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Title: **Energy Recovery Possibilities in Natural Ventilation of Office Buildings**

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Natural ventilation in Sweden → voorverwarmen? = heat-recovery

Vooral voor winter

ENERGY RECOVERY POSSIBILITIES IN NATURAL VENTILATION OF OFFICE BUILDINGS

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1. SUMMARY

The paper deals with energy consumption and heat recovery in office buildings with natural ventilation. Net energy consumption for ventilation is calculated for 7 European countries. The calculations are done with various air flow rates and occupancy. The calculations shows differences between the seven countries, but the net ventilation heat loss is substantial for all. Norway and Sweden will benefit most from heat recovery.
Several heat recovery concepts for natural ventilation are presented. Advantages and disadvantages with the various systems are discussed, also with respect to requirements as thermal comfort, air flow control, air cleaning and operation/maintenance. The paper also analyses the distribution of natural driving forces for ventilation both in various countries and in different parts of the heating season. The calculations indicate a need for assisting fans.

2. INTRODUCTION

A consortium of 7 countries conducts a project aiming at overcoming barriers to low-energy natural ventilation in office-type buildings in moderate and cold climates. The project, which is called NATVENT, is partly funded by the Commission of the European Union under the JOULE Program of the Fourth Framework.

Natural ventilation is the process of supplying outdoor air into a building and extracting the same amount of used or contaminated air from the premises utilising wind and thermal buoyancy as the driving forces. Natural ventilation systems can attain much more interest in the future in moderate and cold climate countries if heat recovery is included. Such systems use very little energy for air transport, they generate very little noise and a good air quality can be obtained. As a basis for further work on developing solutions for natural ventilation with heat recovery the paper focus on practical concepts:

- Controlling the air flow in accordance with what is demanded
- Preventing pollution in urban and industrial areas from entering a building
- Supplying the outdoor air without creating thermal discomfort
- Ensuring low energy consumption
- Ensuring user-friendliness in operation, service and maintenance
- Energy- and cost effectiveness as a total (installation and running costs)
- Preventing outdoor noise (traffic) from entering the building through ventilation openings

Sustainable development in the building sector requires energy efficient building design and operation. This paper shows that heat recovery cannot be neglected in natural ventilated office buildings. As a basis for further work on developing solutions for natural ventilation with heat recovery the paper focus on practical concepts. These concepts also pay attention to thermal comfort, air flow control, air cleaning and operation/maintenance.

3. ENERGY CONSUMPTION FOR VENTILATION

Outdoor air for ventilation must inevitably be heated to room temperature. The energy consumption for heating the ventilation air depends on air flow rates and the outdoor climate. It does not directly matter if the building is thermally well insulated or not, but in well insulated buildings more of the surplus heat can be used to cover ventilation heat losses than in buildings that are not thermally well insulated. Consequently, in order to calculate the net energy consumption for heating outdoor air for ventilation one must analyse the total energy balance of the building, taking into account all the internal heat loads. Table 2 shows calculated net energy consumption for ventilation in different countries. The calculation is done with tsbi-3, which is a Danish energy calculation program. Important input data in the program is listed in table 1. The building model used is taken as a multi-storey building with cellular offices. The office rooms are placed on both sides of a corridor. All the offices have windows. Solar shading devices and office equipment are the same for each country. Outdoor climate data files for a reference year are supplied by the partners.

Table 1. Building data and internal heat loads used in the energy calculations

Country	U-values Watt/m² K		Lighting	Office equipment	Infiltration
	Wall	Window	Watt/office	Watt/office	Ach
N, S	0,22	1,6	200	125	0,21
DK, GB, CH, B/NL	0,33	2,8	200	125	0,21

A lot of international research work is done in the indoor air quality field with respect to the minimum requirements for the supply of outdoor air in office buildings. Some of the reports conclude that for air quality reasons it is not recommended to go below an outdoor air supply of 10 l/s per person during occupancy hours [1]. For thermal reasons the air flow-rate requirements may become much higher than this. We have chosen to present the energy consumption for 10 l/s controlled ventilation and correction data per l/s deviation up and down from 10 l/s. The results are presented in table 2. The table also shows ventilation codes/guidelines in participating countries.

Table 2. Net energy consumption for ventilation

Country	Location	Ventilation codes/ guidelines l/s per m²	Energy consumption kWh per Year per 10 l/s For one office or workplace	Energy consumption Correction if ventilation differs from 10 l/s per workplace (person) kWh per Year Per l/s	Energy consumption kWh/m² per Year Acc. to10 l/s per person 15 m² per person
N	Oslo	1.4	363.1	39.7	24.2
DK	Copenhagen	0.4	316.8	32.6	21.1
S	Stockholm	0.7	380.8	41.3	25.4
B	-	0.8	238.8	25.9	15.9
NL	-	1.4	238.8	25.9	15.9
GB	London	0.8	193.9	22.6	12.9
CH	Zurich	0.4	279.4	30.1	18.6

The data reflects 12h controlled ventilation per day, 5 days a week.

Example - correction to 8 l/s ventilation per workplace for Denmark: 316.8- 2·32.6=251.6 kWh per year or 16.8 kWh/m² per year if the floor area is 15 m² per workplace.

The energy consumption data shown is only for controlled ventilation, 12 h per day, 5 days a week. It is the net energy consumption for ventilation which is shown, based on a complete simulation of two offices located on each side of a corridor. It is assumed that all the offices are equal. The simulations are done for single person cellular offices with a floor area of 12 m² + 3 m² corridor floor area. Changing the office size had only a minor influence on the ventilation energy consumption.

As we can see there are some differences between countries. The ratio between the highest and the lowest number is 1.87. As we can see from the table Norway and Sweden will benefit most from heat recovery, but the net ventilation energy consumption is substantial for all countries. In terms of percentage of the total energy consumption of the whole building, lighting and equipment included, the energy consumption for 10 l/s per person in this example is approximately. 30 % for N and 20 % for GB. The internal heat load used in the calculations are assumed to be average to high. A lower internal heat load will increase the net ventilation heat loss and thus make heat recovery more profitable and vice versa. Also, the ventilation requirements may be higher than 10 l/s, as is the case for Norway, or lower as may be the case for other countries. The energy consumption changes almost linear with ventilation flow rates, according to table 2 column 5. Running time for ventilation other than 12 h per working day matters also.

An ordinary mechanical ventilation system requires approx. a total fan power of 2 - 3 W per l/s for air transport. This represents an energy consumption of 10 - 20 kWh per year per l/s. Most of this energy will be saved in a natural ventilation system (energy consumption for assisting fans: less than 10 % of above).

4. AVAILABILITY OF NATURAL DRIVING FORCES

The driving force is the sum of buoyancy and wind effect. Based on the outdoor climate data files supplied by the participants, the distribution of available driving forces is calculated for the countries. In the calculations it is assumed that 80% of the dynamic pressure of the wind can be utilised in a natural ventilating system. The thermal stack height is taken as 10 m. Fig 1 shows the distribution for the autumn heating period and fig. 2 for the spring heating period. As we can see the frequency of very low driving force is rather high. For example the frequency of a driving force of 10 Pa and lower ranges between 1050 and 2460 hours, lowest for Copenhagen and highest for Oslo. Increasing the stack height to 20 m shifts the distribution some 5 Pa to the right. The ranging between countries becomes however different. The frequency of driving force, now equal to and less than 15 Pa, ranges between 630 and 1560 hours, the lowest value for Sweden and the highest for Belgium. For a 10 m stack height the frequency of driving force less than 15 Pa, fig. 1, would be very high.

hoe berekend?
windrichting?

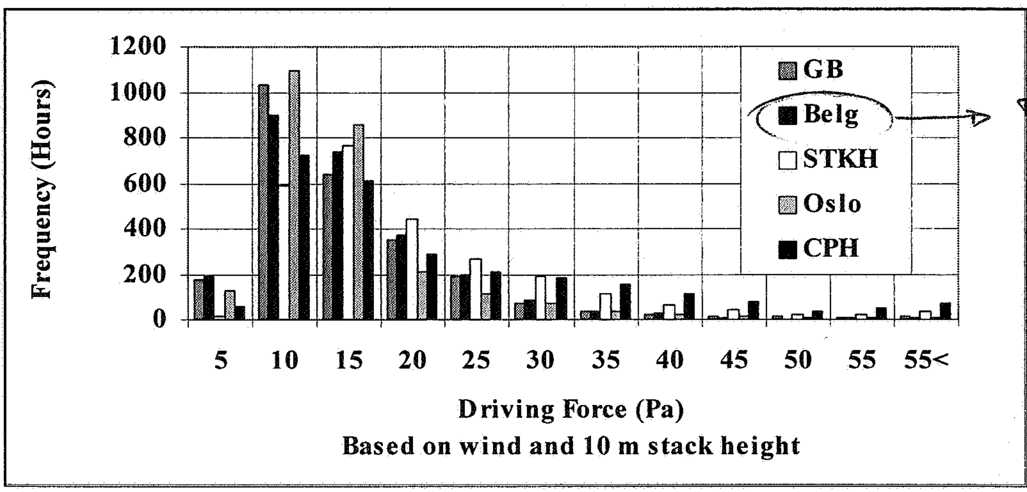


Fig. 1 The distribution of the natural driving forces in the heating season, autumn. The calculations are based on hourly weather data.

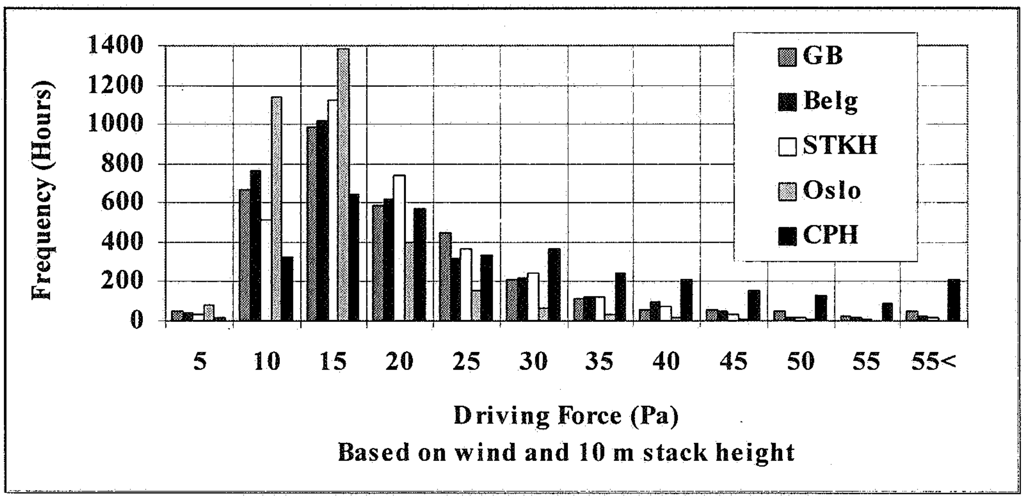


Fig. 2 The distribution of the natural driving forces in the heating season, spring. The calculations are based on hourly weather data.

Detailed calculations for a heat recovery system are not done, but a driving force of 15 Pa is certainly on the lower side.

5. HEAT RECOVERY CONCEPTS

5.1 Principles

There are a number of possibilities and concepts for heat recovery from exhaust air in natural ventilation. The concept to be chosen depends on the possibilities for utilising the recovered energy. In ordinary mechanical ventilation it is very common to use an air to air heat exchanger for direct transfer of heat between exhaust and supply air. It is important to preheat the outdoor air before entering the occupied zones in a building in cold climate countries. Heat recovery systems should consider this. Air to air heat exchangers may be used for this purpose. This solution requires, however, that supply- and exhaust air have to be joined, preferably in an air handling unit. This imposes some severe restrictions on the layout of the systems, especially the ducting system, which may lead to problems in natural ventilation. Introducing a liquid energy carrier instead, the energy can be distributed (run around) in small pipes and the systems become more flexible. Using liquid run around systems, the recovered energy can be used in the most suitable and practical way. The energy can either be used directly for preheating the supply air at appropriate locations in liquid to air heat exchangers or it can be used as the low temperature heat source in heat pump systems where the alternatives for using the energy is hot water heating, room heating or preheating of supply air. Liquid run around systems are widely used in mechanical ventilation systems.

5.2 A simple concept

In principle one way of achieving heat recovery in natural ventilation is to use an air to air recuperative heat exchanger as shown in fig. 3. This is the most simple concept. Using this concept the heat exchanger should be based on counter-flow. One should also bear in mind that the thermal driving force (buoyancy) is dependent both on the stack height and on the heat exchanger efficiency. Heat recovery will decrease the thermal stack effect while increased stack height increases the driving force. This solution is therefore not the most efficient one. The concept is studied by DTH in Denmark [2], but a practical solution is up to now not developed.

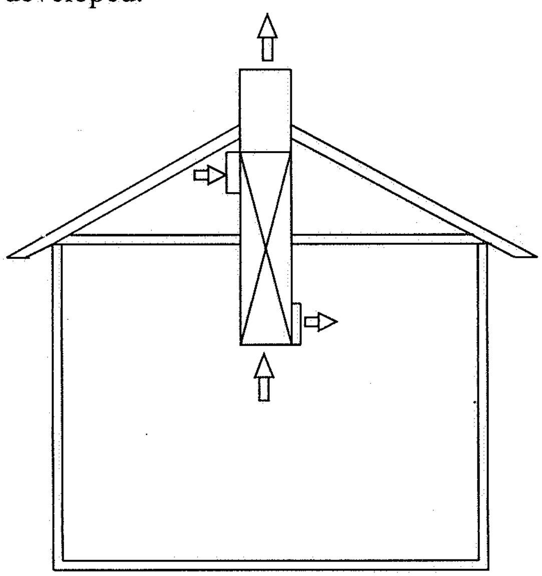


Fig. 3 A simple concept for heat recovery in natural ventilation

5.3 A practical air to air heat recovery concept

A practical and simple unit for a multi storey dwelling has been developed by NBI in co-operation with a Norwegian manufacturer [3], fig. 4. In this case the driving force will obviously be different for the different storeys. Because the heat recovery principle shown will decrease the thermal driving force, it is important to utilise the wind forces. Consequently, both the supply part and the exhaust part of the system should be optimised for that purpose. However, it turned out to be necessary to incorporate an assisting exhaust fan for use in periods with low natural driving forces.

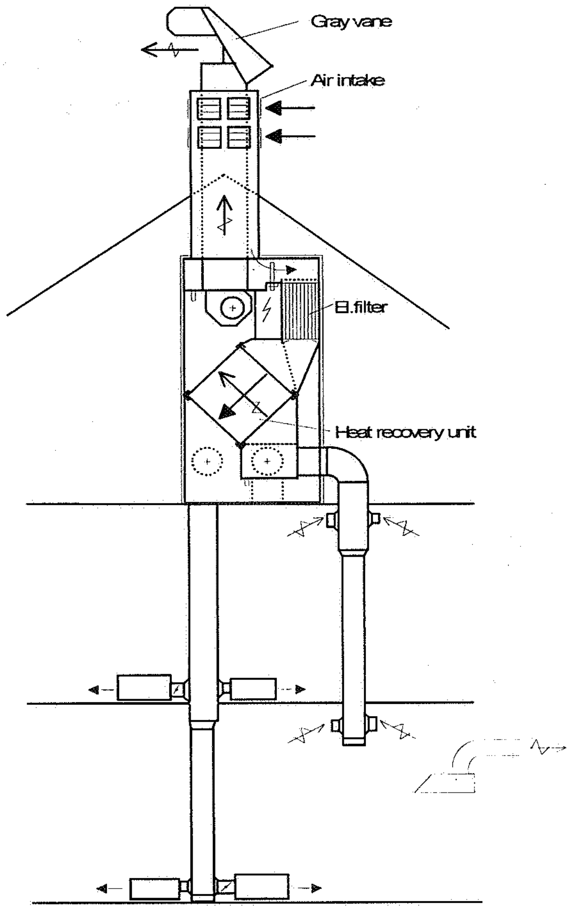


Fig.4. A practical simple unit for a dwelling for natural ventilation with heat recovery using an air to air heat exchanger.

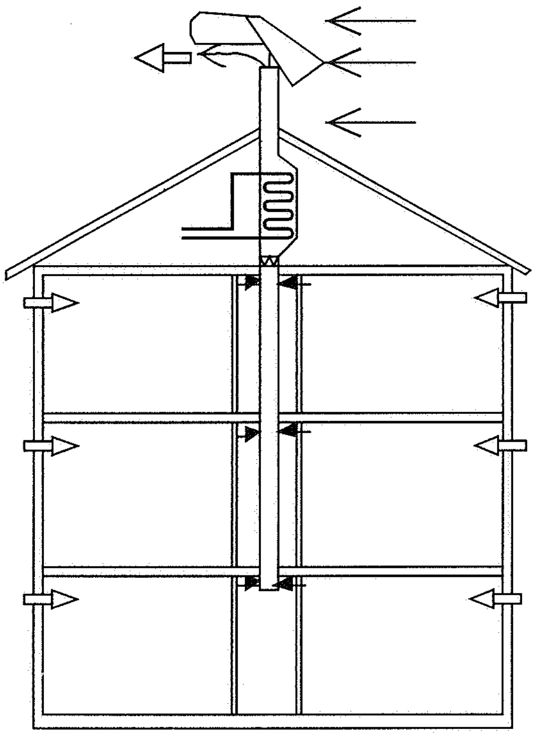
5.4 Separated systems

A more rational approach in developing heat recovery concepts in natural ventilation is to separate exhaust air systems and supply air systems. However, in cold climate countries it is not acceptable, in the cold season, to supply outdoor air which is not preheated. Consequently, we are at the same time looking for air supply systems where the air can be preheated. The functional requirements for a good air supply system is the following:

- The air shall be distributed to where it is needed.
- The distribution should be independent on the wind conditions.
- It should be possible to clean the supplied outdoor air.

5.4.1 Separated heat recovery systems with outdoor air supply through the outer walls

A concept for separated systems is shown in fig. 6. The exhaust air heat is recovered in an air to liquid heat exchanger in the exhaust stack. A practical solution for multifamily houses is developed in Sweden [4]. Both wind- and thermal driving forces are utilised. The recovered heat can be utilised directly by pumping the liquid energy carrier through heat exchangers in the supply openings in the facades. Due to the small temperature difference the efficiency seldom becomes more than 50 %, which means that the air will be too little preheated. The efficiency problem may be overcome combining heat recovery with a heat pump. The heat pump will raise the temperature leading to higher temperature differences and smaller heat exchangers. There are products in the market covering this function, also equipped with particulate air filters.



(Recirculation ?)

Fig. 6. Separated heat recovery system with air supply through the outer walls

In principle the described concept can work, but there are several objections to the solution. The air distribution is sensitive to the wind conditions and the driving force varies between each floor, highest at the bottom floor and lowest at the top floor. The air may go either way through the openings depending on the wind direction. It will be costly both with respect to installation and maintenance cost, and it will also introduce a substantial pressure drop to equip all inlets with heat exchangers to preheat the air. Also, in polluted areas like urban areas and other areas with busy traffic roads, it is a need for at least particulate air filtering. Good supply air filters would be costly and require an additional pressure drop. Sound attenuation may also be required to reduce traffic noise.
Assisting fans, to prevent a too low inside pressure would be difficult and costly to install in a proper way.

5.4.2 Separated heat recovery systems with internal air supply

The air distribution problem can be solved by using an internal air supply equivalent to the simple system in fig. 4. as shown in fig. 7. Because there is no coupling between the air supply system and the exhaust air system, there are several degrees of freedom in solving the air supply problem.

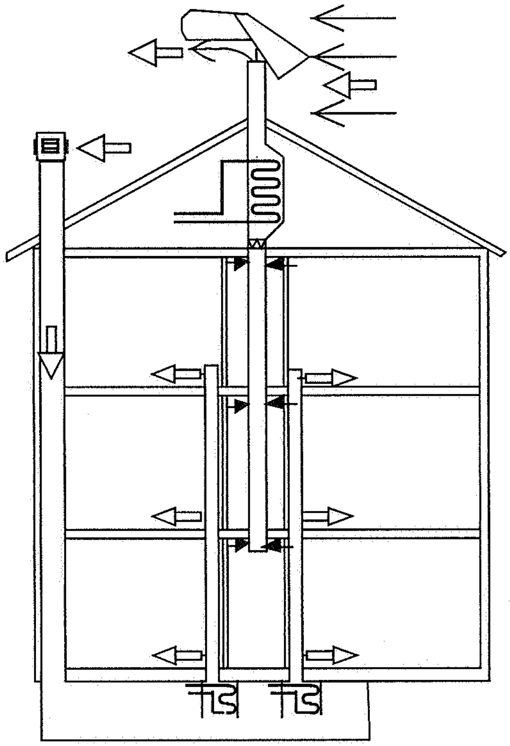


Fig. 7. Separated heat recovery system with internal air supply. Outdoor air intake at roof level.

The supply air system shown in fig 7 is taking the outdoor air in from above, but the most interesting feature in this concept is that the air is lead to underneath the building. Doing so the air can be preheated and fed to the different rooms through risers. In this way the driving forces will become equal for all and each of the storeys. The higher the building the higher the driving force. The outdoor air may be supplied from ground level as well as shown in fig.8. Note that wind forces are utilised for both air exhaust and air supply. More than one exhaust stack may be needed as well as more than one riser system.

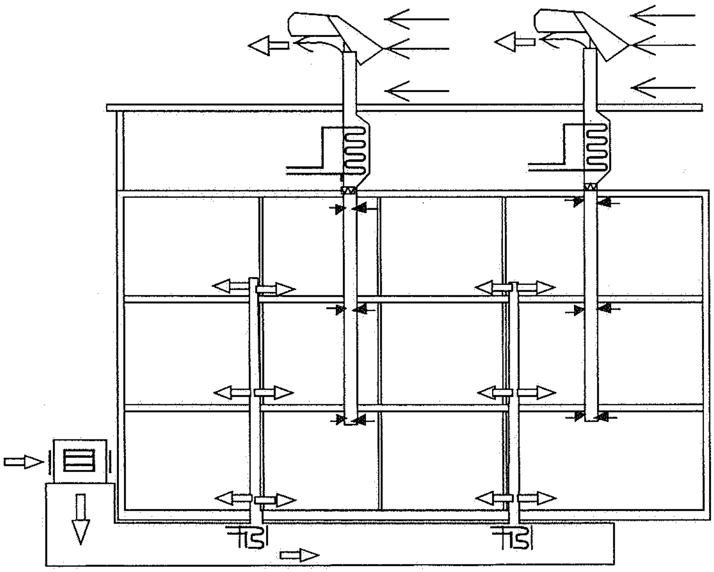


Fig. 8 Separated heat recovery system with internal air supply. Air is taken at ground level.

6. CHARACTERISTICS OF SYSTEMS AND COMPONENTS

6.1 The internal supply air system - characteristics

An internal air supply means to close the facades and supply the air from inside the building. This requires a ducted supply system. In principle there are two main solutions to this:

- Outdoor air is taken in through a vertical stack from the roof top of the building down to a tunnel under the building. From the tunnel the supply air is lead through risers and distributed to where it is needed. In open plan lay-outs, simple distribution systems, like supplying air only to corridors and atriums, may be used. The heat exchanger for the preheating should be located at the bottom of the risers. In this way the full thermal stack effect is utilised as driving force, fig 7. The driving force will further be equal for each floor.
- Outdoor air is taken from an air intake at ground level to a tunnel underneath the building. The solution for the risers and the preheating is the same.

The solutions offer a good possibility for central cleaning (filtering of the supplied outdoor air. Electrostatic filters offers especially high efficient particulate filtering with very low flow resistance (pressure drop). Also traffic noise can easily be reduced by this solution. Depending on the strategy the air intake may be designed to utilise or neutralise the wind forces. Utilising the wind forces is recommended because this will maximise the driving forces. Generally, utilising the wind forces results in periodically rapid changes in driving force which the control system must counteract in order to prevent rapid changing air flow rates. Changing air flow rates may cause both thermal discomfort and excessive energy use if not counteracted. Fortunately, constant air flow devices both exists and new and better ones may be developed and be used.

The concepts shown only show the principle. Practical solutions must involve a close integration with the building design, to reduce the need for ordinary ducting. The building design may be more open, simplifying the exhaust air stack. There are numerous architectural possibilities here. Other interesting features are the horizontal tunnels which opens possibilities for pre-heating and pre-cooling of the supplied outdoor air, by exchanging heat with the surrounding ground. This may specifically increase the efficiency of night-cooling.

6.2 The heat recovery system - characteristics

The exhaust air heat recovery system is the easiest part of the problem solving and the solutions are rather straight forward. In the market there are different types of both air to liquid and air to air heat exchangers to choose between. However, a basic consideration to take is that the pressure drop should be low. This means that the face velocity will be lower than in ordinary systems. This in turn means larger heat exchanging surfaces, and somewhat more expensive components. A benefit from this is possibilities for higher heat recovery efficiencies. An important thing is to keep the heat exchanger surfaces clean by placing a filter in front of the heat exchanger. Because of the larger face area and lower face velocity compared to common practice, cheap plane filters may be used for the exhaust air, which means that the combination heat exchanger/filter may not be more expensive than in ordinary systems. The ducting part of the system may also be rather simple since air can be extracted from a few locations.

Even if there already exist components suitable for heat recovery in natural ventilation, a challenge for the future is nevertheless to develop efficient and cost effective components, especially designed for natural ventilation.

6.3 Assisting fans and flow controllers

The variations in driving force will be large. This is illustrated in fig 1 and 2 in section 4. The figures shows the distribution of driving force for typical stations in the NATVENT participating countries. The necessary minimum driving force for a workable natural ventilating system with heat recovery is not accurately calculated, but a preliminary estimation is that it certainly will not be less than 15 Pa, indicating a need for assisting fans. We also see from the figures that the driving force may become higher than 60 Pa, indicating a need for efficient air flow controllers. Low pressure assisting fans are very efficient throttling devices and may be used for controlling and stabilising the air flow, and make other flow rate controllers superfluous. This means that assisting fans may replace separate flow controllers. The speed of the fans can be controlled based on a flow sensor, and a frequency converter for the power supply.

7. CONCLUSIONS

Heat recovery cannot be neglected in natural ventilated office buildings. Practical concepts exists and may be further developed. These must involve a close integration with the building design, to reduce the need for ordinary ducting. Calculations of available natural driving forces indicates that workable natural ventilating systems with heat recovery require assisting fans. Assisting fans may act as efficient flow controllers.

Acknowledgement
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