2ND EUROPEAN CONFERENCE ON ARCHITECTURE 4–8 December 1989 PARIS, FRANCE Sponsored by Commission of the European Communities

NEW VENTILATION CONCEPTS WITH RESPECT TO INDOOR AIR QUALITY AND ENERGY CONSERVATION

P. Wouters
Belgian Building Research Institute
avenue Pierre Holoffe 21
1342 LIMELETTE - Belgium

ABSTRACT. The strong increase in energy prices during the seventies has focused most of the efforts on energy conservation. The fact that many European countries with a moderate to cold climate (e.g. Belgium, United Kingdom, West Germany, Switserland) haven't yet appropriate ventilation requirements for dwellings reflects the priority given to energy conservation measures. The eighties are more characterised by an increased awareness that a healthy indoor and outdoor environment is not evident. This growing awareness is a result of mould growth problems, the increased number of allergic reactions, the findings with respect to dangerous gasses (radon, ...) and particles (asbestos, ...). It becomes more and more clear that a good indoor air quality has its price.

As a result of it, there is at present in the field of ventilation a clear trend to optimize the combination of a good indoor air quality with a reasonable energy consumption. Many research projects in the eighties were focused on a better understanding of the indoor air quality. At present, the various pollutant sources are better known, the allowable concentration levels in occupied zones are better defined and new ventilation concepts with respect to the distribution system as well as with respect to the control strategy (e.g. demand controlled ventilation), are becoming operational.

A second clear trend is the strong increase in knowledge with respect to ventilation. Most significant is the evolution in computer modelling and measurement techniques.

However, there is still a lot of work to be done with respect to the development of simplified design rules for designers as well as with respect to user friendly software codes for more detailed calculations.

1. INTRODUCTION

To realise a good indoor air quality is less evident than many people thought 5 - 10 years ago. Various types of pollution are possible. The same is true for the outdoor environment. In its first part this paper is focused on the indoor air quality. The important role of ventilation becomes clear from this limited analysis. In the 2nd part more attention is paid to ventilation related research activities and some new trends in building practice.

2. THE SIXTIES AND SEVENTIES : FIRST MORE, THEN LESS

The technology available in the sixties, the strong growth in economy and the increase in income have stimulated new construction types, new heating systems and also new ventilation systems. The main aim of these changes was to increase comfort. The application of mechanical ventilation systems, especially in office buildings and appartments, was increased significantly. Due to the low energy prices, high ventilation rates per person were no real problem. An energy conscious design was in these circumstances less crucial.

The strong increase in energy prices due to the energy crises in the seventies significantly changed this situation. This resulted in :

* increased thermal insulation of the building envelope to reduce heat losses;
* use of appliances with a higher efficiency;
* lower indoor temperatures;
* efforts to reduce ventilation losses, e.g. by draught-stripping and low standard values for ventilation. The 1981 version of ASHRAE-standard 62 /1/ requires only 9 m^3/h person (ASHRAE - American Society for Heating, Refrigerating and Air Conditioning Engineers).

The effect of these changes on the specific energy consumption is clearly shown in figure 1.

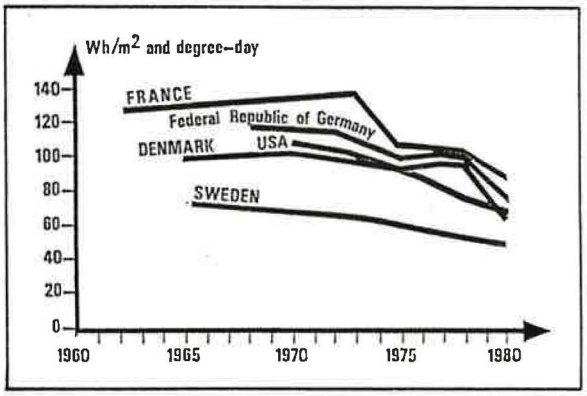

Figure 1 : Specific energy consumption per m^2 of heated floor surface (corrected for degree-days)/2/

Research activities in the second half of the seventies and the beginning of the eighties were primarely focused on strategies to reduce the energy consumption. In most countries the concern for a good indoor air quality was a marginal part in the research activities.

The Programme on Energy Conservation in Buildings and Community Systems (ECBCS), operating within the International Energy Agency (I.E.A.) started various research activities /3/. The Air Infiltration Center (A.I.C.) was created as an international organisation for coordination of research and technology transfer /4/.

One can summarise these 2 decades by stating that on the one hand the sixties have led to a strong increase in energy demand (and ventilation) due to comfort reasons. On the other hand the second half of the seventies and the beginning of the eighties have led to a strong need to reduce the energy demands and ventilation losses due to budgetary reasons. This is illustrated in figure 2.

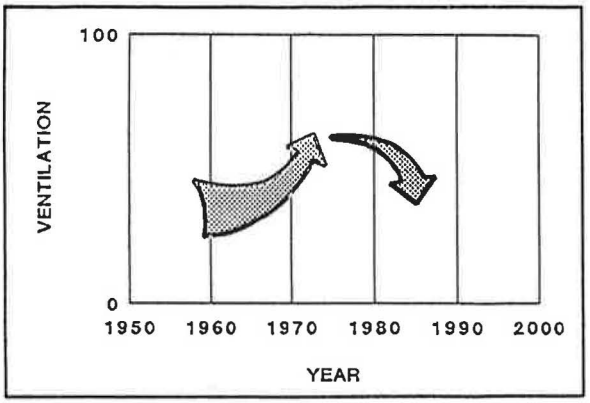

Figure 2 : General trends in energy consumption and ventilation losses

3. THE LATE EIGHTIES : MORE AND LESS AT THE SAME TIME

Health issues related to the quality of the indoor environment have received in the late eighties. large interest by the public and the media :
- radon-related problems;
- asbestos and other particles;
- allergic reactions due to a bad air quality;
- problems in the field of the so-called "sick-building syndrome";
- moisture and mould growth.

Increased ventilation seems to be an appropriate solution to improve the air quality.
The strong reduction in energy prices during the last 5 years has given many people the impression that energy efficiency has become less crucial.
Figure 3 shows the evolution of the imported crude oil price in US $ and ECU according to information and estimations by CEC-DG XVII /5/.

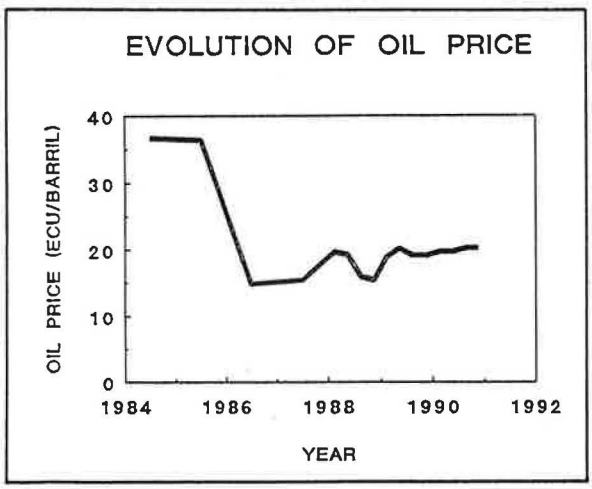

Figure 3 : Estimated evolution of oil price at short term /5/

The reduction in the energy prices has in any case a negative impact on the financial benefits of investments in energy efficiency improvements. The advantage being higher ventilation rates at a reasonable cost.

However, environmental issues have become more and more important towards the end of the eighties :
- a number of important industrial and nuclear accidents have shown how seriously we are at present capable of damaging large parts of the outside environment;
- the problems of acid rain, deterioration of the ozon layer, warming up of the atmosphere due to CO_2-increase are seriously threating our future.

One of the main effects of the growing interest by the public in these environmental problems is the very recent political statements that energy efficiency is an important issue, NOT only for budgetary reasons BUT also for environmental reasons. Important budgets will be reserved in the near future to improve energy efficiency.
Mr. J. Millhone, Director Buildings and Community Systems at the U.S. Department of Energy declared recently at the European Conference on Energy Efficiency in Buildings in Lille (F) /6/, that energy efficiency is again an important issue for the U.S. government for 6 reasons :
. economic efficiency;
. economic competitivity (with other countries);
. global warming (CO_2);
. acid rain;
. ozon depletion (limit emission of CFC);
. national security (limit dependency of energy import).

Figure 4 gives a graphical representation.

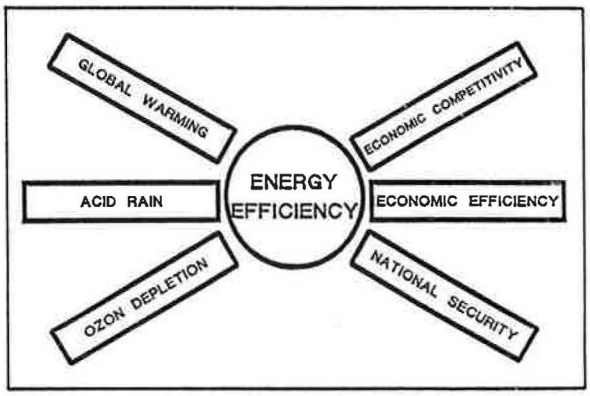

Figure 4 : Main reasons of U.S. Department of Energy for policy of energy efficiency /6/

One can summarize the situation with respect to the ventilation related topics, by stating that 2 types of requirements should be met in the near future :
- on the one hand, better indoor air quality is needed in most building, implicating probably more fresh air;
- on the other hand, the need to reduce to pollution of the outdoor air requires lower energy consumption and less ventilation losses.

This 'more and less'-requirement is shown in figure 5.

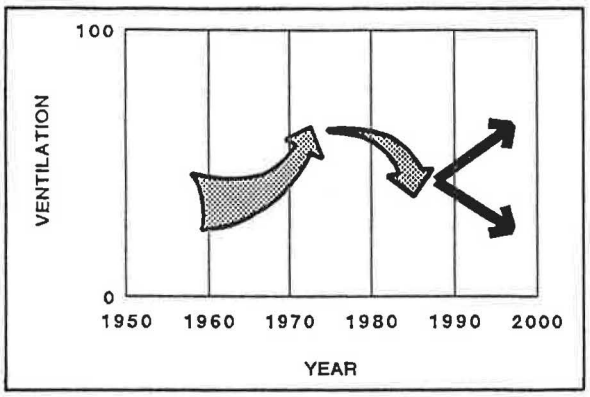

Figure 5 : The 'more and less' trends in the late eighties

One part of this trend is already reflected in the 1989 draft proposal of the ASHRAE- standard 62 which requires 7.5 l/s/person instead of 2.5 l/s/person in the 1981 version.

4. THE ROLE OF VENTILATION WITH RESPECT TO HEALTHY BUILDINGS AND THE SO-CALLED SICK BUILDING SYNDROME (SBS)

Many reports published during the last decade in Scandinavia, North America and Western Europe indicate high incidence of sickness among people in certain office buildings. This phenomenon is often described as the sick building syndrome. It is without any doubt a rather controversal issue, partly due to the commercial misuse by certain firms who want to sell products, houses,... based on doubtful arguments related to the 'building health'.
However it is sure that a number of buildings suffer serious problems.
The most common symptomes in such SBS-buildings are /7/ :
- eye, nose and throat irritation;
- sensation of dry mucous membranes and skin;
- erythema (skin rash);
- mental fatigue;
- headaches, high frequency of airway infections and cough;
- hoarseness, wheezing, itching, and unspecified hypersensitivity (allergic reactions);
- nausea, dizziness.

The WHO (World Health Organisation) identifies a number of features common to sick buildings, /7/, /8/ :
- they often have 'forced' ventilation (WHO does not make specific reference to air conditioning although air conditioning will fall into this general category);
- they are often of lightweight construction;
- indoor surfaces are often covered in textiles (carpets, furnishing fabrics,..);
- they are often energy efficient, kept relatively warm, and have a homogeneous thermal environment;
- they are often airtight, i.e. windows etc. cannot be opened.

According to Sykes in a review paper on the Sick Building Syndrome /7/, many causes have been suggested for sick building syndrome, including :
- airborne pollutants :
  . chemical pollutants from occupants, fabric, furnishing, ...;
  . dusts and fibres;
  . microbiological contaminant from carpets,furniture, occupant, HVAC-system;
- odours;
- lack of negatively charged small air ions;
- inadequate ventilation/fresh air supply;
- low relative humidity;
- poor working environment/discomfort due to
  . high temperatures;
  . inadequate air movement/stuffiness;
  . poor lighting;
- general dissatisfaction or psychosomatic curves.

It is clear that the energy crisis has contributed "to better conditions" for SBS-problems :
- unappropriate thermal insulation techniques have led to mould growth problems;
- financial problems resulted in lower or no maintenance of HVAC systems;
- lower ventilation rates;
- lower indoor temperatures.

Many questions with respect to SBS and healthy buildings still need a precise answer. However, the important role of good ventilation design as an element in a strategy to evacuate the pollutants as well as to reduce air pollution by the system itself is generally accepted.
The second part of the paper is more focused on ventilation related research activities and the impact of these activities on the building practice in the future. The activities are for practical reasons split up in 3 parts :

5. Activities related to a better description of the actual problems and the required performances
6. Trends in detailed research activities on ventilation
7. New trends in ventilation design

5. ACTIVITIES TO EVALUATE ACTUAL PROBLEMS AND TO SET UP AIR QUALITY REQUIREMENT

Many research projects in the eighties aimed to get a better understanding of various aspects of air pollution. A few projects are described below.

5.1. IEA-ECBCS Annex 9 : "Minimum ventilation"

An international project including participants of 12 countries was set up in 1982 to clarify the problem of air pollution and the role of ventilation. Table 1 summarizes the types of pollutant which were investigated.

Indoor Pollutant	Minimum ventilation rate
Tobacco smoke	5 - 120 m^3 per cigaret
Particles	17,5 l/s person (based on average smoking habits)
Body odour	8 l/s person
Humidity	0,5 - 1 vol/h
Radon	no general rules
Combustion products	no general rules
Selected organic compounds	no general rules

Table 1 : Types of pollutant investigated in IEA-ECBCS Annex 9.

This project finished in 1987 and a report is available free of charge for people in the participating countries /9/.

5.2. Research on air quality perception

In order to come at long term to a global evaluation of the air quality as perceived by the occupants, a research project led by O. Fanger /10/, /11/ was set up. As a result of it, 2 new units were defined : the OLF and the DECIPOL /10/.
An important part of the research activities concerned 20 non-domestic buildings in the region of Copenhagen. One very important finding was the determination of the various pollution sources. Figures 6 and 7 show clearly that the occupants by their body odours are on the average, for the 15 office buildings, only responsible for 13 % of the perceived air pollution. The ventilation system and the building materials are responsible for 42 % and 20 %.

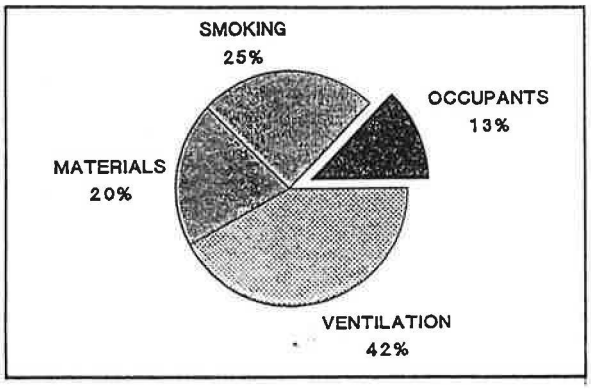

Figure 6 : Average air pollution by various sources in 15 office buildings in Copenhagen /11/.

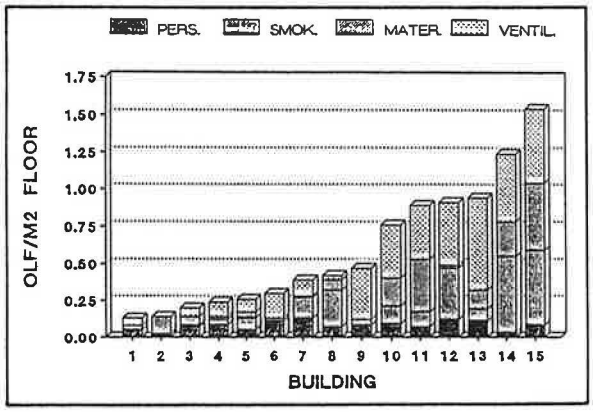

Figure 7 : Air pollution by various sources for 15 office buildings in Copenhagen /11/

5.3. IEA-ECBS Annex 14 "Energy and condensation" /12/

The energy crises of the seventies have directly resulted in a strong increase in thermal insulation of buildings. Mainly due to poor design and/or bad execution of the work, a strong increase in condensation and mould growth problems was found afterwards. Several studies mention figures of 5 to 20 % of social houses with moisture problems.
The IEA project "Energy and condensation" focuses on a better understanding of the causes and the remedial strategies.
Some preliminary conclusions relating to ventilation :

- a continuous even limited ventilation of occupied rooms is very important
- the hygric inertia of building finishing and furnishing may be very important.
  Intensive ventilation of short duration (5 .... 10 min) is therefore not an appropriate strategy with respect to moisture.

It also seems to be proven that a significant part (figures up to 20 %) of occupants living in buildings with severe mould growth problems, have allergic reactions after 2 years.

5.4. Radon

Radon migration into buildings may create health risks for people living in these buildings. Surveys in many countries indicate that the problems largely depend on the ground below the building, the airtightness of the building envelope, the location of these leakages and the ventilation strategy. Ventilation can play an important role :

- it can reduce the radon levels by dillution;
- it can also increase the problems especially in the case of a mechanical extraction system bringing the building in underpressure and sucking the radon into the building.

A project involving several CEC-countries is now set-up by CEC DG XII to study radon source models and counter measures.

5.5. Better understanding of draught conditions

Draught problem is one of the most common complaints in mechanically ventilated buildings with mechanical air supply. A research project, led by O. Fanger /13/ aimed to have a more accurate formula for estimating the draught risk. It includes the air temperature and the turbulency. Figure 8 shows the formula proposed /13/.

MODEL OF DRAFT RISK

$$PD = (34 - t_a)(\bar{v} - 0.05)^{0.62}(0.37\,\bar{v}\,Tu + 3.14)$$

for $\bar{v} < 0.05$ m/s insert $\bar{v} = 0.05$ m/s, for $PD > 100\%$ use $PD = 100\%$

where PD = Percentage Dissatisfied people due to draught (%)
t_a = air temperature (°C)
$\bar{v}$ = mean air velocity (m/s)
Tu = turbulence intensity (%)

Figure 8 : Formala for estimating draught risk /13/

6. TRENDS IN DETAILED RESEARCH ACTIVITIES ON VENTILATION

The limited knowledge on how ventilation really happens in buildings at the beginning of the eighties, the increased importance of ventilation losses in the energy balance and the general feeling that ventilation is an important element in the health issue, has stimulated research on ventilation related topics. They can be subdivided in multi-zone studies and single-zone studies.

6.1. Multi-zone studies

The study of air flows between zones is an important topic, experimental and simulation activities are going on.

6.1.1. Experimental studies

- Tracer gas systems are used for more than a decade in ventilation research. Most emphasis at present goes to the development of new measurement techniques allowing to measure not only the fresh air flow rates from the outside but also the interzonal flow rates. This leads in most cases to the use of several tracer gasses.
- Another important activity is the experimental determination of the leakage paths in buildings. This involves the use of advanced pressurisation techniques. The knowledge obtained by these activities will allow to better evaluate which ventilation systems are appropriate in certain building types. The results of the leakage distribution will be usefull as input data for simulation.

6.1.2. Theoretical studies

The prediction of air flows between zones is an important aid for evaluating the functioning of various ventilation strategies. The COMIS project /14/ (Conjunction of Multizone Infiltration Specialists) was set-up in 1988 to allow the development of a powerfull and well validated programme for predicting air flows in multi-zone buildings.
A market study of available programmes during the preparation phase of COMIS resulted in the data of table 2 /15/.

Table 2 Review of Multizone Infiltration Network Models

Program Language:	FORTRAN	33
	BASIC	6
	PASCAL	1
	C	1
	HPL	3
Computer Type:	Main Frame Computer	23
	Personal Computer	18
Solver:	Newton	22
	others	8
Input Features:	interactive input	10
	CAD-input	1
	weather data from weather files	18
	3-D building description	8
	schedules (e.g. occupants)	14
Output Features:	file of arrays used by the model	23
	graphical output	7
	statistical functions	
Miscellaneous:	combined with thermal model	12
	combined with pollution model	8
Program Available?	yes	7
	no	11
	yes, but	11

Table 2 : Overview of features of multizonal simulation programmes /15/

Some 10 researchers worked together during 1 year in Berkeley (U.S.) and at present a first version of the programme is available.
It is clear that there are still large uncertainties with respect to e.g. the air flow through large openings, the pressure distribution around buildings, occupant behaviour. These topics as well as others are studied in the framework of various national programmes (e.g. Belgium, France, Switserland) as well as in IEA-ECBS Annex 20 "Air flows in buildings".
A very important challenge for the future is the validation of these programmes. It seems realistic to expect a lot of results during the next 5 years.

6.2. Single-zone studies

The study of flow patterns within one zone is a topic to which a lot of attention is paid. This is on the one hand due to the need to know more about the pollution distribution within a room, new ventilation systems, thermal comfort studies, ...) and on the other hand due to new measurement and simulation tools allowing for detailed studies.

6.2.1. Experimental studies

- The need to describe the efficiency of ventilation systems and of the evacuation of pollutants has led to new measurement techniques allowing to determine various kinds of efficiency. A detailed description is found in /17/ and /18/. A number of these methods are already standardised in Scandinavie. These methods allow to evaluate the performance of classical ventilation systems as well as of new ventilation concepts, e.g. displacement ventilation /19/.
- The need to measure the flow patterns within one zone has resulted in research on new measurement techniques. Laser Doppler Anometry (LDA) which allows velocity measurements 'at distance' seems to be a very promising technique.

Many measurements of air flows and temperature distribution with more classical methods are at present done. The purpose of these measurements is on the one hand to evaluate the performances of various ventilation systems and on the other hand to collect data-sets for validating predictions by computer programms (see 6.2.2.).

6.2.2. Theoretical studies

According to P. Nielsen /20/ the cost of full-scale experiments is in the range of 3 000 to 20 000 US $ or even more. The accuracy of the results can be very good. One alternative is flow simulation. The use of flow simulations is a question of the price level and of the quality of the predictions. At present the price of a full-scale experiment and of a flow simulation are of similar magnitude. Airflow simulations will increase in importance in the coming years due to the economics. Chapman /20/ /21/ shows how the relative computation cost is decreasing every year and this trend will continue in the coming years. Figure 9 shows that the cost of performing a given calculation has been reduced by a factor of 10 every 8 years. There is also the trend from mainframe computers in computer centers to work stations located close to the user. This will increase the use of simulations. There are promising results with respect to the future of flow simulations. Figure 10 is an example of results found by Hestad and Nielsen /20/. There is a fairly good agreement between measurements and calculations.

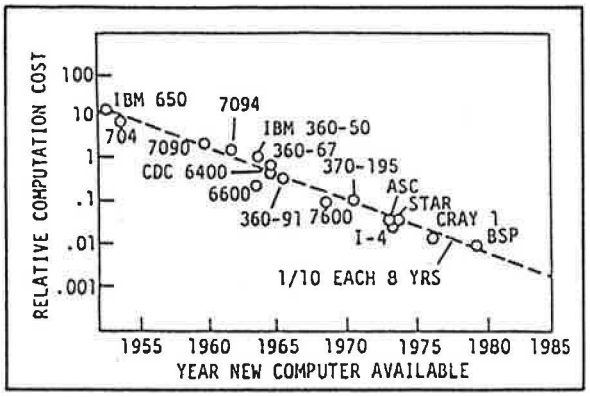

Figure 9 : Trend of relative computation cost for a given flow and algorithm /20/ /21/

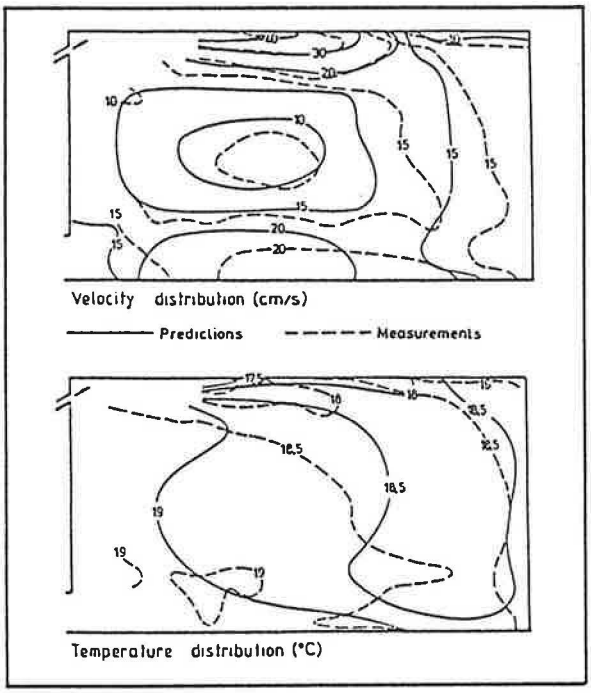

Figure 10 : Isovels and isotherms in a room with 2-dimensional thermal flow according to Nielsen and Hestad /20/

7. NEW TRENDS IN VENTILATION DESIGN

This paper obviously doesn't aim to give a complete overview of the technical evolutions in ventilation systems. It intends to show a number of remarkable trends.

7.1. Installation of ventilation previsions in the domestic sector

In several European countries (France, The Netherlands, Scandinavian countries) the systematical installation of ventilation previsions is more or less the rule. In other countries (e.g. Belgium, Switserland, UK, ...) this is not so at all. The growing interest in air quality issues and the standardisation intentions in a number of these countries indicate the large probability of significant changes in these countries. This trend - not involving new technological findings - is probably one of the most important evolutions with respect to ventilation.

7.2. Demand controlled ventilation

The need to guarantee a good air quality at a low energy cost and the fact that there can be large variations in occupancy and pollution profiles requires optimisation and control strategies. Building Energy Management Systems (BEMS) are at present already used and can control the whole HVAC and technical appliances systems. BEMS systems are studied in the framework of IEA-ECBCS Annex 16 (hardware) and Annex 17 (software) /3/.
The optimal control of the ventilation is at present possible by using e.g. variable air volume (VAV) systems and by installing air quality sensors in various parts of the building. This so-called demand controlled ventilation (DCV) is thoroughly studied in the framework of IEA-ECBCS Annex 18 "Demand Controlled Ventilation" /22/. At present, a list of commercial sensors is available and detailed performance testing of a number of these sensors is started by the Swedish participant. The types of sensors which are under analysis are :

- humidity sensors
- CO_2-sensors
- CO-sensors
- mixed gas sensors

7.3. Integrated components

Various reasons (energy recuperation, no draught problems, higher surface temperatures) have led to the development of building components which combine various functions, one of them being ventilation. Figure 11 and 12 show some examples.

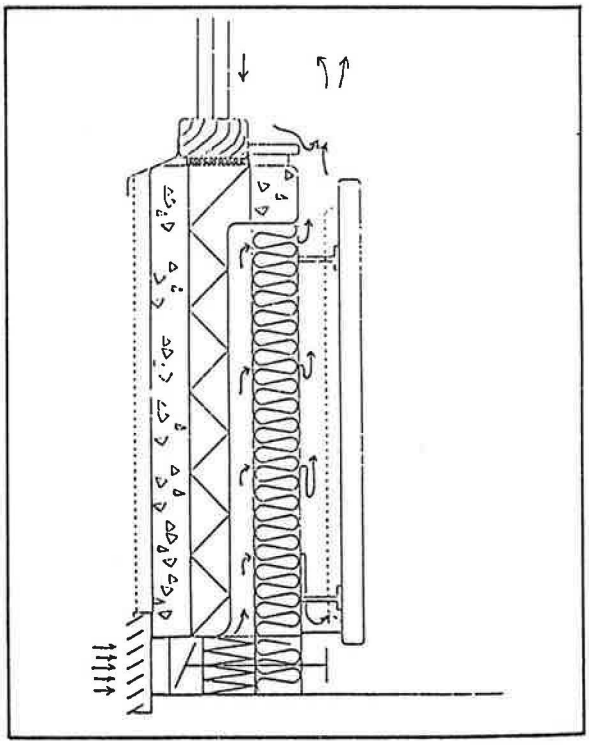

Figure 11 : Wall components also functioning as air inlet aiming to eliminate draught problems /23/

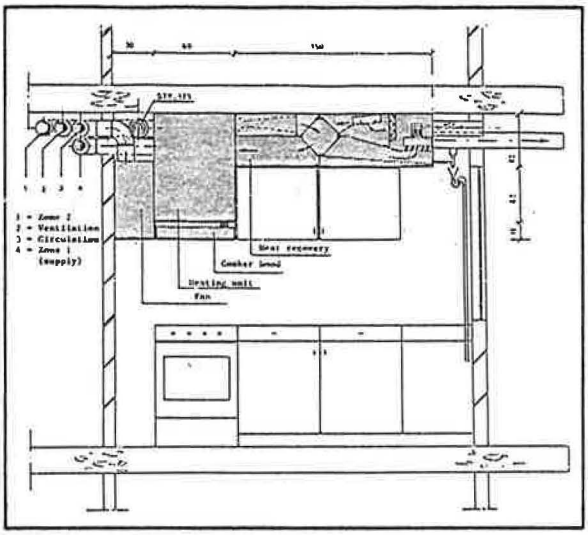

Figure 12 : Example of unit integration of various functions (heating, ventilation, hot water, cooking hood) /24/

7.4. Maintenance procedure HVAC-system

Several studies have highlighted the bad quality of the air entering the room by the HVAC system. The main reasons are : no or poor maintenance and/or no replacement of filters,... It is expected that in the future more attention will be paid (and more budget) to the keeping of the HVAC-system in a good condition.
Several firms are at present specialised in cleaning these systems.

8. CONCLUSIONS

The concern to have a cleaner indoor air and to protect the outdoor environment is a very remarkable fact of the last few years. Ventilation design and use is of paramount importance to reach both goals.

9. ACKNOWLEDGMENTS

The author wishes to thank the organisations who have sponsored various research projects allowing to make this paper : the Belgian Ministry for Science Policy (D.P.W.B./S.P.P.S), the Institute for Encouragement of Scientific Research in Industry and Agriculture (I.W.O.N.L./I.R.S.I.A.), the Ministry for Economic Affairs. The paper itself is the result of the efforts of the author, L. Vandaele, R. Bossicard, E. Bruyninckx, D. L'Heureux and P. Voordecker. Mrs. A. De Keyser, B. Deffense and A.F.Stalport took care of the typing and the lay-out.

10. REFERENCES

/1/ ASHRAE 62-1981, Ventilation for acceptable indoor air quality, ASHRAE Atlanta (US), 1981.
/2/ Swedish Council for Building Research, Energy 1985, Energy use in the built environment.
/3/ International Energy Agency, Energy Conservation in Buildings and Community Systems Programme, March 1985.
/4/ Air Infiltration Review, Publication by Air Infiltration and Ventilation Center, quarterly, AIVC, Coventry.
/5/ Energy in Europe, Short term energy outlook for the European Community, CEC DG XVII, Brussels, May 1989.
/6/ Millhone, J., Energy efficiency in buildings. Conference "Energy Efficiency in buildings", Lille, 28-30 November, 1989.
/7/ Sykes, J.M., Sick Building Syndrome, Building Serv. Eng. Res. Technol, 10 (1) 1-11, 1989.
/8/ World Health Organisation, Indoor Air Pollutants : Exposure and Health Effects, Report Norlingen, 8-11 June 1982, ISSBN 92 890 12 447.
/9/ Haberda, F., Trepte, L., IEA Annex 9, Minimum ventilation rates and measures for controlling indoor air quality, Technical Note 26, AIVC, Coventry, 1989.
/10/ Fanger, P.O., The Olf and Decipol, ASHRAE Journal, October 1988.
/11/ ASHRAE, HVAC Handbook, Chapter 27, Environmental control for survival, ASHRAE 1987.
/12/ IEA Annex 14, Contact person : Prof. Hens, H., Operating Agent, K.U.Leuven, Kasteel Arenberg, 3030 Heverlee, Belgium
/13/ Fanger, P.O., Melikov, A.K., Hanzawa, H., Ring, J., Turbulence and draught, ASHRAE Journal, April 1989.
/14/ The Comis Infiltration Model, The Comis group, 10th A.I.V.C. Conference, Dipoli, Finland, 25-28 September 1989.
/15/ Feustel, H., Mathematical modelling of Infiltration and Ventilation, 10th A.I.V.C. Conference, Dipoli, Finland, 25-28 September 1989.
/16/ Moser, A., Flow Flash Newsletter, ETH Zurich, 1989.
/17/ Liddament, M., A review and bibliography of ventilation effectiveness - definitions, measurement, design and calculation, Technical Note 21, AIVC, Coventry, 1987.
/18/ A new, more detailed technical note will be published by A.I.V.C. in 1990.
/19/ Nielsen, P., Hoff, L., Pedersen, L.G., Displacement ventilation by different types of diffusers, 9th A.I.V.C. Conference, Gent, Belgium, 12-15 September 1988.
/20/ Nielsen, P., Airflow simulation techniques, progress and trends, 10th A.I.V.C. Conference, Dipoli, Finland, 25-28 September 1989.
/21/ Chapman, D.R., Computational Aerodynamics Development and Outlook, AIVC, J., vol. 17, pp. 1293-1313, 1979.
/22/ Demand Controlled Ventilation Systems : State-of-the-art-Review, IEA-ECBCS, Annex 18, 1989.
/23/ Werner, G., Outlet air inlet without draught problem, 10th A.I.V.C. Conference, Dipoli, Finland, 25-28 September 1989.
/24/ Stork Ventilatoren, b.v. Zwolle, Nederland.