Hybrid Ventilation: Our first Choice!

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ABSTRACT

Hybrid ventilation is a ventilation system that uses natural air intake through wall inlets in combination with mechanical extraction.
Natural ventilation systems generally score well in studies of satisfaction with the indoor environment in offices. However, these systems perform less well in conditions of high wind and/or low external temperature. The users often close their ventilation inlets in these conditions so as to prevent draughts. Problems can also occur during warm summer weather because there is no driving force for the ventilation.
Hybrid ventilation combines the main advantage of natural ventilation (direct air intake from outside) with the stability of mechanical ventilation. It also avoids some drawbacks of both systems. This paper points out problems in connection with hybrid systems and indicates solutions for them. It also gives some examples of hybrid ventilation systems, some of which are already in use and others are still being implemented.
The design of hybrid ventilation systems is not easy. Responsibility for the design and smooth operation of a hybrid ventilation system should therefore be entrusted to the obvious expert, the HVAC engineer, and not to an architectural engineer.

1. INTRODUCTION

It is nearly five years since I published an article in TVVL Magazine questioning whether natural ventilation was a good idea for offices and proposing a "symbiosis of nature and technology" in the form of hybrid systems.(Bronsema 1996). The following year, I had an opportunity to put the ventilation concept which I described in the article into practice (office building of Waterschap "Vallei en Eem" at Leusden, the Netherlands). The experiences that people have had with this system have been so positive that the Dutch Building Research Foundation SBR has issued a publication about it. Several other projects of this kind are now in progress or complete.

2. WHY HYBRID VENTILATION?

Hybrid ventilation has the following advantages over natural ventilation:

- Much higher reliability.
- The possibility of heat recovery by means of a heat pump.

Compared to mechanical ventilation, it has the following advantages:

- Better quality of ventilation air owing to the direct intake of air from outside the building.
- Simpler system, thus requiring less maintenance.
- Higher acceptance by users.
- Lower power consumption.
- By eliminating the air supply system, less material input and space requirements

In most natural ventilation systems, air enters through openings in the outer wall. Excessive wind pressure, low external temperatures and traffic noise can substantially nullify the benefits. Adjustable ventilation inlets and duct silencers can partly counteract these problems, but high wind pressures continue to be a nuisance; in many buildings users may be irritated by "whistling" ventilation inlets. When the weather is calm, on the other hand, the ventilation inlets may fail to deliver sufficient fresh air in low buildings because there is insufficient thermal draught. Natural ventilation systems are thus not 100% reliable in these respects.
A Swedish study on this subject (Kronval 1994) concluded that "*natural ventilation systems are unable to maintain acceptable ventilation rates during a certain number of hours throughout the year*". Several studies have moreover revealed that the indoor air quality drops considerably during the winter because people close their draughty ventilation inlets (Indoor Air and Healthy Buildings conferences 1988-2000).

3. CONTROLLED NATURAL VENTILATION INLETS

There are several reasons why it is desirable to replace the customary manually operated ventilation inlets by self-regulating alternatives that meet the following requirements:

- The ventilation flow rate must be constant despite changing wind pressures on the exterior of the building. This prevents over-ventilation, draughts and energy wastage.
- Rooms on the lee side of a building must not be ventilated with exhaust air from rooms on the windward side. Air must therefore not be allowed to flow from inside to outside, and the ventilation inlets must be equipped with back flow preventers.
- The ventilation inlets must be closable to prevent superfluous ventilation outside working hours during the winter.
- The ventilation inlets must be openable by a central control system to enable increased night ventilation during the summer.
- Users must be able to regulate the inlets themselves from the ventilated room.

Several manufacturers have marketed self-regulating ventilation inlets in recent years. There are two actuation principles, pressure controlled (stand alone) and demand controlled (micro-electronic).

4. MECHANICAL EXTRACTION

Every room is connected to a central air exhaust system which must create a sufficient pressure drop between the interior and exterior to ensure the desired flow of ventilation air under all weather conditions. The central exhaust fan is normally equipped with flow rate control which operates on the basis of maintaining a constant underpressure in the central air exhaust duct or on the basis of the number of ventilation inlets which are open.

The exhaust fan is set to a higher operating speed on summer nights to provide effective night cooling. The increased noise level is not usually a problem at night in many environments e.g.

offices and schools. The inlets are actuated to 100% open in this operating mode.

The central air exhaust duct is fitted with a cooling coil with a heat pump to extract heat from the exhaust air during the winter.

5. HEAT RECOVERY

The above-mentioned cooling coil extracts heat from the exhaust air. This heat is transformed by means of a heat pump to a temperature of approximately 50°C and returned to the building through the central heating installation. This system can save more heat, measured over the whole heating season, than heat recovery using plate-type heat exchangers or twin coil heat exchangers. This is because the cooling medium has a constant, low, temperature and is independent of the external temperature.

6. LIMITING CONDITIONS FOR APPLICATIONS

Heat loads should preferably be restricted to prevent room temperatures from rising to excessive levels in the summer. This should not be too difficult with present technology. For exterior heat loads, the glass industry has come to our aid, having made major progress in recent decades in developing glass that combines a low solar heat transmission value with a high light transmission value, without the nuisance of excessive reflections. Interior heat loads in offices have continually declined in recent years thanks to the introduction of LCD and TFT monitors, PCs with power management, putting printers and copiers in the corridors and the use of HF light fittings with natural/artificial light control system.

If measures such as these fail to reduce the heat load sufficiently, or if stricter standards are set for interior conditions, thermal panels can be mounted on the ceiling above the worksites. These panels are heated in winter and cooled in summer and are capable of creating a high level of comfort all the year round, including when combined with natural ventilation through wall inlets.

7. QUALITY OF OUTDOOR AIR

Outside air is generally cleaner than inside air. This is something we may be thankful for, because it makes it possible for us to improve the indoor air quality by ventilation. Still, in industrialized regions, the outside air is never really all that clean. Table 1 shows the major pollutants of outside air. Under certain conditions, some of these substances, termed precursors, can cause secondary pollution problems such as summer or winter smog, ozone and fine dust.

Table 1 - primary pollutants of outside air

Pollutant	Gaseous	Particulate	Precursor
SO_2 - Sulphur dioxide	•		•
CO – Carbon monoxide	•		
VOCs - Volatile Organic Compounds	•	•	•
PAH's Polycyclic Aromatic Hydrocarbons	•	•	•
Fine dust – PM_{10} – $PM_{2,5}$		•	•
Black Smoke		•	
NO_2 – Nitrogen dioxide	•		•
Heavy metals (arsenic, cadmium, copper, lead, zinc)		•	

A general review of the permissible limits for pollutants is currently taking place in the EU, with much more stringent values becoming applicable from 2010 onwards. Although all the above-mentioned substances can be detrimental to public health, a recent study identified the concentration of nitrogen dioxide (NO_2) alone as a usable working criterion of air quality. A maximum annual average norm of 40 μg/m3 was set for this pollutant from 2010 onwards. However, vehicle traffic remains an important source of air pollution, and relatively high concentrations of these substances are still to be expected, particularly in the vicinity of motorways.

8. "HOUSES TO GO BECAUSE OF AIR POLLUTION"

A recent news agency report under this headline suggested that 4,000 to 4,500 homes would have to be demolished in the vicinity of Dutch motorways because they would overstep the above-mentioned norms for air pollution. Probably things will not reach that juncture, because much improvement should be possible through traffic-reducing measures and cleaner vehicle engines. The report was based on a study in which air quality along the whole Dutch motorway network was assessed against the EU limits for NO_2 as applicable in 2010 (40 $\mu g/m^3$). Estimates indicated that the limit would be exceeded at distances of up to 200 m from a motorway.

At the conference *Indoor Air 99*, several experts argued that buildings where people stay permanently or for long periods should not be built in high-traffic areas, and that *"it should no longer be permitted under any circumstances to erect a new building within, say, 150 metres of a busy highway"* (Bronsema 2000)

In a densely populated country like Holland it is of course impracticable to ban building in huge strips of land along every stretch of motorway. But it would be unwise to build schools, nursing homes etc. in these zones. And all buildings which are in *"unhealthy"* locations, e.g. close to motorways, should comply with the following rules:

- Do not use natural ventilation through wall inlets but mechanical ventilation instead.
- The air intake position should be as remote as possible from the source of pollution, and/or
- Apply high quality air filtering using HEPA and activated carbon filters, or if possible using electrostatic filters and air washers (Bronsema 1998).

9. QUALITY OF INDOOR AIR

However concerned we are about the quality of outdoor air, it must not be forgotten that it is the indoor air that matters. People in contemporary society spend some 85% of their time in an indoor environment - at home, in cars, trains and buses, at the office etc. (Fitzner 1999) mentions a target value for the quality of indoor air as 4 dP - made up of 1 dP for the outdoor air, 1 dP for the HVAC installation, 1 dP for the interior and 1 dP for the people in the interior.

Using natural ventilation through wall inlets, we can dispense with 1 dP for the HVAC installation and immediately improve the indoor air quality by 25% to 3 dP. The *"art of omission"* is surprisingly effective here.

Causes of air pollution indoors include human bio-effluents (body odours, in other words) and other products of human activities, mainly dust. Compared to the substances that pollute outside air these interior pollutants are relatively harmless, although the same does not apply to germs, cooking fumes and tobacco smoke. The greater the level of physical activity, the higher the concentration of dust particles in the indoor air. In schools, for example, the air is generally dustier than in offices.

The aim of ventilation is to remove pollutants from the indoor environment, and because outside air is generally of better quality than mechanically supplied air (see Fitzner's target value), natural ventilation should in principle perform better than mechanical ventilation. We must then of course make sure that people do not close off their ventilation inlets because they are irritated by draughts or and/or noise, for example when there is a brisk wind blowing onto their side of the building or it is particularly cold outside.

Many naturally ventilated buildings suffer from this problem, especially in winter, and it results in serious under-ventilation and poor indoor air quality. Schools, which generally have low-standard ventilation systems, are particularly prone to this. One child with the measles or mumps can quickly reduce a class of thirty to ten.

The link between ventilation rate and the infection risk has been studied scientifically. (Nardell and Keegan 1991)

10. AIR FILTERS

Wall ventilation inlets must be equipped with at least a gauze filter of mesh width 2 to 3 mm to keep out insects and larger air-suspended particles. Some manufacturers offer pollen filters as an option, and these can be useful in locations with pollen-producing trees and shrubs. It would be even better to choose non-allergenic trees and plants for gardens around buildings, but horticulturalists are not necessarily knowledgeable in this respect. (Ogren 2000)

Gauzes and filters must be easy to clean properly, and should preferably be visible from inside the building. In the home, people can clean these components themselves, but offices and schools are recommended to contract cleaning with the supplier. The service engineer can also check the operation of self-regulating inlet vents.

11. INDOOR THERMAL ENVIRONMENT

The indoor climate must satisfy normal requirements if users are going to accept natural air ventilation systems completely. This is especially problematical in winter, but it is surprising how little attention is paid to this problem in handbooks on natural ventilation. A classic in this area is *Natural Ventilation in Buildings* (Santamouris et all 1998) and what it has to say is that *"designers must provide the means to avoid draughts when the occupants so wish but, at the same time, still provide enough air exchange. This is an exercise in compromise and careful design, requiring some experience and knowledge of physics on the part of the designer".*

The CIBSE Manual *Natural ventilation in non-domestic buildings* (CIBSE 1997) goes as far as to suggest the following solution: *"Close all natural ventilation openings in cold weather and use a separate mechanical ventilation system which can pre-heat the air".* We may be excused for wondering whether the authors have thought about the problem at all.

The possibility of improving the interior environment during the summer with a static cooling system is not mentioned in any of the handbooks. So, HVAC engineers and technicians, grab your opportunity. The indoor environment is too important to leave to semi-experts. In any case, we don't want people stealing the bread out of our mouths!

12. INDOOR THERMAL ENVIRONMENT IN SUMMER

A building with low thermal loads and sufficient effective thermal mass will not be all that susceptible to overheating problems in the summer. As long as the building is reasonably cool in the morning - and night ventilation is essential for this - the occupants usually adapt well to the gradually rising temperature during the day. This has been shown unequivocally be research into how well people adapt to temperature changes as long as they have sufficient means of adaptation (clothing, operable windows, sunshades etc.) Opening a window results in some additional air movement, and the welcome draught compensates for a higher room temperature even when it is hot outside. People moreover tend to assess environmental comfort more generously in a naturally ventilated room than in a fully air-conditioned room.

When the standards to be met are high, cooled ceiling systems or ceiling panels can be used in combination with natural ventilation to create comfortable indoor conditions even at high thermal loads.

13. INDOOR THERMAL CLIMATE IN WINTER

Air conditioning installations are generally designed not to supply air colder than 14^0C during the cooling season. With natural air intake through wall vents, the air supply temperature can be considerably cooler than that during the heating season. Temperatures as low as minus 3^0C must be considered an alarming prospect for most HVAC engineers. Who in his right mind would try to deal with a cooling load of 6.000 W by supplying 750 m^3/h of air at -3^0C into a space at a temperature of 21^0C a ΔT of 24K! But this is precisely what could happen in an extreme situation in a naturally ventilated school classroom with 30 pupils (2.500 W), lighting (500 W), a hot convector (2.600 W) and 400 W of external load (net solar heating after heat loss) - a total of 120 W/m^2.

There are two possibilities here:

A There is so much draught that the occupants immediately close the windows or ventilation inlets. This is usually the case with natural air intake systems, with predictable consequences for the air quality and, in schools, sick children.

B The air is supplied in a draught-free manner and the ventilation flow is maintained. Achieving this requires a thorough knowledge of heating and ventilation engineering, the will to put this to use for innovative development, and the willingness of clients to allocate a budget for a full-scale test and/or CFD analysis. It is to be hoped that this will no longer be necessary in a few years time by when sufficient know-how will have been accumulated.

One thing must be clear: air flows usually stubbornly refuse to follow the arrows that creative architects add to their drawings. HVAC engineering should accept its responsibility and develop knowledge on how such systems must be designed. Thanks to the dedication of some innovative pioneers, we do not find ourselves completely empty-handed at present.

14. NATURAL VENTILATION INLETS

A doctoral research study at Delft University of Technology has shown that draughts can be avoided by admitting ventilation air at high velocity (> 2m/s) just under the ceiling through slotted air inlets.(Engel v.d.1995) The air stream clings to the ceiling as a result of the Coanda Effect, and the resulting thin sheet of cool air quickly settles to the same temperature as the rest of the room.

This principle can not easily be implemented for the following reasons:

- Slotted ventilation inlets are not commercially available.
- Ventilation inlets are usually integrated into window frame units. The ideal placing (just below ceiling level) requires a specific window height which can not always be realized in practice. The use of a thermally open ceiling, which does not touch the walls, also interferes with the required positioning. Positioning immediately beneath the structural floor necessitates tall, narrow windows, and thus places an undesirable restriction on the architectural design.
- The required air velocity of > 2 m/s implies a fairly high pressure drop across the air inlet. At a ζ of 1,5 the corresponding pressure difference is approx. 4 Pa, which means that a fair amount of outside air is likely to enter through chinks and cracks. It would be wise to take this into account when dimensioning the air inlets.

15. USE OF THE CEILING CAVITY

The ceiling cavity is eminently suited to the prevention of cold downdraughts, particularly if the positioning of air inlets prevent advantage being taken of the Coanda Effect. A thermally open ceiling is necessary for this purpose. The difficult part is to persuade the cool ventilation air to traverse the gap between the outer wall and the suspended ceiling without descending into the room. The intention is that the incoming air stream will interact with a heat supplying body and heat sources in the room to effectuate a cyclic ventilation airflow which is confined largely or entirely within the ceiling cavity. By the time the moving air reaches the far side of the room, the temperature difference between the ventilation air and the room air should be completely equalized.

Persuading the incoming ventilation air to cross the gap between the outer wall and the lowered ceiling can be brought about in one of the following ways:

- Bevelling the space between the top edge of the air inlet and the structural floor so that the Coanda Effect occurs to some extent. This method is usable as long as the gap is not too large. (Figure 1)
- Equipping the air inlet unit with a spoiler to deflect the incoming air stream diagonally upwards. This method is applicable when the gap between the air inlet and the suspended ceiling is too large for the method described above. The spoiler could be made adjustable with a summer and a winter setting.

16. HEATING

For heating in combination with natural ventilation through wall inlets, unless LT (Low Temperature) heating with thermal ceiling panels is used, heating elements must be placed on the intake side of the room. The warm, rising air will help the cold ventilation air to reach room temperature quickly. Convectors are preferable to radiators for the following reason:

- Convectors produce a stronger warm air stream than radiators.
- Convectors react more quickly than radiators owing to their lesser mass and water content.

Since the opening of the ventilation inlets can take place quickly, a fast-reacting heat source is preferable. It must be borne in mind that more than 80% of the thermal capacity is often required for heating the ventilation air.

When LT panels are used, the ventilation air is heated directly by these panels. During the cooling season, these panels are used as an HT (High Temperature) cooling system for cooling the ventilation air.

17. VENTILATION EFFINCIENCY

The achievable ventilation efficiency is dependent on the quantity of air that can be brought into movement in the system (induction ratio) and of the place where the exhaust air can be extracted from the above-mentioned cyclic ventilation airflow. The induction fold is not easy to establish, as it depends on the heat sources in the room and the velocity with which the ventilation air leaves the intake vents.

Ideally, the air should be extracted only after a complete 360^0 cycle of the ventilation airflow, but this is difficult to achieve and not essential. The ventilation efficiency is practically 1 after only 270^0. An efficiency of 0.9 is reached after a 90^0, and with two-step extraction at 90^0 and 180^0, an efficiency of 0.95 may be expected.

18. HYGROMETRIC COMFORT

Humidification - friend or foe? was the heading of an article I published in REHVA Newsletter a few years ago (Bronsema 1997). To put it briefly, healthy people in a clean and healthy environment do not need artificial humidification.

The initial requirement of a clean and healthy indoor environment is something we can achieve with sufficient effort and persistence, in collaboration with architectural engineers and building physicists.(Bronsema 2001). Effort is also required from the building management, as well as a substantial budget for cleaning and maintenance, to keep the building clean when in use.

An important factor is to keep the indoor temperature as low as possible within comfort limits in the winter. Research has shown convincingly that many of the symptoms of Sick Building Syndrom vanish like bad dreams as long as the room temperature is kept below 21^0C. Many heating and ventilation systems are supposed to maintain this temperature, but it is an illusion. They bring the room temperature precisely to 21^0C at the start of the working day, but as soon as people set to work, turn on the lights and boot up their PCs, the temperature rises to 23^0C or more. The system then cuts out the heating, but there is usually too little cooling capacity available to compensate for the internal heat load and possibly for a solar heat load as well.

When natural ventilation through wall inlets is used, on the other hand, the cold intake air usually provides sufficient cooling capacity in the winter to keep the room temperature at the desirable level of 20^0-21^0C.

Our specialism can only make a limited contribution to people's health. What can there be done about people who have genuine complaints of dry air, dry skin, dry or itchy eyes, a dry throat, a stuffed up nose etc.

A simple solution which is often preferable humidifying the air is to encourage the use of skin creme, eye-drops, a saline nasal spray etc. These are products which have no harmful side effects and which are obtainable from any chemist's shop. Personally, I find a saline nasal spray a highly effective way of relieving a stuffy head after a plane trip.

The people who suffer from these complaints could also be helped by a "*personal humidifier*", which could if necessary be supplied on medical prescription. Out of considerations of hygiene, it is recommended that the care and maintenance of these humidifiers should not be left to their users but should be entrusted to the building services department or company. If large numbers of local humidifiers are in use in a building, they could be connected to switched power sockets with humidity sensors, connected to the building automation system, to safeguard against over-humidification.

A problem still to be considered is that of dusty rooms, e.g. where people work with large amounts of paper. Here too local humidifiers could provide a solution, but an alternative is to use compact air purifiers that clear the air by recirculation. These operate by generating negative ions (popularly known as *"air vitamins"* which are capable of oxidizing and neutralizing particles of dust and microbes. Your own personal ionizer will no doubt turn into a status symbol and thus offer some psychological compensation for less than ideal working conditions!

I recommend consulting a consumer magazine before purchasing personal humidifiers and ionizers.

19. EXAMPLES

- Office Building Vallei en Eem:

Figure 1 shows how the ventilation air circulates through an office room. Mark the bevelling of the space between the top edge of the air inlet and the structural floor. The return air flows through floor grilles and ducts in the structural floor to the structural steel columns, thus integrating the exhaust system in the building structure.
A full scale test was performed at -3^0C outside temperature in order to ensure a good thermal comfort in winter. The user's satisfaction is better then in average office buildings. Details will be presented.

- Office Building Triodos Bank:

In this building LT (low temperature) thermal ceiling panels are used for heating. Results and experiences with this system, in use since 2000, will be presented.

- City hall Barendrecht:

This building will be delivered 2001. Thermal ceiling panels are installed for LT heating and HT (high temperature) cooling. Test results will be presented.

- Art & Cultural Centre Zoetermeer:

This building is provided with floor heating and cooling, which is a slow reacting system. In order to comply with the fast reaction demands of the ventilation, finned tube heating elements are installed above the ceiling; probably the first time ever in heating history. Experiences and results of this recently delivered building will be presented.

- Elementary school Voorschoten:

In this new school building (the construction has started February 2001) the ventilation inlets are situated well under the false ceiling. In order to force the cold air in winter in the ceiling cavity, spoilers will be installed under the ventilation inlets. (See par. 15). A CFD analysis proved that in summer and winter the air circulation in the classrooms will be satisfactory. A full-scale test should prove that this unbelievable result is reliable. A thermal load of 6,000 Watt is handled by 750 m^3/h air at a temperature of minus 3^0C!! See par. 13.

20. CONCLUSION

Hybrid ventilation offers many advantages to mechanical ventilation systems with regard to user's satisfaction, indoor air quality, maintenance and power consumption. If the outdoor quality and the building location are not prohibitive hybrid ventilation should be the first choice of HVAC engineers to ventilate office buildings, schools and the like.

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Figure 1: Office Building Vallei en Eem – Cross section office room