PROGRESS AND TRENDS IN AIR INFILTRATION
AND VENTILATION RESEARCH

10th AIVC Conference, Dipoli, Finland
25-28 September, 1989

Poster 21

INFILTRATION AND VENTILATION DEVELOPMENTS IN NORWAY

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OVERVIEW OF INFILTRATION AND VENTILATION DEVELOPMENTS IN NORWAY

Introduction

This paper gives an overwiew of air infiltration and ventilation developments and trends in Norway. The paper is devided in an infiltration part and a ventilation part.

Some key figures for Norway:

Inhabitants	4.4 mill.
Low rise housing	1.3 mill.
Block of flats	0.3 mill.
Degree days (base: 20 °C)	3500 - 7600 °C D

INFILTRATION

Building code

In Norway we did not have any quantitative code for the airtightnes until 1981. From then the n_{50} -value, one can obtain from a pressurisation test, should be as follows for the different kinds of buildings:

Low rise housing	$n_{50} < 4$ ach
Other buildings up to 2 stories	$n_{50} < 3$ ach
Other buildings more than 2 stories	$n_{50} < 1.5$ ach

In adition we have a functional requirement:

> The building constructions shall be so airtight that the effect of the heat insulation will not be reduced and so that there will not be any draught or moisture problems.

Building constructions and components

After the oil crise in 1974 towards 1980 the buildings became more airtight because the builders became more aware of the tightness´ effect on the energy consumption. In 1979 airtightness of 71 randomly picked single family houses were measured. The houses were located in different parts of Norway, see fig. 1.

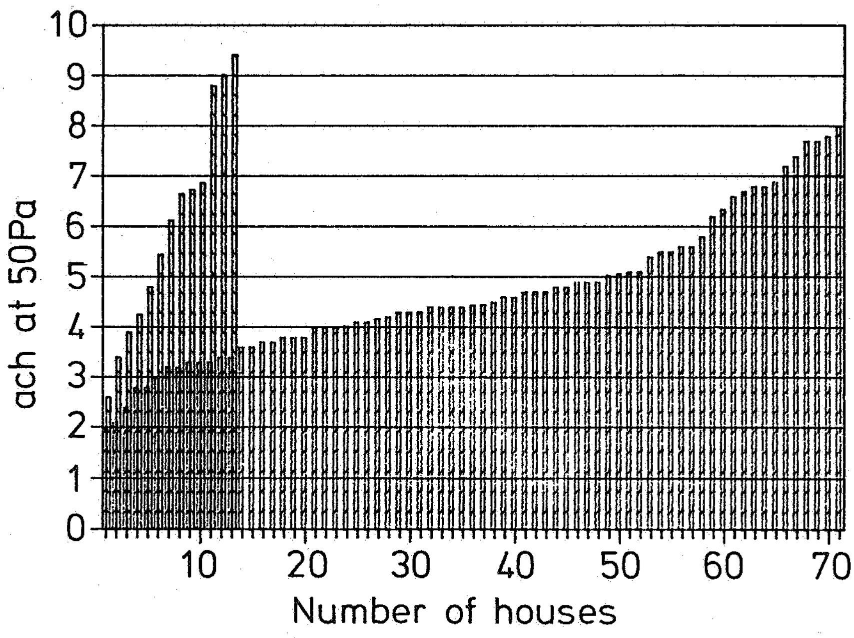


Fig 1. Results from airtightness measurements of 71 randomly picked new single family houses in 1979 and 13 new single family houses and rowhouses in 1988.

The number of houses we have measured is too small for drawing any conclusions but they indicate that new houses in Norway have not been more airtight the last decade. From other measurements we can see the same tendency.

However in the same periode we have seen a lot of new developments in building constructions and components that should have made the buildings more airtight. Among these are:

- thicker polyethylene film as vapour barrier
- new techniques for making the joints in the vapour barrier tighter (welding, sealants, clamping)
- use of rubber gaskets between different kinds of constructions
- more use of sealants in general
- new and lighter wind barrier with larger format which means fewer joints
- tighter windows and doors

A typical single family house construction from today is shown in figure 2.

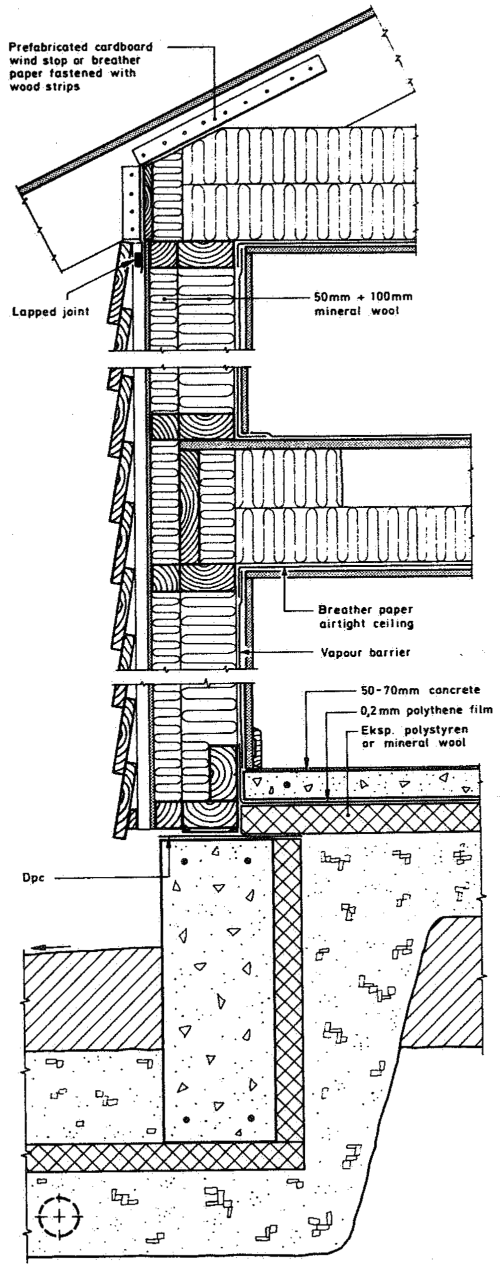


Figure 2. A typical single family house construction in Norway today. More than 90 % of the houses in Norway are wood frame constructions.

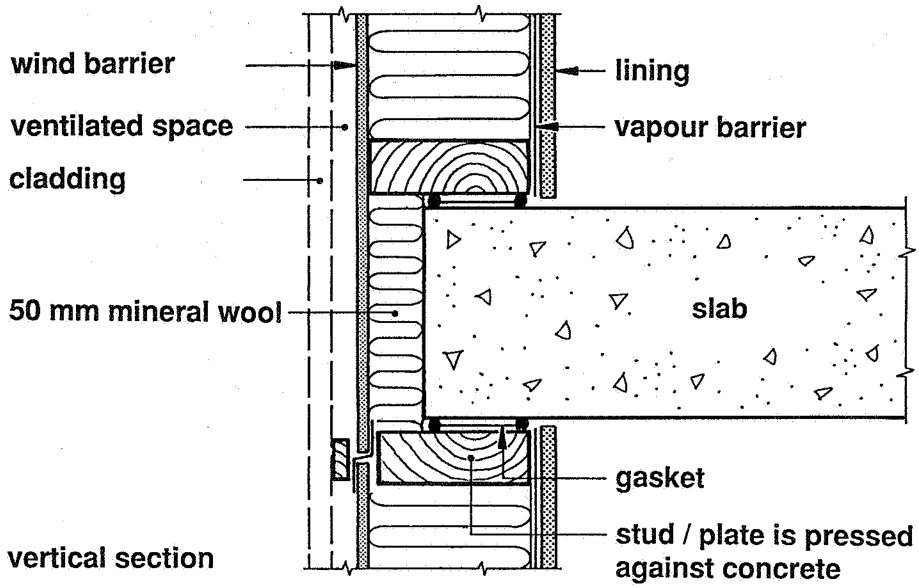


Figure 3. A typical multi family house construction.

There might be several reasons that the buildings are not more airtight today than 10 years ago. The most probable are:

- the form of the houses are more complicated today than 10 years ago
- the sick building syndrome has wrongly been connected to tight buildings and has given the builders an excuse not to put an emphasize on the tightness
- the high building activity in Norway the last years has resulted in lack of qualified persons to the building industry

Research Activity

Rather few research projects have been carried out within this field in Norway the last years. Here is a summary of the most interesting projects in which one of the goals was to improve the tightness of the constructions.

The effect of Vapour Barrier Thickness on Air Infiltration

This project was a comparativ study of the air leakage performance of the two vapour barrrier thicknesses 0.06 mm and 0.15 mm. The study considerd 10 identical single family houses, five which were constructed using the thin film and five which used the thick film. The results show that the houses with 0.06

mm film on average were 17% more leaky than the houses with the 0.15 mm film when they were new. The n_{50}- values were 3.4 ach and 2.9 ach respectively.

The Importance of Wind Barriers for Insulated Wood Frame Construction

The main goal of this research project was to get more information about the influence of wind on the heat loss from wood frame constructions. The project was devided into three parts: calculations, hot-box measurements and wind pressure measurements on a rotable test house. The results show the importance of protecting the insulation layer with a wind barrier to achieve full effect of the insulation in wind exposed constructions, see figure 3.

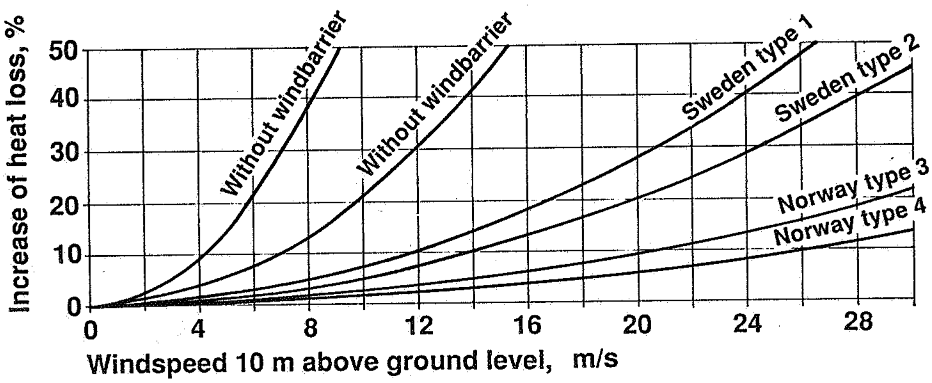


Figure 4. Estimated increase of heat transfer through a stud frame wall caused by wind blowing from outside into the insulation and out again. The two curves without wind barriers represent two different ways of mounting the insulation.

Air Leakage in Old Timber frame Houses with Blown-in Mineral Wool Insulation

Air leakages of 10 old timber frame houses were measured before and after blowing mineral wool into the cavities in the wall and roof constructions. The mean air leakage before insulation was n_{50} = 10.1 ach and n_{50} = 9.0 ach afterwards. This gives an average improvement of 10%. Improvements of 20% were registered on houses where both walls and ceiling were insulated. A couple of houses had no improvement at all.

Infiltration Rates Measurements in Buildings

Infiltration rates meaurements have been carried out in 8 different buildings to find the influence of the weather and the users. The measurements have been carried out with the constant consentration tracer gas technique using SF_6 as the tracer gas. This project is not yet reported but some of the preliminary results are shown in the figure below. The most interesting findings are

- in dwellings about one half of the ventilation is caused by the inhabitants
- in commercial buildings there is a very wide range of what people can accept of high temperature and air quality before they open their windows

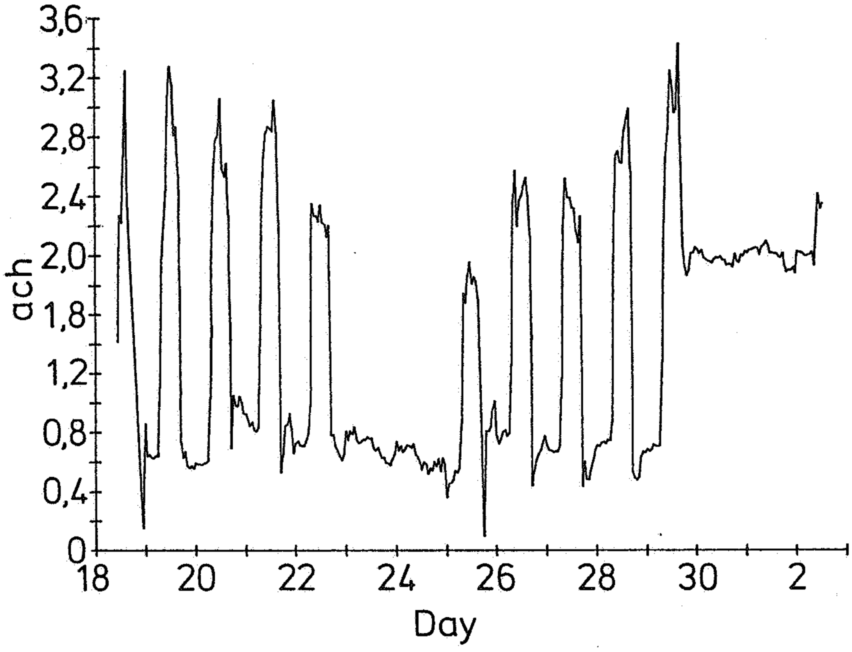


Figure 5. Example of results from air change rates measurements in an office building using the constant consentration tracer gas technique. The building have balanced ventilation system which is turned off during the nights and normaly the week-ends. The last measured week-end it was on and no people was present in the building. When comparing that week-end with the week-days we can see how much the people influence the air change rate. During the first week-end the air change rate is only caused by infiltration.

Infiltration work in the future.

The more we insulate our buildings, the higher is the relative influence of infiltration on the energy consumption in the buildings. We therefore have to carry on with measurements on parameters which effect infiltration including the effect of the occupants. These measurements will give us a better understanding so that better constructions and better calculation methods can be developed.

In Norway we can see a trend in using larger, prefabricated elements in the building industry. To ensure good quality and airtight constructions in the new houses we have to develop better systems for sealing the joints between the elements.

VENTILATION

Ventilation is a mean to secure acceptable indoor air quality. There are a number of consequences of indoor air pollution on both inhabitants and building. These may be grouped in three types.

> Health risk for inhabitants. The sources are among others: Formaldehyde, tobacco smoke, radon, combustion products, organic compounds, humidity and moisture (moulds and fungis)
>
> Annoyance of inhabitants. Main factors are: Body odour, other odours and irritants.
>
> Damage to building fabric. Main factors are: Humidity and moisture.

Many of the pollution sources have their origin in building materials, building furnishing and decorations and processes and activities taking place within the building. Ventilation requirements has to take all the mentioned factors into account.

CODES AND GUIDELINES

The Norwegian regulations concerning building design and construction are composed of laws, codes and guidelines. There has been a shift from codes containing detailed requirements to codes based on functional requirements supported by guidelines containing information on how to fulfill the codes. The guidelines give examples of solutions that complies with the functional requirements, other approved solutions may be accepted as well. A collection of approved solutions is found in the Building Research Series published by The Norwegian Building Research Institute. These series cover solutions to design/construction details and technical installations as well as planning solutions.

Functional requirements

> Building shall have ventilation securing a satisfactory indoor climate in each and every room.
>
> The ventilation plant shall be built in such a way that good energy economy is secured, it is easy to control and easy to maintain.

Those parts of the plant that must be cleaned in order to function properly has to be made in such a way that all these parts can be cleaned from dust and other airborne depositions.

The ventilation plant shall be built in such a way that the capacities according to the requirements can be measured and adjusted.

Before the building is taken into use the ventilation plant should be controlled and adjusted in order to satisfy designed capacities.

The air quality within a room shall be kept at a level that will not, the use of the room taken into account, lead to discomfort or health risk.

The air flow between rooms shall be from a room with a low concentration to a room with a higher concentration.

The ventilation plant shall prevent the spread of gases and particulate matter that smells and/or are dangerous to health. Such pollutants shall be captured by means of local exhaust.

The ventilation plant shall prevent the spread of contaminants to the outside if this represents a danger to health or discomfort.

The guidelines supporting the building codes give recommended minimum ventilation rates which for public and commercial buildings are given as m^3/h m^2 floor area. For dwellings the requirements are a certain crossection of stacks for natural exhaust from specific rooms or specific exhaust air flow rates from the same rooms when applieing mechanical exhaust.

Public and commercial buildings

Room	Outdoor air	Pers./m2	Outdoor air/pers.	IEA Annex 9 Outdoor air req.
Work rooms	5 m3/h m2	0.3	16.5 m3/h	0.5-1.0 ach for
Assembly halls	10 "	1.5	6.7 "	moisture and
Sporting halls	10 "	0.3	16.5	humidity.
Kitchen	15 "	0.3	50	20-30 m3/h pers
Offices	5 "	0.1	50	for body odour.
Stores	5 "	0.3	16.5	30-70 m3/h pers
Class rooms	7 "	0.5	14	for tobacco smoke.
Waiting rooms	3 "	0.6	5	

As we can see from the tables, the ventilation for office rooms can be said to be of a high standard compared with the recommendations found in the IEA annex IX, minimum flow rates, while the standard is very low for class rooms and assembly halls. This is also reflected in practice where one almost without exceptions have complaints in classrooms, kindergardens and assembly halls ventilated according to the recommendations in the codes.

Dwellings

Room	Natural exhaust. cm^2	Mech exhaust m^3/h	Suppl. air grilles , slots, ducts
Living rooms	-	-	Openable window or 100 cm^2
Kitchen	150	60	Slot over under door 100 cm^2
Bathroom with or without WC	150	60	"
Sep. shower or sep. WC	100	40	"
Washing- and drying room	150	80	Openable window or 150 cm^2 in outer wall, 150 cm^2 between adjacent rooms

The ventilation standard will vary according to how many rooms requiring exhaust there are in the house. Typically, the ventilation, using mechanical exhaust, will vary between 0.5 and 1.0 ach. In natural ventilated dwellings the ventilation is not under control and the ventilation standard is usually rather low. Many homes financed by the The State Bank for Housing have only natural ventilation. The effect of this is that the ventilation in houses financed by the State Bank for Housing will be rather poor compared with larger dwellings of higher standard.

General comments

The recommendations in the codes obviously do not take properly into account all the pollution sources in a building not even the number of persons occupying the space. For this reason one can say that the ventilation standard is rather uneven.

The shortcomings of the present guidelines are obvious and they will be revised in the future. The Nordic Committee for Building Regulations is working on a revision of the air quality section of The Nordic Guidelines for Indoor Climate. The outcome of this work will have a great impact on the future Norwegian air quality and ventilation guidelines.

SYSTEMS AND COMPONENTS

Codes and guidelines are still governed by the view that the human beeing is the main source of pollution indoor, which is no longer the real case. Up to the sixties this was probably more true since the general practice before that time was to use well known "natural" building materials. Since the sixties the development in the field of materials for the building and its furnishing has been allmost explosive in an historical time perspective. This is especially the case for surface materials like panels, wallcovers, carpets and paintings, introducing a large, ever increasing number of chemical cmponents in the indoor environment, components which not at all are good for our health.

Dwellings

The building codes are generally the bases for ventilation requirements.

Natural ventilation was dominating up to mid sixties. However, mechanical exhaust was used for kitchen ventilation either as a genaral exhaust or through exhaust hoods above the stoves.

Gradually total mechanical exhaust was taken into use, first of all in dwellings not financed by the State Bank of Housing. Exhaust air was taken from kitchen, bathrooms, WC and washingrooms, in the same way as for natural exhaust. The principle of exhaust ventilation is shown in fig.6.

The change to mechanical exhaust led to better standard of ventilation. Especially, problems with moulds and fungis in the "wet-rooms" were reduced. Nevertheless, mechanical exhaust is not without problems. Fans and ducts are not maintained in a proper manner. Fans stop running and ducts become dirty. When this happens the ventilation becomes worse than with all natural exhaust, because of the smaller dimensions of the ducts. This is still a problem.

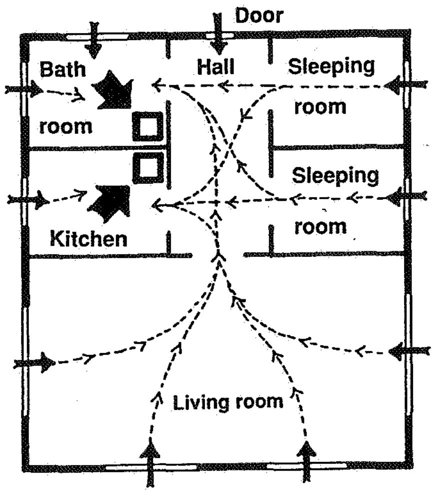
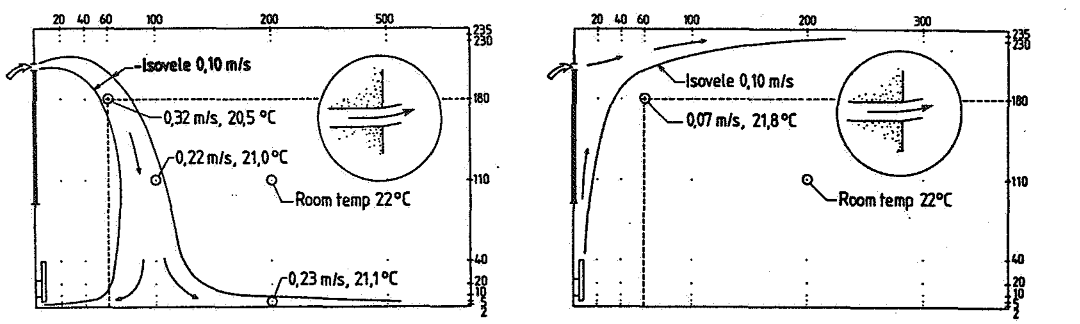


Figure 6. The main routes of the ventilation air flowing through a building with exhaust ventilation.

After the oil embargo in 1973 the standard of ventilation was reduced because of the great focus on energy saving, where the simpliest mean was to reduce the infiltration and/or ventilation of the buildings. This was done by tightening the building and closing the air valves. Buildings with natural ventilation suffered most from this. Buildings with mechanical exhaust suffered also because the fans were not sized for the resulting smaller inlet flow crossections. The need for ventilation because of the new development in building materials required in reality an opposite approach.



a. Air flow pattern with a slot outlet. The supply air temperature °C. Outdoor air flow rate 5 l/s. Panel heater 0 watt.

b. Air flow pattern with a slot outlet. The supply air temperature °C. Outdoor air flow rate 5 l/s. Panel heater 350 watt.

Figure 7. Exhaust ventilation. When the heater is on, draught can be avoided.

Mechanical/natural exhaust ventilation are installed with outdoor air supply openings/valves in the outer walls, generally located in the upper window frame, but also other locations are used. This may lead to drauhgt problems. Investigations carried out at the Norwegian Building Research Institute have shown that this is of no problem when the room heaters under the windows are not shut off, fig.7. However, when using radiators with thermostats the heat will go on and off, resulting in draught risk.

There has been some activity developping components overcoming this problem. One method has been to integrate the radiator and the outdoor air supply, fig.8. Another has been to develop supply devices (diffusers) giving draughtfree ventilation with unheated outdoor air. The principle is to create a more intense mixing with room air, in and close to the diffuser.

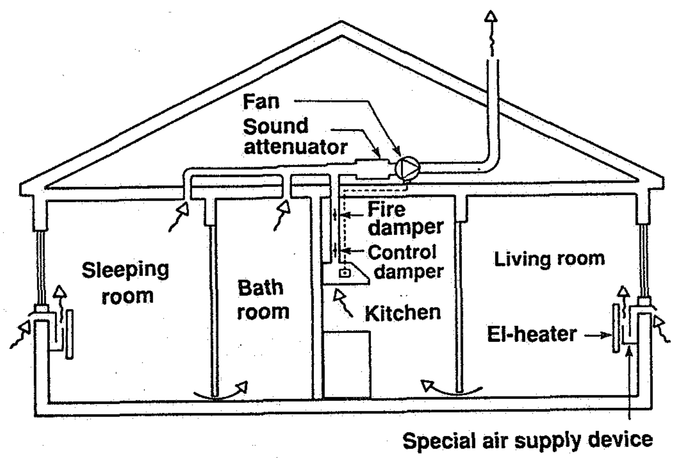


Figure 8. Mechanical exhaust ventilation. The fan is placed in the attic. The figure shows how draught problems can be solved by using special components integrating the room heating device and the air supply device.

The oil embargo also resulted in an activity developping balanced ventilation systems with heat pumps and heat recovery. Such systems allow a higher standard of both ventilation and thermal comfort, see fig.9, without an increase neither in energy consumption nor in the total cost per year of owning and running the building. However, the State Bank of Housing does not finance such solutions.

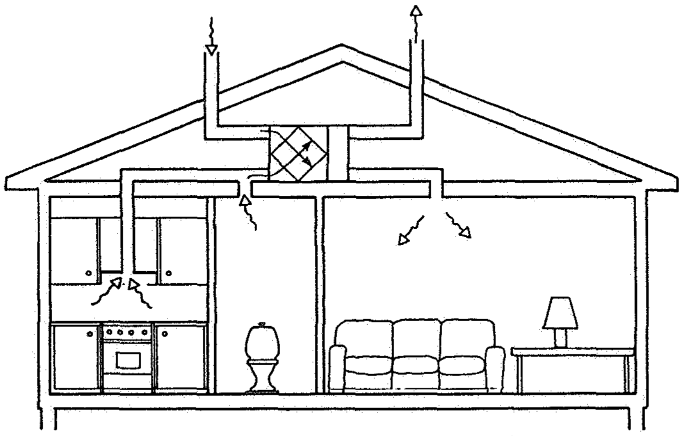


Figure 9. Building equipped with balanced, mechanical ventilation and heat recivery unit.

Systems with heat pumps using the exhaust air as heat source for heating the warm water sypply, is increasing in popularity, fig.10. Such systems are now made for also preheating the ventilation air.

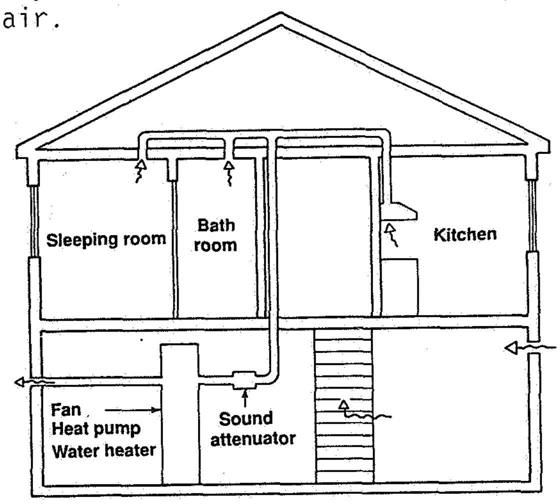


Figure 10. Example of mechanical exhaust ventilation combined with a heat pump. The fan is placed in the basement. Fresh air is taken throug the basement and is supplied to the living rooms via the stair well. In this way a certain preheating of the fresh air is achieaved.

The future

Future ventilation systems will certainly be balanced systems with heat recovery and/or heat pumps because we will have tighter constructions in the future. The solutions will take advantage of the possibilities for using cheap microprocessor technology in what we may call "intelligent" ventilation. This will be some kind of demand controlled ventilation. The strategy will be to supply ventilation air to that part of the building which is occupied or in use. In day time to the living area, in night time to the sleeping area in combination with timer control of for example bathroom exhaust, either user activated or occupancy sensor activated. This will lead to much better air quality and comfort without a substantial increase in total ventilation airflow requirements. A certain minimum basic ventilation must be secured all the time to unoccupied areas. The exhaust air will be from the same zones as we find in existing practice in addition to other "intelligent" exhaust points.

The use of heat pumps and solar assisted preheating of the ventilation air will be common.

Public and commercial buildings

The minimum ventilation requirements in the codes are generally the bases for outdoor air flow rates. Higher flow rates are occasionally used. On the other hand, source control are generally not properly applied. However, due to lack of maintainance and adjustment, lower flow rates than the design values are generally found in practice.

Mechanical balanced ventilation has been the most common practice the last twenty to thirty years, allthough mechanical and natural exhaust systems has been used to some extent. Natural and mechanical exhaust has been most common in smaller office buildings, schools and kindergardens. Because of the very low ventilation requirements in the codes for schools and kindergardens most of the sick building problems are found in these types of buildings.

The oil embargo led on the one hand to reduced ventilation through more recirculation (reduced outdoor air supply) and no ventilation during nonoccupancy and on the other hand to more energy economic ventilation like the development of heat recovery equipment.

Systems that has been used:

Induction systems with heating and cooling facilities. Not widely used to day.

Single duct systems with zonal reheating, with/without fan coils for cooling.

Single duct systems with zonal reheating and cooled ceilings.

Single duct systems with separate roomheating without/with cooled ceilings or fan coils for cooling.

Dual duct systems. Very little used.

VAV systems.

All these are mixing ventilation systems, fig.11.

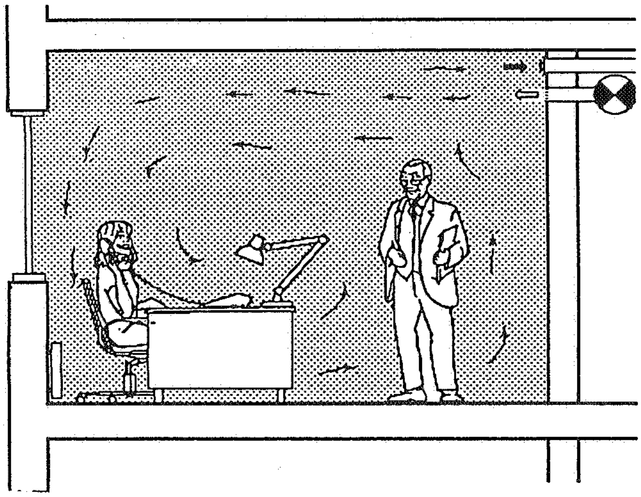


Figure 11. Mixing ventilation. Good mixing results in even concentrations in the whole ventilated space. The concentrations are the same as in the return air duct.

All-air systems have been demonstrated to have a substantial reduced ventilation effectiveness when the heating demand requires supply air temperature more than a few centigrade above room air temperature.

Recirculation leads to unfavourable spreading of pollutions and it is now a trend to less use of such solutions. Heat recovery is now allmost 100 % used and it is for this reason less arguments for using recirculation as a mean for energy saving.

In spite of increased knowledge and technical development the sick building problems seems to be increasing all the time in Norway. The reasons are likely to be that ventilation requirements and system solutions are not adjusted to the ever increasing sources of bad air quality or on the contrary, the pollution sources are not properly identified in order to apply the right measures for eliminating the sources. Another problem seems to be ventilation plants which are not properly cleaned neither at the time the building is taken into use, nor afterwards.

Norway has during the last decade been among the leading parties in the field of research in ventilation efficiency. The outcome of this is a new ventilation strategy which is called displacement ventila- tion, fig.12.

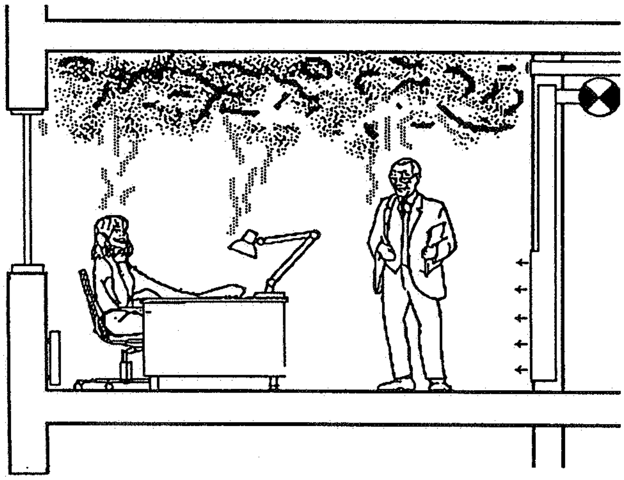


Figure 12. Displacement ventilation. The pollution concentrations increase with height. The air is transported upwards by convective currents. The concentrations in the breathing zone are lower than in the return air duct.

Another name is soft ventilation becasuse the ventilation air is supplied with low velocity (low momentum) directly to the occupied zone. Allthough this ventilation strategy for a long time has been utilized in industrial ventilation , it has been too little knowledge of the physical behaviour and theoretical discription of the method. The lack of theoretical treatment may be the reason for that, allthough treated in the litterature more than 100 years ago, there has been little application of the principle in the past.

The concepts of ventilation effectiveness is based on the age concept where age is defined as the time elapsed since the ventilation air entered the room, fig.13.

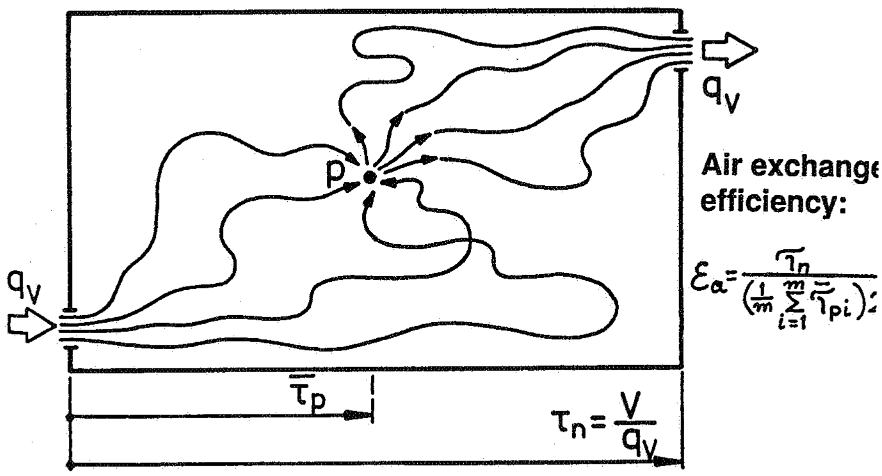


Figure 13. The local mean age, $\bar{\tau}_p$, of thew air is defined as the average time which will elapse after the air entered through the supply opening until it arrives at a certain point. The average age is the mean of the local ages.

Local age is the age of the air at a point in the room. Average age is the average age of all the air in the room. The shorter the age relative to the nominal time constant the better the ventilation potential is. The relative age is called air exchange efficiency. The shortest possible ages are found when the ventilation air flows like a piston through the room (plug flow). Displacement ventilation is to create a flow pattern that is as close to plug flow as possible, fig.14. The realative air quality or contaminant removal effectiveness is measured as the ratio between the concentration of pollutions in the return air and the concentrations in the breathing zone. The heat removal effectiveness can be defined in the same way, changing concentration with temperature.

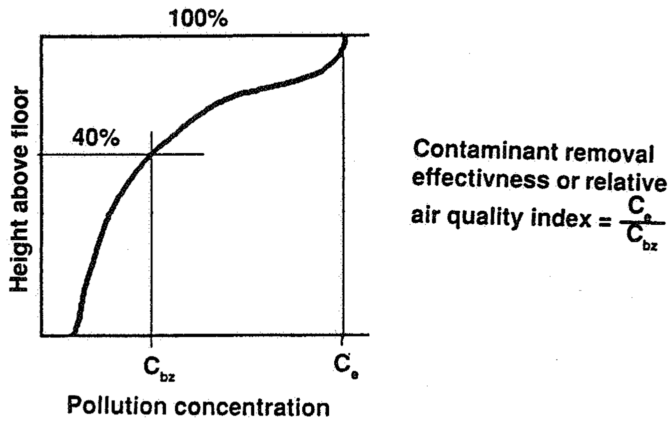


Figure 14. The shape of the vertical concentration gradient shows the displacement effect.

It has been demonstrated that the displacement principle results in a better ventilation effectiveness than mixing ventilation, and it also makes it possible to utilize free cooling with outdoor air in a much larger scale. However, it has also been demonstrated that it is necessary to adjust the ventilation flow rates to the number and strength of the heat sources present in the ventilated space. In normal Norwegian office rooms it is required to have ventilation flow rates as high as 7-8 m^3/h and m^2 floor area in order to have a significant displacement effect. For all ventilation systems there is for thermal comfort reasons a limitation in cooling capacity. Displacement ventilation is no exception to this. The cooling capacity is limited because of the limitation in vertical temperature gradients in the occupied zone. Increasing the cooling capacity means increasing ventilation air flow rates, better diffusers or installation of separate cooling systems like radiative cooling or a combination of radiative and convective cooling. There is at present research and development activities in all these areas.

Using displacement ventilation it is necessary to have separate heating systems. The trend in Norway is now to separate all three functions, ventilation, cooling and heating. Doing this one can optimize all three functions and get a more relieable operation of the HVAC systems in a building.

Ventilation strategy in the future

The objective is to secure healthy buildings with a comfortable indoor climate.

There will be strict requirements to the building, its furnishing, activities and processes. Among other things we will see building materials with health declarations.

Since there is difficult to use only quite "clean" materials there will be a requirement for increased ventilation during the first year of a new building or the first year after a renovation.

It is of great importance that the user can have an influence on his environment, therefore, individual control will be a basic requirement in future ventilation.

Of energy economic reasons, demand controlled ventilation will be a requirement, like a requirement for high ventilation effectiveness (displacement ventilation, spot ventilation).

Another important requirement is ventilation plants which are easy to clean and maintain, equipped with operating instructions which the building owner easyly can understand and also are easy to use.

Last but not least it will be necessary to put into practice a better quality control procedure in the building construction phase and a procedure for repeated control of the indoor air quality, for instance every second year.

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