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A Storm Building Up - Low Energy Housing in the Orkney Islands

by Malcolm Orme, AIVC Scientist

Introduction

The Orkney Housing Association's (OHA) Low Energy Housing Pilot Project has demonstrated that it is possible to construct airtight buildings in the UK with minimal additional expenditure. This was achieved by careful planning, the incorporation of good building practice into the initial design and on-site supervision of the builders. The aim of the project was to construct two pairs of semi-detached single storey houses, with additional energy conservation features in one pair. Ventilation in the "low energy" dwellings is provided using balanced mechanical systems with heat recovery, and trickle vents in the "standard" dwellings. Measurements have revealed that the low energy pair are as airtight as many houses in colder regions of the world, such as Scandinavia. It is now planned to compare their performance over a two year period, by measuring energy use in relation to external climate in each occupied dwelling.

Project Background

The overall management of the project was by OHA, with technical contributions by the following organisations:

- Building Research Establishment
- Heriot-Watt University
- International Centre for Island Technology
- Scottish Homes
- Scottish Hydro Electric PLC
- Orkney Housing Association Ltd
- Orkney Islands Council

The project is especially important for OHA, who provide low cost housing for the local population. Due to the local climate, fuel bills can typically account for 30% of the cost of rented accommodation in the Orkney Islands, so reductions in wasted energy can lead directly to a higher standard of living.

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Figure 1 The low energy houses (UK Crown Copyright 1994)

Geography of the Orkney Islands

The Orkney Islands (population 20,000 people) are situated approximately 10 km off the north coast of Scotland at 59° N 3° W (similar latitude to Oslo and Stockholm), extending in the region of 70 km in length. Seventeen of the Islands are inhabited. The local terrain is mainly comprised of windswept hills with few trees.

Average wind speeds on the Islands are typically 50% higher than the Scottish mainland, with an annual mean wind speed of 7 m.s⁻¹ (Kirkwall Airport). The predominant range of wind directions is from the west to the south-west, and rainfall tends to be persistent, but not high, with temperatures rarely falling below freezing. The minimum night-time average ambient temperature is 2 °C (February), whilst the maximum daytime average ambient temperature is 16 °C (August).

Construction Techniques

Both housing blocks have been built at right angles to each other, with the low energy block oriented to minimise wind-chill (convective heat loss) and to take

advantage of solar gains. The front doors of all four houses are recessed in order to reduce their exposure to wind and to lessen the likelihood of water penetration. There is also an inner door to each entrance lobby. In addition, all windows were double glazed and those in the low energy houses were fitted with low emissivity glass. The low energy houses are shown in Figure 1.

The floors of the dwellings comprise several layers starting at the base with a damp-proof membrane, followed by 5 cm of polystyrene insulation, finishing with a layer of poured concrete. The exterior walls consist of a rendered concrete block outer leaf, an air cavity, and a timber-framed inner leaf, with 15 cm of glass fibre insulation between the wall studs, backed with plywood and building paper. The walls are lined internally with foil-backed duplex plasterboard.

In every house, the hinged ceiling hatch through to the loft is insulated and draught sealed, together with a positive catch to close it firmly. (The framing for the loft hatch was sealed with mastic in the low energy building). The loft itself also contains glass fibre 20 cm thick, which insulates the living space below. Each roof has been constructed from interlocking concrete tiles, over roofing felt and plywood sheathing.

After the standard block had been completed, a BRE site visit to the incomplete low energy block took place, to supervise the correct sealing of all joints. In particular, silicone sealant was applied around any service pipes or electrical fittings that penetrated either a wall, or a ceiling. Also, window and door frames were made airtight with the walls using expanded foam sealant. Furthermore, mastic sealant was used between the plasterboard drylining and external walls, and between the wallplate and the foundation.

Ventilation System

A balanced mechanical ventilation system has been installed in the low energy houses, which incorporates a heat pump and a flat plate heat exchanger. The unit, which is situated in the loft

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Editor: Janet Blacknell

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Conclusions and opinions expressed in contributions to Air Infiltration Review represent the author(s)' own views and not necessarily those of the Air Infiltration and Ventilation Centre.

above the living space, delivers air to all the rooms in the house, and extracts air from both the kitchen and the bathroom. (The air from the hallway is recirculated.) Unless the system is switched off, it supplies constant ventilation at a rate of 0.5 volume air changes per hour (ach). A thermostat is located in the living room, and the system maintains an internal building temperature 5 °C below the thermostat setting, whenever the heating is off.

Ventilation is provided in the standard houses by means of trickle vents in the window frames, with an extract fan in the kitchen and bathroom.

Airtightness of the Houses

The airtightness of each of the four dwellings was measured by a team from BRE, in which the author was invited to participate. A tandem pressure test was performed on each pair of houses simultaneously. A portable fan (shown in Figure 2) was sealed into the entrance doorway of both houses being tested and the air flow rate required to maintain a given pressure differential across the building envelope, was recorded. This was done over a range of pressure differentials.

The procedure for pressure testing involves sealing all service penetrations (e.g. sink waste pipes), securing the loft hatch, and sealing ventilation system diffusers and vents (plus extract fans where fitted). Also completely closing all external doors and windows, and fully opening all internal doors. In theory, this creates a single zone at a pressure that differs uniformly with local atmospheric pressure.

The standard houses were found to compare very favourably with other UK dwellings that had been previously measured by BRE, thus indicating that the contractors were already capable of a high standard of construction. As intended, the low energy houses were even tighter, with an average of about 1 ach at 50 Pa. (See Table 1 and Figure 3 for more complete results.) This level of airtightness is comparable with many houses in very cold climates (such as Canada and Scandinavia).

It should be noted that, regardless of the kind of system used, ventilation in an airtight building can potentially be controlled to provide good indoor air quality without wasting energy. In the 'low energy' case it was particularly desirable to make the houses as airtight as possible, because unwanted air infiltration would effectively by-pass the heat recovery unit. This would result in not only the heated

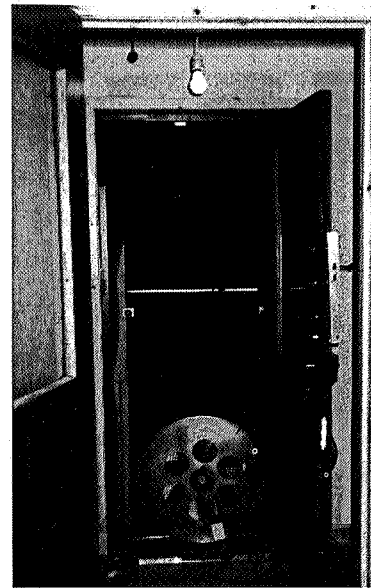


Figure 2 Blower door (UK Crown Copyright 1994)

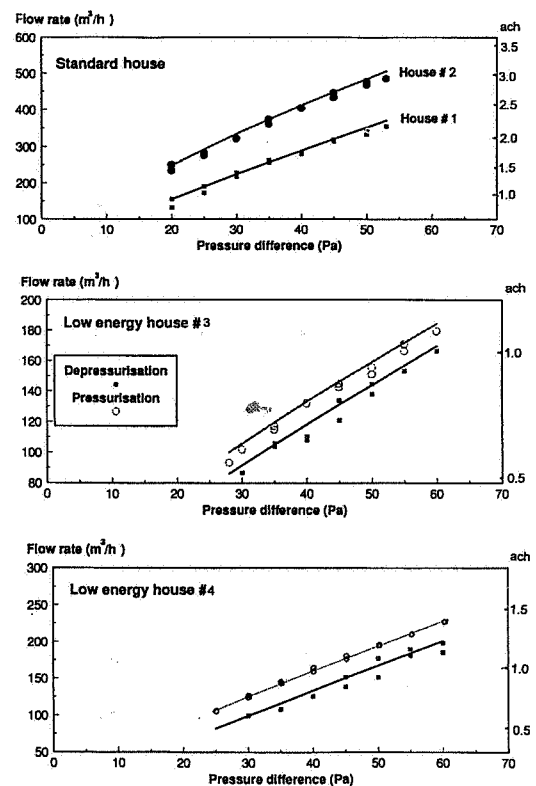


Figure 3 Results of the pressurisation tests

House	Volume /m ³	Surface area /m ²	Condition	K /m ³ .h ⁻¹ .Pa ⁻ⁿ	n	(Q ₂₅ /S) /m ³ .h ⁻¹ .m ⁻²	(Q ₅₀ /V) /h ⁻¹
Standard #1	165.3	150.0	depressurisation	10.62	0.89	1.26	2.13
Standard #2	165.3	150.0	depressurisation	27.37	0.74	1.95	2.94
Low energy #3	165.3	150.0	pressurisation	6.85	0.80	0.61	0.96
Low energy #4	165.3	150.0	pressurisation	6.01	0.89	0.70	1.19
Low energy #3	165.3	150.0	depressurisation	4.40	0.89	0.52	0.87
Low energy #4	165.3	150.0	depressurisation	3.05	1.02	0.55	1.01

Table 1 Measured airtightness characteristics of the houses

internal air being lost directly to the outside, but also being replaced with unheated external air, thus cooling the living space.

Long-Term Monitoring

The project is now several months into a two year monitoring programme. This involves automatically recording both external meteorological conditions at the site and also internal temperatures in each room, plus wall temperatures for each of the four dwellings. Additionally, the rate of water consumption (meters fitted to the mains supply and cold feed to hot water supply) and electricity use (meters fitted to the hot water supply, lighting, power, and heating circuits) are being measured at the same time. The occupants' perceptions about their thermal comfort will also be noted.

Through this long-term monitoring programme, it should be possible to judge how significant the energy saving precautions prove to be in practice.

Conclusions

The techniques investigated in this project can be easily replicated elsewhere, producing high quality and affordable homes. They are particularly suited to regions such as Orkney, Shetland, and the Western Highlands. By explaining the motives behind the project to the builders, it was ensured that they

achieved the high level of airtightness required, through vigilant quality control.

It is anticipated that, through the energy saving measures taken, savings of at least 60% of present annual household heating costs will be realised. Another possible benefit of building to a high standard at the onset, is that although it involves marginally more expense initially, it should be cheaper than retrofitting and tightening at a later date.

For further information concerning this project, please contact, Mr David Murdoch, Director, Orkney Housing Association Ltd, 39a Victoria Street, Kirkwall, Orkney, KW15 1DN, Scotland.

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AIVC 16th Annual Conference

Implementing the Results of Ventilation Research

Hyatt Grand Champions Resort, Palm Springs, USA

19-22 September 1995

Considerable effort has been devoted to research into ventilation technology and its impact on indoor air quality and energy demand. The purpose of the AIVC's 16th Annual Conference is to review the implementation of the results of recent research. Papers on the following topics are to be presented:

- Energy efficient ventilation strategies
- Maintenance and long-term performance
- The application of mathematical models in design
 - Ventilation heat recovery
 - Controls and user interaction
- Measurements for design and diagnostic analysis

The conference fee includes accommodation, meals and banquet, and access to facilities at the Resort, including health and fitness centre.

For attendance details, contact Mrs Rhona Vickers at the AIVC (address at back of this newsletter),
Tel: +44 (0)1203 692050, Fax: +44 (0)1203 416306

Experiences of Measures Taken to Improve the Air Quality in Schools

Jan Gusten (*) and Ove Strindehag (**), (*)

Assistant professor, (**) Associated professor,

Dept for Building Services Engineering, Chalmers University of Technology, Gothenburg, Sweden

Abstract

The ventilation standard was investigated in a large number of school buildings located in Gothenburg, Sweden as part of a current large-scale renovation programme. This article reports on experiences from the reconstruction work involved. Results from air quality measurements comprising TVOC (total volatile organic compounds) and CO₂ measurements are presented. The results show that the indoor air quality is considerably influenced by outdoor contamination sources and that cleaning products and floor polish can, temporarily, add to the pollution content in classrooms. Furthermore, reconstruction work, such as painting interior walls and ceilings should be followed by an airing period of several weeks before the rooms are suitable for use.

Introduction

A comprehensive reconstruction and renovation programme of school buildings in an urban environment has been carried out in Gothenburg, Sweden. As an important part of the reconstruction work, a great deal of attention has been paid to improving the ventilation standard and, thereby, the indoor air quality. The building stock comprises 185 schools with a total floor area of 700,000 m². Most of the schools are older than 20 years and do not comply to current standards laid down for ventilation requirements.

The risks for health problems caused by such buildings, together with an alarming increase in the number of children and youngsters with allergy symptoms, raise the question of stricter and partly new demands on the administration of school premises. Investigations in Gothenburg have shown that in 55% of the schools, complaints have been lodged relating to smell, damp or mould in one or more rooms of the buildings. In 133 of 185 schools, i.e. 72%, teachers reported that the air was stuffy. These results are in accordance with experiences from other parts of Sweden. The observations have resulted in a number of technical measures being carried out in the buildings, principally concentrated on damage caused by moisture and in a general renovation programme.

This paper briefly reports experiences from the research and follow-up work which has run parallel to the retrofitting of the schools. The aim of this study

has been to form a basis for the ventilation standards to be fulfilled. Measures necessary to improve the defects in a large building stock are associated with excessive costs. Hence, it has not been possible, nor desirable, to replace those ventilation systems which are functioning satisfactorily.

Identification Of Problems

Identification and isolation of the defects relating to the building or to the ventilation system is a prerequisite for making successful improvements to the ventilation system in schools. The work, which is aimed at improving the indoor climate, has been preceded by a large-scale clean-up of the technical defects of the buildings, and damages due to water leakage or problems caused by high moisture content in the ground. Consequently, building-related problems have been identified and taken care of before measures to improve the ventilation systems have been taken.

Based on the analysis of a comprehensive inquiry, the problems could in many cases be located to one or two classrooms in the school building. Therefore, the extent of problems was less than was feared from the beginning. Very often, complaints concerning noise and lighting were found in classrooms classified as so-called problem rooms.

Air Quality And Ventilation Demands

Air quality should be treated as an important part of a complex system which constitutes the indoor climate. Indoor climate includes not only quantitative parameters such as daylight, room acoustics and thermal climate, but the perception is also influenced by factors such as the atmosphere of the school. There are reasons to believe that improvements concerning the above mentioned factors can completely change the concept of the indoor air quality in question. Discontentment with the performance of the ventilation systems can have its origin in what can be named "factors of discontent" relating to the design of the rooms, colouring, lighting conditions or simply pedagogic factors.

Besides ventilation, the activity in the premises is of great importance, i.e., the number of pupils, length of lessons, breaks and the airing periods all influence the indoor quality, for instance, the content of CO₂.

Inadequate cleaning can sometimes be reflected in the particle content of the indoor air.

In addition to the internal load of volatile organic compounds and particulate contamination, the exterior climate outside the classroom is of great importance for the indoor air quality. Of course, this is mainly of interest in urban environments, especially in the vicinity of lively trafficked streets.

In Sweden, the ventilation systems in non-residential buildings which were originally ventilated by natural ventilation have usually been reconstructed into mechanical ventilation, i.e., either exhaust ventilation or balanced ventilation with heat recovery. In connection with the renovation and reconstruction programme, all schools within this project were equipped with one of the mechanical systems mentioned. The air flows were designed for a basic ventilation of 0,35 l/s and m² floor area, completed with a contribution based on activity corresponding to 7 l/s per person.

Measurement Programme

A comprehensive measurement programme for five different schools, Figure 1, has been accomplished in order to quantify the indoor air quality before and after reconstruction of the ventilation systems. The programme includes measurements of the contents of CO₂, (total) volatile organic compounds, (TVOC), and the contents of airborne particles.

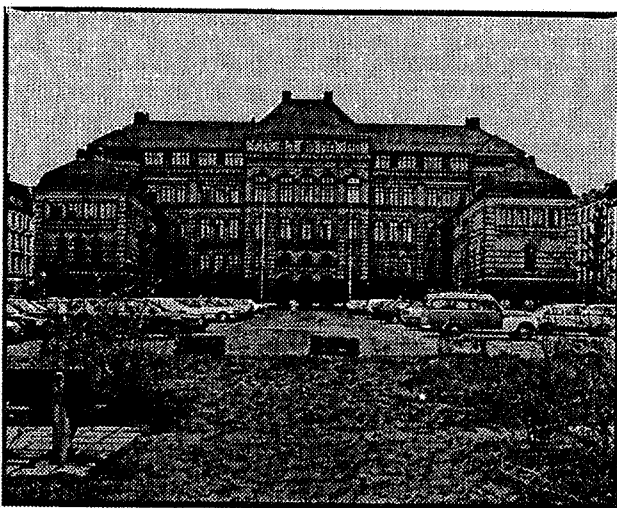


Figure 1: One of the five school buildings where a comprehensive measurement programme has been performed in connection with the reconstruction work.

Based on the measured contents of TVOC and VOC, it is possible to discern the pollution load related to:

- outdoor air, generally traffic-generated air pollution
- emissions from building material and furnishings
- educational activities and cleaning.

The measured contents of TVOC and CO₂ very often show considerable contributions from activities in the rooms. This is illustrated by Figure 2 showing the contents of TVOC and CO₂ during a day with large variations in the load caused by human activity, (1). The measurements have been performed with a PAS- instrument (Photoacoustic spectroscopy, Bruel & Kjaer, type 1302). The TVOC values shown are the difference between the content in the indoor air and in the supply air to the building. During the afternoon between 2.30 p.m. and 6.00 p.m. the classroom is empty (i.e. no generation of CO₂) and during this period, as can be seen from the figure, the content of TVOC is approximately the same for both the supply and the indoor air. This indicates that the extra contribution of TVOC from the surface layers of the rooms is small. The building materials can in this case be characterized as traditional well-known building materials.

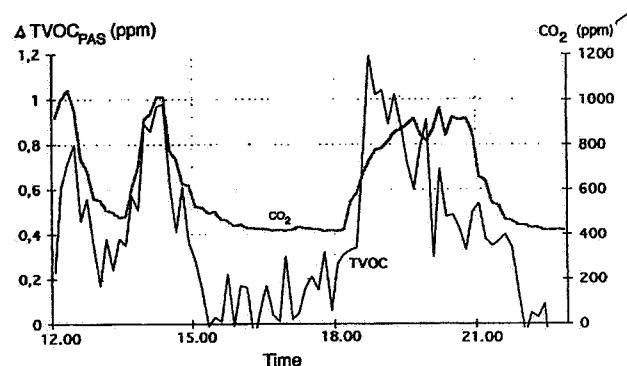


Figure 2: Measured content of TVOC and CO₂ during a period with varying activity. The level of TVOC shown is the difference between the content in the room and in the supply air, measured with a PAS- instrument.

From an emission point of view, the selection of furnishings has not usually been taken into account to the same extent as for the selection of building materials. Furthermore, management and cleaning of surface layers has to be considered. The results from measurements in the investigated school buildings show that even several weeks after polishing the floor, a high content of organic compounds can be found, which exceeds the recommended value of 300 micrograms per m³ air (2). Consequently, this type of work ought to be done during the holidays when the premises are not in use.

Figure 3 illustrates how the contents of volatile organic compounds from cleaning liquids and floor polish have decreased in two schools with different air exchange rates, 0,8 ach and 2,4 ach respectively (3). The content of TVOC has, in this case, been determined by using tubes filled with Tenax sorbents. (The number of air changes and the indoor temperatures for each school were approximately the same during the two measurements). Figure 4 indicates, as could be expected, that an increased ventilation rate leads to a more rapid reduction of the TVOC content.

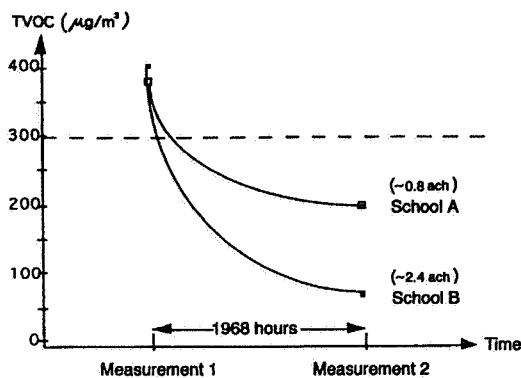


Figure 3 The decrease of the TVOC content originating from cleaning liquids and floor polish in two schools with different air change rates. (TVOC has in this case been sampled on Tenax sorbents).

Results And Discussion

After renovation there is a need for what can be designated as an airing period before the premises are taken into use. This is an analogy to the requisite drying-out period for building materials after the erection of a building. A rough outline of the decrease of contamination, for example the TVOC content, shows that the abatement time can be divided into three periods, see Figure 4. The first period corresponds to the reconstruction time when factors of the working environment should be taken into consideration, the second period is an airing period when the premises are empty and not in use and the third period when the rooms are in use and the content of contaminants has been reduced to a level that is considered to be harmless.

Premises not in use usually lead to costs or loss of rent yields. Therefore, it is necessary that the airing period is planned to be part of the general building process. Measurements in one of the schools in question indicate that an airing period of at least three weeks is needed. Therefore, from an emission point of view, a reduction of ventilation rates at night-time is very doubtful. A lower air exchange rate causes an increased content of gaseous contaminants in the indoor air.

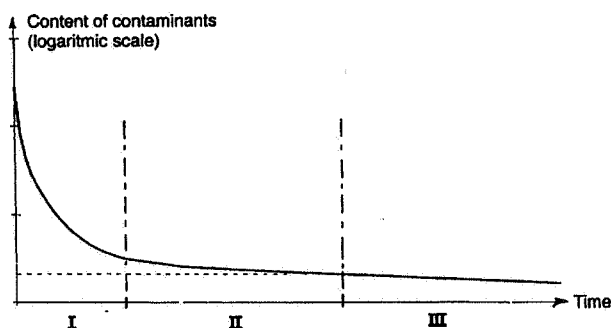


Figure 4 Schematic abatement of the content of contaminants in the indoor air after reconstruction/renovation of a building. (I = period of reconstruction, II = airing period, III = period of usage)

When comparing the amount of pollution in outdoor and indoor air, the influence of traffic is evident in many school buildings. A temporary load from traffic, for instance, in connection with traffic peaks near to a school, can result in an increased content of hydrocarbons such as benzene and toluene inside the building. Therefore, the location of supply air intakes should be chosen with care.

In one of the school premises investigated, the air inlet is placed on the roof of the building, approximately 25 metres above the ground. As can be seen from Figure 5, this is a favourable location for the air intake due to the fact that the content of TVOC in the supply air is considerably lower than the content in the outdoor air at street level. The measurement point at street level in this case was placed close to the building facade only 4 metres from a heavily trafficked street. The content of TVOC was measured with a PAS-instrument.

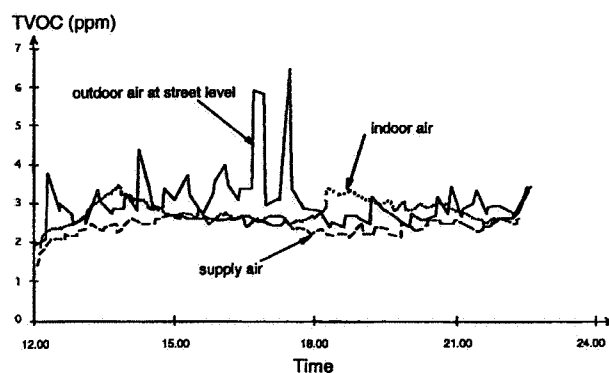


Figure 5 The content of TVOC in outdoor air, supply air and indoor air (measured with a PAS-instrument) in a school building with two heavily trafficked streets in the neighbourhood. The air intake is located on the roof of the building.

Conclusions

When estimating the quality of the indoor air, it is important to take into consideration the contaminants in the outdoor air. For school buildings exposed to pollution caused by vehicles, measures to avoid congestion of traffic can, thus, have a very favourable influence.

It is also of great importance that deficiencies in the operation and maintenance of the ventilation systems are considered. Furthermore, attention must be paid to children and youngsters' disposition to allergy. When designing and planning ventilation systems, it is necessary to observe the changes in educational procedures that may influence the use of classrooms. Teamwork in small groups and varying lengths of lessons give new prerequisites for the need of ventilation air and the location of air inlet devices.

The measurement results indicate that traditional building materials give a rather low emission of volatile organic compounds. Nevertheless, after renovation an airing period of three to four weeks is

recommended before the premises are taken into use. Activity, not least cleaning, can increase the content of contaminants temporarily. For schools situated in an urban environment and exposed to traffic emissions, a strong correlation between the quality of indoor and outdoor air can be found. Consequently, the location of air inlets and the efficiency of filters for the supply air are of great importance.

Acknowledgements

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The ISH International Trade Fair - Frankfurt, Germany

This bi-annual show is one of the largest international trade fairs for heating, ventilation and air conditioning, attracting 230,000 attendees during its period of opening. The vastness of the Mess Exhibition Centre in Frankfurt provided plenty of room for displays and demonstrations.

Of special interest was the stand of FGK, the German nominated organisation to the AIVC. This stand provided demonstrations of the AIVC's Airbase database, odour perception and air quality controlled ventilation. Odour testing consisted of an "Olf" bar with calibrated 1.5 and 10 Olf samples. Three further samples represented "healthy", "normal" and "sick" buildings. Other odour samples covered cigarette odour, contaminated filters, and newsprint. Demand controlled ventilation was demonstrated by means of a "mixed gas" sensor into which it was possible to breathe. This caused a fan to operate until the air was restored to ambient conditions. A system for evaluating the performance ventilation heat recovery units, being developed at the University of Essen was produced as a poster display. This system is designed to measure total energy balance and therefore provides a good indication of true heat recovery performance.

Several of the major ventilation manufacturers demonstrated latest developments in ventilation technology. This included a launch by LTG Lufttechnische GmbH of their "new wave" air cooling system in which a silently oscillating damper draws room air at ceiling level over banks of chiller coils. Krantz GmbH provided a comprehensive test

chamber demonstration illustrating the effectiveness of a wide range of ventilation strategies covering displacement and mixing systems.

Air quality control systems and monitors were demonstrated by several manufacturers and distributors. Carbon dioxide control was especially in evidence for use in occupied office and conference locations.

On the measurement front, TracerTech GmbH was offering a simplified postal system for evaluating air change rate. This comprises a set of six syringes, one of which is filled with SF₆ tracer gas. This is injected into the space to be measured, by the occupant, who then uses the remaining syringes to collect air/gas samples at fixed time intervals. The sample syringes are capped and posted back to the laboratory for tracer concentration decay analysis.

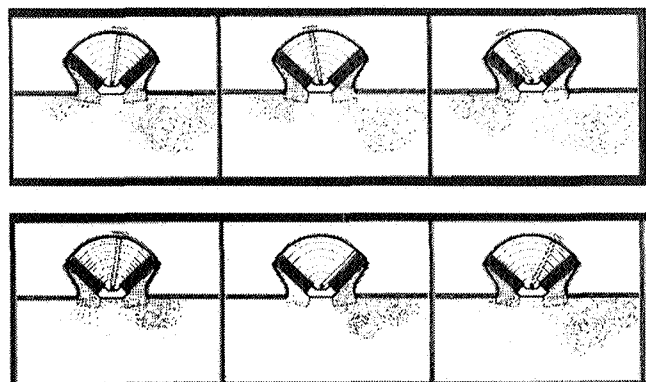


Figure 1: LTG new wave air cooling system

Decision-Making on Domestic Ventilation Systems: the Results of a Dutch Marketing Research Project

by Peter Op 't Veld, Cauberg Huygen Consulting Engineers, Maastricht, the Netherlands

In the Netherlands, many attempts have been made to introduce and implement advanced energy efficient domestic ventilation systems. This especially applies to balanced ventilation with heat recovery, one or multizone air heating systems with heat recovery, and multifunctional appliances (combined systems for heating, hot tap water, ventilation with heat recovery from exhaust air and flue gases).

Although over the last fifteen years, market introduction in the Netherlands has been supported by numerous demonstration programmes and much technical research, the number of dwellings with advanced ventilation systems is still limited to one or two percent.

This was a reason for considering how a bigger market share for advanced ventilation systems could be achieved.

Novem (the Netherlands Agency for Energy and the Environment) and ISSO (The Dutch Building Services Research Institute) initiated marketing research, focusing on the reasons for selecting and assessing domestic ventilation systems and for decision-making.

This research and field work was carried out by R&M Research and Marketing.

The framework of the marketing research

The research was set up as follows. Discussion sessions took place in various locations in the Netherlands, in which several building parties were involved:

- building contractors and installers (2 groups);
- architects (2 groups);
- principals, especially housing corporations (2 groups).

The discussions were led by a trained and experienced discussion leader with no specific knowledge of ventilation and ventilation systems. No ventilation experts were involved in the discussions although experts could follow the discussions on a closed video-circuit. During the discussion they could contact the discussion leader to adjust or clarify the discussion if necessary.

The objectives of the discussions were to demonstrate:

- how important ventilation is for those groups;
- what kind of arguments are important in decision-making;
- what kind of problems we face in introducing advanced ventilation systems.

The discussion topics were:

- Ventilation in general:
 - first thoughts;
 - how important is ventilation;
 - in which phase of the building process;
- what is the influence of the building code.

- Decision-making;
 - which arguments:
 - costs;
 - technical demands;
 - energy and the environment;
 - design;
 - maintenance costs of the system;
 - maintenance costs of the dwelling.

- How to assess and evaluate ventilation systems.
- The acquaintance with balanced and other advanced ventilation systems.
- Ventilation in general

For nearly all the participants the first thoughts about ventilation were related to problems. Architects mention the problems of purpose-provided openings influencing the architectural design of the facade. Contractors (and also architects) have problems with the sizes and the number of ducts. Housing corporations face many problems with occupants' behaviour in relation to the use (or misuse) of ventilation systems. All participants mention the interaction between occupants and the ventilation systems as one of the main problems. It occurs that

there is an important relation between the increasing and energy saving campaigns from the government and energy distributors as well as the increasing importance of conscious ventilation behaviour of the occupants. Another important problem mentioned was the noise of fans. This often appears to be a reason for turning off ventilation systems.

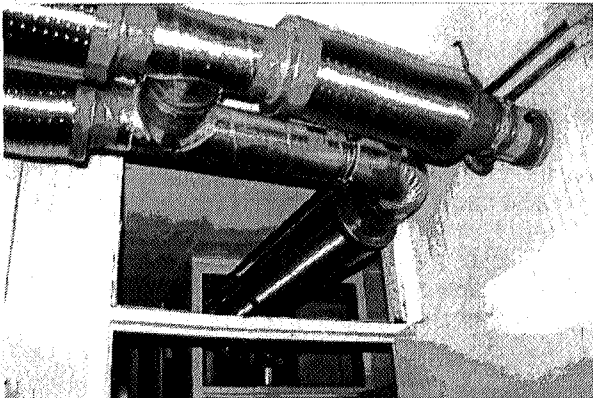


Figure 1: Constructors and architects have problems with the sizes and number of ducts

Ventilation in the building process

All participants think that ventilation is more or less an important subject in the building process. The main reason for this is not the awareness of the need for good indoor air quality and health; it is obligated by the building regulations. (Since 1992 there has been a new building code in the Netherlands which gives strictly defined performance requirements and determination methods). The interest in ventilation, however, does not go any further than the minimum level required by the building code. Increasing ventilation quality does not seem to have a high priority. This applies to social housing as well as to non-social housing. Some participants are skeptical about the excessive building code, especially the efforts to meet the regulations and the occupants' behaviour, which can undo many results.

Selection of ventilation systems

The selection of the type of ventilation system (natural ventilation, mechanical exhaust, balanced ventilation or more advanced systems) is determined by the principal. In very few special cases architects or installation consultants can advise in the assessment of different types of systems, e.g. building projects in noise loaded areas and retrofitting. There are also some municipalities that have drawn up special programmes and requirements on energy and the environment.

Techniques like balanced ventilation with heat recovery, airtight building, and passive and active solar energy are necessary to meet these requirements.

Contractors and installers only engineer the ventilation system in accordance with the specifications, i.e. they don't select the type of

ventilation system. The contractors' selection of an installer as a sub-contractor is based on the lowest price, not on quality. This, of course, has a very negative influence on the quality of the components.

Most of the participants mention that, especially in social housing, the selection of the type of ventilation system is principally dependent on the (minimal) requirements of the building code and the budget of the principal. Budgets for new buildings in the social housing sector are limited. However, as a rule for retrofitting there are more financial means. Another fact is that the decision makers who are involved in retrofitting are much more aware of the problems caused by a poorly functioning ventilation system.



Figure 2: There are more financial means for retrofitting. In this project in Hengelo the Netherlands, completely new facades and MFAs (multifunctional appliances) were applied

In practice this means that for most of the newly built houses a ventilation system is selected that just about meets the requirements of the building code and which components are lowest in price. Only for retrofitting there seems to be more focus on the quality of the system.

In spite of this rather negative conclusion the participating housing corporations were aware of the problems that are introduced by this way of selecting ventilation systems and components. There is growing interest in the possibilities for maintaining ventilation systems, the sensitivity to inadequate occupants' behaviour and also in the extra maintenance costs for the dwellings caused by a poor functioning ventilation system (mould growth, condensation, etc.).

Criteria for the assessment of ventilation systems

All participants were asked to state which criteria may or may not be important for the assessment of ventilation systems.

These criteria are:

- indoor air quality
- energy consumption
- thermal comfort
- environment
- noise of fans
- outdoor noise
- user friendliness
- maintenance
- installation
- acceptance by occupants
- fitting in the building design

The most important criterion for all participants was thermal comfort, followed by noise and indoor air quality. Also the acceptance by the occupants is an important criterion, especially for housing corporations. For this group too, maintenance and user friendliness are more or less important. For most architects, the possibility of fitting a ventilation system in an architectural design is very important. That is why "natural ventilation" is very popular amongst architects (in fact they mean window ventilation or airing; not ventilation through purpose-provided openings, slot vents or trickle vents etc).

Energy consumption and the environment are criteria that most participants consider less important. There was some discussion about energy consumption. Housing corporations mention that the benefits of energy saving due to heat recovery or other measures are for the occupants. On the other hand, in some cases low energy use also has indirect, positive effects. The rentability increases (this is important for more expensive, rented houses). Also, the possibility of turning off systems or not using ventilation provisions because of energy use decreases.

Outdoor noise was only important for those participants building in noisy areas.

Acquaintance with balanced ventilation with heat recovery

Most of the participants were acquainted with balanced ventilation and heat recovery. The actual knowledge of this system was very limited. Balanced ventilation appeals to most of the participants, mainly because of the fact that there is a continuous ventilation, independent of the occupants' behaviour and weather conditions. But there are also many questions, prejudices, and also negative experiences with regard to balanced ventilation. Negative experiences are often a result of poor design and engineering of the system.

However, the biggest obstacle for applying balanced ventilation with heat recovery is, again, the (initial) costs. Only if heat recovery is indirectly obligated by the building code will it be applied on a larger scale.

(This refers to the Dutch Energy Performance Regulation in which the total energy performance of buildings, including installations, is regulated; this regulation will be enforced as of the end of 1995).

However, there are some exceptions. In noise loaded areas balanced ventilation systems are sometimes applied because natural ventilation through (sound proofed) vents in the facade is not possible. This is because of the required noise reduction of the facade. But even in some cases where sound proofed vents are possible, the initial costs of a balanced ventilation system can be lower than the costs of these vents and other acoustic measures. Studies and data were available but none of the participants had seen them.

Some of the participating housing corporations are aware of a certain relation between the additional costs for advanced ventilation system and reduced maintenance costs as there is less damage caused by poorly functioning ventilation systems. It could help to express these costs as life cycle costs.

Conclusions

Not the awareness of the necessity of ventilation but the building code and standards determine the quality of the ventilation system.

Contractors consider ventilation an unwelcome aspect and try to apply the cheapest possible system and components that just meet the requirements.

Architects often have problems with the design of facades, especially in noise loaded areas.

Housing corporations have lots of problems with ventilation systems in relation to occupants' behaviour.

Principals choose the type of ventilation system. The most important decision factor is initial costs. There is a growing awareness of the relation between the quality of the ventilation system and the maintenance of the building. Also the maintenance of ventilation systems is getting more attention.

The more important criteria for the assessment of ventilation systems are thermal comfort, indoor air quality and noise. Less important were energy consumption and the environment.

Most participants think that the new Dutch energy performance regulations will increase the application of advanced energy saving ventilation systems.

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Sick Building Syndrome - Dangerous Game with Spread Characters

Dr. Ing. Johst H. Weber

The majority of architects appear to liken ventilation and air conditioning techniques to the human appendix; it does not appear to have a vital requirement but can threaten life if it malfunctions!

In order to determine whether the architectural world's opinion has any validity, some terminological clarification is called for. Many terms are used, throughout the scientific and pseudo-scientific world, to describe the reputed problems; "Building Disease", "Building Illness Syndrome", "Stuffy Office Syndrome", "Tight Building Syndrome".... However, it appears that just two terms may be considered as certain: the so called "Sick Building Syndrome" (SBS) is used to describe a series of unspecified sufferings associated with certain buildings, but without any definite disease diagnosis., and it seems certain that "Building Related Illness" (BRI) is a clinically verifiable disease or frailty which can occur because of specific conditions present in a building.

A report issued in 1991 by The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) highlights the fact that possibly at least 10% of the buildings in the United States suffer from "SBS" and "BRI". A further 20% already display the symptoms of "SBS" and although the remaining 70% of buildings have no classification, it would be unsafe to assume they are healthy, because in most cases no tests would have been carried out yet.

Why do buildings become sick? Possible causes could be fibres, bacteria and viruses, mould fungi, ozone, nitrogen oxides, sulphur dioxide, organic pollutants, pollen or dust. All these things could cause adverse reactions to the central nervous system, the skin and especially the mucous membrane. This in turn gives rise to headaches, sore throats, aching limbs, as well as allergic reactions and irritations affecting both taste and smell. The World Health Organisation (WHO) has produced an accurate categorization of the different kinds of suffering experienced. Quite often it is difficult to verify the reasons and effects by experimental means, for instance, who can accurately fathom the cause or extent of a migraine attack on a laboratory mouse?

How much blame should be attributed to ventilation technique when the SBS/BRI complex is being investigated? Possibly the results of two investigations shown in Illustration 3 could provide some of the answers. This shows the outcome of a series of occupant interviews conducted in 1991 by the German Trade Union, Bank and Insurances (HBV), wherein they found that 65% of occupants

questioned felt it was the general climate in their particular room which created the discomfort problems, and listed other influences such as noise, lighting, stress, etc., much lower down the scale. This survey was verified by an Infratest-inquiry which was published by the Association of Ecological Research Institutes (AGOeF), and they found that 50% of those interviewed blamed SBS symptoms on "controlled" rather than "natural" ventilation systems.

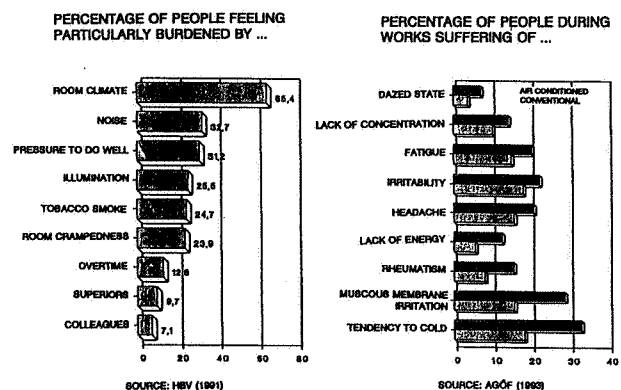


Figure 1

This would definitely appear to show the correlation between ventilation technique on the one hand and SBS/BRI on the other, but this does not spare anyone the crunch questions "Did ventilation technique make the buildings sick and was then therefore considered the appendix?" Or, was it because of the fashionable tendency to place ventilation technique as the "underdog" and reluctance to take the trouble to assess its risks and potential, which doomed it to failure?

Let us try to find some solutions by way of the following four steps.

1.0 It is a fact that, initially, it was the aim of ventilation technique to improve the living conditions of human beings.

In the middle of the last century, Max von Pettenkofer, Germany's main protagonist in ventilation technique, investigated the hygiene aspects of ventilation. Also, the economic development of many countries, particularly in the hot areas of the USA, such as Texas, made a distinct impression on the improvement of ventilation know-how. Areas in which the natural weather conditions produced both high humidity and soaring temperatures could only be developed with the support of artificial air conditioning. As shown in illustration 2, it has been proved that in certain parts

of the world, the mental performance of building occupants decreases when the temperature goes above the ideal 20 degrees C.

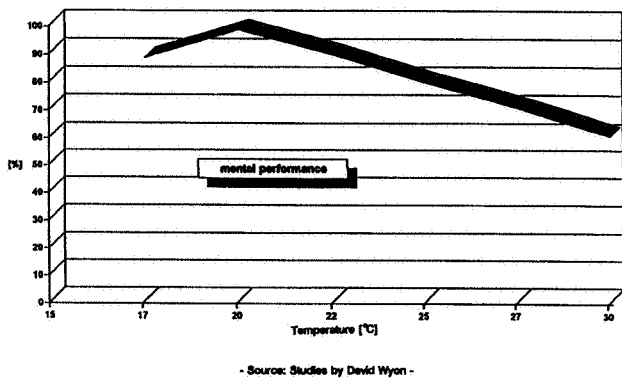


Figure 2

2.0 It is a fact that most of the relevant Sick-Building Pollutants are carried by the Air

The outside air is full of pollutants such as exhaust components and allergy-carriers which affect everyone's health, even to the extent of causing cancer in extreme cases. A study of the ozone emissions in Giessen (Germany) during April to September 1992 demonstrated the significance of these outdoor pollutants. Illustration 3 shows clear passings of the MIK-values, which is the maximum concentration of emission according to VDI. This phenomenon gives cause for concern but it is not surprising when one considers the summer-smog events. A similar view is obtained when looking at the pollutants that are building-exogenous. For instance, in 1992 the emissions of nitrogen-dioxide were also higher than the MIK-value, even without the winter smog which was prevalent at the time, and it should also be noted that the city of Giessen does not have either a high population or industrial density. A Harvard study claims that the probability of succumbing to heart disease or cancer is 20% higher for people living in cities than those situated in the countryside.

OZONE-IMMISSIONS

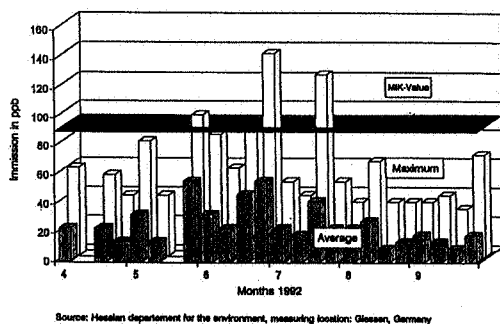


Figure 3

Apart from the pollutants outside, there are also ones developing inside - see illustration 4. These may be

emitted, for example, by furnishings (formic aldehyde) or office machines (ozone). Also it should be mentioned that human beings cause pollution, not least in the form of tobacco smoke.

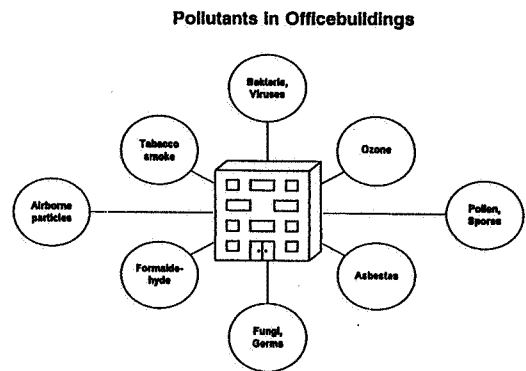


Figure 4

POLLUTANT POTENTIAL OF A VENTILATION INSTALLATION

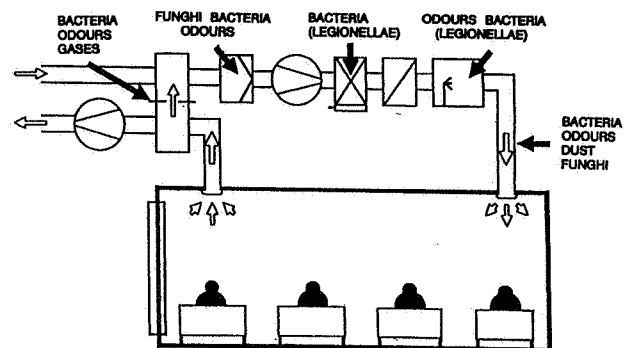


Figure 5

A potential source of pollutants which must be ultimately addressed is the use of ventilation systems (see illustration 5). By mixing fresh air with room air - which makes sense according to the view of energy balance - bacteria, odours and gases which are extracted from the room will be pretty well reintroduced by this type of circulation. In addition, conventional particle filters are perfect breeding grounds for microorganisms which flourish there and eventually grow through to the (so called) "clear Air" side. Equally, condensing coolers and humidifiers for final conditioning can also provide ideal conditions for various harmful bacteria to appear, such as *Legionella pneumophila*. Complex air conditioning ductwork can be highly susceptible to contamination and is likened to a "black box", which is seldom, if ever, monitored. Users and owners of buildings are generally unaware of the potential dangers, and even when these are pointed out, either the cost of cleaning the offending ductwork is too high, or it cannot be guaranteed that by just doing that the entire problem would not be solved. It would be easy to conclude that, as the major SBS/BRI pollutants are being carried via the air, the solution to the SBS/BRI problems would be to increase the rate of fresh air via the ventilation system, particularly to get rid of the indoor loads. However, you can only do this if the outdoor air is considered to be fresh, i.e. without pollutants.

3.0 It is a matter of fact that both noise and draught increase with a higher (fresh) air supply and, more importantly, so does energy consumption.

ASHRAE gave this putative contrast the possibly slightly exaggerated title of "Energy versus Indoor Air Quality". The reasons behind this statement are more likely to be linked to energy consumption during the oil crisis of the 70's, than air quality. However, even though the USA adopted ASHRAE's initiative to minimise outdoor supply air, (see illustration 6), in the final review they were obliged to make the statement: "We won the energy battle, but we lost the quality war"! Not surprisingly, a new US federal standard (comparable to the German DIN) emerged, clearly raising the rates of outdoor supply air. But, publishing success on one hand for the quality of the air and admitting defeat on the other hand for the energy consumption battle cannot really be considered the peak of discovery.

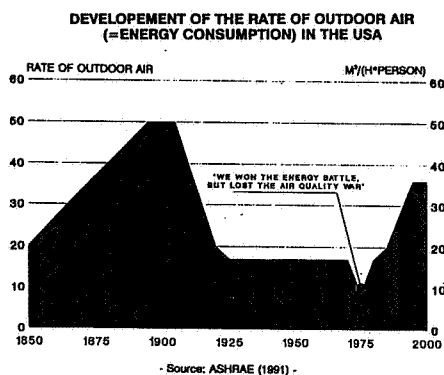


Figure 6

However, in the Federal Republic of Germany it has also been very difficult to find a solution to the conflict between energy consumption and air quality. In fact, the following five different logistic variants are used in our degrees of latitude, more or less with impunity:

- The blowing variant, which also covers the free ventilation, means that the air is supplied to the room directly through windows and simple ventilation grilles, which have no mechanisms to avoid the problems of pollutants, loss of heat and draughts.
- The inducing variant uses swirl diffusers to achieve an early mixing of both "fresh" supply air and "loaded" room air. A specific cooling performance can be realized with the tendency to lower air volume rates without creating draught problems.
- Using source diffusers is a characteristic of the displacement variant. These outlets supply the air to the room with lack of impulse through flow rectifiers in order to avoid the double edged mixing of both "fresh" and "loaded" air by selective displacement of the latter in the direction of the extract openings. But, this variant has another side, because lower restriction for the supply air's temperature is very limited depending on the behaviour of the occupants. In order to reach particular room

conditions, it may be necessary for this variant to achieve higher air flow volumes.

- The convective variant is limited to cooling and heating and does not have the ability to supply air to the room. This method is quite advantageous from the energy point of view. Cooler conditions are achieved via "cooling ceilings" which work on the principle that warm air flows upward and the cool air, which is heavier, flows to the bottom, but with no improvement of air quality.
- The radiation variant is similar to the convective variant in that it also can only heat or cool and does not supply fresh air to the room. The heat transfer into the room takes place by long-wave heat transfer between water-and-air warmed up areas of specific elements like cooling or heating ceilings, and the warmer or cooler surfaces of the occupants or inventory.

It is felt that a long discussion at this point on the optimum amounts of ventilation required, or the necessity of air conditioning, should be avoided. However, no one should ignore the uncomfortable truth that none of the conventional variants are achieving the ultimate solution to the problems of energy and quality, and in fact most of them are of a bygone age and should be replaced by new ventilation techniques.

4.0 A new ventilation technique must, on the one hand, be sophisticated enough to be able to reach a limitation of the air volume (and energy consumption), and on the other hand ensure the highest possible air quality.

Better, rather than more, technique is needed to reach this target. Where possible, the task of air change should have its emphasis moved from load extraction to hygienic renewal. In other words, the demand is: Less Air Flow By Higher Quality".

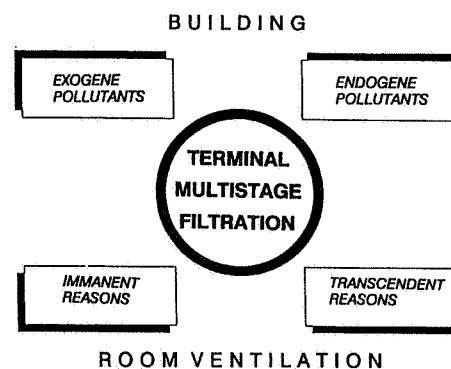


Figure 7

To improve the air quality without increasing the air volume is really only possible by equipping the conventional ventilation variants with so called HumanAir systems which work as final multiple step filter systems. Ventilation-specific causes, shown in illustration 7, can only logically be controlled by diffusers, or in the case of ventilation via windows, by integrated collectors which must be able to collect

more than dust particles. It is curious to consider that clean room techniques have been in existence for a long time to protect valuable machinery, products, etc., yet a demand to install a system such as HumanAir in order to protect human beings is met, usually, with astonishment. Nevertheless, in the light of increasing SBS problems and several fatalities in clinics in Hamburg, Frankfurt and Tuebingen, the blame is being increasingly accredited to the ventilation techniques.

The principle of the HumanAir diffusers is very simple and they could be considered as state-of-the-art technology. They are equipped with filters consisting of a particle filter layer, two active carbon layers - one of them of adsorptive and the other chemisorptive effect - and a protection fleece. With the combination of these filter layers precipitation rates are practicable which result in a significant improvement in the air quality. Illustration 8 shows the results of tests and measurements taken by TUeV-Southwest, an independent examination institution in Germany. According to their report, gaseous pollutants (both winter and summer) are eliminated at a rate of 80-90%, germs and bacteria up to 90% (killed off during the process), the cancerous BTX group (benzene, toluene and xylene) highlighted by the increasing use of unleaded fuel and PAH (polycyclic aliphatic hydrocarbons) are contained at a rate of about 70%.

Additionally, the filter also acts to reduce or eliminate noise (i.e. mechanical or aerodynamical sound), whereas the insertion loss of a common filter with three layers is higher than 15 dB. The HumanAir diffusers are equipped with a testing device in each room which displays updated information concerning the proper functions of the filter and warnings when cartridges require replacement.

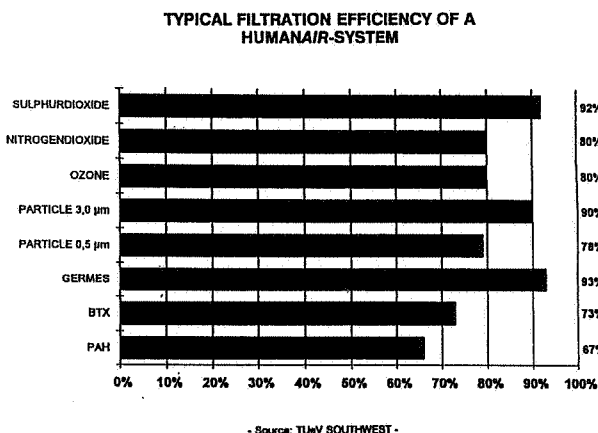


Figure 8

Ventilation techniques which have been equipped as clear air systems can avoid the various important weak points detailed in Illustration 9. From the psychological point of view, healthy air is supplied by a clean air system with a reduced noise level and a function display which can be controlled.

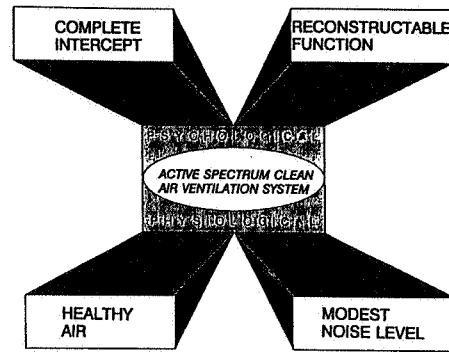


Figure 9

The clear improvement of the supply air quality through the use of HumanAir systems, opens up the possibility of reducing the rate of outdoor air (and a drop of energy costs).

So the ASHRAE statement "Energy versus Indoor Air Quality" may possibly be cancelled due to lack of basis. All the possible variants for clean air systems, i.e. "blowing or inducing HumanAir ventilation", "displacing HumanAir ventilation in combination with convective or radiant air conditioning", are fulfilled simultaneously, both ergonomic and energetic requirements so that they are generally considered to be ecologically harmless.

After the initial cost of purchase and maintenance, the use of clean air systems can bring many advantages to investors including increased performance from employees. Several studies, such as the New York Rensselaer Institute, report a two digit percentage improvement in alertness with the use of a clean air system. Illustration 10 briefly clarifies the economic efficiency of these systems by stating; even high uncertainty about the real value of performance gain by HumanAir systems is not causing doubts about their economical advantage, and the curve of better performance is higher than the block of additional costs.

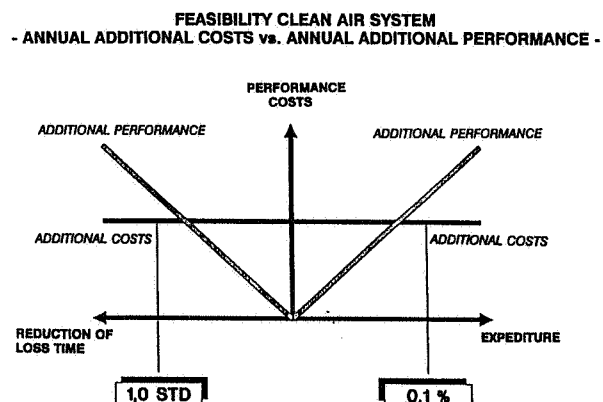


Figure 10

This evaluation of economic efficiency does not take into consideration the dangers to health and life associated with unprotected ventilation and air conditioning systems. Each person must decide for themselves the importance of these criteria. The question of liability should be mentioned as this also

plays a major part in the "pros and cons" of clear air systems. Just the principle of responsibility places the operating authority in a position of blame for injuries to persons due to the use of a ventilation system. In the event of a claim for such damages, many questions can be asked, "What has been done?, What could have been done additionally?, Which consequences could have been avoided by eventual additional actions? The burden of proof being firmly on the side of the putative cause. In 1988 a test case trial against air pollution took place between a computer programmer and various professional bodies such as architects, constructors,

consultants, manufacturers and salespeople of ventilation components, curtains, floor coverings and even copier toner. The assembly of offenders were subsequently fined approximately US\$622.500. As we are all in the same boat so to speak, in order to lower the risks, there should be a concerted action by all those involved in architecture to dispense with old prejudices and consider the ideal of a healthy indoor environment. Ventilation technique alone cannot win out against Sick Building Syndrome. It also requires architects to take up the challenge to produce buildings that are well thought out ecologically as well as economically.

Internet Access at the AIVC

by Martin Liddament, AIVC

A trial internet service has been established aimed at bringing information about the Air Infiltration and Ventilation Centre to anyone with e-mail access. This system is based on a "mail server" that automatically responds to e-mailed requests for information.

Current files include articles from Air Infiltration Review, news about the AIVC and general information on infiltration and ventilation. These can usually be received within a few minutes of requesting. Unlike more complex "telnet" and "ftp" services, this system is aimed at users with e-mail only access.

Despite its simplicity, this server is capable of delivering complex file formats including binary picture files and even complete reports. Throughout the trial period, use has been enthusiastic with information requests being received from several countries.

One particular purpose of the mail server is to maintain a showcase of material for the benefit of non AIVC participating countries. This service thus provides non participants with an opportunity to learn of the work of the AIVC and to share in some of its activities.

Quick Start Instructions

Anyone who has an e-mail connection should be able to access the AIVC mail server. For newcomers this means connecting an inexpensive 14400/19600 Baud modem to the serial interface socket of a standard PC and taking out a basic e-mail subscription with a "dial up" internet provider. Such a service should cost no more than a few dollars per month and, by careful selection, may include unlimited logon time. At this entry level, the service is reached via an ordinary telephone voice line, often at local call charge rates. Once the equipment is in place, all that is necessary to access the AIVC is to

send a "request" e-mail message to the Centre's mail server. Normally within minutes, a return message will contain the requested information. To access the mail server, use your e-mail editor to prepare a message to be sent to:

aivcreq@exnet.co.uk

Subject:REQUEST %help

Internet Use within Energy Conservation in Buildings and Community Systems

ANNEX 23 Multizone Air Flow Modelling (COMIS)

Annex 23 has developed a mathematical air flow model designed to predict air and pollutant transport within a multizone or multiroom building. The Program User Guide is now accessible as a series of PostScript (PS) files, either from an e-mail server or by file transfer protocol (ftp).

The e-mail server is reached by sending a message to:

annex-info@epb8.lbl.gov.

The main body of the e-mail should contain the instruction:

send USERGUIDE/user.No.ps

where No is the relevant chapter number.

Files through "ftp" are obtained by using the command:

ftp-i epb8.lbl.gov

(use ftp as the login name and your e-mail address as the password).

ANNEX 26 Energy Efficient Ventilation in Large Enclosures

Annex 26 is making extensive studies on the behaviour of air flow in case study buildings throughout the world. Measurement and numerical calculation techniques are being applied in an attempt to quantify the key parameters important for energy efficiency and good indoor air quality. Reports are available using file transfer protocol (ftp). To gain access type: ftp guinevere.ethz.ch. You will be prompted for "Name": type: ftp and "Password": type your e-mail address. Once connected, typing help will provide basic commands. The "get" command can be used to download a "README.2" file.

Connecting to the "World Wide Web"

The Air Infiltration and Ventilation Centre is gradually extending its Internet service by providing pages on

the "World Wide Web". This is aimed at enabling those who wish to know about AIVC related topics to locate the centre directly and download information, data and reports. This is possible because the WWW is a comprehensive information retrieval system that is able to trace and link designated key words. Current plans are to provide 5 MBytes of AIVC information covering its newsletter, unrestricted literature and papers of topical interest. This service will be promoted over the next few months.

Internet services such as "WWW" are seen as ways in which information can be disseminated by the AIVC at a relatively low cost. To complement this facility, all current and future publications of the Centre are being produced entirely in machine readable form. This will enable completely formatted reports to be downloaded without the need to maintain high stocks of printed copies. It is expected that the first such report will be based on the AIVC's Guide to Ventilation.

New Publications

Empirical Validation of Thermal Building Simulation Programs Using Test Room Data Volumes 1, 2, and 3 plus disk

*International Energy Agency, Annex 21
Subtask C/Task 12 Subtask B*

*Volume 1: Final Report
Volume 2: Empirical Validation Package
Volume 3: Working Reports*

Energy Efficient Communities Final Report

*International Energy Agency, Annex 22
by R Jank, J Johnsson and S Rath-Nagel*

*For information about obtaining
copies of the above reports,
please contact the AIVC
(address at back of this newsletter)*

Forthcoming Conferences

International Symposium

Indoor Air Quality in Practice: Moisture and Cold Climate Solutions

19-21 June 1995

Oslo, Norway

Contact: Ms Lise Olaussen, Norwegian Society of Chartered Engineers, Dr Maudsgt. 15, PO Box 2312, Solli, N-0201 Oslo, Norway,
Fax: +47 22 94 75 02

Topics: The main sessions are as follows: 1. Materials and construction, 2. Indoor air quality and health aspects, 3. Identification, control and remediation, 4. Annual costs versus investment costs.

Engineering Solutions to Indoor Air Quality Problems

24-26 July 1995

Sheraton Imperial Hotel, Research Triangle Park, NC, USA

Contact: Kelly Leovic, US EPA, MD-54, Research Triangle Park, NC 27711, USA, Tel: 919 541 7717, Fax: 919 541 2157

International Building Performance Simulation Association

Fourth International Conference

14-16 August 1995

Madison, Wisconsin, USA

Contact: Conference Secretariat, John Mitchell, Professor, University of Wisconsin, 1500 Johnson Drive, Madison, WI 53706-1687, USA,
Tel: +1 608 262 5972, Fax: +1 608 262 8464,
email: mitchell@engr.wisc.edu

ISES 1995 Solar World Congress In Search of the Sun

9-16 September 1995

International Conference Centre, Harare, Zimbabwe
Contact: In search of the sun, PO Box 2851, Harare, Zimbabwe,

Tel: 263-4 730707, Fax: 263-4 730700,
email: xcarse@zimbix.uz.zw

Healthy Buildings '95 an international conference on healthy buildings in mild climates

11-14 September 1995

Milan, Italy

Contact: Conference Organising Coordinator, Dr Maria Grazia Colombo, International Centre for Pesticide Safety, Via Magenta, n. 25, 20020 Busto Garolfo (Milano), Italy,
Tel: +39 331 568091/499371-2,
Fax: +39 331 568023

Tsinghua - HVAC '95 2nd International Symposium on Heating, Ventilation and Air Conditioning

23-25 September 1995

Beijing, China

Contact: Prof Yi jiang, Secretariat of the Symposium, Dept of Thermal Engineering, Tsinghua University, 100084, Beijing, P R China,
Tel: +86 1 2561144 ext 2746, Fax: +86 1 2545093

4th UK National Conference on Heat Transfer

26-27 September 1995

Manchester Conference Centre, UK

Contact: Hazel Anderson, Conference Services Department C510, Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1H 9JJ, UK
Tel: 0171 973 1317, Fax: 0171 222 9881

Topics: The session headings are as follows: Radiation and combustion; convection; conduction; two-phase flow and condensation; boiling (pool and flow); numerical techniques and modelling; heat exchangers and heat transfer augmentation; applied heat transfer and measurement.

Seminar on Indoor Air Pollution and Health: Principles and methods for investigation of the relation between environmental health and comfort and air pollution.

22-29 October 1995

Aarhus, Denmark

Contact: Lars Molhave, Dept of Environmental and Occupational Medicine, Aarhus University, Universitetsparken, bygning 180, DK-8000 Aarhus C, Denmark, Tel: +45 8942 2907, Fax: +45 8942 2970

ESS 95

7th European Simulation Symposium

26-28 October 1995

Friedrich-Alexander-University, Erlangen, Nuremberg, Germany

Contact: Philippe Geril, The Society for Computer Simulation International, European Simulation Office, University of Ghent, Coupure Links 653, B-9000 Ghent, Belgium

Tel: +32 59 800 804

Fax: +32 9 223 4941

email: philippe.geril@rug.ac.be

Topics: Simulation methodology and applications; Computer and telecommunications systems; Dependability evaluation; Analytical and numerical modelling techniques; Simulation in automation; Simulation in business; Symposium: Mission Earth.

7DBMC

7th International Conference on the Durability of Building Materials and Components

19-23 May 1996

Stockholm, Sweden

Contact: Executive Secretariat 7DBMC, Division of Materials Technology, Department of Built Environment, Royal Institute of Technology, PO Box 88, S-801 02 Gavle, Sweden,
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Fax: +46 26 14 78 01

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Representatives and Nominated Organisations

Belgium

*P. Wouters, Belgian Building Research Institute (WTCB/CSTC), rue de la Violette, 21-23, 1000 Brussels, Belgium. Tel: + 32 2-653-8801 Fax: + 32 2-653-0729

P. Nusgens, Université de Liège, Laboratoire de Physique du Bâtiment, Avenue des Tilleuls 15-D1, B-4000 Liège, Belgium. Tel: + 32 41 66 56 74 Fax: + 32 41 66 57 00

Canada

*M. Riley, Buildings Group, Energy Efficiency Division, Efficiency and Alternative Energy Branch, Energy, Mines and Resources Canada, Ottawa, Ontario, K1A 0E4 Canada Tel: + 1 613-996-8151 Fax: + 1 613-996-9416

J. Shaw, Inst. for Research in Construction, National Research Council, Ottawa, Ontario, Canada K1A 0R6 Tel: + 1 613-993-1421 Fax: + 1 613 954 3733

Duncan Hill, Research Division, Canada Mortgage and Housing Corporation, Montreal Road, National Office, Ottawa, Ontario, Canada K1A 0P7 Tel: + 1 613-748-2309 Fax: + 1 613 748 2402

Denmark

*O. Jensen, Danish Building Research Institute, P.O. Box 119, DK 2970 Hørsholm, Denmark. Tel: + 45-42-865533 Fax: + 45-42-867535

P.F. Collet, Technological Institute, Byggeteknik, Post Box 141, Gregersensvej, DK 2639 Tastrup, Denmark. Tel: + 45 42-996611 Fax: + 45-42-995436

Finland

*J. Sateri, Senior Research Scientist, VTT Building Technology, Indoor Climate, PO Box 1804, FIN-02044 VTT (Espoo), Finland Tel: + 358 0 4564710, Fax: + 358 0 455 2408, email: jorma.sateri@vtt.fi

France

*P. Hérant, ADEME, Route des Lucioles, 06565 Valbonne Cedex, France Tel: + 33 93 95 79 00 Fax: + 33 93 65 31 96

Ph. Duchêne-Marullaz, CSTB, 84 Ave. Jean Jaurès, BP 02 Champs sur Marne, 77421 Marne la Vallée, Cedex 2, France Tel: + 33-1 64 68 83 13 Fax: + 33-1 64 68 83 50

Germany

*Prof. Dr.-Ing. F. Steimle, Universität Essen, Universitätsstr. 15, 45141 Essen, Germany, Tel: + 49 201 183 2600, Fax: + 49 201 183 2584

J. Gehrmann, Projektträger BEO - Biologie, Energie, Ökologie, KFA Jülich, Postfach 19 13, 52425 Jülich, Germany Tel: + 49 2461/614852

G Mertz, Fachinstitut Gebäude Klima e.V., Danziger Strasse 20, 74321 Bietigheim-Bissingen, Germany Tel: + 49 7142 54498 Fax: + 49 7142 61298

Netherlands

*W.F. de Gids, TNO Building and Construction Research, Dept of Indoor Environment, Building Physics and Systems, P.O. Box 29, 2600 AA Delft, Netherlands, Tel: + 31 15 608608 (Direct: + 31 15-608472) Fax: + 31 15-608432, email: w.degids@bouw.tno.nl

New Zealand

*M. Bassett, Building Research Association of New Zealand Inc (BRANZ), Private Bag, Porirua, New Zealand. Tel: + 64-4-2357600 Fax: + 64 4 2356070

Norway

*J.T. Brunzell, Norwegian Building Research Institute, Forskningsveien 3b, PO Box 123, Blindern, N-0314 Oslo 3, Norway. Tel: + 47 22-96-55-00 Fax: + 47-22-965542, e-mail jbrunsel@ulrik.uio.no

H.M. Mathisen, SINTEF, Division of App Thermodynamics, N-7034 Trondheim,

Norway. Tel: + 47 73-593000 Telex: 056-55620

Sweden

*J. Kronvall, J&W Consulting Engineers AB, Slagthuset, S-21120 Malmö, Sweden, Tel: + 46 40108200, Fax: + 46 40108201

J Lagerström, Swedish Council for Building Research, Sankt Goransgatan 66, S-112 33, Stockholm, Sweden Tel: + 46 8-6177300 Fax: + 46 8-537462

Switzerland

*V. Dorer, EMPA, Section 175, Ueberlandstrasse, CH 8600 Dübendorf, Switzerland. Tel: + 41 1-823-4789 Telex: 825345 Fax: + 41 1-821-6244

UK

*MDAES Perera, Environmental Systems Division, Building Research Establishment, Garston, Watford, WD2 7JR, UK Tel: + 44(0)1923 664486 Telex: 923220 Fax: + 44(0)1923 664095, e-mail pererae@bre.co.uk

S. Irving (Operating Agent), Oscar Faber Consulting Engineers, Marlborough House, Upper Marlborough Road, St. Albans, Herts, AL1 3UT, Great Britain. Tel: + 44(0)181-7845784 Telex: 889072 Fax: + 44(0)181-7845700

USA

*M. Sherman, Indoor Air Quality Division, Building 90, Room 3074, Lawrence Berkeley Laboratory, Berkeley, California 94720, USA. Tel: + 1 510/486-4022 Telex: 910-366-2037 Fax: + 1 510 486 6658 e-mail: MHSherman@lbl.gov

A. Persily, Building Environment Division, Center for Building Technology, Building 226, Room A313, National Institute for Standards and Technology, Gaithersburg MD 20899, USA Tel: + 1.301/975-6418 Fax: + 1 301/975-4032

J. Talbott, Department of Energy, Buildings Division, Mail Stop Ce-131, 1000 Independence Avenue S.W., Washington D.C. 20585, USA Tel: + 1 202/586 9445 Fax: + 1 202 586 4529/8134



Head of Centre Martin W Liddament

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Tel: + 44(0)1203 692050
Fax: + 44(0)1203 416306
e-mail: airvent@AIVC.org