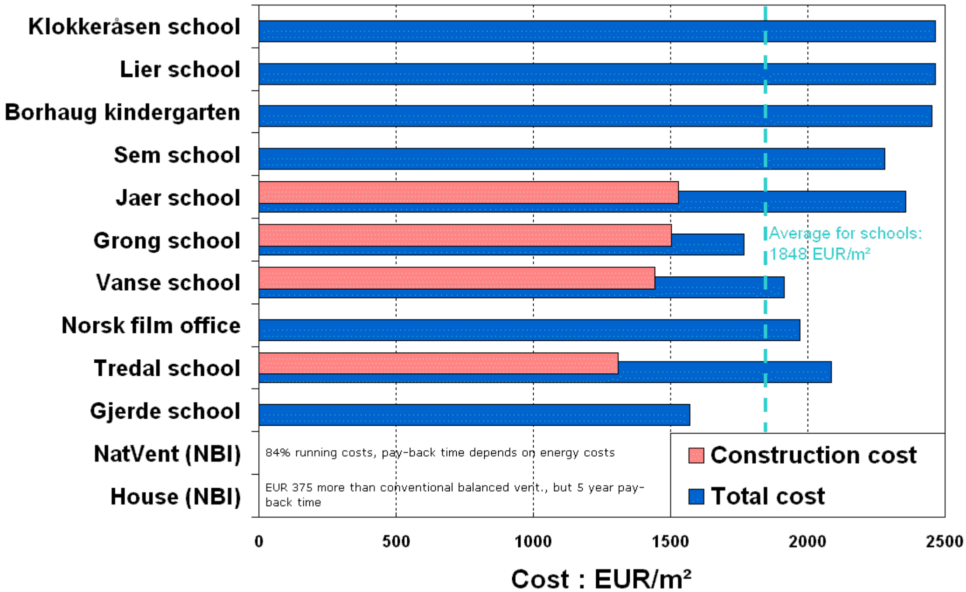
General evaluation

As you can see from the previous few pages, a broad range of design approaches has been applied in the different Norwegian hybrid ventilated buildings. As most of these buildings are still being ‘run-in’, it is too early to be able to observe any general pattern in how well they perform.

Most of the building occupants report a sense of ‘fresher air’ in their new hybrid buildings, though this is not yet quantitatively documented by questionnaire. Some of the buildings have reported draught problems, rain ingress and noise. An equally positive response might well be observed in new buildings with well-designed modern balanced mechanical ventilation and good environmental design features.

However, virtually all of the buildings covered in this paper have suffered controls problems of varying degree, and consequent energy wastage; this seems to be due to a prevalent attitude or lack of competence among installation and maintenance workers, and also reflects the problem of the ‘built it and forget it’ approach imposed upon responsible architects and design consultants due to little money or time for follow-up work.

A summary of available construction costs and total project costs for the buildings is shown below.



The *Total* project costs above include landscape work, and other outside works, which explains in part why some buildings appear to cost significantly more than the national average of approx. 1848 EUR/m². Another factor is the use of brick instead of wood, which explains 4 of the most expensive buildings. *Construction* costs are a more appropriate measure for comparing costs of different ventilation systems, but cost-breakdowns are difficult to get hold of.

It has been very difficult to obtain energy data for most of the buildings – people seem understandably reluctant to provide such data when their building is still being run in, or when they are experiencing controls problems. Therefore data from only three of the buildings could be plotted below on a distribution of specific energy consumption (not degree-day corrected) in kWh/m² heated area from the national database of energy consumption in 356 school buildings [7].

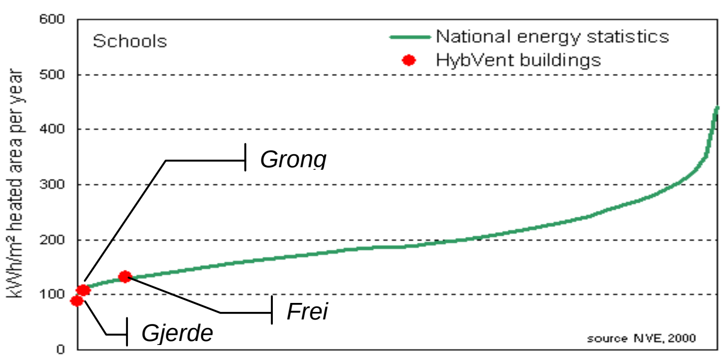


Figure 6: Distribution of specific energy consumption (not degree-day corrected) in kWh/m² heated area from the national database of energy consumption in 356 school buildings [7]. Three HybVent buildings are plotted as red dots.

Future Trends: Planned buildings

Figure 7 overleaf shows the distribution of floor area among existing Norwegian HybVent buildings (red) and among buildings currently being designed/constructed (green). From the chart, it is clear that confidence in hybrid ventilation is growing, as larger projects are now being tackled, and the risks are conceived to be reducing as interest grows and people gain more experience. Also the number of ongoing HybVent building projects is growing. Although the majority of ongoing buildings projects are schools, there will hopefully be increasing interest from the commercial building sector.

Figure 7: Distribution of floor area among existing Norwegian HybVent buildings (red) and among buildings currently being designed/constructed (green).

Conclusions

Hybrid ventilation has now achieved a good foothold in Norway; it has proved its merit in that it has been shown to be able to provide improved air quality, with low running costs, though not always. It is difficult to draw general conclusions about investment costs; they seem to be roughly in line with conventional buildings with comparable extra energy saving investments. More research is needed here, preferably using life-cycle costing (LCC).

Existing HybVent buildings have proved to be an operations & maintenance challenge — the building trade seems to lack competence and experience in supplying high quality economical control systems, and facility managers (or caretakers) seem to have a hard time solving the problems that dogger such advanced systems. This is possibly the greatest challenge that faces all new HybVent projects. On the other hand, conventional ventilation systems are also increasingly inflicted by these same problems, as increasingly advanced control systems are brought into use.

More information on hybrid ventilated buildings in Norway, with photographs and references to relevant literature can be found on Internet [3].

Acknowledgements

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DESIGN PROCEDURES FOR HYBRID VENTILATION

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Abstract

This paper presents an overview of the early stages of the design process and the simple tools used to be used for any ventilation design. The decision of target values and the characterisation of outdoor climate and building use as the basis for choice of ventilation solution is shown.

Introduction

The goal with climatisation of indoor environment is to maintain sufficient air quality and thermal comfort for occupants while energy use of the building is kept at a lowest possible level.
The last decade has shown a low price on energy for heating and cooling. In the same period there has been no or low penalty for the release of contaminants to the environment.

We see today an increasing trend in natural catastrophes, said to be due to global warming caused by release of greenhouse gases – among them CO_2 from the heating of buildings with fossil fuels.

Environmental-friendly buildings are not easily accomplished with the requirements of the last decade when a lifetime and payback time for a building is normally considered less than 30 years, and the lifetime of any technical installation is less than 15 years.

The ultimate vision must be to work towards a built environment with healthy condition, with no need for energy supply, and with no release of contaminants to the environment. As most of the buildings we will see in ten years already are built today, it will be most important to focus on retrofitting of the existing building stock.

The key parameters for environmental friendly and sustainable design are: Health, productivity, energy, cost and environmental load. These parameters should be kept within bonds, and an optimum solution should be found. However, this is not an easy task. The interpretation of "cost" is particularly difficult, involving uncertain variables as real lifetime of the building and its installations, need for refurbishment and development in property value.

A design procedure

A design process for climatisation of buildings should be open to end up with the "best" solution. The solution for ventilation must evolve from the design process. Dependent on all variables the solution may come out as mechanical, hybrid or pure natural ventilation. Some HVAC consultants say: "80% of the final solution is decided in the first 20% of the design process", and they are probably right. A design procedure and tools to make good decisions in the early stages of the design process are therefore needed.

An example of a complete design procedure for climatisation of indoor environment is shown in Table 1. The first columns of Table 1 are shown in Table 2. The present work will focus on columns B and C in that table.

	A	B	C	D	E	F
1	***Design phases*** ==>	**Initial conside-rations**	**Building initial design**	**First design of room environment**	**Building, system first design**	**Final design of room environment**
2	***Involved parties***	Owner,arch., users, consultants	architects, IAQ-experts	indoor climate eng., architects	HVAC syst. eng, indoor climate eng	indoor climate eng., architects, HVAC syst. eng.
3	***Building, site, use, room***		from B7	from C7 update on occupant use, heat- and con-taminant emission	from C7 update with new informat-ion	from D3, E3 update information, especially on use and sources
4	***Design speci-fications***		no healthpr. few com-plaints good pro-ductivity	normative: airflow rates summer, winter indoor temp. normative filter use	from D4 add normative energy consumption	thermal comfort indices, air quality indices, energy effici-ency indices as agreed on in B7, and coarsened to detail-level of tools, methods used
5	***Design scenario***	typical use scenario	updated typical use scenario	design summer and winter conditions	"design year"	design summer and winter conditions other load scenario
6	***Tools, methods***	questions to involved experience case stud. discuss: occup.use intern.heat cont.sourc. solar heat	arch. guidelines regulations case studies experience	load evaluation: occ. use, int.heat- and contaminant loads, solar load climatisation: guidelines, experi-ence, case studies assumption of ven-tilation efficiency assumption of infiltration rate	system guide-lines calculation methods for coarse yearly energy con-sumption and peak power	reevaluate contaminant- and thermal loads and consider source control/ use of local extracts, cons. local air supply guidelines for space climatisation (possibilities for large spaces) improved assumption of infiltration rate, location engineering methods: flow element models, zonal models
7	***Results***	location space demand, functions building size, form, cost limit room target indices for IAQ, thermal comfort, energy efficiency, noise	interior: material use exterior: U-values, airtightness windows cost estimate	suggested solutions: load reduction local ventilation space ventilation, heating, cooling	arch. drawings energy consumption system layout ductwork layout	optimum design for climatisation, energy use: type and location of air terminals, heating, cooling, selected equipment for air supply, extract, heating, cooling control strategy, sensor placements
8	***Specs. O.K. ?***		reconsider or decide to build	redesign or proceed	redesign or proceed	redesign or end room environment design work

Table 1: A complete design procedure for climatisation of indoor environment.

	G	H	I	J	K	L
1	**Building, System final design**	**Validation of room environment design**		**Building, system commiss.**	**Commissioning of room environment**	
2	HVAC -syst.eng.	indoor climate/ CFD-expert		HVAC- syst.eng.	indoor climate/ measurement expert	
3	from F3 update with info from E7, F7	from F3, F7		from G3		
4	as for F4	thermal comfort indices air quality indices energy efficiency indices as agreed on in B7		From B7, G3, G7	thermal comfort indices air quality indices energy efficiency indices	
5	hour by hour through a «design-year»	scenario selected from building dynamics simulation evaluation	**CONSTRUCTION PERIODE**	design summer, winter cond.	as for H5 if possible	**MAINTENANCE PERIODE**
6	building dyna-mics sim.codes (FRES, TSBI3, DEROB, DOE2 etc.)	CFD-codes to compute: velocity,temp.,conc.fields (FLOVENT, TASKFLOW, FLUENT, KAMELEON, TEACH, FLOW-3D etc.) guidelines for CFD-use calc. PPD, DR, VTG, RA calc. of occupant contam. expos. CFD-simulations to f ind ventilation effectiveness indices (physical models may be used)		methods and equipment to measure: airtightness airflow rates supply air temperatures	methods and equipment to measure IAQ, thermal comfort and efficiency indices, contaminant exposure, thermal stress	
7	optimum design for building and system yearly energy consumption peak loads first cost, running cost, life cycle cost	prediction (detailed) of air quality, thermal comfort, contaminant exposure, thermal stress indices etc. as agreed on in B7 eventually: investigate problems by analyzing CFD-simulation results in detail calculate appropriate ventilation and efficiency indices		comparison with plans, assumptions	at measurement points: PPD value directly air temperature mean radiation temp. radiation asymmetry air speed, turbulence intensity, humidity cons. of actual contaminants	
8	redesign or end building, system design work	redesign or make decision to construct as designed		rectify or proceed	redesign and rectify or end work task	

	A	B	C
1	*Design phases* ⟹	**Initial conside-rations**	**Building initial design**
2	*Involved parties*	owner, arch., users, consultants	architects, IAQ-experts
3	*Building, site, use, room*		from B7
4	*Design speci-fications*		no healthpr. few com-plaints good pro-ductivity
5	*Design scenario*	typical use scenario	updated typical use scenario
6	*Tools, methods*	questions to involved experience case stud. discuss: occup.use intern.heat cont.sourc. solar heat	arch. guidelines regulations case studies experience
7	*Results*	location space demand, functions building size, form, cost limit room target indices for IAQ, thermal comfort, energy efficiency, noise	interior: material use exterior: U-values, airtightness windows cost estimate
8	*Specs. O.K. ?*		reconsider or decide to build

Table 2: Early stages of the design process.

Initial considerations

Involved parties

Normally the idea for a new, say office building, comes out of the need for more space, more suitable space for the process or organisation, better working conditions with respect to indoor environment and more cost-efficient running of the building. A new building may also be looked upon as an investment.
Refurbishment of a building is normally a bit more limited in possibilities but basically the same procedure should be followed.

The idea to build or to refurbish must be followed by some considerations on financing. Often, the builder, or owner, also has got his hands on a lot. To achieve the optimum building design, it can be questioned if this is very wise as some alternatives for ventilation design then might be ruled out.

Normally the builder will approach an architect to present his idea, needs and financing plan. That start of the design process may be typical for a one-time builder. He will be very dependent on the architect and his ability to bring in other consultants into the design process.

Another kind of builder is the professional builder. He is typically working in a big company or in a governmental or community organisation. He might have an education in architecture, civil engineering or similar. And he will normally have architects and other of the needed consultants in his own organisation, and they can do a major part of the initial design work.

The builder will normally be the person in charge and responsible for all decisions. It is extremely important that the builder is aware of his responsibilities, and that put time and effort into the early stages of the design process when goals and limits are decided.

He must also be ready to take decisions during the project. In a larger company or organisation, the builder will normally take advice from a building committee where also users of the building are represented. It is very important that user interests are well represented in the early design.

The construction of a large building will normally involve many parties. Consultants for the design process, the design team, are typically:

- Architectural design.
- Indoor environment engineering.
- Environmental engineering.
- HVAC engineering.
- Civil engineering.
- Electrical engineering.
- Fire safety engineering.
- System integration.
- Project management.

When the design is completed, a large number of contractors and suppliers are involved during the construction phase.

First-time builders are not capable of taking many decisions on their own. They lack a lot of knowledge. Professional builders are often very capable but they may need new knowledge in some fields where development has gone a step forward. Each member of the design team should therefore take it as a serious task to give the builder the needed background information to make the best decisions.

Building, site, use and space

Based on ideas, needs, wishes and possibilities, use of building, need for space for different activities, architectural design, running costs and health-, productivity- and environmental issues should be discussed. Also, the design lifetime of the building should be brought into the discussion. The lifetime is a very important parameter when a first cost limit for the building structure and for installations with expected long lives are discussed.

Target values

Building codes and other governmental regulations are meant to take care of users of buildings with respect to safety, exposure to contaminants and otherwise to ensure acceptable work environments.

However, the kind of threshold limit values or similar given values are in some cases too low to ensure good productivity among workers. In other cases, the values given are based on assumptions that are unrealistic and that limit energy saving actions.

Therefore, the different requirements, especially for the indoor environment and for energy use, should be worked through to come up with a set of target values that is recommended to, and hopefully accepted by the builder.

The target values should be used during the different stages of design to check if the suggested design is going in the right direction. Because of that, the target values may need to be specified to different levels of detail for use at different stages of design. While general thermal comfort in the zone of occupancy might be specified as a PPD-value for the detailed final design, it should also be specified as air temperature and operative temperature at earlier design stages. Goals for energy use, at specified occupancy of the building, should also be set.

As important as producing the target values is to come up with a list of non-acceptable conditions to avoid future indoor and outdoor environmental pollution problems. Instead of using a traditional financial payback time of 30 years, an evaluation of life-cycle cost should be used to evaluate the cost effectiveness of the building.

Thermal comfort target values

People in buildings will be more likely to complain about general and local thermal discomfort than poor air quality. A typical thermal comfort range is considered below.

The following assumptions are made:

- The metabolism is 1.2 met (sitting activity; school, office, home).
- The occupants are able to regulate the clothing insulation between 0.5 and 1.0 clo.
- The mean radiation-temperature is equal to air temperature.

As an example, target values for acceptable thermal comfort conditions are chosen, for some rooms in a building, to be bound in an area between the following points in an h-x diagram for moist air:

A. 20% RH, 21°C and <0.15 m/s
B. 60% RH, 20°C and <0.15 m/s
C. 20% RH, 28°C and 0.25 m/s
D. 70% RH, 28°C and 1.5 m/s

Referring to the moist air diagram, humidification is needed for outdoor air at a condition to the left of A-C. Cooling is needed above C-D, heating is needed below A-B, and dehumidification is needed to the right of B-C. However, the equipment and power needed is dependent on the load of heat and humidity.

The comfort range shown above is typical for mechanically ventilated buildings, even if most air-conditioned buildings are kept at temperatures below 24 °C.

An investigation by Brager and de Dear /1/ concludes that people in naturally ventilated office buildings are more satisfied with the thermal comfort at indoor temperatures at the lower and upper end than in air-conditioned buildings. This is explained as psychological adaptation due to that occupants control ventilation themselves with operable windows. Such effects might extend the area of acceptable thermal comfort.

In an office building productivity is important. The paper does not discuss if productivity can be directly related to acceptability. Negative factors related to the opening of windows, like outdoor noise and pollution, are not mentioned either.

Air quality target values:

Satisfactory air quality should be ensured by ventilation. If good materials are applied to keep the indoor pollution low, human odor emission might be the major pollution. Then the CO_2 level can be measured to characterise the odor level. Normally, a CO_2-level of up to 650 ppm above outdoor concentration will be satisfactory in the breathing zone of occupants.

Target values to avoid problems with moisture:

Moisture seems to be the second biggest cause of indoor air quality problems after smoking.

In order to avoid the growing of molds, with resulting air quality problems, the relative humidity of indoor air should be below 50% at low outdoor temperatures to avoid high moisture content on thermal bridges in the building envelope. A detailed discussion of this matter can be found in Hens /2/.

Moisture is also a concern with respect to the building itself. Pressurisation of the building should not occur during cold periods. In cases of hot and humid outdoor climate and cooled buildings the indoor should not be under pressurised to avoid moisture accumulation in walls. See Harriman et. al /3/ for a discussion of the matter.

There are several reports on biological growth and molds related to ventilation air intake in mechanically ventilated buildings. Air intakes are not sufficiently shielded against precipitation, and there is often a short way between the intake opening and the air filter. A filter with biological particles combined with moisture will for sure cause indoor quality problems. This should be avoided. Of coarse water leaks into the air intake system should be avoided as well.

Outdoor climate classification

All locations are more or less exposed to seasonal variations in the outdoor climate. The variations are seen in air temperature and humidity, precipitation, solar radiation due to latitude, altitude and cloud factor and wind speed and direction.

The condition of the outdoor air is the most important factor when ventilation system properties are designed. Therefore outdoor conditions are coarsely characterised as compared to acceptable thermal conditions to humans. The characterising can be done as shown in Table 3 where outdoor air handling needs are indicated.

Climate ⇓	**Enthalpi load⇒**	**Very low**	**Low**	**Intermediate**	**High**	**Very high**
Example load ⇒	Example site ⇓	Warehouse	Home	Office	Classroom	Concert hall
Hot and humid	Singapore	Dehumidify	Dehumidify and cool	Dehumidify and cool	Dehumidify and cool	Dehumidify and cool
Hot and dry	Denver, Summer	No need	Cool	Cool	Cool	Dehumidify and cool
Intermediate	Oslo, Summer	No need	No need	No need	Cool	Cool
Cool	England, Winter	Heat	Heat	No need	No need	No need
Cold	Røros, Winter	Heat and humidify	Heat and humidify	Heat and humidify	Heat	Heat

Table 3: Typical conditioning of supply air in air handling unit or in room to keep thermal comfort.

The cooling or heating and the humidification or dehumidification can take place fully or partly in the air handling system or in the room. The outdoor airflow rate can be increased to keep the temperature and the humidity at certain levels in a room. In the zone of occupancy air speed can be increased to enhance cooling of the human body.

Building and system initial design

General guidelines for climatisation

Ventilation is accomplished for good air quality and thermal comfort at low energy cost, cost and environmental pollution.

The basic rules for any climatisation are:

- Minimise pollution loads.
- Minimise thermal loads when not useful.

This implies for example to use shading, to use low-emission materials, to avoid installation of mechanical cooling, to reduce consumption of electricity use for fans and to use low energy bulbs for artificial lighting.
A thermally well-insulated and airtight building envelope is important in areas with cold winter in order to keep the energy demand low.

The energy consumption for heating of a building is dependent on the outdoor airflow rate for ventilation. To save energy, the airflow rate should be kept as low as possible when indoor climate is within accepted values.
The following measures can reduce energy consumption for supply air heating:

- Displacement ventilation utilizing body plume for transport of fresh air to the breathing zone.
- Demand controlled ventilation in rooms – preferably with sensing of CO_2 and temperature for upper zone in room.
- BEMS for CO_2- and temperature control of upper zone position and for control of fans according to ventilation demand.
- Heat recovery from exhaust air.

Negative facts about most mechanically ventilated buildings

Common facts for mechanically ventilated buildings less than 10 years old:

- The ventilation system has a pressure loss of at least 10^3 Pa through the supply air system and through the extract air system.
- A constant and high airflow rate for ventilation during hours of occupancy as most systems have CAV.
- High consumption of electricity for fans.
- About 1-2 K increase in supply air temperature through the supply air system -> less possibility to utilise “free cooling”.
- Most ductworks are not easily inspected and cleaned.
- Noise from central air handling unit and from air inlet diffusers.

Negative facts about pure naturally ventilated buildings

Experience from pure naturally ventilated buildings:

- Noise and dust from outside is a problem when window opening is used in city-like environments.
- Draught from supply openings are common when there is no preheating of outside air in cold environments.
- Because occupants are adapting to stuffy air, the air quality is often really bad before someone open for ventilation in manually operated systems.
- Manual ventilation control by occupants may cause windows to stay open, and the result is waste of heating energy.
- Unwanted cross ventilation may occur in buildings with windows on two sides and with open doors.
- Unwanted and inefficient ventilation may occur when stack effect and wind forces are combined with opening of windows and doors in multi-floor buildings.

The use of natural opportunities for climatisation

- Except for hot and humid climates it is possible to use nocturnal cooling of a thermally heavy building or supply air culvert system in warm periods.
- Evaporative cooling can be applied to cool ventilation air in hot and dry climates.
- Wind and buoyancy can be used at times to provide ventilation airflows in buildings. Regularity can be found by monitoring wind and outdoor temperature.

The outdoor temperature graph on Figure 1 shows the potential for buoyancy driven ventilation while Figure 2 shows the potential for wind driven ventilation. It is interesting that low outdoor temperatures, with a good potential for using the stack effect, occurs at low winds. Thus, for the period shown it looks like natural driving forces are available to a certain level for most of the time.

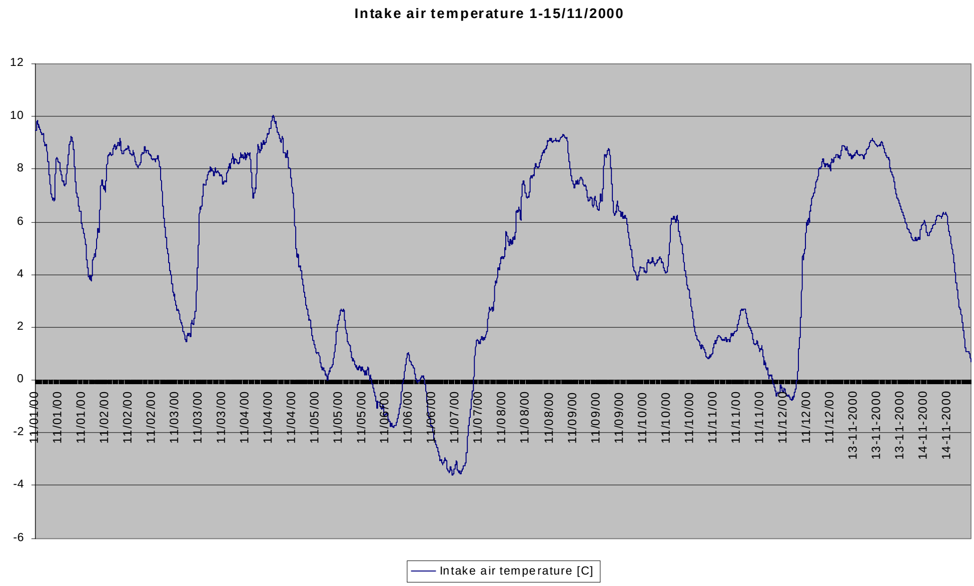

Figure 1: Outdoor air temperature in Grong, Norway.

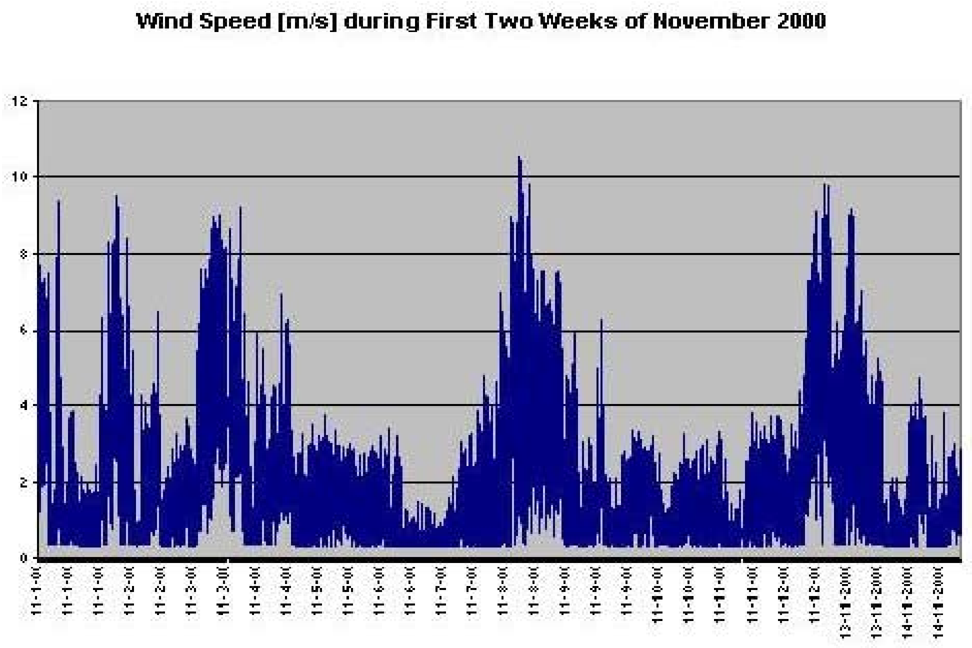

Figure 2: Wind speed measured 10m above ground in Grong, Norway.

Conclusions

Is the solution natural-, hybrid or mechanical ventilation?

From the previous we can conclude:

- Target values for thermal comfort must be considered together with outdoor climate to evaluate possibilities for nocturnal cooling.
- The general guidelines for ventilation should be followed in any case.
- The negative facts about mechanical ventilation should be avoided.
- The negative facts about natural ventilation should be avoided.
- A ventilation system that can be easily inspected and maintained for the life-time of the building is preferable.
- A long-lasting building and system with low first cost and low running costs is preferable
- Site-related parameters may be of paramount importance.

The different factors must be weighted because all requirements can evidently not be fulfilled for one building. The weight given to the different factors may even come out different in different countries. Anyway, the matter must be analysed and discussed in order to give architects and other consultants a better basis for their decisions.

However, it is most likely that most future ventilation systems:

- have low pressure drop in the airways;
- be demand controlled;
- utilise natural driving forces when available.

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ANALYSIS METHODS AND TOOLS FOR HYBRID VENTILATION SYSTEMS

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Abstract

This paper presents an overview of the main available analysis methods and tools that are applicable to hybrid ventilation. It also includes a review of some new development, key application issues, problems encountered and recommendations.

What is it – A new design philosophy

As a new design philosophy, hybrid ventilation and cooling technologies combine the advantages of both existing HVAC systems and natural ventilation. It has the potential to reduce energy consumption, improve the satisfaction level of the occupants' comfort and minimise the sick building syndromes (Arnold, 1998). Analysis methods and tools are to assist, evaluate and, where possible, optimise design of natural and hybrid ventilation of buildings. Analysis methods are defined as the physical descriptions and computational algorithms for building ventilation, while analysis tools are defined as the computer software packages or design tools that engineers and architects can use.

An ideal analysis method for hybrid systems should integrate the following three items:

- Modelling of the natural ventilation mode.
- Modelling of the mechanical ventilation mode.
- Modelling of the control strategy.

Such tools will be able to answer such questions as if and when the natural driving forces fail to fulfil the ventilation demands, and if and when mechanical ventilation is more energy efficient than natural ventilation.
Analysis methods can be used to carry out one or more of the following tasks:

- To size ventilation systems for both ventilation modes.
- To evaluate the system performance, e.g. indoor air quality and thermal comfort parameters, e.g. evaluate flow rates for the whole building and/or through each opening and predict airflow patterns in the whole building, and in each room.
- To select control and ventilation strategies for the optimum energy efficiency.

Why different? – Two comparisons

Key differences between natural and mechanical ventilation

In terms of analysis methods, the key difference between natural and mechanical ventilation lies in the fact that neither velocity nor flow direction at the ventilation openings are predetermined in the former system. Natural forces drive natural ventilation. The stack pressure is determined by the temperature difference between the indoor and outdoor air, which is in turn affected by ventilation flow rates. The wind pressure is strongly affected by the microclimate around the buildings, which is again affected by landforms, vegetation and other surrounding buildings.
It is well known that ventilation flows driven by natural forces are more difficult to predict

than those driven by fans. Wind flows around buildings are very complex and unsteady. Some ventilation openings are difficult to quantify. One example of such difficulties was illustrated by an earlier attempt by Smith (1951) to simulate wind-driven flows in a wind tunnel (see Figure 1). Different flow patterns were obtained when there were very small changes in the inlet details.

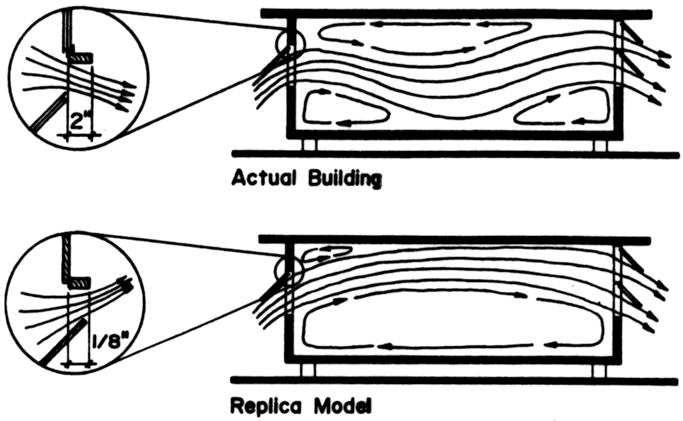

Figure 1: Different flow patterns obtained by wind tunnel tests when there were small changes in the inlet details.
Note that the inner edge of the window was projected slightly inside the wall compared to the actual building (Smith, 1951).

Key differences between hybrid systems and conventional systems

The control strategy is a key factor in hybrid ventilation and it is what makes it different from other ventilation systems. There is a need to model the control strategies and its implementation in analysis tools. Multi-zone airflow/thermal coupled methods offer the most attractive approach. Control strategies can be incorporated into such an integrated program. Indeed, a commercial program, Tas-Flows, has already been available for hybrid ventilation analysis (EDSL, 1996). CSIRO's CHEMIX program has also been used to model a hybrid ventilation design (Li and Delsante, 1997). It appears that in both Tas-Flows and CHEMIX, only very simple control strategies are available. The opening area control is simply influenced by a range of internal variables and/or outdoor climate parameters.

How to analyse – Three mostly used methods

Two basic sets of fluid dynamics equations are often used to model a ventilation process:

- The Bernoulli's equation – The effects of wind flows around buildings are generally included by using a wind pressure coefficient concept. The airflow in the room is assumed to be almost stagnant. This equation is mainly used by the simple analytical methods and the multi-zone methods.
- The Navier–Stokes equations – The Reynolds-averaged or space-filtered equations are generally used to model turbulent flows. These equations are solved numerically. This is computational fluid dynamics.

Simple analytical and empirical methods

They are generally applied to simple geometry buildings, e.g. single-sided ventilation, including both wind-driven and stack-driven flows (CIBSE, 1997) and one-zone buildings with two openings, including wind-driven, stack-driven and combined-driven flows (CIBSE, 1988; BSI, 1991), when the indoor air temperature is known.

Multi-zone methods

A building is represented by a number of zones. Zones are interconnected by flow paths, such as cracks, windows, doors and shafts, to form a network. The network methods can predict overall ventilation flow rates for the entire building and individual flow rates through openings. The network methods can consider the effects of outdoor climate, location and size of openings, stack ventilation and mechanical ventilation. However, they cannot predict detailed flow patterns in each zone of the building. Their compatibility with most zonal-based thermal modelling programs is the most significant feature in terms of natural ventilation design.

Computational fluid dynamics methods

With CFD techniques, the geometrical domain is subdivided into a large number of small cells over which the equations of conservation of mass, energy and momentum are discretised and solved. CFD methods are particularly suitable for air movement analysis in and around buildings, and they allow the airflow patterns and contaminant distribution inside a ventilated space to be analysed in detail. Many CFD codes use unstructured grids and can handle very complex geometry's. CFD simulations are more time-consuming than a multi-zone approach. For whole-building performance modelling of hybrid ventilation during its yearly operation, a full integration of CFD methods and a realistic thermal model is not only beyond most computer capacity, but may also be unnecessary. There are also other theoretical methods such as statistical methods, neural network methods and so on.

What ANNEX 35 has done – Four new ideas

You may have more than one stable solution

Li and Delsante (2001) recently found that unlike mechanical ventilation, natural ventilation is a non-linear dynamical process and the solution that a numerical model gives might depend on initial conditions. For a simple two-zone opening building with stack effect and opposing winds, there are two stable solutions when using the simple Bernoulli's equation, which is almost universally used in multi-zone methods, see Figure 2 and Figure 3. This theoretical solution has been experimentally confirmed using a water bath method. Even such a simple system has multiple solutions, what will happen to more complex systems such as those in realistic buildings?

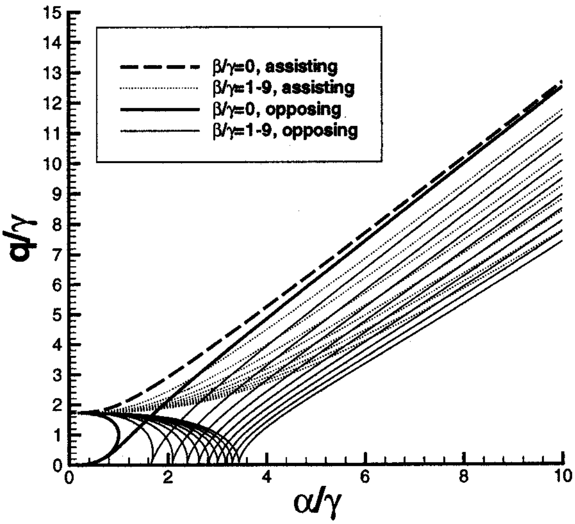

Figure 2: *Ventilation flow rates for combined forces – both opposing and assisting winds. Where q is the ventilation flow rate, α, β and γ are the thermal buoyancy-, envelope heat loss- and wind- air change parameters, respectively. For a certain range of α/γ, there are two stable solutions and one unstable solution.*

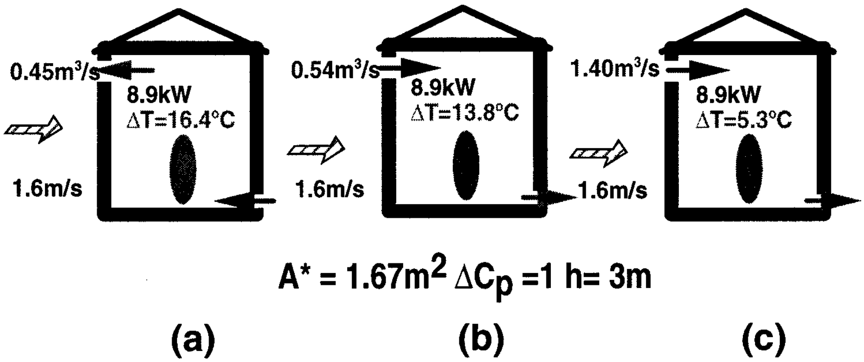

Figure 3: *Three flow states in a building with identical ventilation parameters. The downward flow of 0.54 m^3/s is not stable, as shown by Li and Delsante (2000).*

How to treat uncertain input data

The three deterministic models that we discussed do not consider the fluctuations of the input parameters. Stochastic models have been considered by Annex 35 experts, see Brohus et al (1999). In stochastic methods, the parameter values such as wind speed and wind direction are considered to have a certain probability. The values are defined as random processes. This method is based on the stochastic differential equation, which provides the statistical characteristics of the variables of interest.

How large can you go?

In modelling wind-driven natural ventilation, wind pressure coefficients are specified at all openings. Most of these wind pressure coefficients were obtained through wind tunnel measurement of *sealed* building models. Are these measured C_p values applicable to buildings with openings, e.g. open windows? The interaction of flow around buildings and flow in buildings was studied in some detail by Vickery and Karakatsanis (1987) in a wind tunnel. They concluded that if the wind is not strongly inclined to the vented faces, for wall porosity's less than 23% on two opposite cases, the internal flow rates could be predicted with about 10% accuracy from the external pressure distribution on a solid model. Further detailed studies are currently under way in Annex 35 (Sandberg, 2000).

Thermal and airflow are coupled

Thermal and airflow models need to be coupled, due to the fundamental coupling effect of air temperature and stack-driven natural ventilation. Also, most existing thermal models and most existing multi-zone ventilation models assume that the indoor air temperature is uniform. The assumption of uniform air temperature distribution is not valid in most buoyancy-driven natural ventilation and displacement mechanical ventilation situations. We found that the effect of thermal stratification on airflow can be very significant. Ignoring it can lead to significant under-estimation of the neutral levels in the building. The linear vertical air temperature profile is suggested for simulating thermal stratification effect in natural ventilation, see Li et al (1999).

Application to design – Five significant issues

Choose the right methods/tools

At the conceptual and preliminary design stages, the available input data can be very limited. Architects and engineers are to decide on a basic ventilation strategy and possibly a quick sizing of the ventilation system. Thus, quick and easy methods are preferred. But the detailed design stage requires more reliable output from the design tools, so that different design options can be evaluated and the design parameters can be optimised.

At the conceptual and preliminary stages, one might only be interested in the system performance under a set of design weather conditions, but the detailed design stage might need to run the software for a yearly weather data set. At the same time, the users of the analysis tools (e.g. architects) might not be experienced in physical and mathematical modelling at the conceptual stage. The analysis tools need to be robust and easy to use. At the detailed design stage, more sophisticated design tools can be used.

Thus, analytical and simple empirical methods are very useful in the conceptual design and preliminary stages, while multi-zone and CFD methods are applicable to the detailed design stage. However, as more friendly graphical user interfaces are developed, complex analysis methods may be used at the concept development stage, if the input data is available or default values are used.

Find the right input data

For most simple analytical methods and all multi-zone methods, there are two coefficients that are difficult to provide:

- Component flow characteristics and discharge coefficients for large openings, which are a function of not only the opening geometry, but also the airflow conditions. Etheridge and Sandberg (1997) provided a good summary of various empirical discharge coefficient relationships as a function of temperature and opening geometry. The treatment of various openings in analysis methods needs to be based on the physics of the flows through the openings, such as solar chimneys.
- Wind pressure coefficients around buildings. Typical data is given in a tabular form in the literature (see for example Liddament (1986)). Parameter studies of the local pressure coefficients on a rectangular prism-shaped model are available from Akins and Cermak (1976) and Hussein and Lee (1980). A technique for predicting wind pressure coefficients which takes into account the effects of building form and surrounding shielding is given in Knoll *et al.* (1995). Wind tunnel tests and CFD methods can also be used to provide pressure coefficients if possible.

Translate the wind profile from airport to local site

Climate data is crucial in ventilation analysis, in particular in natural ventilation mode analysis. Translation of meteorological data into ventilation input data is not easy, considering the complex local ambient effects such as canyons. This is particularly true for wind speeds. If needed, analysis or measurement of local wind profiles might become necessary.

How can you be confident with your prediction

There have been significant efforts in recent years to evaluate both multi-zone models and CFD models, but no evaluation results have been reported so far for hybrid ventilation. For example, in the last 20 years there has been much work done on validating or verifying different CFD methods and different turbulence models for building airflow, but mainly when the inflow and outflow velocities are known prior to simulation, i.e. mechanical ventilation. There is a need to establish a set of benchmark solutions or problems for the evaluation of analysis methods. For example, a new analytical solution has been developed for a stack-driven natural ventilation system with two openings and a supply fan, which can be used for evaluating hybrid ventilation analysis, see Figure 4 and Leung and Li (2001).

Don't stop here, there are more issues to consider

There are many other design parameters, such as noise, outdoor air pollution, fire safety, indoor security, costs, energy and so on. The discussed analysis methods and tools are just a part of a big picture of hybrid ventilation design. An integrated design approach is needed in hybrid ventilation design with a team work between engineers, architects, developers, contractors and building owners/occupants.

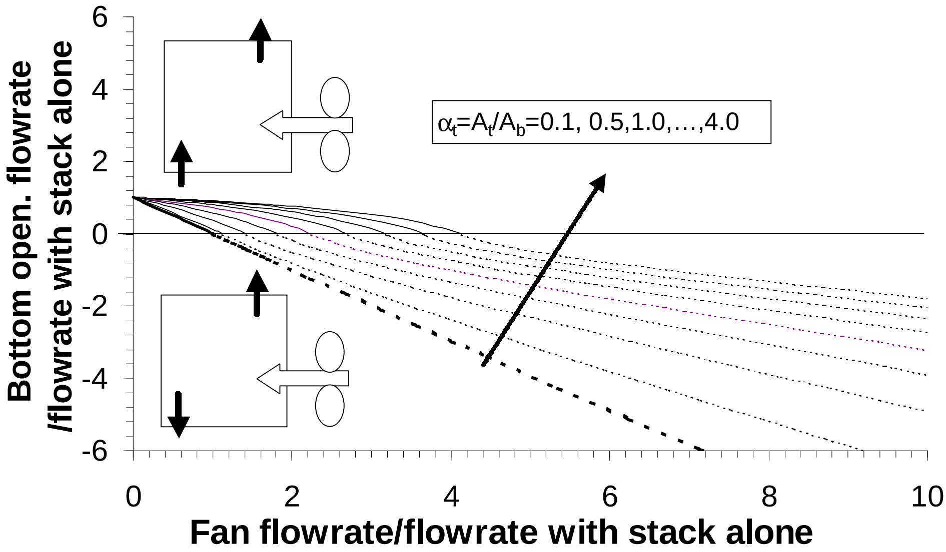

Figure 4: Flow rate through the bottom opening in a two-opening mixed-mode building with stack driven ventilation and a supply fan.

Conclusions

A wide range of analysis methods, ranging from simple to very sophisticated, are available for designing and evaluating hybrid ventilation in buildings. Each method has its special place in ventilation analysis and design, and there are no universal tools. Multi-zone methods offer opportunities for whole-building performance modelling of hybrid ventilation. CFD is capable of predicting detailed flows in each room/zone of the building, or in part of a complex building. Lastly, these analysis methods and tools are required to be applied in an integrated design procedure for hybrid ventilation and the analysis methods and tools are just one of the variables in the whole equation.

Acknowledgement

This paper draws heavily from the Chapter 5 of the State-of-the-Review of hybrid ventilation (Edited by A. Delsante and T. A. Vik), completed by a team of Annex 35 experts. The author would like to thank his Annex 35 colleagues for many useful discussions and contributions.

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ASSESSMENT OF ENERGY PERFORMANCE TARGETS IN STANDARDS AND REGULATIONS

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Abstract

This paper describes the assessment of innovative ventilation systems in standards and regulations. Intelligent (hybrid) ventilation systems are not rewarded in standards and regulation, whereas these systems have a large potential for energy savings. An energy performance assessment method allows taking into account the potential benefits of hybrid ventilation. Guidelines are proposed for the evaluation of hybrid ventilation systems.

Intelligent and hybrid ventilation systems

The search for improvement of the indoor air quality and the reduction of the energy consumption leads to the development of innovative ventilation systems. In figure 1 an overview is given of the actual developments in ventilation systems. The developments take place in natural ventilation systems as well as in mechanical ventilation systems. In the field of natural ventilation systems there is a trend towards preheating of air with passive sources, constant-flow grills and heat recovery with low-pressure heat recovery and heat pumps. In the field of mechanical ventilation the developments tend towards high efficient heat recovery low-pressure ducts and reduction of fan energy. In both fields there is a need for better control.

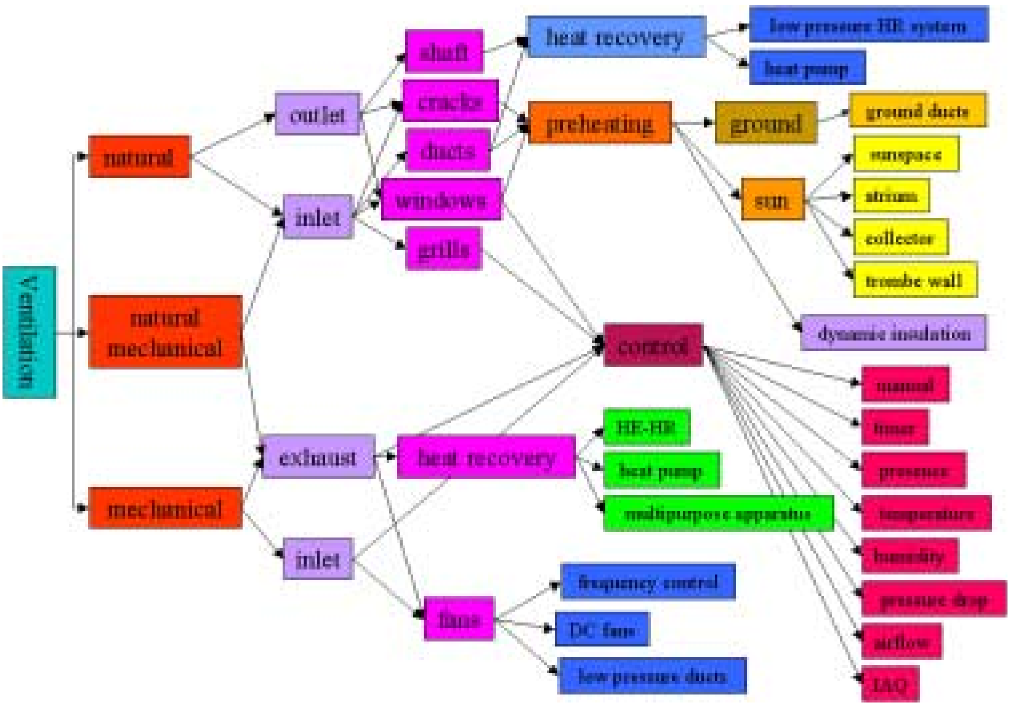

Figure 1: Trends in ventilation systems.

The trends in the improvement of ventilation systems can be subdivided in:

- Possibilities for the reduction of air flows (based on controls).
- Developments in the field of heat recovery.
- Developments in the field of preheating of supply air by natural heat sources.
- Reduction of support energy.

A further improvement of ventilation systems requires the access to both ventilation modes in one system depending on the actual outdoor conditions and the actual and required indoor conditions. This has to be controlled by an intelligent control algorithm that uses the best suitable ventilation mode, with respect to the indoor air quality, thermal comfort and energy consumption. These ventilation systems, which are capable of switching between two modes in an intelligent way, are called hybrid ventilation systems.

Where indoor air quality meets energy consumption

Traditionally there is a focus on maintaining a fixed ventilation rate where the optimum is approached between the indoor air quality and the energy consumption as given in figure 2. Too low flow rates lead to insufficient IAQ, whereas too high flow rates lead to increasing energy demands.

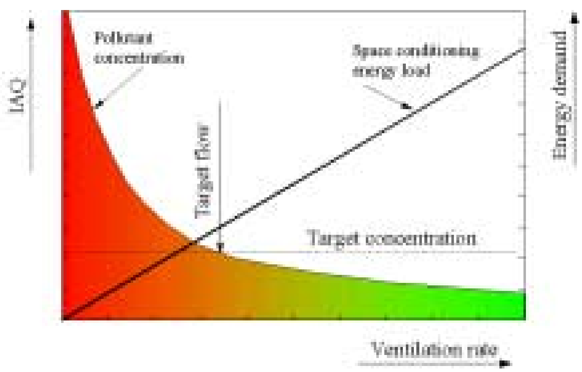

Figure 2: Traditional approach IAQ versus energy.

As hybrid ventilation systems aim to optimise the balance between energy consumption and indoor air quality depending on the outdoor condition, the traditional approach has to be extended as presented in figure 3. In this figure a third axis is adjusted with the outdoor temperature. The energy load for space conditioning is dependent of the outdoor temperature. Projecting the area with a too high energy demand for heating or a too high energy demand for cooling (in case of active cooling), results in the area with the best possible IAQ, related to the energy consumption.

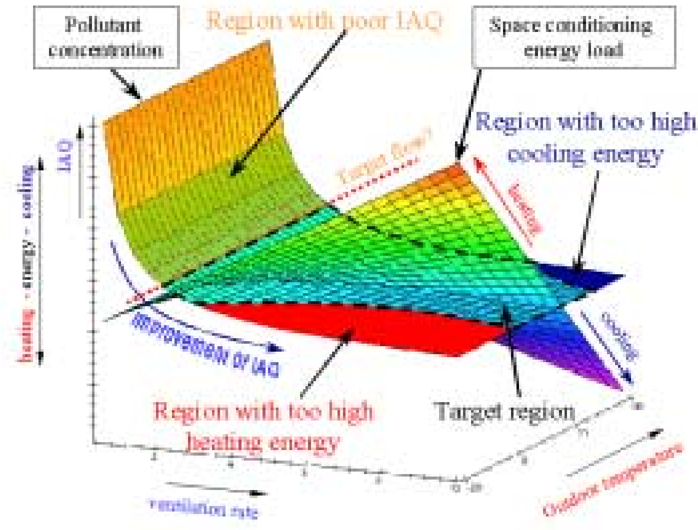

Figure 3: New approach IAQ versus energy.

The challenges for hybrid ventilation systems are given in this area. Where natural ventilation systems perform insufficient in times of lack of driving forces and mechanical ventilation systems only perform at one constant level, hybrid ventilation systems adapt to the actual occurring circumstances. These qualities can lead to a significant reduction of the energy consumption for heating and cooling and for fans, and in addition when there is no energy penalty, a further improvement of the IAQ can be achieved. However, these benefits of hybrid ventilation systems are not awarded in the building regulations.

Ventilation systems in standards and regulations

Indoor air quality

The ventilation standards focus on maintaining a required ventilation rate depending on an assumed occupancy of the building. The occupants in a building make two requirements of the air in a room. First, the health risk of the breathing air should be negligible. Secondly, the air should be perceived fresh and pleasant. Besides that, a too high air humidity can lead to mould problems, which has an indirect effect on human health but also can lead to damage on the materials in the building construction.

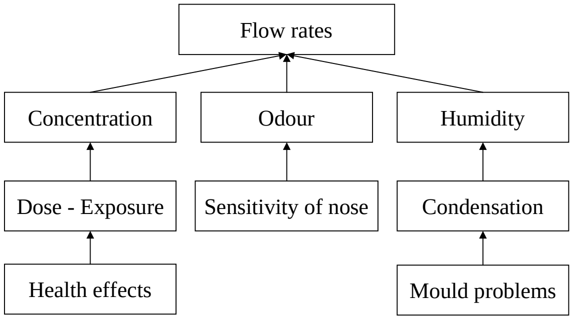

Figure 4: Relation between ventilation and indoor air quality.

In practice comfort requirements usually determine the required ventilation rate in non-residential buildings. The desired ventilation rate depends on the desired indoor air quality, the indoor pollution sources, the outdoor air quality and the ventilation effectiveness. In most non-residential buildings the production of human bioefflents is responsible for the experienced freshness of air. The indoor concentration of CO_2 has been applied as a good indicator of the concentration of the bioefflents. Monitoring the concentration of CO_2 has proven to be an effective way to control the supply of outdoor air.

Energy consumption

The introduction of the energy performance regulations as part of the Building Decree in The Netherlands has generated quite a number of developments in the field of energy savings. Examples of this are high efficient heat recovery (HE), the introduction of thermal solar systems and low temperature heating systems, a substantial improvement of the U-value of glazing, heat pumps, etc. The energy performance regulations have proven to be a booster for new developments.

However, the level of most standards and regulations for energy consumption is rather basic. Most standards hardly make a distinction between natural and mechanical ventilation. And if so, most of the time it is done by rough imposed coefficients. The Dutch standards NEN 2916 “Energy performance of non-residential buildings” and NEN 5128 “Energy performance of dwellings and residential buildings” can be counted to one of the most refined standards. But, they only take into account a fixed flow rate, heat recovery, fixed values for a time fraction of operation and fan energy.

As the energy consumption of ventilation forms a substantial part of the total energy consumption, there is a large potential for energy savings. All sorts of control (IAQ, presence detection, flow rate control), occupancy aspects (internal heat, times of usage), and environmental aspects (wind situation) are however not counted. One of the reasons is, as described in the preface of the Dutch standard, the intended sake of unequivocalness and the lack of testability. On the other hand it is hardly possible for standards and regulations to keep pace with the development of innovative systems.

To avoid the regulations to limit the development of new technologies, the equivalent principle has been introduced. This equivalence principle offers the opportunity to deviate from the given regulations. In that case one has to test the supposed solution against the intention of the regulations.

Different approach leads to different results

The Dutch school building "Waterland" at Leidschenveen is one of the pilot projects in the IEA Annex 35 research program and is equipped with a hybrid ventilation system. The requirements of the property developer for this building were to build a school which has a 15% lower energy consumption then required in the Building Decree. The building has a gross floor area of approx. 5000 m^2 over 1-2 floors and is divided in three schools and a day nursery. Figure 5 gives an artist impression of the building.

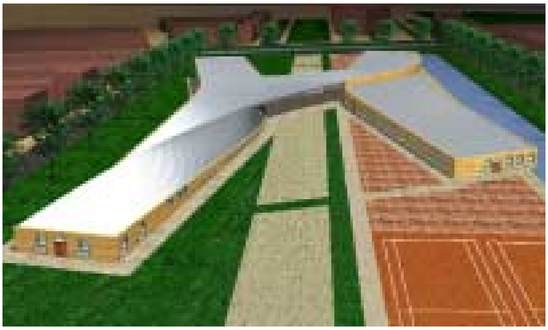

Figure 5: School building Waterland at Leidschenveen.

As mentioned, a calculation procedure for the energy performance of a hybrid ventilation system is not described in the standard. Therefore the performance of the system is compared to a system with a natural air supply and a mechanical exhaust. First of all an EPC calculation was carried out for the school building, equipped with a mechanical exhaust. The most important measures taken to fulfil the EPC requirements are given in table 1. With these measures the calculated EP** of 0,98 meets the level as given in the Building Decree.

Measure	Calculation
U_{floor} [W/m²K]	0,31
U_{roof} [W/m²K]	0,37
U_{facade} [W/m²K]	0,37
U_{window}[W/m²K]	1,8
Shading	No
Infiltration $q_{v;10}$ [dm³/s]	200 per 3000 m³
Ventilation	Natural inlet / mechanical exhaust
Fan [kW]	P_{eff}=8,0
Heating production	Gas fired HE-boiler
HVAC system	Class I: Mech. ventilation, radiators
DHW production	Gas fired HE-boiler
Lighting [W/m²]	12 HF lighting + local switch
EP* [-] Qperf;tot/Qperf;adm	**0,98**

Table 1: Energy saving measures to reach the imposed EP.

* The Building Decree states that for buildings with more than one building type the calculated characteristic energy consumption should be equal or less than the admissible characteristic energy consumption. The author has called this EP*.

To compare the performance of the hybrid ventilation system with a mechanical ventilation system, simulations have been carried out with the object oriented simulation model 20-sim. In this model a multi-zone ventilation model has been coupled to a thermal model. The results of a simulation for the hybrid ventilation system have been compared to those of the mechanical exhaust system. The proportional alteration of the heating energy and running hours of the fans have been applied to the known results of the energy performance calculation of a mechanical exhaust system. Comparing the simulation results of a mechanical exhaust system with a hybrid ventilation system, shows that the heating energy consumption reduce with 24,3% and the running hours of the fans reduces with 77,9%. Table 2 shows the calculation results. The result is an EP^* of 0,80. This is a reduction of 18% compared to a mechanical exhaust system.

Consumption	**Prim. energy consumption [MJ]**		
	Mechvent	**Alteration [%]**	**Hybvent**
Heating	2441597	-24.3	1848289
Fans	228000	-77.9	50388
Lighting	1229738		1229738
Pumps	67987		67987
DHW	157397		157397
Qpres;total	4124719		3353799
Qpres;adm	4193046		4193046
EP^* [-]	**0.98**		**0.80**

Table 2: Calculation of equivalent EP^* coefficient.

The impact of varying boundary conditions

The way an equivalent approach has to be carried out is not prescribed and can lead to quite different results. In the viewpoint of the author reasonable starting points have been chosen for the calculation, but a watertight analysis is hard to deliver yet. Depending on the way the equivalent solution is approached, or which interests have to be served, various results can be achieved. To show what this means, a sensitivity analysis has been carried out for several parameters. Reasonable parameters have been chosen which can be defended and which are found in reliable literature.

The following aspects have been examined:

- Pressure distribution.
- Occupancy pattern.
- CO_2 production.
- Acceptable IAQ (CO_2).
- Night temperature control.
- Internal heat production.

For each of the starting points simulations have been set up. The variations have been carried out, by changing one parameter at a time, with regard to the medium variant. In table 3 the impact of the various starting points on the EP^*-value are indicated.

Parameter	EP*[-]	Variant maximum	EP*[-]	Variant medium	EP*[-]	Variant minimum
Wind pressure	0.79	sheltered	0.80	semi-sheltered	0,81	exposed
Occupancy	0.75	low	0.80	medium	0,81	high
CO2 max	0.78	1500 ppm	0.80	1300 ppm	0,83	1000 ppm
CO2 production	0.78	15 l/h	0.80	18 l/h	0,83	23 l/h
Nighttemp.setback	0.81	3 °C	0.80	6 °C	0,80	9 °C
Internal heat	0.81	36 W/m^2	0.80	41 W/m^2	0,80	51 W/m^2

Table 3: Results of EP dependent on different starting points.*

Based on the calculation results the various starting points have been combined to a minimum (decent) and maximum (evil) approach. For both approaches simulations have been carried out. The results are given in figure 6a and 6b.

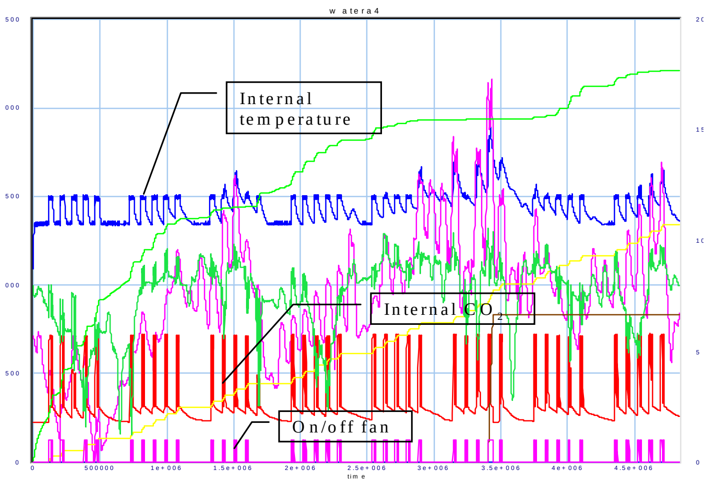

Figure 6a: Simulation results of decent approach.

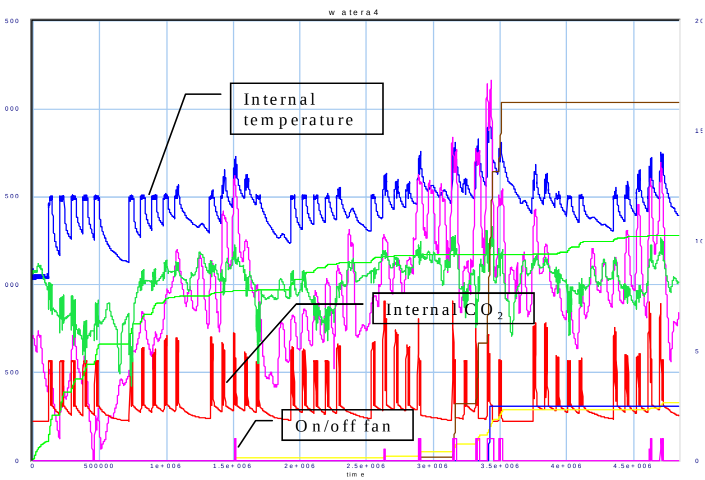

Figure 6b: Simulation results of evil approach.

The simulation results for the decent approach tend to the performance of a mechanical ventilation system. The results of the evil approach point to a natural ventilation system.

The results of these extremes have been compared to the performance of a mechanical ventilation system, with the same starting points. Figure 7 shows the results of the comparison.

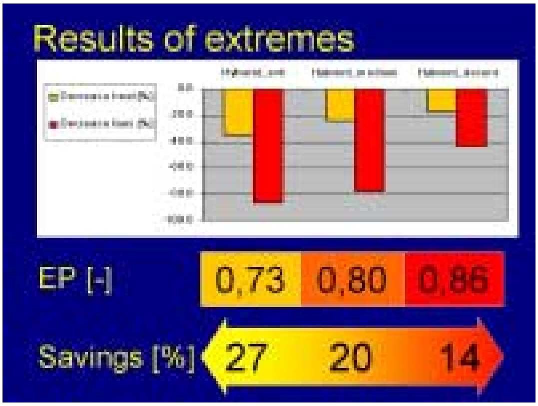

Figure 7: Final results of extreme variants.

Depending on the approach, the reduction of the heating energy varies between 20 to 45%. The reduction of the fan energy varies between 37 to 90%. This leads to an EP* of 0,67 to 0,85, or a calculated total energy saving between 15 to 33%.

It is clear that the various approaches can lead to discussion with the authorities who judge the equivalent solution or with the customer who has to pay extra money for the calculations. To get a more common agreement on what reasonable starting points are, guidelines have been developed for the approach of innovative ventilation systems in general and hybrid systems in particular.

Guidelines for an equivalent approach

In workgroup A2 of IEA Annex 35 a source book is being developed to give recommendations and guidelines for the assessment of innovative ventilation systems in the framework of standards and regulations.

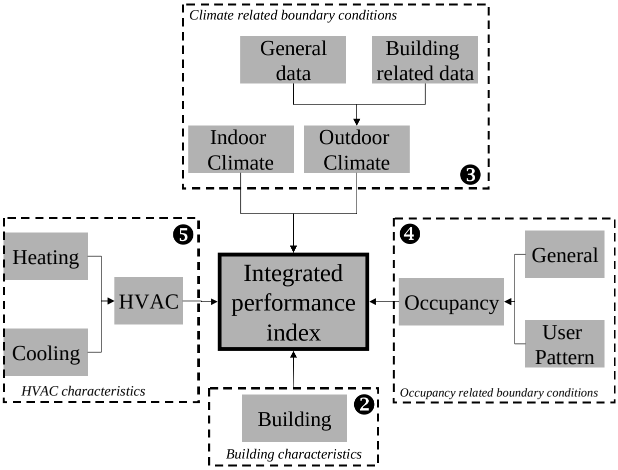

Figure 8: Relevant issues of concern.

As it is not possible to determine the performances of innovative systems within the standard procedures it is necessary to make use of the principle of equivalence.

In the source book guidelines will be given for:

- Assumptions on the outdoor climate:
  - Outdoor temperature;
  - Wind speed and direction global and local;
  - Wind pressure coefficients around buildings.
- Assumptions on the indoor climate:
  - Occupancy profile;
  - Humidity sources;
  - Tobacco smoke;
  - Emission of building materials;
  - Internal heat gains;
  - Internal temperature;
  - Control strategies of ventilation system;
  - Window use.
- Assumptions on the building characteristics:
  - Building function;
  - Building layout;
  - Thermal insulation performances and solar gains;
  - Building air tightness and leakage distribution.
- Assumptions on the HVAC systems.
- Assumptions on acceptable indoor climate:
  - Simple maximum value;
  - Limit values for concentration or dose approach;
  - Inter-relation between various pollution strategies.
- Other issues of potential concern:
  - Reliability;
  - Maintenance;
  - Handling of outdoor pollution.
- Model choice.
- Minimum set of parameters to be considered.

The intention is to give certain classifications which has to be kept, dependent on the necessary level of accuracy. The performance of a full mechanical ventilation system with high efficient heat recovery needs a less refined approach than a hybrid ventilation system with an advanced control system. The work is still in progress, but some of the preliminary results are shown.

Table 4 gives of a classification of the climate data sets that can be used. In table 5 the classification for occupancy related assumptions is given.

Class	Description
	Possibility of local correction?
CL1x	One unique climate for the whole region under consideration, no possibility for local parameters
CL2x	Possibility for taking local parameters into account – predefined values
CL3x	Possibility for taking local parameters into account – specific procedure
	Time related aspects
CLy1	One typical day
CLy2	Seasonal approach
CLy3	Simplified (condensed) reference year
CLy4	Full annual data (daily, hourly)

Table 4: Classification of climate data
Example:
CL13: Unique climate for the whole region whereby use of a condensed reference year. This approach is used in The Netherlands whereby the condensed year consists of 3 days for each season with hourly values for wind and temperature.

Class	Description
Occupancy profile	
	No information on occupancy
	Typical average occupancy profile
	Time-variable occupancy, occupancy never above nominal occupancy
	Time-variable occupancy, occupancy sometimes above nominal occupancy
Spatial dimension	
	Average for whole building or each room same occupancy profile
	Different profiles for various rooms
Predictability	
	1 single pre-defined occupancy profile
	Multiple pre-defined occupancy profiles
	Statistical approach (e.g. Monte Carlo)

Table 5: Occupancy related assumptions.

Conclusions

The search for improvement of the indoor air quality and the reduction of the energy consumption leads to the development of innovative ventilation systems. These improvements however are not covered and rewarded in the European standards and regulations. As the implementation of innovative systems in the standards is hardly achievable, the principle of equivalence is a suitable aid. There are no prescribed regulations how to judge the principle of equivalence. This can lead to quite various results. A more uniform and well-founded basic guidelines and recommendations are being developed by workgroup A2 of IEA Annex 35.

Acknowledgement

This paper has partly been composed from the work of IEA Annex 35 workgroup A2. The author would like to thank his Annex 35 colleagues for many useful discussions and contributions.

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MODEL QUALITY CONTROL AND COMMISSIONING FOR VENTILATION SYSTEMS - THE DUTCH APPROACH

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Abstract

The primary objective of the process of realisation of a climate installation (also including hybrid ventilation systems) is to build an installation that meets very well specified Terms of Reference with respect to performances on indoor climate, energy consumption and costs. To realise this precise defined design guidelines will have to be followed and tests will have to be carried out on several moments during the process. Also communication must be defined. In The Netherlands the Model Quality Control Climate Installations (MQC) system is introduced. MQC makes it possible to obtain a clear-cut view of a climate installation during the total process of realisation, from programme phase until the operational phase. It becomes clear which requirements will have to be met, which design guidelines, communication and tests will have to be carried out and which tools can be used for this.

Introduction

There is a growing attention for controlling the overall quality of the building process, including building services. Especially controlling quality of ventilation systems is of concern because there is a strong relation between the realised quality, (i.e. according the specifications and terms of reference), and energy use as well as indoor environment (IAQ, thermal comfort, noise). Commissioning is a powerful instrument to realise this quality. In this perspective it is necessary that commissioning is embedded in a total structure for quality control of the process instead of (only) components, from programme phase up to and including the operation phase (i.e. until the end of the life time of the building).
A structure for this overall quality control is the Model Quality Control Climate Installations (MQC). It is also suitable for process certification. Its intention is to control the total production process including specifications, design, construction, hand-over and operation. It focuses on avoiding failures on all strategic aspects and moments in this process. MQC clearly has another status then ISO-certification for company-related quality control systems: MQC controls the quality assurance between all partners involved in the process. MQC is totally focused on projects and its processes, not focusing on specific company management structures but purely on the specific properties of a project. In this way MQC is in fact nothing more then a logical way of recording all necessary aspects, action and responsibilities in the sequential phases of a (production) process. It is applicable for every kind of production process, like the construction and operation of buildings, building services including ventilation systems, industrial processes etc. In fact this system has been originally developed and applied in the off-shore industries.
In The Netherlands a general model is developed for building services which resulted until now in two applications for heating systems (ISSO publication 50) and for (domestic) ventilation (ISSO publication 61).

Quality control for ventilation systems

The MQC is an instrument for controlling the total process of making building services. It contains all operational techniques and activities, necessary to realise a defined level of quality. The quality level has to be precisely formulated.
In this framework “Quality” means that the delivered performance matches the required and precisely formulated requirements and expectations of the principal, including time planning, budgets as all technical aspects.
MQC is focussed on avoiding failings in all the phases of the process, starting with the programme phase up to and including the operational phase.
In order to deliver a good final product the activities of all individual building partners must be geared to one another. In all the phases of the process several activities will be carried out (or not!) that have an impact on the quality of the final product. For example, a principal is perhaps not able to formulate his requirements and expectations in the program phase. This leads to the risk that technical ideas are developed in the design phase and elaborated in the elaboration phase that will not be financial feasible. Another risk is the development of technical ideas in the design phase that have a certain level of technical complexity. If the required skills of installers are not well defined there is a major risk of failures during the execution and the operation of the installation.

It will be clear that MQC is not only for consultants and installers. All partners in the building process have to deal with the MQC and will have to confirm to it. Also the principle must be aware of the fact that his responsibility reaches further then only the financial aspects. He has an important role during the program phase to formulate functional specifications, that can be “translated” by his consultants in a technical design and specifications.

MQC structure

Model Quality Control is a general model that can be applied for all kinds of processes (building and building services, industrial etc.). Regarding HVAC systems it is possible to elaborate a MQC system for the total ventilation system or for separate elements (i.e.: heating, cooling, ventilation). In The Netherlands the MQC structure is elaborated for heating systems and domestic ventilation systems.

The most important characteristic for MQC for ventilation systems however is a structure that follows all the process phases. This enables to build in a number of strategic decision moments in the (building) process and to assess if a ventilation system meets the targets and requirements, as defined in the program phase. As the total quality is determined by several aspects (not only technical but also financial, organisation and communication) 10 different quality control aspects are discriminated.
This leads to a so-called quality matrix. On the horizontal axis of the matrix the phases of the process are distinguished. On the vertical axis of the matrix ten distinguished quality control aspects are listed.

Quality control aspect	Project phase				
	I programme	II design	III elaboration	IV realisation	V operation
0 general					
1 organisation					
2 communication					
3 requirements					
4 means					
5 purchase					
6 time					
7 finances					
8 realisation					
9 experience					

Process phases:

I. Programme phase:

In the programme phase an inventory takes place of requirements, demands and expectations of the ventilation system. Also all limiting boundary conditions must be listed and formulated. For the preliminary selection of the concept and type of ventilation system the main consequences are visualised.

At the end of the programme phase the principal, architect and (ventilation) consultant have enough information to make a first selection of the ventilation concept/system.

II. Design phase:

In the design phase the ventilation concept, as preliminary selected in the programme phase, is elaborated by the ventilation consultant. Communication with architect and constructor takes place to tune building technical and architectural boundary conditions with the ventilation concept and vice versa. There will feedback to the starting points of the programme phase. At the end of the design phase a final selection of the ventilation concept takes place.

III. Elaboration phase:

In the elaboration phase the ventilation concept will be elaborated to a system level and a component level. Specifications will be elaborated and materialisation takes place in this phase. This includes also detailed financial calculations.

IV. Realisation phase:

In the realisation phase the actual construction of the ventilation system takes place. This phase ends with the acceptance and hand-over of the installation. Note that during this phase, and in particularly during the acceptance, "commissioning" takes place according to the "English" definition (i.e.: testing of the installation of realisation to check if it meets the terms of reference).

V. Operation phase:

In this phase the actual operation of the building and ventilation system takes place after the acceptance and hand-over of the installation. In ASHRAE publication 1996-1 this phase is cold "post-acceptance phase". In this phase commissioning is the continued adjustment optimisation and modification of the ventilation system, including maintenance to meet and to maintain the specified requirements.

Quality Control Aspects:

0. *General*
   Description the general objective(s) of each phase including the starting points, boundary conditions and points of particular interest.
1. *Organisation*
   Description and allocation of tasks and responsibilities.
2. *Communication*
   Description and recording of the necessary information exchange between all parties involved in the process is reported including a description about the necessary consultations including which parties, when, the objective and deliverables of each consultation.
3. *Requirements*
   Inventory of internal and external requirements including a base level of legal requirements like buildings regulations, standards and others as well as recommendations, according to (higher) quality level.
4. *Means*
   Listing of all necessary calculation methods, execution protocols, assessment and evaluation tools including references to standards (like calculation, determination and measurement methods) measurement instruments and literature.
5. *Purchase*
   Description of necessary external expertise that has to be purchased.
6. *Time*
   Guarding of the object planning as well as process planning.
7. *Finances*
   Controlling and guarding of the object costs (i.e. ventilation installation) as well as the process costs (co-ordination, consulting, commissioning).
8. *Realisation*
   Reporting of the input and output of all sequencing phases.
9. *Experience*
   Evaluation of the process at the end of the phases.

From the main cells in the matrix the will be references to other cells. In these cells is stated which subjects and partial subjects are addressed. In separate specification sheets these (partial) subjects are further elaborated:

	MQC matrix				
	Project phase				
aspect	**I**	**II**	**III**	**IV**	**V**
0					
1					
2					
3		II.3			
4					
5					
6					
7					
8					
9					

Cell contents		
Subject	**Partial subject**	**Specification sheet**
II.3-1		
II.3-2		
II.3-3		

Specification sheet II.3-2	
Characteristic	**Specification**

Using MQC or making a document conform the MQC structure it is not necessary (and often not possible) to fill in all cells. But every information that is available can be "recorded and stored" in logical way in a cell, elaborated in specification sheets. Often this information is spread over two or more phases, consequently, over several specification sheets, corresponding with the distinguished phases and/or quality control aspects. It is important to analyse exactly in which phase and for what quality control aspect the information is necessary. Therefor it is important to know the meaning of each different quality control aspect.

Quality control aspect “0 - General” describes the general objective(s) of each phase. This means that also starting points, boundary conditions and points of particular interest must be described as well as the documents and contracts that have to be elaborated in the particular phase.

Quality control aspect “1 - Organisation” gives a description and allocation of all tasks and individual and collective responsibilities. Organisation structures like process certification, the appointment of “official” commissioners etc. can be described in this quality control aspect. Also activities that are necessary for (building) permits, application for grants etc. are described in this chapter.

Quality control aspect “2 - Communication” describes the necessary information exchange between all parties involved in the process is reported. This includes a description about the necessary consultations including which parties, when, the objective and deliverables of each consultation. It also can give descriptions meeting structures, schemes and frequencies. Also description of the information carriers (digital, paper etc.) can be given.

Quality control aspect “3 - Requirements” gives an inventory of internal and external requirements that have an impact on the design or the following phases. This starts with a base level of legal requirements like buildings regulations, standards and others. However, in this aspect also recommendations can be given, according to (higher) quality level. Important, especially in the programme phase, is that the consequences of legal requirements versus quality recommendations are visualised. Quality control aspect “Means” can give tools and instruments for this.

Quality control aspect “4 - Means” includes all necessary calculation methods, execution protocols, checklists, assessment and evaluation tools. It also gives references to standards (like calculation, determination and measurement methods) measurement instruments and literature. In general, often references will be used to avoid unnecessary text. For example, for thermal comfort aspects requirements are given in “3 – Requirements”; in “4 – Means” the determination and measurement methods are given. This can be just a reference to ISO 7726.

In quality control aspect “5 - Purchase” is arranged which necessary external expertise has to be purchased including a description for which subjects. For example, if a ventilation concept is selected with a certain level of complexity it can be required that consultants with a defined level of expertise have to be concerned in the design phase of the project. If balancing of a ventilation system is required in the realisation phase the organisation of this activity is described in “2 - Organisation”; the purchase of specialised balancers is described in “5 – Purchase”.

In quality control aspect “6 - Time” object planning as well as process planning is guarded.

Quality control aspect “7 - Finances” organises the control and guarding of the object costs (i.e. ventilation installation) as well as the process costs (co-ordination, consulting, commissioning).

Quality control aspect “8 - Realisation” organises the reporting of the input and output of all sequencing phases. This includes a description of which specific documents (drawings, calculations, details, instruction manuals, completion and commissioning reports etc.) must be realised at the end of a particular phase.

Quality control aspect “9 - Experiences” reports the evaluation of each phase based on the expected (technical) quality and the continuation of the process (organisation, communication). This aspect can also be used as a tool for project management and steering. For example, if it appears that communication is not passed smoothly measures can be taken to improve the communication process.

It will be clear form these descriptions that it is not possible and necessary to address all the quality control aspects. The chapters 5, and specially 6, 7 and 9 are much more related to specific projects. On the other hand it is possible to write general guidelines for quality control of ventilation systems within this MQC structure without addressing these aspects.

Dutch ISSO publication 61

The Netherlands Institute for Building Services ISSO publishes guidelines for all kinds of building services (heating, ventilation, cooling, DHW etc.). ISSO has adopted and implemented the MQC for all major publications.

Until now two publications have been published providing a framework for quality Control for the total production process:

- ISSO publication 50: Design Technical Quality Requirements and Guidelines for Heating Systems.
- ISSO publication 61: Design Technical Quality Requirements and Guidelines for Domestic Ventilation Systems.

These two publications are fully written within the MQC structure. Within these publications references are made to specific and detailed publications on partial subjects. For heating this includes a publication on Heat loss calculations (ISSO 51), Measurement and control points (ISSO 31), Emission systems (ISSO 49 - Floor and Wall heating, ISSO 66 - Radiators, ISSO 58 - Warm Air heating), hydronic schemes (ISSO 46) etc.
For ventilation references are made to ISSO 62 - Mechanical Ventilation with heat Recovery. Other reference publications will follow.

Regarding ventilation, ISSO 61 emphasises on the programme phase and design phase. Quality aspect “1 - organisation” is not elaborated yet. However, at this moment there is a study going on about the organisation of certifications of domestic ventilation systems. Once this action is completed it can be embedded in ISSO 61 under “1 – organisation”.

At this moment ISSO 61 gives information in following MQC cells:

	Project phase				
Quality control aspect	**I programme**	**II design**	**III elaboration**	**IV realisation**	**V operation**
0 general	I.0 ToR building	II.0 Boundary conditions	III.0 Boundary conditions		
1 organisation					
2 communication	I.2 Information exchange	II.2 Information exchange	III.2 Information exchange		
3 requirements	I.3 IAQ thermal comfort outdoor noise installation noise energy user aspects reliability sustainable building	II.3 quality supply air thermal comfort fire safety airing air tightness	III.3 fans energy use fans ventilation grilles ducts dampers fire dampers HRU	IV.3 installing demands	V.3 operation maintenance
4 means	I.4 air tightness classification ventilation balance openings noise reduct. facade energy occupants impact maintenance-reliability costs	II.4 capacity duct design air resistance calcul. execution types air quality grilles installation noise cross talk outdoor noise fire safety airing air tightness energy use	III.4 selection of fans selection grilles - facade - wall, ceiling selection ducts selection fire dampers selection HRU building technical measures for noise control	IV.4 installing guidelines balancing procedures	V.4 operation instructions maintenance
5 purchase					
6 time					
7 finances	I.7 costs				
8 realisation	I.8 reporting	II.8 Reporting	III.8 specifications		
9 experience					

Commissioning within the MQC structure

The MQC structure provides a perfect basis for the implementation of commissioning within a (production) process. Within the matrix cells can be identified which should be addressed for commissioning. Specification sheets can be further elaborated. As a commissioning document on (hybrid) ventilation has a general character (i.e. not related to a particular project) not all cells can be filled in. More over all descriptions and specification sheets will give in many cases guidance how to fill in specifications related to a “real” project (this will be the case for organisation, communication, purchase, time, finance and experience). On the other hand, aspects as requirements, means and realisation can be elaborated in detail.

In general, following MQC cells can be filled regarding commissioning:

	project phase				
Quality control aspect	**I programme**	**II design**	**III elaboration**	**IV realisation**	**V operation**
0 general	I.0			IV.0	V.0
1 organisation	I.1			IV.1	V.1
2 communication	I.2			IV.2	
3 requirements	I.3	II.3	III.3	IV.3	
4 means	I.4	II.4	III.4	IV.4	V.5
5 purchase				IV.5	
6 time				IV.6	V.6
7 finances			III.7	IV.7	V.7
8 realisation				IV.8	V.8
9 experience				IV.9	

I Program phase:
In 0 commissioning must be mentioned as one of the boundary conditions in a project. This means that in the programme phase provisions must described in the ToR to execute all necessary activities for commissioning (like BEMS, measuring points, balancing provisions, provisions for scheduled maintenance etc. etc.). In 1 can be stated who will be responsible for organising commissioning (as described in 0) in the programme phase and in following phases and which other parties should be involved. In 2 can be described during which phases which parties should discuss commissioning, what kind of meeting(s) are necessary as well as the deliverables of the meetings.
Very important is 3, in a direct way as well as in an indirect way. Indirect means that proper specifications and the understanding that a principal knows what he asks and what he gets (i.e. that the specifications meets his expectations) is the beginning of good commissioning. Of course all necessary provisions for commissioning (mostly needed in phase IV and V) must be specified already in phase I. Of special concern is specification of components and provisions that allows maintenance and cleaning.

II Design phase:
In the design phase all necessary provisions for commissioning must be take into account in the final design and specifications.

III Elaboration:
In the elaboration phase final selection of provisions for commissioning are selected. This means that component specifications must be given under 3 and selection criteria and methods for components must be given under 4. Purchase costs must be reported and guarded under 7.
Special concern is that for the final selection of components special requirements must be given to allow maintenance and cleaning. For example, if a hybrid ventilation concept contains metal ducts special requirements must be given for duct joints to avoid clogging and to allow cleaning (no screws!).

Hybrid ventilation provisions in the facade must be selected such that cleaning is possible without the risk of destroying the controls and mechanisms or without the change to disturb adjustments.

IV Realisation:
In this phase actual commissioning takes place. This means that in 1 the organisation of the commissioning must be arranged (i.e. definition of responsibilities, who is doing what, commissioning authority/organisation, installers, etc.). If specialist and external expertise must be hired in it must be reported under 5. Under 2 is arranged if meetings to arrange and discuss commissioning and commissioning results are necessary.
Directives and guideline values are reported in 3. Tools, instruments, checklist procedures, measurement methods etc. etc. are listed in 4. Guarding of planning and costs are described in 6 and 7. In 8 is precisely described how the commissioning results must be reported and documented; (note; in 2 the authorisation and approval of these reports is arranged).

V Operation:
In the operation phase the continuous commissioning process is arranged. Although the organisation and management structure that was operational during a building process is not available anymore in the operational phase the organisation of the continuous commissioning can be described. It clearly will be another organisation and management structure then reported under I – IV. The tools and instruments as described under 4 will be partly the same as described in phase IV. Special attention in phase V is needed for maintenance. This also includes schedules for maintenance, to be reported in 6, and costs (i.e. cost reservations), to be reported in 7. As in phase IV precisely described commissioning results must be reported in 8.

Note that this description only gives a preliminary idea how to arrange and organise commissioning in a logical way in the sequential phases of a production process. This structure can be elaborated if necessary. It can also be used to fill in specification sheets on particular places where they are needed. In practice this can often follow from quality control aspect “9 – Experiences”.

Costs

Implementation of MQC for ventilation systems does not mean that the building process or in particular ventilation systems will be more expensive. In the beginning however, the implementations requires extra efforts and costs, inherent to the introduction of all new kings of methodologies or technologies. It delivers however a ventilation concept and system with a high and very well defined level of quality and, on the longer run, cost and time saving. It is important to distinguish process costs and object costs. As MQC leads to a very clear project management cost and time saving can be expected once it is implemented. However, in the beginning much effort and time is necessary to elaborate the necessary cells within the MQC matrix.

The impact on the object costs can be as well as negative as positive. Quality control needs extra measuring and control points in an installation. This can lead to extra investments. These investments will be paid back during the operation phase. Especially the reduction of non-scheduled maintenance (i.e. failure and complaint maintenance) due to commissioning and scheduled maintenance will lead to a major cost reduction. But also a reduction in investment costs id possible. Precisely defined design and calculation methods avoid over-dimensioning. Within the aspects organisation and communication the principal is informed in time about possibilities for grants etc.

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