Air Infiltration Review

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Duct Cleaning - A Literature Survey

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Abstract

An effort has been made to gather the information available about duct cleaning. The major sources of information were AIRBASE (Air Infiltration and Ventilation Centre, Great Britain) and a database on ASHRAE Publications (BSRIA, Great Britain). The emphasis in the survey was on the hygienic aspect of the cleaning of supply air ducts. Most of the literature deals with cleaning of exhaust ducts. Guidelines for the cleanness of duct surfaces have been given by some organizations, but the scientific basis for such guidelines needs more research.

Introduction

Cleaning of air duct systems is one of the efforts to eliminate the contaminant sources inside the HVAC system and thus the pollutant transportation inside the building. Cleaning of an air conditioning system includes the following steps [17]:

1. Initial test to determine presence/absence of contaminants, and to identify the contaminants in the system;
2. Source removal;
3. Encapsulation (when determined to be necessary) of materials not removed during the source removal process;
4. Disinfection (when determined to be necessary) to inhibit growth of fungi (moulds), bacteria, viruses, etc.;
5. Final testing to detect the success of the cleaning.

The cleanness of HVAC components is important as regards to indoor air quality. Water condensation on the surfaces of the cooling coils and the humidifying process at the air handling units may cause stagnant water in the drain pans, which may offer suitable conditions for microbial growth [e.g. 1]. Also supply air filters may act as indoor air pollutants [e.g. 2]. This survey concentrates on the cleanness of supply air ducts.

Dust settled in the interior surfaces of the supply air ducts

The amount and content of dust settled in the supply air ducts has been studied by Nielsen et al. [19] in Denmark and by Laatikainen et al. [12] and Pasanen et al. [22] in Finland. Nielsen et al. [19] loosened the dust with a trowel and moved it to a glass sheet for further analysis. Laatikainen et al. [12] took samples from duct surfaces with swabs, and Pasanen et al. [22] collected the dust samples by a specially designed T- shaped nozzle connected to a filter cassette and a vacuum pump.

The parameters evaluated were surface density, yearly accumulation of dust, organic proportion and viable bacteria and fungal spore counts. Viable fungal spore counts and bacteria in the dust were determined by the cultivation method. The results are shown in Table 1.

Table 1: Some parameters of the dust settled in the inner surfaces of supply air ducts in schools and office buildings (n=number of buildings studied).

Analysis	Nielsen et al. [19] (n=13)	Laatikainen et al. [12] (n=6)	Pasanen et al. [22] (n=8)
Average surface density	6,8 g/m^2	18,2 g/m^2	10,6 g/m^2
Accumulation of dust per operating year	0,7 g/m^2 year	2,3 g/m^2 year	3,5 g/m^2 year
Macromolecular organic components in dust	0,9...8,9 mg/g dust	-	-
Proportion of organic components in dust	-	20 %	18 %
Average count of viable fungal spores	70...6200 cfu/g	6100 cfu/m^2	990 cfu/g
Average count of viable bacteria	50...5000 cfu/g	7020 cfu/m^2	1980 cfu/g

Generally, the greater part of the dust was found at the bottom of the ducts. The yearly accumulation ranged between 0.7 - 3.5 g/m^2 per year. The amount of organic components in the dust was less than 20 %. Nielsen et al. [19] concluded that the dust found in supply air ducts did not differ from the floor dust in offices. Pasanen et al. [22] found that the content of the dust was similar to the dust in outside air.

Nyman and Sandstrom [20] investigated the amount of viable fungi and bacteria on the interior surfaces of outside air ducts, supply air ducts and heat exchangers in 20 air conditioning systems by the swab method. The buildings studied included schools, offices, day care centres and dwellings. The average counts of viable fungal spores and bacteria in the surfaces of supply air ducts were about 10 - 100 times higher than the average counts reported by Laatikainen et al. [17] (Tables 1 and 2). However, microbial counts seemed to decrease along supply air duct work. The surface density of dust was not determined.

Table 2. Concentrations of fungi and bacteria on the interior surfaces of ventilation systems [20].

Measuring point	Fungi, cfu/cm^2			Bacteria, cfu/cm^2			Number of buildings
	Lowest	Average	Highest	Lowest	Average	Highest	
Outside air duct; surface	<1	156	1000	<1	129	670	17
Heat exchanger; surface	2	126	400	<1	615	2000	4
Supply airduct; surface	<1	6	30	<1	48	600	20
Exhaust air duct; surface	<1	320	1900	1	88	500	6

To date, the analysis of the dust accumulated in the duct work is seldom done in conjunction with duct cleaning contract. The inspection of the cleanness of the interior surfaces of ventilation ducts is most often done visually, though remote controlled video inspection and recording robot, borescopes and fiberscopes are available to help to observe the duct systems internally [8].

Source removal

Four cleaning processes of air ducts are used for source removal: vacuum, steam, compressed air and chemical/disinfection [14]. As an HVAC system includes different components with different kinds of dirt, more than one of the processes may be used in the cleaning of an HVAC system. Cleaning method recommended for example by Olson [21] for hospital air conditioning systems could be summarized as, vacuum cleaning with brush attachment for air grills, traditional duct-cleaning contractors' method for occasional cleaning of ductwork, high pressure air for dry dirt and high pressure water for impinged dirt for pre-heat and cooling coils. The technical solutions for the vacuum extract units are numerous. The difference between truck mounted vacuums and portable vacuums is that the former discharges the contaminated air into to outside, whereas the latter may discharge the contaminated air from the system into the indoor air through a HEPA-filter [8]. Nylon brushes are used for loosening the debris (Figure 1).

Air Infiltration Review

Editor: Janet Blacknell

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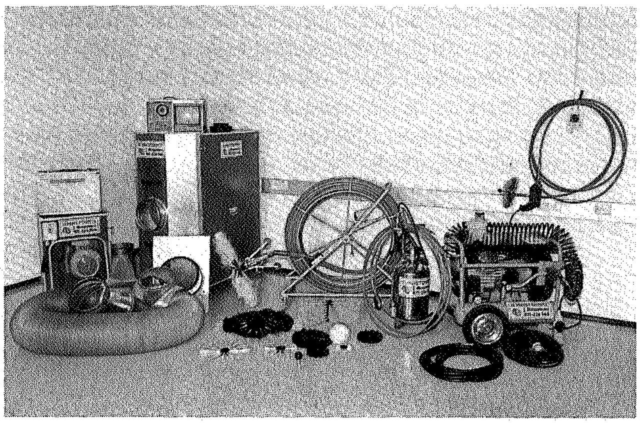

Figure 1. Brushes used in duct cleaning.

In the vacuum method, sufficient velocity is necessary to move the loosened dirt to the collection point. Deposition of particles on the duct walls is due to e.g. diffusion, electricity and gravity. In theory, a 15 μm particle is air borne for 3.2 m in a horizontal duct [27] before deposition. The sedimentary dust stays at the bottom of the duct if the air velocity is less than 7 m/s [27]. On the other hand, the velocity needed to carry such a particle through a 10 m horizontal duct is at least 17 m/s [15].

The cleaning aspects are not always taken into account in product design, as Flatheim [7] points out with ventilation ceilings. Leskinen [13] lists needs for research from the point of view of the manufacturing industry. He regards the development of a test method for the tendency of components to accumulate dirt on surfaces in order to compare different products and constructions as the most urgent need.

The optimal cleaning frequency in regard to economic periodicity was evaluated by Wallin [11]. The main principle in his evaluation was, that the designed air flows must be always achieved. For example the air flow rate of an HVAC system is 9000 m^3/h and the yearly accumulation of dust decreases the air flow rate by 25 %. The designed air flow rate can be maintained by either short cleaning intervals or over sizing the ducts. He calculated that the optimal cleaning frequency for that HVAC system was 7 months. Thus, the cost of cleaning and the energy cost of oversizing the air flow rates would be at its minimum. According to Wallin, the optimum cleaning frequency of exhaust air ducts is between 1-2 years depending on the cleanness of the outside air and the activities in the building. In general, there are no guidelines for cleaning of supply air ducts.

Encapsulation is one method used for removal of microbial problem from porous duct materials. In this method, the non-combustible, non-toxic, non-offgasing (VOC) liquid or water miscible resin solutions are sprayed or wet-fogged to adhere bond, or fibre- fixed particulates, not removable by mechanical cleaning [17].

Disinfection

Biocides are substances that destroy or inhibit the growth of microorganisms. Antimicrobial treatments differ in chemical nature, mode of operation, durability, effectiveness, toxicity, safety and cost. According to their principles, biocides can be divided into two groups: bound and unbound biocides. Bound agents have ability to bind themselves chemically to the surface and they work continuously when contacted with microorganisms. Therefore they are considered to be effective and safe to use. Unbound agents have to diffuse from the treated surface and they must be consumed by the microorganisms in order to be effective. The effect of unbound biocides decreases or vanishes when they evaporate or they are washed off from the surface [10].

According to chemical composition, biocides can be divided into the following groups. Hypochlorides are widely used and accepted for sanitary use. They are effective against many microbial groups and act well particularly in acid environments, but they are very corrosive even at low concentrations. Hydrogen peroxide is recommended for disinfection of surfaces and devices as 3-5% water solution. Quaternary ammonium compounds are effective especially against gram positive bacteria. Alcohols have been used as biocides for many years; ethanol, propanol and isopropanol are effective against bacterial cells but they are relatively ineffective against bacterial and fungal spores. Alcohols are most efficient in the concentration range between 50-90% with 70 % being generally recognized as optimal. Phenols, aldehydes (glutaraldehyde, formaldehyde) and iodides are also used for disinfection but they are very odorous and corrosive [5, 25].

Some risks can be involved in the use of biocides; many effective biocides (hypochlorides, quaternary ammonium compounds, phenols, aldehydes and iodides) are potential irritants for eyes, skin and mucous membranes. On the other hand, less harmful biocides, such as alcohols and diluted hydrogen peroxide, may not be efficient enough because of their evaporative properties and short-term effect. The possible health effects associated with the use of biocides are mainly directed to users and, thus, sufficient personal protective devices should be used. When biocides are used for example for disinfection of air ducts in occupied spaces, the occupants may be also exposed to biocides and suffer from symptoms caused by biocides. This is a reason why use of biocides cannot be recommended for routine use in cleaning ventilation systems [1, 3, 4, 5, 6, 9, 25, 28]. If the ventilation system is heavily contaminated by microorganisms, the use of biocides is acceptable in order to attain complete cleaning. During disinfection the ventilation system should be shut off and occupants should be evacuated from the spaces. Proper work also provides careful cleaning of air ducts before disinfection because the presence of organic matter and dirt decreases the effectiveness of many biocides.

Final testing

Air flows
Nielsen et al. [19] estimated, that the dust layer they found in supply air ducts was too small to reduce the air flows of HVAC-systems. Wallin [11, 26] measured the air flow rates before and after the cleaning of exhaust ducts and found a 20-30 % increase in exhaust air flows achieved by duct cleaning. Thus cleaning of small diameter exhaust ducts is needed to maintain designed flow rate values in multistorey residential buildings.

Cleanness of the inner duct surfaces
In a draft report, The Nordic Ventilation Group [9] evaluates the amount of floor dust for three categories as regards to risking indoor air guality: low risk (less than 0.2 g/m^2), medium risk (0.2-0.5 g/m^2) and high risk (more than 0.5 g/m^2).

Furthermore, The Nordic Ventilation Group gives values for the microbial content of the floor dust [9]. Low risk level for fungal spores is less than 1000 cfu/g, medium risk is 1-3000 cfu/g and high risk is more than 3000 cfu/g. Correspondingly, low risk level for bacteria is less than 6000 cfu/g, medium risk level is 6-10000 cfu/g and high risk level is more than 10000 cfu/g.

The National Air Duct Cleaners Association (NADCA) in the US developed a standard on mechanical cleaning of non-porous air conveyance system components [18]. A vacuum test is introduced to be used to verify the cleanness of non-porous surfaces, in which loosed debris is collected from a defined area. According to the standard the surface density of debris must not exceed 1 mg/100 cm^2 (0.1 g/m^2).

There are no standards dealing with the microbiological content of the dust on the interior surfaces of ventilation ducts. However, the studies [19, 24] give an impression on the counts of fungal spores and bacteria in the dust; the fungal spore counts ranged between 70-6200 cfu/g dust and the bacteria counts between 50-5000 cfu/g dust.

Odour emission of the HVAC components
Pejtersen et al. [23] utilized an odour panel technique to evaluate the odour emissions of HVAC components before and after cleaning. Cleaning decreased substantially the odour emission of the humidifier. The odour emission for the whole HVAC unit was 202 olf before the cleaning and 104 after the cleaning. However, the odour emission of the outside air duct increased after cleaning, but the reason for that was not found.

Indoor air quality
Pejtersen et al. [23] evaluated the effect of cleaning of the HVAC system on the occupants' perceptions on indoor air quality, although, in the investigated building the changes in the perceived air quality were small. They concluded that cleaning tends to improve indoor air quality. Puhakka and Jyrkiinen [24] measured particle concentrations in indoor air before and during the cleaning of a ventilation system and found that the particle concentration of indoor air was three times higher during the cleaning than before the cleaning. The disinfection of supply air ducts also increased the concentration of volatile organic compounds in a home for the aged [24]. The indoor air concentration before the disinfection was 675 g/m^3 and after the disinfection 21 100 g/m^3 (average for 15 hours).

Conclusions

HVAC systems can be a source of indoor air pollutants. Duct cleaning is on the one hand a preventive means to avoid health effects and discomfort caused by indoor air pollutants and on the other hand a step in remediating the causes of these problems.

To date, periodical cleaning of HVAC systems is recommended. In order to avoid frequent duct cleaning, facility managers would welcome guidelines telling what amount and content of debris is acceptable. The scientists hesitateto give recommendations to such guidelines, because forecasting resuspension and microbial life cycles in HVAC systems is complex. Manufacturing industry is willing to develop HVAC components which have a lower tendency to accumulate dirt than the existing components.

The first industry standard for the surface density of dust on the interior duct surfaces after cleaning is published and it recommends that surface density of dust should not exceed 1 mg/100 cm^2. A guideline for dust surface densities on floors and the microbiological content of the dust on floors are given for low risk, medium risk and high risk categories by a Nordic group of scientists. The dust surface densities of dust measured from 13 Danish and 8 Finnish buildings ranged between 0.7-3.5 g/m^2 [12, 19, 22]. The ducts had not been cleaned recently. The surface densities exceeded by far the target values set for clean ducts [18] (and clean floors [9]).

The microbiological analysis of the dust collected on the interior duct surfaces shows that the dust can act as a growth medium to viable fungi and bacteria and is thus a risk factor for the indoor air quality in the case, when the surfaces get wet or the relative humidity rises. E.g. rain penetration occurs relatively frequently [20]. Maybe the main reason for preventive duct cleaning is to minimize the possibilities for microbial sources, rather than to prevent the particle resuspension, decrease in air flows or fire spreading.

Methods used for the collection of dust from the interior duct surfaces rely on collecting the dust from a defined area by e.g. vacuum cleaning. The amount of fungi and bacteria in dust have been determined by cultivation methods. The sampling methods vary, e.g. swab method [20] has been used. Harmonization of the sampling and analyzing methods would make it easier to compare the results from different studies.

Usually disinfection is included in cleaning methods in HVAC systems with heavy microbial contamination and also in systems which have no signs of microbial contamination. The use of biocides may give only a temporary disappearance of microbial problem if favourable circumstances for micro-organisms are not eliminated. Many risks such as the occupational safety of cleaners and raised indoor air pollutants are included in the use of biocides.

The number of articles on the effect of duct cleaning on the hygiene of the system is small compared with the number of articles published on various aspects of indoor air quality. Also published information about the best practice in cleaning of HVAC systems is scarce. Important questions to be answered are the optimal size of vacuuming zones, the effectiveness of different cleaning methods in loosening the debris, the effectiveness of different disinfection substances and the risk related to their use, just to mention some. The duct cleaning contractors have more thorough knowledge gained by experience about the hygiene of ventilation systems and efficiency of different duct cleaning methods than can be obtained by studying the literature available.

References

[1] Ager, B. P. & Tickner, J. A., The control of microbiological hazards associated with air- conditioning and ventilation systems. Ann. Occup. Hyg. 1983. Vol 27, No 4, pp. 341 - 358.

[2] Bluyessen, F., Do filters pollute or clean the air? Air Infiltration Review, 1993. Vol. 14, No. 2, pp. 9 - 13.

[3] Brief, R. S. & Bernath, T., Indoor pollution. Guidelines for prevention and control of microbiological respiratory hazards associated with air conditioning and ventilation systems. Appl. Ind. Hyg. 1988. Nro 3, pp. 5 - 10.

[4] Burge, H. A., The fungi. In: Biological Contaminants in Indoor Environments. Edited by P. R. Morey, J. C. Feeley & J. A. Otten. Philadelphia, USA, ASTM, 1990. Pp. 136 - 162.

[5] Burge, H. A., Feeley, J. C., Kreiss, K., Jilton, D., Morey, P. R., Otten, J. A., Peterson, K. & Tulis, J. J., Guidelines for the assessment of bioaerosols in the indoor environment. American Conference of Governmental Industrial Hygienists. Cincinnati, USA, 1989.

[6] Feeley, J. C. & Morey, P. R., Two consultants' views of tomorrow. In: Biological contaminants in indoor environments. Edited by P. R. Morey, J. C. Feeley & J. A. Otten. Philadelphia, USA, ASTM, 1990. Pp. 221 - 227.

[7] Flatheim, G. & Brantland, T., Klimahimling - et nytt bomskudd?. Norsk VVS 1985. Vol. 28, nro 11, pp. 869 - 871. (in Norwegian).

[8] Gerhard, D., Techniques & equipment for cleaning commercial air conveyance systems. DucTALES, 1992. Vol. 4, nro 3, pp. 12 - 13.

[9] Indeklimaproblemer. Undersokelse og afhjaelping. 2. utgave. Denmark, Statens Byggeforskningsinstitut, 1992. 108 pp. (in Danish).

[10] Kemper, R. A. & White, W. C., Sustained reduction of aerobiological densities in buildings by modification of interior surfaces with silane modified quaternary amines. In: Indoor Air Pollution, Radon, Bioaerosols, & VOC's. Edited by J. G. Kay, G. E. Keller & J. F. Miller. Chelsea, USA, Lewis Publishers, 1991. Pp. 47 - 58.

[11] Klimat och byggnader. Nr 1/1991. Second edition. Stockholm, Kungliga tekniska hgskolan, Intitutionen fr uppvrmnings- och ventilationsteknik. 1991. 76 pp. (in Swedish).

[12] Laatikainen, T., Pasanen, P., Korhonen, L., Nevalainen, A. & Ruuskanen, J., Methods for evaluating dust accumulation in ventilation ducts. Healthy Buildings, Washington, DC, 4 - 8 September, 1991. ASHRAE, 1991. pp. 379 - 382.

[13] Leskinen, S., Elimination of product related indoor air quality problems. Indoor air quality management, Lausanne, 27 - 28 May, 1991. Lausanne, The Swiss Federal Office of Energy. Pp. 145 - 150.

[14] Loyd, S., Ventilation system hygiene - a review. Berkshire, BSRIA, 1992. 34 pp. Technical Note TN 18/92.1.

[15] Luoma, M., Pasanen, A - L. & Pasanen, P., Cleaning of air conditioning systems. Espoo, Technical Research Centre of Finland, 1993. Research Notes. 60 p. + app. 6 p. Research Notes (in print) (in Finnish, abstract in English).

[16] Morey, P. R., Hodgson, M. J., Sorenson, W. G., Kullman, G. J. & Rhodes, W. W., Environmental studies in mouldy office buildings: biological agents, sources and preventative measures. Ann. Am. Conf. Gov. Ind. Hyg. 1984. Nro 10, pp. 21 - 35.

[17] Mulhern, F. J. & Mateson, J. F., Duct cleaning, myths, misconceptions, and facts. H&V Engineer. Vol 64 No. 707, pp. 5 - 9.

[18] NADCA 1992-01. Mechanical cleaning of non-porous air conveyance system components. Washington DC. National Air Duct Cleaners Association. 1992. 11 pp.

[19] Nielsen, J. B., Valbjorn, O., Gravesen, S. & Molhave, L., Stov i ventilationsanlaeg. Horsholm, Statens Byggeforskningsinstitut, 1990. 34 pp. SBI-Rapport 206. (in Danish).

[20] Nyman, E. & Sandstrm, N - ., Mikroorganismer i ventilationssystem. Sweden, Byggforskningsrdet, 1991. 38 pp. R45:1991. (in Swedish).

[21] Olson, R. W., The effect on hospital air conditioning system operation on soiled system elements. ASHRAE Trans. 1986. Vol. 92, Part 1b, pp. 388 - 398.

[22] Pasanen, P., Nevalainen, A., Ruuskanen, J. & Kalliokoski, P., The composition and location of dust settled in supply air ducts. 13th AIVC conference, Nice, 15 - 18 Sep. 1992. Air Infiltration and Ventilation Centre. Pp. 481 - 488.

[23] Pejtersen, J., Clausen, G. & Fanger, P. O., Olf och energi. Fase 2: Olf-vaerdier for og efter rensning af ventilationsanlaeg. Lyngby, Lab. of Heating and Air Conditioning, Technical University of Denmark, 1992. 43 pp. (in Danish) Draft.

[24] Puhakka, E. & Jyrkiinen, J., Cleaning of supply air ducts, an example. Seminar on indoor air quality. Espoo, 4th June, 1992. Espoo, Technical Research Centre of Finland. Laboratory of Heating and Ventilation, 1992. Pp. 82 - 88. LVIS 2000 Research Program. Report 14. (in Finnish).

[25] Serceau, R., Grellety, J. L., Rindel, D., Perbost, J. C. & Guisnet, P., Aerobiological measurements in air conditioning systems. In: Quality of the indoor environment. Edited by J. N. Lester, R. Perry & G. L. Reynolds. Pp. 239 - 257. Lontoo, Selper Ltd, 1992.

[26] Wallin, O., Erfarenheter frn rensning av ngra ventilationssystem i flerfamiljhus uppfrda under 1950-talet. Stockholm, Kungliga tekniska hgskolan, Inst. fr uppvrmnings- och ventilationsteknik, 1978. Pp. 96 - 117. Tekniska meddelanden 123- 124. (in Swedish).

[27] Wallin, O., Stoftavsttning efter en bj i en ventilationskanal med cirkulrt tvrsnitt. Stockholm, Kungliga tekniska hgskolan, Inst. fr uppvrmnings- och ventilationsteknik, 1982. 158 p. Tekniska meddelanden 237. (vol. 12). (in Swedish).

[28] WHO. Indoor air quality. Biological contaminants. Report on a WHO meeting. Copenhagen, WHO, 1990. Regional Publications, European Series No. 31.

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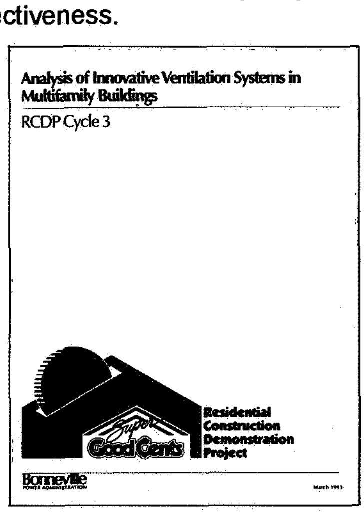
New Books

Analysis of Innovative Ventilation Systems in Multifamily Buildings
Residential Construction Demonstration Project: Cycle III, Final Report
by Jonathan Heller
Bonneville Power Administration, Super Good Cents, RCDP, March 1993

The purpose of this study was to examine the effectiveness of ventilation systems installed in Super Good Cents multifamily buildings. Extensive field testing was done in seven case study buildings to collect information on envelope tightness, ventilation system capacity and run-time, inter-apartment air leakage, occupant effects, system costs, and other factors to evaluate the ventilation systems. Field testing included: blower door tightness testing, short term sulphur hexafluoride tracer gas testing (SF_6), long term perfluorocarbon tracer gas testing (PFT), flowhood measurements, sound level measurements, smokestick analysis, differential pressure measurements, and occupant surveys. The ventilation systems were also evaluated for quality of installation and cost effectiveness.



MORE INDOOR AIR?
A Review of Indoor Air '93

Helsinki, Finland 4th - 8th July 1993

Martin W. Liddament, Head of Air Infiltration and Ventilation Centre

Indoor Air '93 was attended by 1300 delegates from 52 countries. Almost 700 papers were presented, making this one of the largest of recent conferences on the indoor environment. Much of the focus was on the ever increasing sources of pollutants to be found in buildings, detection methods, comfort and health impacts. The programme took the form of plenary sessions, parallel presentations, workshops and poster displays. Several sessions and workshops addressed ventilation issues, some of which are summarised below.

How much ventilation?

On this issue there is currently much apparent conflict, not least because there is uncertainty over whether ventilation rates should be area based, occupant based or specific pollutant based.

In a workshop entitled "New Criteria for Ventilation: Sensory Effects", a European research report entitled "Guidelines for Ventilation Requirements in Buildings" was introduced. These Guidelines concentrate on the building as a polluter and assess air quality 'comfort' conditions on the basis of perceived odour intensity when entering or 'visiting' a space. Since odour intensity cannot be measured with instrumentation, results are based on the assessment of either trained or untrained panelists. Implicit in this approach is that odour from different sources can be summed to obtain a total odour value, even although the types of odour may differ (e.g organic compounds, occupant sources etc). Thus it is assumed that a total odour value can be derived based on the individual values of all odour emitting sources. Results suggest that it is possible to equate the level of dissatisfaction of visitors to a space against odour intensity or 'perceived' air quality. The key units are the 'Olf', which is the odour emission rate from a 'standard' person, and the 'decipol', which is the intensity of odour or 'perceived' air quality derived from a source of one 'Olf' ventilated by 10 l/s of fresh air. It is assumed therefore that all odours can be equated with human bioeffluent. Observations have indicated that the percentage of 'visitors' to a space who are dissatisfied with the intensity of odour can be directly correlated with the decipol value (and hence ventilation rate) as indicated in Table 1. Other contributors to this workshop considered ventilation on an occupant loading basis, with some evidence being presented which suggested that the prevalence of sick building problems was more likely at ventilation rates below 10 l/s.p. Although discussed during the course of the workshop, no consensus could be established on what contaminants constituted a health risk.

Table 1: Perceived indoor air quality

Quality level (Category)	Perceived Air Quality		Required Ventilation Rate (l/s.Olf)
	% Dissatisfied	Decipol	
A	10	0.6	16
B	20	1.4	7
C	30	2.5	4

The divergence of approach to ventilation was also apparent in many of the papers and presentations. Cain et al (1,21) point out that it is not possible to ventilate a space with levels of outside air sufficient to achieve a criterion of no odour. However, by controlling odour to sensible levels, other contaminant concentrations are often adequately controlled. Minamino et al (1,83) argue that carbon dioxide is an effective indicator of odour intensity in rooms where smoking does not take place. They also point out the significance of odour emission from the building interior and conclude that this increases with building age. Tamblyn et al (1,133) state that, in cold climates, a balance needs to be struck between the adequate dilution of indoor contaminants and the maintenance of adequate indoor air quality. Their research showed that air quality complaints from some workers were from those who received a higher proportion of outdoor air. This was thought to be associated with the very low humidity of the incoming ventilation air. Ruotsalainen et al (5,127) found that lethargy was more prevalent among day-care workers receiving less than 5 l/s.p of outdoor air. However, they could not identify ventilation related sick building symptoms even in buildings with low ventilation rates. Light et al (6,563) emphasise the need to increase office fresh air supply from the former ASHRAE value of 2.5 l/s.p to the current ASHRAE 62:1989 recommended value of 10.0 l/s.p to improve the indoor environment.

Gene Tucker (3,525) outlined the philosophy behind the current review of ASHRAE Standard 62 - 'ventilation for acceptable indoor air quality'. The proposed first step is to determine a minimum ventilation rate based on occupants and polluting sources unique to a particular space. The second step is to determine whether additional ventilation is needed to account for other high emitting sources. Under consideration, is the possibility of using certified low emission products as an alternative to requiring additional ventilation. In any event, the designer has an incentive to consider source management as an alternative to additional ventilation. Continuing with Standards, Fitzner (3,531) discussed revisions to the German ventilation Standard, DIN 1946. Four methods are applicable to the calculation of outdoor air flow rate; these are: - occupant density (e.g. 40 - 60 m3/h.p for offices) - floor area (e.g. 4 - 6 $m^3/h.m^2$ for offices) - pollutant source strength (eg 1000 - 1500 ppm of CO_2) - Decipol Rating as for European Guidelines.

Edmund Skaret (3,513) outlined the Nordic Committee on Building Regulations approach to Ventilation which (for offices) is based on the European Guidelines 1.4 decipol value (see Table 1). Clause 4.1.1 of the Regulations (based on $10m^2$/occupant and low emitting surfaces) recommends a ventilation rate of 10.5 l/s.p. This is raised to a minimum of 20 l/s.p in offices where smoking is permitted.

Rengholt (3,519) described a 'quality assured' approach to indoor air quality introducing the 'Scanvac Guidelines' on indoor climate. This incorporates three thermal classes, two air quality classes and two sound level classes. Maximum permitted pollutant concentration in the air quality classes are specified for carbon monoxide, carbon dioxide, ozone and volatile organic compounds. Both air quality classes specify a maximum CO_2 concentration of 1000 ppm.

A summary of some of the ventilation values presented at the conference is illustrated in Figure 1.

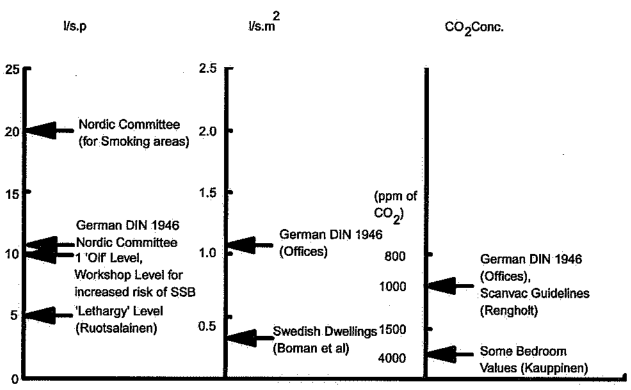


Figure 1: Examples of ventilation rates

Residential Ventilation

Aspects covering the ventilation of dwellings were reviewed in a workshop entitled 'Criteria for Codes and Standards for Residential Ventilation' The purpose of this workshop was to assess the appropriate bases for residential ventilation, evaluate the usefulness of basing ventilation on air quality indicators and reviewing the need for mechanical ventilation. Pollutant source management and the need to satisfy health criteria were emphasised as key ventilation needs. Discussion on pollutant indicators resulted in the conclusion that much more research was needed to establish acceptable pollutant concentrations of many common pollutants but that, unlike offices, VOC's and CO_2 were not generally useful air quality indicators for the home. Mechanical systems seemed to be the preferred choice for domestic ventilation among many of the workshop participants, although others expressed support for purpose provided natural ventilation.

A brief analysis of the conference papers also revealed a preference for the mechanical ventilation of dwellings. Sometimes, however, natural ventilation systems used in comparison studies were often not clearly defined or did not necessarily represent a 'best practice' approach. Kauppinen(5,103) et al argued that natural ventilation in modern detached houses do not achieve the required air change rate. They showed that CO_2 concentrations could reach 4000ppm in an unventilated bedroom compared with a maximum observed level of 1800 ppm in a mechanically ventilated dwelling. Perah et al (5.115) concluded that mechanical ventilation combined with airtightness is needed to provide energy efficient ventilation. Riberon et al (5,121) reported that approximately 90% of new French homes have mechanical systems which are needed to meet the requirements of fresh air to habitated rooms and to extract exhaust air from service rooms. Ekstrand-Tobin (1.185) concluded that dwellings with natural ventilation showed more indication of damp, considerably higher bacteria counts in dust and greater quantities of particles in the air than mechanically ventilated houses. Boman et al (5,3) reported the results of ventilation measurements made in Sweden on over 3500 single family and multi-family homes. Ventilation rates were found to vary between 0.2-0.38 $l/s.m^2$ compared to the current Swedish Standard of 0.35 $l/s.m^2$. The lowest ventilation rates were found in naturally ventilated houses constructed between 1961-1975. On an occupant basis, average ventilation varied between 12-18 l/s.p.

Office Ventilation

In contrast, much of the published evidence from this conference for the office environment seemed to support natural ventilation for reduced symptoms associated with sick buildings. William Fisk, (1,279) indicated that results from a recent Californian Healthy Building Study showed that occupants of mechanically ventilated and air conditioned offices had significantly more SBS symptoms than those from naturally ventilated offices. Jaakholu (1,285) from Finland indicated similar results. Vincent et al (1,423) outlined the results of a study of 2300 French workers in air conditioned and naturally ventilated offices. They found no association between air conditioning systems and respiratory health effects. However, the environment was perceived as 'less comfortable' in the air conditioned buildings. Burge from the United Kingdom (6.572) showed that SBS symptoms increased for a group of office workers who were moved from a naturally ventilated to an air conditioned office. Valbjorn et al (5.503) reported that the acceptance of indoor climate was high and poor air quality symptoms were rare in naturally ventilated Danish office buildings, even although many of these buildings have ventilation rates below Nordic Guidelines. Bourbeau (1,297) et al concluded that SBS symptoms are reduced if improvements are made to mechanical ventilation systems.

How much energy?

Energy aspects were considered at a workshop entitled 'Indoor Air quality and Energy' This attempted to establish the impact of ventilation rate on indoor air quality, the most cost effective methods of controlling indoor pollutant and the most energy efficient approaches to ventilation. The main conclusions were that emphasis needed to be placed on pollutant source control and that purpose provided rather than adventitious ventilation design was essential. Systems should also be sized to tolerate inaccuracies in design, construction and use. Amongst the presentations and papers on energy, Traynor et al (3,595) reported on an energy impact of ventilation study carried out in the United States. The estimated annual energy consumption for all building types amounted to 5.8 exajoules at a cost of $US 33 billion. Savings of between $US 3-8 billion were seen as feasible by improved ventilation control. Mudarri et al (5,21) investigated the theoretical energy impact of increasing the rate of ventilation in Washington office buildings from 2.5 l/s.p to 10 l/s.p. Depending on the ventilation system and building layout, energy costs were found to be only marginally increased or even reduced. The paper explains that the increased cooling energy demand in Summer and heating need in Winter is offset by reduced (concurrent) cooling energy need in Winter and a reduced cooling need in the transitional seasons. Similar results are reported by Zmeureanu et al (5.151) for an office building in Montreal. They estimate that an increase in ventilation rate from 2.5 l/s.p to 10 l/s.p would result in a ventilation energy increase of approximately 5.9%. These two case studies indicate the complexities of ventilation energy estimation, especially in large office complexes. Essentially both studies balance increased space heating demand against reduced refrigerative cooling load. Care needs to be exercised in applying such results to other climates, where such a trade-off may not be as advantageous.

Other Aspects

Other papers presented at the conference covered pollutants, micro-biological contamination, air cleaning, ventilation system performance, ventilation efficiency, demand controlled ventilation, case studies and radon mitigation. The approximate number of papers referencing selected pollutants is compared with the distribution for Indoor Air '90 (Air Infiltration Review, Sept 1990) in Figure 2. References to VOC's, dust, fungi, tobacco smoke and moisture show a considerable increase. Smaller increases apply to odour and radon.

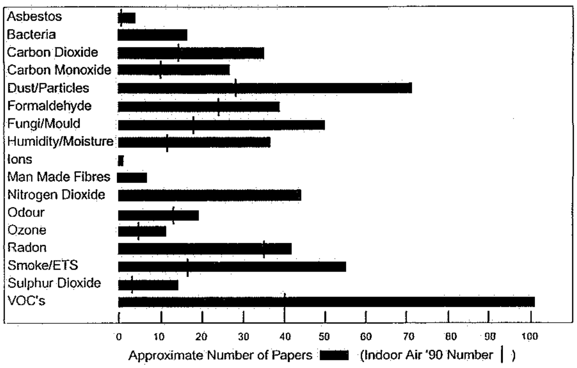


Figure 2: Selected pollutants referenced in Indoor Air '93

Conclusions

It is difficult to draw too many conclusions from such a wide range of papers and results. Climatic and building differences also make it difficult to make generalisations as do the differing interpretations applied to ventilation terminology. However, it seemed that there are still many unanswered health and comfort problems. For example, is good indoor air quality a matter of source control, ventilation or both? Also, when it comes to ventilation, what new practical guidance is there for the designer? Can odour be treated as a lumped parameter and does the presence of an odour to a 'visitor' indicate a health or comfort problem to an occupant? The general indication of the conference was that apart from some well defined pollutants, the health and safety risk associated with many pollutants is unknown. Nevertheless, it could be accepted that interior surfaces and furnishings in a building emit pollutants. To keep these concentrations to a minimum, low emission products should be used and some 'background' ventilation may be necessary, irrespective of occupant density. At a certain level of occupant density, the prime source of pollutant becomes the occupant and therefore an occupant related ventilation rate should be applied (e.g. 10 l/s.p). Whether or not the ventilation requirement for occupants should be added to that needed for building emissions must still remain debatable.

Clearer definitions of ventilation systems are needed so that valid comparisons between the performance of each type of system can be made. Without an explanation of exactly how a system is configured, it is difficult to identify the true cause of ventilation related problems. Energy impact studies also need to be intensified since energy use has a wide impact on the global environment. Ventilation related energy implications reported at this conference were limited and tended to concentrate on very specific scenarios.

Occasionally, the concept of ventilation seemed to be introduced as an infinite resource that could be supplied as needed to cure air quality problems. In reality such an approach is unrealistic. Clearly ventilation has a vital role to play but, ultimately, fresh air requirements must be based on criteria that can be established at the design stage of a building. To return afterwards, adding ventilation on a piecemeal basis in attempt to mitigate problems as they arise, will inevitably lead to failure. Ultimately source control and good housekeeping must signpost the route to good indoor air quality.

References and Proceedings

The references cited in the text refer to the volume number and page number of the published paper in the Proceedings. Proceedings of this conference are available as a 6-volume set which may be purchased from Indoor Air '93, PO Box 87, SF-02151 Espoo, Finland, Fax: +358 0 451 3611, price FIM 900 plus 200 for handling and mailing.

... and INNOVATIVE HOUSING Vancouver, Canada 21st-25th June 1993

Another large international conference, Innovative Housing attracted over 250 papers and 700 participants from more than 30 countries. The focus was entirely devoted to sustainable housing of the future. It drew upon latest developments in building technology including approaches to solar design, passive cooling, low emitting products, insulation methods and ventilation. The significance of housing as a global environmental issue was emphasised by Eugene Flichel, president of the Canadian Mortgage and Housing Corporation. He highlighted housing as a major consumer of material, waste and energy. Approximately 20% -30% of Canada's energy consumption, for example, is used in the home.

Papers on environmental impact covered environmental assessment methods, energy embodied in building materials, the absolute energy need of buildings and the problems of building waste. On the indoor environment, papers and presentations covered the emission characteristics of building materials and the role of ventilation. One of the points emphasised in this session was that the emission characteristics of certain pollutants may not be constant and, therefore, do not necessarily respond to ventilation control. Several papers provided design guidance on producing dwellings with minimal emission characteristics for occupants with allergy complaints. An important consideration in much of these designs was the need to comply with the cost constraints imposed by local authorities.

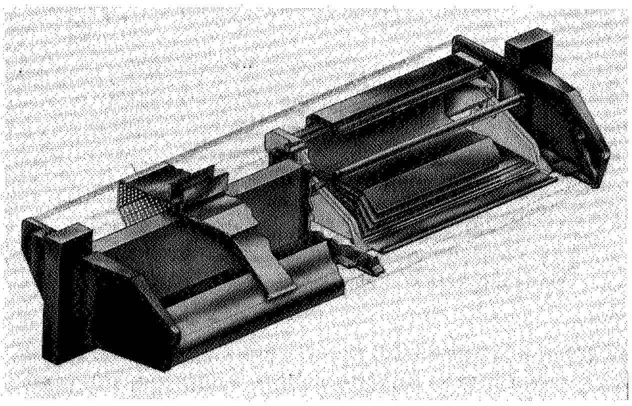
A session on hot climate applications stressed the peak electrical load problems associated with the transient use of domestic air conditioning systems. Much emphasis focused on house design to minimise or eliminate the need for refrigerative cooling. Aspects covered architectural features, orientation, thermal mass and night cooling.

The proceedings of this conference are scheduled for publication later this year. Orders should be sent to Innovative Housing Conference Proceedings, Publications, ENR/CANMET, 580 Booth Street, 7th Floor, Ottawa, Ontario, Canada K1A 0E4, Tel: 613 943 2259, Fax: 613 996 9416 or 613 995 6146.

For further information on Indoor Air '93 or Innovative Housing, please contact Martin Liddament at the AIVC. Abstracts of many of these conference papers will be appearing in future editions of 'Recent Additions'.

New Low Pressure Controlled Air Inlet

by B Knoll, TNO Building and Construction Research, The Netherlands



Applied research at TNO gives an insight into the functioning of products and systems. It leads to ideas for advanced or new products and systems. In the ventilation field such an idea has led to a new product, the COMPRIAL I(A)Q-unit, a pressure controlled air inlet of COMPRI Aluminium at Zwijndrecht (NL). It operates at significantly lower pressure differences than existing devices. This product will be commercially available in June 1993.

The Motive

In dwellings with natural ventilation or mechanical exhaust a plain casement window or grille supplies air; the more air the higher the wind velocity or the colder the outside air.

However, a change of wind direction and surrounding obstacles like trees and building may interfere with this.

It is also interesting to note the unattended influence of occupants' behaviour on other rooms. Windows, grilles and doors are being opened or closed. The kitchen hood or a local exhaust in the bathroom is intermittently operated. All these actions influence ventilation in the room without being noticed.

Present Effects

At one moment there is a draught of cold air and the heating is doing overtime, leading to high energy demands; at the next moment occupants will complain about poor indoor air quality, condensation on glazing and other construction parts occur and even mould growth is possible.

The Solution

The search was on. At TNO ideas were generated. Promising ideas were tested using laboratory models in the wind tunnel. Before there was any product the functioning was established and improved by computer simulation in the ventilation model [1].

The designers and constructers of COMPRI finished it.

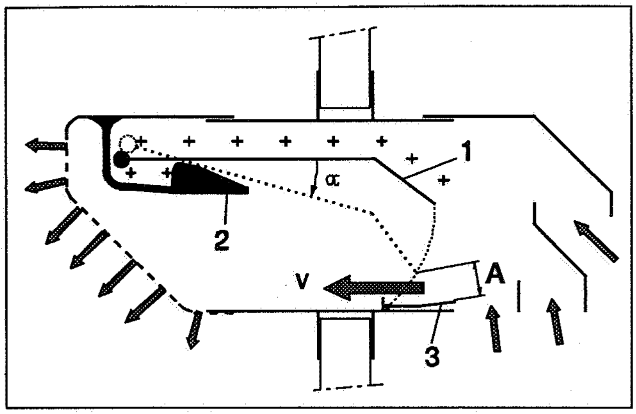
In this way, the new low-pressure controlled air inlet was born. With this device unnecessary energy consumption, poor indoor air quality and (in moderate climates) draughts will be past.

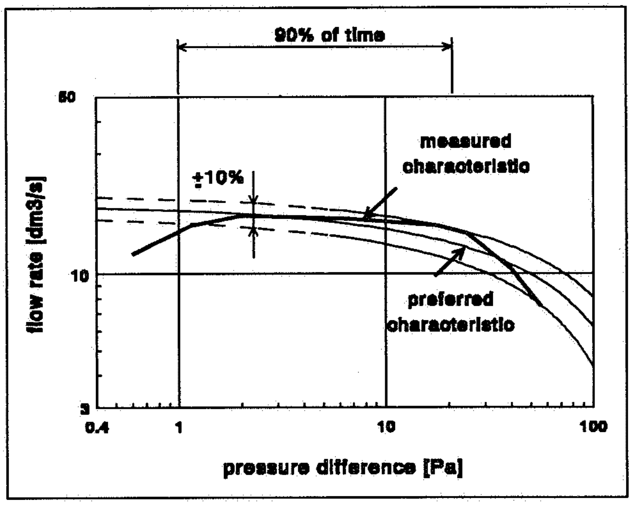
Operation

The low pressure controlled air inlets operate surprisingly simply. No auxiliary power is needed, so it needs no batteries or electrical wiring. The wind or temperature change provides the power to operate it. The device contains a curved plate (1) which balances on a curved surface (2). Due to increasing wind or temperature difference the overpressure (+) on the plate increases. This will make the curved plate role over the curved surface, giving it a declination (α), thus restricting the passage opening (A) underneath the plate. At the same time the flow velocity (v) through the passage opening is increased with the pressure difference over the vent. Therefore the flow rate (A*v) through the small passage at storm is the same as through the large passage with a smooth breeze.

An option of the pressure controlled air inlet is to operate on different ventilation demands. Therefore the bottom plate (3) is lifted, thus decreasing the passage opening (A) in every position of the restrictive plate (1) with the same percentage.

The device may also be closed off easily by pulling down the restrictive plate (1) with a bar above it (only shown on the photograph).





Leakage Compensation

The pressure controlled air inlet even compensates for an average air leakage of the facade. In principle it is possible to change the set-point for other levels of air tightness.

The flow through leaks increases with the pressure difference over it. Therefore at every pressure difference the flow through the inlet device is diminished with a comparable amount. It explains the downward curved characteristic, presented in the graph.

Almost Ideal Characteristic

The graph shows the measurements on the prototype. It appears that the measured curve matches with the preferred characteristic, within =/- 10%. This goes for pressure differences between 1 and 25 Pa, which in most climates will occur over 90% of time.

Minimum User Interference

For optimum automatic control the interference of the occupants have to be diminished. Therefore the inlet opening on the outside is constructed to shield against rain, burglary and outside noise.

For high outdoor noise levels the possibility of an extra sound attenuation is being studied now. It may be obtained from additional absorbing inner material.

To minimise draught problems the inlet terminal at the inside is shaped to give a multidirectional distribution and a high induction (quick mixing) of cold incoming air.

For severe climates additional possibilities of locally pre-heating the supplied air and of pre-mixing it with room air are studied.

Comparison with Existing Pressure Controlled Inlets

For a number of years several pressure controlled air inlets have been commercially available. In general it concerns devices which will start control in the range of 20 pa. These pressure differences will only occur for about 5% of the time, at high wind velocities and low outside temperatures. In other words these devices are not distinguished from plain grilles or window vents during 95% of the time. In this period all disadvantages mentioned before will occur.

The new device however, will control the air supply during of time, thus preventing these disadvantages. Because of its unique features the new pressure controlled air inlet is patented.

Wide Field of Application

The pressure controlled air inlets are applicable in all new dwellings and in retrofitting. The controlled natural supply may be used in combination with all types of natural exhaust, preferably natural stacks, and with mechanical exhaust.

Dwelling types may be single family and multi family as well as apartments.

Also in small offices or other commercial buildings the application may be advantageous.

Easy Installation

The inlet devices may be installed within each type of window frame or glazing, either fixed or movable. The standardized height is about 10 cm (4 inches). The length of the grill may vary betwen 60 cm and 300 cm (2 and 10 feet). A standard control unit for a two persons ventilation demand will be integrated within this length. In the taller grilles even several control units may be installed to meet higher ventilation demands. Your order must state the thickness or the surrounding window frame or glazing, the length of the grill and the number of control units preferred.

No Extra Maintenance

The new device is very sensitive. To give you an impression, it will react if you put a sheet of paper on the movable portion.

Nevertheless, the device does not need any special treatment. The designers of COMPRI have paired a rigid construction to the right sensitivity. Even at extremely high pressure differences and strong gusts of wind the pressure controlled air inlet will keep its good properties.

The occupants have to clean the device now and then. By clicking off the indoor terminal this task may be performed easily.

Especially in areas with high pollutant loads or many insects regular cleaning is recommended. For this cases an extra filter may be added on the inlet opening.

Reference

[1] 'Controlled Natural Ventilation', B Knoll and W Komaat, AIVC Conference Proceedings, Sept 1991.

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French Ventilation in Dwellings

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Abstract

For more than twenty years French Regulations for dwellings have been the mover of technological progress in ventilation.

For instance, in 1969 ventilation had to supply fresh air to the habitable rooms and to exhaust stale air from the service rooms (this point of the French regulation has been continuously used since) with an air change rate about 1 volume/hour; the technological consequences were the use of self regulated inlets and outlets (whatever the weather - wind, temperature etc, the flows remain constant and known in each service room).

After the energy crisis (1974) research on occupied dwellings came to the conclusion that almost 50% of dwellings were over-ventilated; with the 1982/83 regulations the flow rate depends on the number of habitable rooms with the possibility of reducing the ventilation rate during under-occupancy. One of the technological consequences is the development of humidity controlled ventilation systems.

We describe how basic studies (detailed simulations) have been used to define the calculation of energy losses due to ventilation in French regulations, and the "on going" research aiming towards a better assessment of air quality.

Introduction

The present state of ventilation in France is the result of a long history of habits and requirements: in order to understand it, we need to go back as far as the post war reconstruction period.

1 The Post War Period

In the early 50's, higher and higher buildings were constructed because they were less expensive and quicker to build, thereby making housing available for as many people as possible within the shortest time. At that time, a clause in the building regulations expressed the recommendation that all dwellings should be provided with some sort of heating system. As central heating was not as widespread as it is now, that particular requirement often turned out to be a mere duct for fumes; each dwelling had its own duct connected with the roof level.

Due to this requirement and its interpretation, the contractor considered a vertical duct for transporting air and joining each flat to the roof as standard. Once the practice was adopted, it remained valid even in later years, when central heating proved to be reliable.

1.1 The Shunt

In 1955 manufacturers in the concrete industry designed a new type of duct: the "shunt". It was in fact a double duct which was composed of a small one for the individual flow from each dwelling and a larger one as a collector to gather the individual air flow. In that way, the shunt duct made it possible to collect the polluted air from more than one dwelling with one plant, thereby saving space and decreasing the cost of construction.

Ventilation was still limited to the occupants opening the windows occasionally. Some grilles in lower and higher positions were fitted in the service rooms such as kitchen, bathroom, etc using passive ventilation.

1.2 The Reversed Shunt

At the end of the 1950's a new architectural tendency appeared which grouped the service rooms in the middle of buildings, leaving the principal outside space for the habitable rooms. Such a design allowed both sides of the building to be used. The existing shunt duct made building construction easier by permitting the ventilation of the service rooms although they no longer had any common wall to the outside atmosphere.

The ventilation was then ensured by a double shunt system: it associated a classical shunt for the exhaust of foul air from the service rooms to the roof through high level grilles and a reversed shunt for the fresh replacement air, coming from the ground floor through low level grilles.

Because foul air replaced fumes in those ducts, the design enabled seven flows to the collecter instead of five. The ventilation was still passive; induced by the combined actions of wind and thermal draught (stack effect).

Each service room was ventilated separately, being connected with a double shunt shaft.

The habitable rooms were not ventilated in a coherent way, only submitted to cross ventilation, which could be either in the right or in the wrong direction spreading various pollutants from the service rooms. At that time, however, in France, the air leakages were rather high and therefore only a few problems with condensation occurred.

2 The First Regulation (1969)

2.1 The Regulation

The 1969 regulation was designed to overcome all the drawbacks mentioned previously. The ventilation was required to continuously provide one air change per hour in each habitable room. It had to supply fresh air to the habitable rooms to exhaust stale air from the service rooms.

This was the beginning of central exhaust mechanical ventilation in France although the technique had already been known and used in Switzerland and Sweden for a little while.

Its advantages are significant: whatever the weather, wind,or temperature, the flow of ventilation air remains constant and known in each service room.

In the 1969 regulation, as in later ones, passive ventilation was still allowed; requirements were then to be met on an average winter's day.

2.2 Evolution

It became necessary to test that the requirements were fulfilled either with one technique or another.

Several control organisations were set up. In a short time, they found that mechanical ventilation was the best solution to comply with the requirements. It was easier to control, more constant and closer to the required rates.

The existence of a regulation made possible a great extension of the ventilation market and stimulated the development of many new products and new technologies for exhaust or inlet valves.

The quality of the different components of the complete system improved: the self regulated air inlets took diffusion into account, tried to fight cross ventilation and use to avoid cold draughting when the wind is strong. The outlets allowed the flow to remain fixed and independent of the pressure in the ducts without any adjustment on site, allowing extended networks with one large fan on the roof. The noise of the elements was strongly reduced and new requirements appeared. In order to limit sound levels, fans became more and more reliable, and their lifetime increased, reaching 10 to 15 years of continuous work.

In France, essential requirements are given in the "Code de la construction" and means to comply with this requirement are given in the "Solutions Techniques". This code of good practice makes it possible to avoid condensation problems so that condensation should not occur, but if it did should only be momentarily. Some cases were brought before the courts, where dwellings had become insalubrious within a few months after initial occupancy.

After a mechanical ventilation system had been installed, the courts observed that condensation had disappeared and ordered the builder to refurbish the dwelling and to use mechanical ventilation instead of passive.

So, by the early 70's the market for control and mechanical ventilation was growing at a rate of 20% per year.

Assuming this growth to continue for a while, and believing that, when written, a requirement becomes effective at once, the French authorities decided to include the energy loss due to the ventilation in the total energy loss of the buildings:

$$El = \sum (Ui.Si) + 0.34\, q$$

where:

El	total heat loss in W/°C
Ui	thermal transmission coefficients of walls (W/m^2. °C)
Si	area of internal wall (m^2)
0.34	specific heat of air (Wh/m^3.°C)
q	total extract flow (m^3/h)

This point of the French regulation, which has been continuously used since then is very specific and very important: it makes it possible to compare all losses whatever the source, hence allowing the choice of either saving energy ventilation, or normal ventilation with a larger thickness of insulation.

3 After the Energy Crisis

1974 was the year of the first energy crisis and attention was focused on heating costs. At that time, about one third of this cost was caused by ventilation, due to increasing insulation. Dropping continuous ventilation was considered as a possible method of saving energy.

3.1 The Survey

In 1978, the French authorities decided to undertake a general survey of ventilation collecting data from all parts of the country, in order to determine if it was possible to reduce the air change rates and/or to allow intermittent use.

The considerable amount of data which was collected also precisely showed how different types of houses were occupied. It made it possible to know the number of habitable rooms in respect of occupancy and to give a percentage of residences which were over-, well- or under-ventilated.

A significant result of the survey was to establish that almost 50% of dwellings were over-ventilated.

3.2 Consequences of the Survey

The main consequence of the survey has been to change the reference for ventilation rates which since then has been linked to the number of habitable rooms.

It was also decided to lower the air change rates in order to minimise energy loss.

New labels were set up, corresponding to different classes of energy consumption, and thus to different amounts of money given as incentives to build houses as thriftily as possible.

Some competitions and extended period monitoring were set up to find new solutions and to involve everybody in energy saving.

4 The 1982 Regulation

The 1982 regulation was in fact established in 1980 but the requirements only became effective in 1982 (in order to give the industry sufficient time to develop products according to the new requirements). Since then these rates have been calculated as follows:

$$q = 15\ (n+2)$$

where:

q is the total exhaust flow rate in m^3/h
n is the number of habitable rooms

Additionally, a higher flow rate level for kitchens was proposed, depending on the size of the dwelling.

1983 Alternative

At that time, the pollutant connected with occupancy was found to be water vapour which was strongly related to human activity: breathing, cooking, washing, etc. Each of these activities gives off some vapour at a specific quantity which can be averaged.

This enabled the development of some possible scenarios and the proof, before manufacturing any product, that it was possible to save energy while adapting ventilation rates closely linked to needs.

All these findings were presented to the French authorities and the regulations were amended in 1983 to authorise new systems, allowing the reduction of ventilation rates during under-occupancy periods and the re-establishment of normal ones when necessary. The first system was humidity controlled ventilation.

5 The Present State of Ventilation in French Dwellings

Air leakage through a building envelope can disrupt the intended operation of heating and ventilation. In view of the high stakes, research was conducted at the CSTB into air infiltration in buildings [1]. It involved improvement in heat loss calculation due to cross ventilation and development of air leakage measurement methods.

Using the computer code GAINE which includes climatic data, a new way of calculating cross ventilation flow rate was derived [2]. Cross ventilation heat losses do not only depend on flow rate through the building envelope, but also on flow rate due to the ventilation system operation. They decrease when the negative pressure inside the building, caused by the operation of the ventilation system increases.

The 1991 regulation ("Règles Th-G") describes how to calculate thermal losses due to ventilation: [3]

$$Ev = 0.34\ (Qv+Qs)$$

where:

Ev heat losses due to ventilation in W/°C
0.34 specific heat of air ($Wh/m^3.°C$
Qv air flow due to the ventilation system (m^3/h)
Qs air flow due to wind effects (m^3/h)

5.1 Air Flow Due to the Ventilation System

The air flow due to the ventilation system is the total air flow through the outlets

$$Qv = (1-a)\ Qm + a\ QM$$

where:

a=1 fixed area outlet
a=1/12 outlet with manual additional flow rate
a=1/24 outlet with time controlled (30 minutes) additional flow rate
Qm and QM are given in table 1

Table 1: Values of air flow due to ventilation system

	number of habitable rooms						
	1	2	3	4	5	6	7
Qm (m^3/h)	35	60	75	90	105	120	135
QM (m^3/h)	105	120	150	165	210	210	210

5.2 Air Flow Due to Wind Effects

The expression of the air flow due to wind effects (cross ventilation) is:

$$Qs = P\frac{e}{1+\frac{d}{e}\cdot\left(\frac{Qv}{P}\right)^2}$$

where:

P	air leakage rate of the dwelling (m^3/h for 1 Pa)
e	coefficient depending on wind exposure (from 0.15 to 1.35): depends on: location in France, altitude of facade, single or multiple front dwelling
d	d=1.55 (single front dwellings) or d=1.15 (multiple front dwellings)

5.3 Assessment of Demand Controlled Ventilation Systems

The above formulae are used for standard mechanical or passive stack ventilation systems. For particular DCV systems such as humidity controlled ones, the SIREN code is directly used to calculate the equivalent thermal air flow rate to be taken into account in the thermal calculations. The air quality is also appreciated by comparison of some indexes (CO_2 values, condensation risks, etc.) with the results of a standard mechanical system.

Conclusion

By taking into account the effects of ventilation on energy needs, French regulation for residential buildings enabled the improvement of ventilation system efficiency and helped to reduce the air leakage of buildings. If the calculation can be considered accurate enough for the thermal loads, some improvements are needed for a better assessment of indoor air quality.

Research is now being conducted in CSTB in this field, which should help to compare the different ventilation systems with the same basis in both energy needs and air quality.

References

[1] J Ribéron "Guide méthodologique pour la mesure de la perméabilité à l'air des enveloppes de bâtiments" Cahier du CSTB no2493, Paris, May 1991

[2] J Ribéron, D Bienfait, J Chandelier, "Révision des Règles Th-G, partie ventilation" CSTB GEC/DAC 90-18D, Marne la Vallée, February 1990

[3] "Règles Th-G: règles de calcul du coefficient GV des bâtiments d'habitation et du coefficient G1 des batiments autres que d'habitation" Cahier du CSTB no 2486, Paris, April 1991

The Dutch E'Novation Program: Indoor Air Quality in Dwellings Before and After Renovation

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Abstract

The Dutch "E'novation program" is a national demonstration program in which dwellings with high energy consumption, moisture and mould problems and poor indoor air quality were renovated, with special attention to the selection of the heating and ventilation systems, thermal insulation and the buildings' physical details. A number of indoor air quality parameters were monitored before and after renovation, showing an important improvement in the indoor air quality. Moreover, total energy consumption decreased by 33%, which meets the targets of the Dutch National Environment Policy.

Introduction

In 1988 NOVEM (Dutch Company for Energy and Environment) started a national demonstration program in The Netherlands, involving the renovation of 2800 dwellings with high energy consumption, moisture and mould growth, poor indoor air quality etc. This program is called the "E'novation program". E'novation is a contraction formed by the two key words of this program: "Energy" and "Renovation". Many post-war buildings in The Netherlands have the above mentioned problems. The characteristics of these buildings are: no or insufficient thermal insulation, many air leakages, often no central heating, unvented geysers and inadequate physical details. The addition of thermal insulation often causes problems with moisture, ventilation and indoor air quality. The purpose of the E'novation demonstration program is to achieve both energy savings and good indoor air quality through an integrated handling of energy retrofitting, ventilation and heating systems and good physical details. In some projects special energy saving techniques were applied, such as heat recovery, passive solar energy and demand controlled ventilation systems.

The Dutch Ministry of Economic Affairs has made available USD 3.800.00,-- for this program. This amount also includes the costs of a pre-study, the evaluation and measurement program and "knowledge-transfer" about this program. An amount of USD 1.100,-- per dwelling will be paid to the building corporations. NOVEM manages the program.

All the projects were supported by an extended program of measurement and evaluation. The measurement and evaluation program concerns:

- the performance of the ventilation, heating and heat recovery systems applied;
- the predicted and achieved energy consumption for space heating and warm water;
- the airtightness of the building envelope;
- evaluation of the overall quality of the renovation;
- evaluation of the experiences and opinions of the occupants.

In some projects a special measurement program was carried out to monitor indoor air quality. The measurements were taken before and after the renovation. The dwellings and the measured indoor air components and pollutants were chosen in such a way that the quality of the renovation process and its impact on the indoor air quality was measured as accurately as possible. Therefore any disturbing influence on the part of occupants (i.e. smoking) was eliminated.

This paper will focus on indoor air quality measurements in relation to energy savings.

Methods

The measurement program is set up as follows. In each dwelling the measurements were taken over the course of one week. CO_2, CO, CH_2O, TVOC (ref. to CH_4), relative humidity and temperature were continuously sampled and monitored in four rooms (living room, kitchen and two bedrooms) as well as outdoors by a B&K 1302 gas monitor and B&K 1303 sampler and doser unit combination. NO_2 was measured by passive sampling by means of Palmes diffusion tubes. Volatile organic compounds (VOC) were measured by active sampling and a G.C. analysis of aromatic hydrocarbons and halocarbons.

Respirable dust was measured continuously by a tyndallometer. Radon was measured for four months by passive sampling in the living room and in the crawl space.

The measured concentrations were checked with the guideline values of the WHO (1), and the target guidelines for VOC's (2).

Results and Discussion

Indoor Air Quality

Before renovation most of the dwellings had unvented geysers in the kitchen. A number of these dwellings had local heating. During the renovation all unvented geysers were replaced by combi-boilers for heating and hot water supply with a closed combustion system (direct combustion air intake). The ventilation is improved by applying an individually controlled mechanical exhaust ventilation or by a balanced ventilation system.

In Table 1 a summary is given of a number of measured indoor air quality parameters. It shows the averages during one week, measured in dwellings before and after renovation. In Table 2 a summary is given of the measured concentrations of VOC before and after renovation.

Before renovation the indoor air quality was generally poor and in some cases even hazardous. The main sources were unvented geysers installed in most of the homes. It was known that these geysers could result in the guidelines for NO_2 and in some cases for CO and CO_2, being exceeded. Continuous measurements showed that CH_2O also frequently exceeded the guideline values.

After the renovation there was an obvious decrease in all measured indoor air quality parameters. The following was observed:

- The most significant decrease was the reduction in the NO_2 concentrations. Before renovation the weekly average values measured in kitchens exceeded the 24 h guideline value. After the renovation these values decreased to values much lower than the guideline values.
- The CH_2O concentrations also showed a large reduction. A comparison with the guideline value of 120 ug/m^3 is not quite correct because the filter reacts upon formaldehyde as well as upon a number of other aldehydes and upon C_5H_{12} and C_6H_{14}. Figure 1 shows a typical example of CH_2O concentrations measured in a kitchen before and after renovation. Before renovation extreme peak values occurred during the moments that the unvented geyser was in use. After renovation these peaks disappeared.
- The measured CO concentrations were reduced by 50% or more in the renovated dwellings. Table 1 shows that the weekly averages measured did not exceed the guideline value. Nevertheless there were situations before the renovation in which this limit had been exceeded in shorter periods (about 10 to 12 hours) such as in the living room as a consequence of the flue gas backdraft from gas heaters.

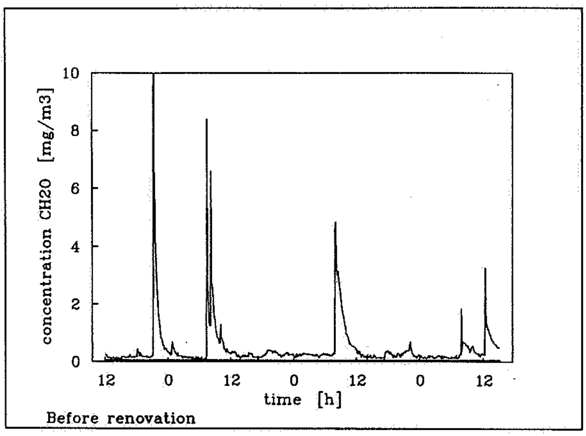
Table 1 Measured indoor air quality parameters before and after renovation (mean values and standard deviations, n=16).

		before renovation			after renovation			
		living room	kitchen	bedrooms	living room	kitchen	bedrooms	guideline values
CO_2 (ppm)	mean	1024	1013	927	882	836	672	1200
	std	184	277	193	160	122	148	
CO (mg/m^3)	mean	3,9	4,3	4,2	2,2	2,0	1,4	10 (8h)
	std	0,4	0,2	1,6	1,0	0,5	0,5	
CH_2O* (ug/m^3)	mean	665	577	530	405	357	231	120 (0,5h)
	std	214	51	234	167	153	188	
TVOC (ref CH_4) (mg/m^3)	mean	-	-	-	4,5	4,1	2,9	-
	std	-	-	-	1,0	1,0	1,0	
NO_2 (ug/m^3)	mean	84	160	30	30	34	16	150 (24h)
	std	40	127	9	16	14	3	
Resp.dust (ug/m^3)	mean	30	-	-	30	-	-	70 (PM10 24h)
	std	16	-	-	15	-	-	
RH(%)	mean	42	41	57	45	44	45	30-70%
	std	4	6	9	4	3	4	

* including a.o. other aldehydes, C_5H_{12}, C_6H_{14}

Table 2 Concentrations of VOC in ug/m^3 before and after renovation.

	before renovation		after renovation	
	living room	kitchen	living room	kitchen
benzene	8.6	12.3	1.3	2.1
ethylbenzene	2.6	3.3	1.9	1.7
toluene	38.0	40.0	32.0	21.0
xylenes	3.0	7.0	1.3	1.4
styrene	1.1	0.9	0.6	0.4
n-propylbenzene	16.7	8.3	0.2	0.3
i-propylbenzene	0.2	0.2	<0.1	<0.1
1,2,4-trimeth.benz.	3.0	3.4	1.2	1.7
1,3,5-trimeth.benz.	1.4	1.5	0.7	0.6
naftalene	0.5	0.5	0.1	0.3
chlorobenzene	2.1	1.1	<0.5	<0.5
1,2 dichl.benzene	0.8	0.8	<0.5	0.5
1,3 dichl.benzene	<0.6	<0.6	<0.5	<0.5
1,4 dichl.benz.	0.8	0.8	<0.5	<0.5
1,2 dichl.ethene	2.1	1.3	0.7	0.7
dichloromethane	6.1	3.4	1.6	2.0
trichloromethane	2.1	2.1	1.7	2.3
1,2 dichl.ethane	<0.6	<0.6	<0.5	<0.5
trichl.ethene	11.5	11.5	7.3	7.7
tetra chl.ethene	6.6	7.8	5.9	6.2
tetra chl.ethane	1.4	1.4	<0.5	0.9
1,1,1.trichl.ethane	1.4	1.9	0.8	<0.5
1,1,2.trichl.ethane	1.4	<0.6	0.9	1.5



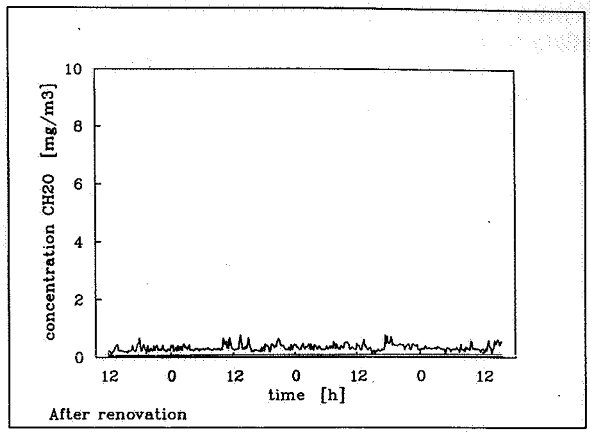


Figure 1 Concentrations of CH_2O (and o.a. other aldehydes, C_5H_{12}, C_6H_{14}) measured in a kitchen before and after renovation.

Before and after renovation the weekly averages of the CO_2 concentrations were lower than the hygienic limit value.

However in many shorter periods these limits were exceeded.

The measured respirable dust concentrations appeared to be far below the limits both before and after the renovation.

Almost all concentrations of VOC's showed a reduction. Before renovation the sum of the aromatic hydrocarbons exceeded the target value of 50 ug/m^3. In some of the dwellings benzene exceeded the guideline value of 12 ug/m^3. After renovation the target guidelines for the aromatic hydrocarbons and halocarbons were not exceeded.

Energy Savings

As a part of the evaluation of the E'novation program, energy use has been calculated and monitored, both before and after renovation. The calculations concerned gas use for space heating, cooking and warm water and also electricity use. Before renovation the total average gas use (heating, cooking and warm water) was about 2250 m^3 gas/year. After renovation this average declined to about 1500 m^3. This means a decrease of 33%. Figure 2 shows the expected gas consumption for space heating for a number of projects before and after renovation (5). The mean saving is about 50%. While gas use for space heating decreased by 50%, gas use for warm water almost doubled. This was because in almost all the projects, the unvented geysers were replaced by combi-boilers for heating and hot water supply. This gives a large increase in the warm water supply from 2,5 l/min to 5 to 7 l/min (60 Deg. C).

The gas savings for space heating appear to be less in a number of projects. This is due to the fact that in these projects a local heating system was used before renovation (only a gas heater in the living room) and a central heating system after renovation.

This meant that the average temperature of the dwelling and also thermal comfort increased.

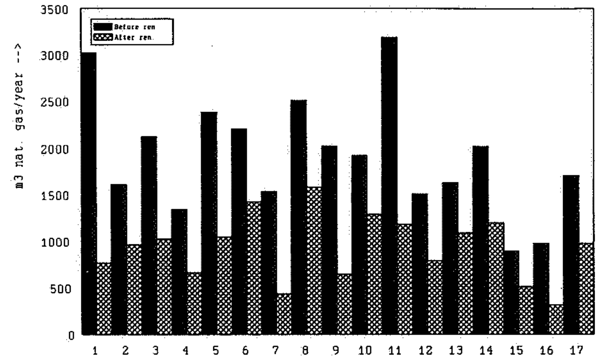


Figure 2: Energy consumption of space heating for some E'novation projects before and after renovation.

Conclusions

The selected dwellings for the E'novation program had problems with high energy use and poor indoor air quality, often in combination with moisture and mould growth.

The measurements carried out in all the dwellings did indeed show poor indoor air quality. For example NO_2 and CH_2O frequently exceeded the guideline values.

The E'novation program, in which a well-considered choice has been made between various heating and ventilation installations in combination with improved physical details, results in significant improvement of indoor air quality.

In all projects, problems with moisture and mould growth were consistently eliminated.

The total gas saving of 33% meets the target of the Dutch National Environment Policy. It appears that these savings are accompanied by an increase in thermal comfort, a larger warm water supply and improved indoor air quality. This also indicates that a renovation on "E'novation level" will be necessary if the same goals are to be achieved in most of the existing dwellings in The Netherlands.

References

1. WHO (1987). Air Quality Guidelines for Europe. WHO Regional Publ., Europ. Series nl 23, Copenhagen.
2. Seifert B. (1990). Regulating Indoor Air. Proceedings of Indoor Air 1990. 5:35-49, Ottawa.
3. Lebret E. (1985). Air pollution in Dutch homes. Department of Air Pollution and Department of Environmental and Tropical Health, Wageningen, Agricultural University, r-138.
4. Thijssen I. Korbee H. (1991). E'novatie kennisoverdracht in 1991, 369.1. Woon/Energie Gouda, The Netherlands.
5. Poel A., Eydems H. (1993). E'novation: A demonstration program for low energy retrofitting. Proceedings of CIB Symposium Stuttgart 1993.

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