Organised by the IMechE's Environmental & Safety Engineering Group
Co-sponsored by AIVC, BSRIA, CIBSE, ASHRAE and BRE

Building Ventilation Design

Thursday 28th October 1999
IMechE HQ

ASHRAE Standard 62 and Developments

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Contents

International Perspective on Ventilation Standards

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Air Infiltration & Ventilation Centre (AIVC)

4. ENERGY EFFICIENCY

Ventilation becomes an energy issue when conditioned air (either heated or mechanically cooled) is unnecessarily lost from the building and/or when excessive energy is used to drive a ventilation system. In addition to introducing ventilation rate guidelines, evolving standards to cover these aspects include the use of ventilation heat recovery devices and energy targets for the performance of mechanical systems (i.e. in terms of Watts/litre.second of power to drive the system). Sweden (7), for example, requires heat recovery for buildings in which ventilation heat loss exceeds 2MWh.

5. THE OUTDOOR CLIMATE

Very often the strategy towards ventilation and building airtightness has been driven or has evolved through climate. In the severe climate of Northern Canada, for example, airtightness is an essential feature of building construction. Apart from the discomfort caused by cold draughts, at the point where warm and moist indoor air reaches dry outdoor air (at as low as –30° - -40°C), the moisture instantly freezes. This, inevitably, can cause serious damage to the building fabric. For this reason, airtightness combined with good ventilation control is a necessity. Once introduced, it makes sense to develop mechanical ventilation and incorporate heat recovery. A similar approach has developed in Scandinavia, spurred on, especially in Sweden, by the absence of indigenous energy.

In the United Kingdom, the climate is relatively mild, thus the need for airtightness, apart from draught sealing, has not, in the past, been as critical. Unfortunately, this has sometimes resulted in the inappropriate use of ventilation strategies. Attracted, for example, by the promise of ventilation heat recovery, systems designed for very airtight structures have sometimes been incorporated into UK buildings. The risk is that benefits are not realised, especially in smaller buildings, where there is a significant probability that such systems will consume more primary energy than they recover.

6. BUILDING AND COMPONENT AIRTIGHTNESS

The tightness of the building shell is critical to the energy performance of the ventilation system. A tight shell can also provide a barrier to transient outdoor pollution. Some ventilation systems, especially those incorporating air to air heat recovery systems, cannot function correctly unless the building is virtually completely airtight. On the other hand 'adventitiously' ventilated buildings rely on the natural porosity of the building.

Standards for airtightness must not only cover the performance of individual components but also must cover the construction as a whole and site practice. Where airtightness has been successfully introduced, methods are covered within building practice guidelines. These cover every aspect of the component and construction technique.

Before the level of airtightness is specified, it is paramount that the ventilation approach is understood. This is covered in further detail in the section below.

Where mechanical systems are used, the sealing of duct joints is critical, since many studies show these to be poor. Regulations and proposals for future developments are covered in a recent European Report (8).

7. VENTILATION STRATEGY

The type of ventilation system installed and the presence and type of any combustion appliance significantly influences requirements, especially in relation to the tightness of the building shell. Natural ventilation means that purpose provided openings must be installed to meet ventilation need. If mechanical extract or supply only systems are installed, then 'natural' intakes or outlets are required to provide unrestricted airflow. Should an extract only system be installed, and an open flue combustion appliance is present, then additional openings are needed to prevent large suction pressures from causing back-draughting. In the case of balanced mechanical supply/extract systems, no additional airflow routes should be present and, for maximum energy efficiency, the building should be completely airtight. In practice, this means an airtightness of <1air change rate/hour at 50Pa. In Canada and much of Scandinavia, building techniques have been developed to achieve the required level of airtightness as part of normal building practice. Without specific design and building site care, this level of airtightness will not be achieved.

8. BUILDING TYPE

Ventilation needs and requirements depend on the type of building and the purpose for which it is used. The principle issues for the main building types are:

8.1 Dwellings

The main characteristics of dwellings are:

- The ratio of building volume to the envelope surface area is particularly high. In other words, a high proportion of the conditioned space is in contact with the building envelope;
- Dwellings are particularly polluting. Within the occupied space pollutants from cooking, unvented combustion appliances, people and their activities are present. It is almost impossible to estimate the likely polluting load in each dwelling;
- Water vapour equivalent to between 9 – 15 litres of water is produced by a family each day. The wider use of showers, clothes dryers, dish-washers etc. is resulting in a steady increase in vapour generation. In many cases, direct venting from these appliances is an unused optional extra;
- The ability of the air to accommodate moisture is very sensitive to air temperature. Temperature distribution, especially in a poorly insulated home, is very non-uniform. For this reason, air can be dry and uncomfortable within a limited zone around a heating appliance yet condensation can stream down windows and walls in the same room;
- Warm moist air can quickly enter the roof space, from the bathroom and kitchen. Primary routes include soil pipe and water pipe duct runs. In cold roof spaces, considerable condensation can occur, even if the roof space is well ventilated.

Airtightness in dwellings is beneficial because:

- It prevents moisture reaching the roof space;
- Combined with good insulation, improve temperature distribution and assist in maintaining an acceptable indoor air temperature;
- Infiltration heat losses are minimised.

However, extreme airtightness may result in inadequate ventilation. For this reason any airtightness requirements must be combined with requirements for the separate provision of ventilation. Extreme airtightness might also promote backdraughting through flues, especially in the presence of mechanical extract ventilation.

Several countries have now introduced airtightness standards and requirements for dwellings, these include: Canada, Sweden, Norway, Switzerland, Belgium and the Netherlands (1). In all cases, requirements depend on the type of dwelling and the type of installed ventilation system. The airtightness requirement is usually expressed for a building in which all purpose-provide openings are sealed during testing. Commonly, for dwellings, the airtightness is given in terms of an 'airchange rate' at an artificially induced pressure of 50Pa. This pressure has been selected because it is above that induced on a building under typical natural weather conditions but is below the pressure that is needed to cause openings in the fabric of the building to materially change. An airtightness test method standard, on which many tests are based, has been produced by the International Standards Organisation (9). Much information on relevant Standards, occupancy patterns, ventilation strategies and pollutant loads in dwellings has becn produced Mansson (10).

8.2 Non Residential Buildings ('Low' Occupancy Density e.g. Offices, Shopping Malls, Warehouses)

Non residential buildings can be divided into those with relatively low occupancy densities such as offices, shopping malls and warehouses etc. and those with high occupancy densities such as schools, lecture theatres and concert halls. The key features of 'low' occupancy density buildings are:

- Enclosed volume of space relatively large compared to surface area;
- Occupancy and occupancy activity generated pollution can be relatively low (especially where smoking is banned);
- Potential for high heat load generation (e.g. through intensive use of electrical appliances and/or poor building design);
- Pollutant emissions from fabrics and furnishings are a concern);
- May be mechanically ventilated and air conditioned;
- These buildings can be very 'leaky'. This means that heating and cooling systems either don't providc sufficient heat or are over-sized or supplemented (discomfort and/or excessive energy waste);
- If air conditioned, poor airtightness results in insufficient cooling and/or excessive cooling load.

In low occupancy buildings, air quality in relation to oxygen provision for metabolism and dealing with metabolic pollution is not usually an issue, even in quite airtight buildings. The main problem is dealing with emission from office furniture, fittings and wall coverings, allowing for activities such as smoking and coping with summer overheating. Also, air intake positioning can be critical, especially in urban areas or high traffic density areas.

Because these buildings tend to be larger than dwellings, airtightness tends to be expressed in terms of a flow rate at a given pressure difference averaged over a unit area of exposed envelope surface, e.g. $m^3/m^2.h$ at 50Pa pressure difference. The development of suitable standards is still taking place. Sweden (6), for example, specifies a range between $3 - 6$ m^3/m^2 at 50 Pa. This is comparable to the range being considered in the United Kingdom.

Ventilation requirements for this type of building are currently in a state of flux, mainly because of concern about the source and types of pollution. Typical minimum standards vary from about 5 – 10 litres/second.person (l/s.p). To reflect the different sources of pollutant (i.e. people, fabric and furnishings etc.) some countries (e.g. US) proposed revision to ASHRAE 62 Standard (5). These proposals include attempting to split ventilation requirements between the occupant density and the floor area of the building. The setting of such standards is still largely on-going.

8.3 Non Residential Buildings ('High' Occupancy Density e.g. School Classrooms)

While these buildings have many of the same characteristics and problems of other non-residential buildings, the high level of occupancy density often means that metabolism is the dominant pollutant load. Metabolic carbon dioxide concentration can often rise rapidly, indicating a relatively low rate of ventilation. Because of this rapid rise, CO_2 monitoring can be used to control the ventilation system. Ventilation requirements are typically between 5 - 10 l/s.p for non-smoking aeas.

9. MAINTENANCE AND DURABILITY

Examples of poor ventilation design, performance and maintenance have been reported in many countries. Problems include inaccessibility, poor durability and lack of awareness about cleaning and servicing needs. Increasingly, Standards and requirements are focusing on maintenance and durability issues. The Nordic Committee on Building Regulations (11), for example, has given comprehensive guidelines. In Sweden, the compulsory testing of ventilation systems has been introduced (12) covering regular inspection for dwellings, offices and many other types of buildings. Much valuable advice is given in the international literature cited to prevent problems occurring.

10 CONCLUSIONS

The building envelope forms the boundary between the outdoor and the indoor environments. It therefore performs a critical task in protecting building occupants from extreme outdoor climate conditions as well as from transient outdoor air quality problems. Any uncontrollable leakage across the envelope reduces the ability of the envelope to perform this task.

Dealing with this issue, in the past, has largely been country dependent and has often been driven by climate and policies towards ventilation strategy. In cold climates, tight building structures have necessarily 'evolved' and alternative provision for mechanical ventilation is common in all building types. In milder climates, this need has not been so evident and envelope leakage is traditionally quite high. Difficulty then arises if:

- Complex mechanical ventilation strategies are introduced into buildings that have not been constructed to the correct level of airtightness (excessive energy consumption, draughtiness etc.);
- If a building has been constructed to a high level of airtightness without proper provision for ventilation (e.g. serious risk to health, condensation and mould growth).

Successful Standards need to recognise the coupling of the many parameters that influence ventilation need and performance.

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Standard 62 Overview

ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality

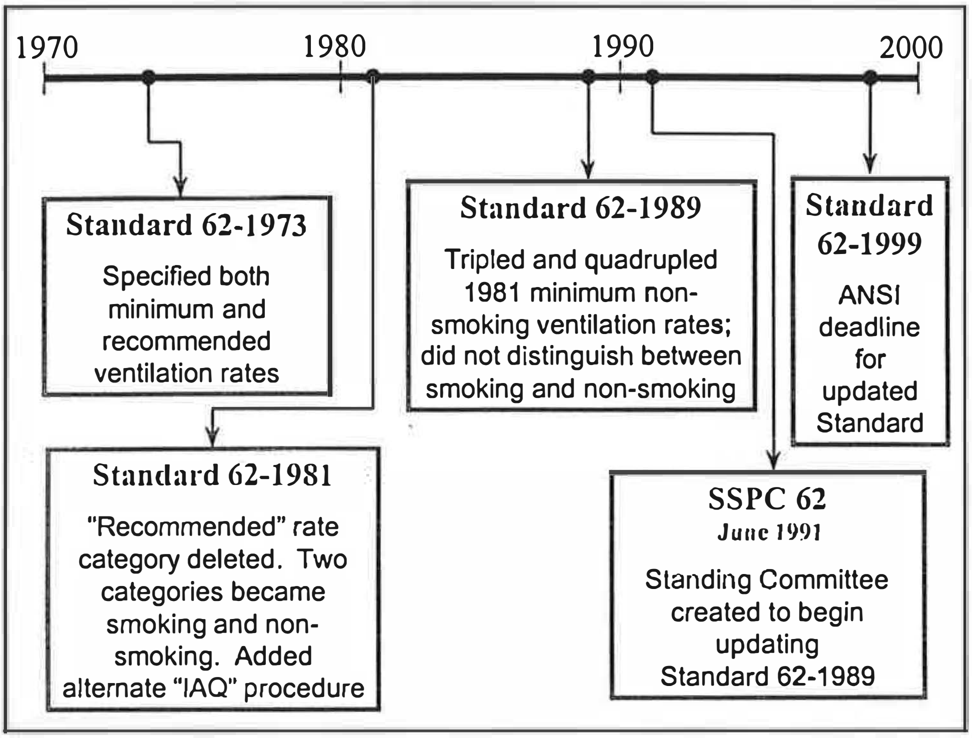
by Steven T. Taylor, P.E.
Chair SSPC 62.1

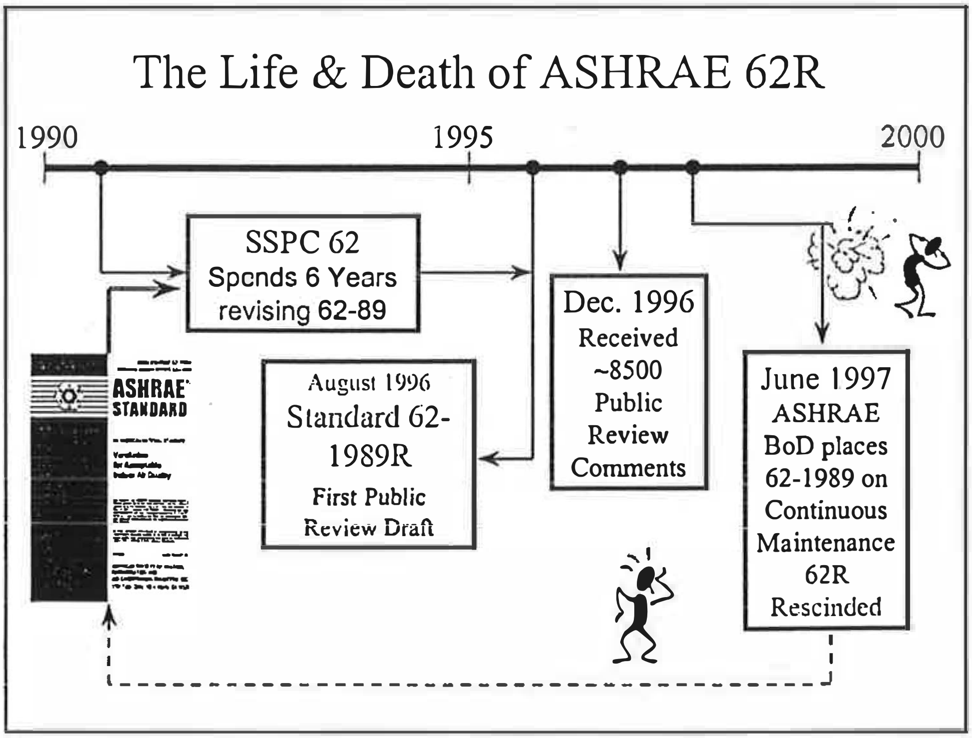
Taylor Engineering, Alameda, CA

Agenda

ASHRAE IAQ/Energy '98

- What's happening with Standard 62; where are we and how did we get here?
- What changes to Standard 62 are being considered; which are high priorities?
- What changes are in the works now?
- What changes are we considering in the near future?
- When will it be "done"


1970
1980
1990
2000
Standard 62-1973
Specified both minimum and recommended ventilation rates
Standard 62-1981
"Recommended" rate category deleted. Two categories became smoking and non-smoking. Added alternate "IAQ" procedure
Standard 62-1989
Tripled and quadrupled 1981 minimum non-smoking ventilation rates; did not distinguish between smoking and non-smoking
Standard 62-1999
ANSI deadline for updated Standard
SSPC 62
June 1991
Standing Committee created to begin updating Standard 62-1989


The Life & Death of ASHRAE 62R
1990
1995
2000
SSPC 62
Spends 6 Years revising 62-89
ASHRAE STANDARD
August 1996
Standard 62-1989R
First Public Review Draft
Dec. 1996
Received ~8500 Public Review Comments
June 1997
ASHRAE BoD places 62-1989 on Continuous Maintenance
62R Rescinded

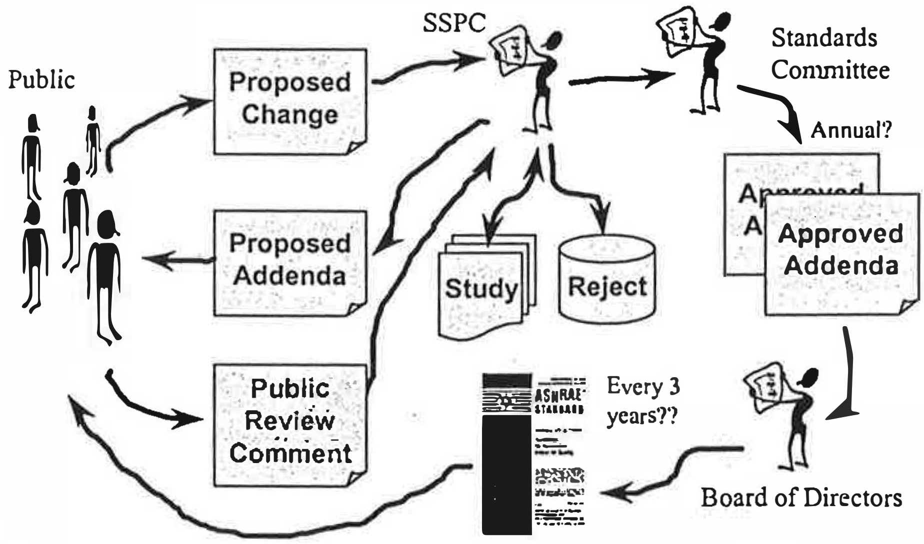
Continuous Maintenance ...

Why Change to CM?, continued

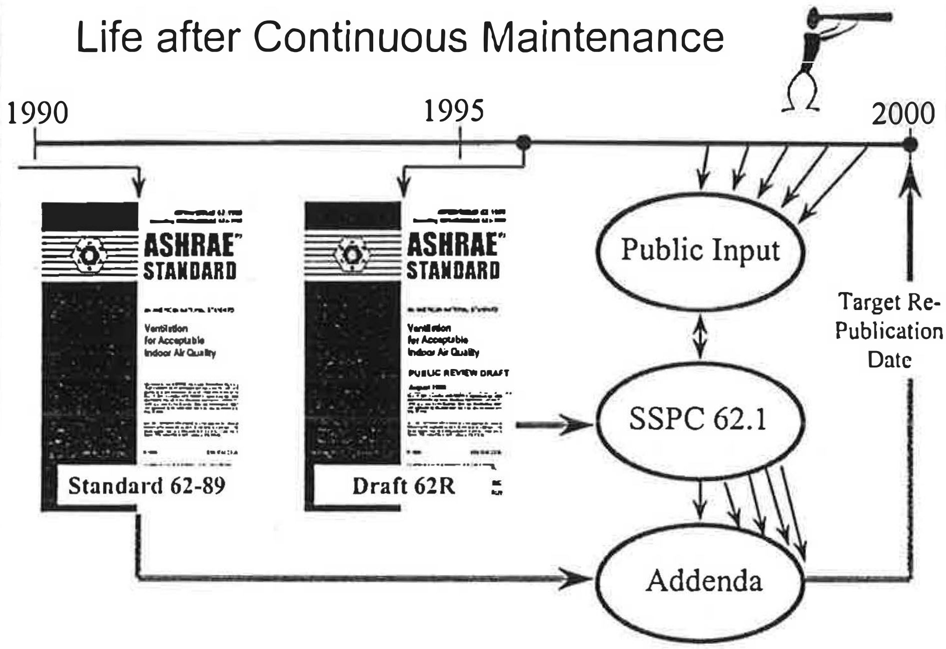
- **Legitimate Concerns about 62R**
  - Complexity
  - Health vs. Comfort Dilemma
  - Code vs. Standard Dilemma
- **Not so Legitimate Concerns about 62R**
  - Lobbyists
  - Gospel singers
  - Politics...

Continuous Maintenance ...

How Will CM Work?



Life after Continuous Maintenance



Any Downsides to CM?

- Frequent changes - tough for users to keep up with latest addenda; moving target
- Hard to make changes quickly - several addenda could be pending at the same time on the same issue
- Each change requires majority vote, independent review and comment; more paperwork
- 62-1989 is not a good starting point for a code-intended document

Proposed Changes ...

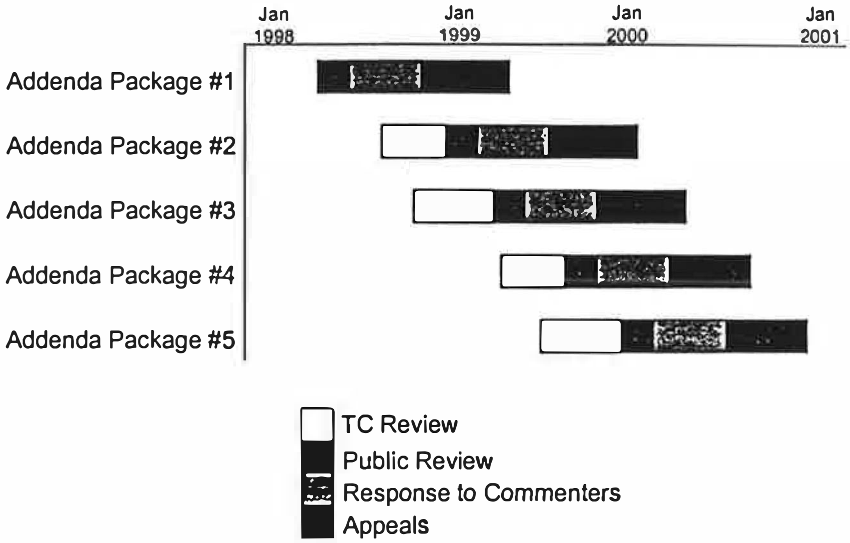
How do I comment or propose a change?

- **Second addenda package out for 60 day public review November 15 thru January 14**
  - 5 separate addenda
  - See November ASHRAE Journal for summary of addenda
- **Anyone can propose a change**
  - February 20 and September 20 deadlines each year
- **For instructions and forms**
  - Surf the web to **www.ashrae.org**
  - Or call **404-636-8400**

Addenda Priorities

- Change language to code style
  - Delete vague and non-mandatory language
  - Goal: Cohesive, code-language standard by the year 2000
- Incorporate new title, purpose, and scope for 62.1 and change body of standard accordingly
  - Delete residential (now in 62.2)
  - New buildings only (except in limited areas)
  - Eliminate thermal comfort considerations
  - Caveats

Timeline - Year 2000 Goal



Standard 62-1989

Ventilation for Acceptable Indoor Air Quality

Current Outline

- 1. Purpose
- 2. Scope
- 3. Definitions
- 4. Classification
- 5. Systems & Equipment
- 6. Procedures

    Ventilation Rate Procedure

    Indoor Air Quality Procedure

Probable Outline

- 1. Purpose (AP#5)
- 2. Scope (AP#1, 5)
- 3. Definitions (AP#4, 5)
- 4. Application & Compliance (AP#2)
- 5. Systems & Equipment (AP#3, 4, 5)
- 6. Design Ventilation Rates

    Ventilation Rate Procedure (AP#4)

    Indoor Air Quality Procedure (AP#2)

- 7. Construction & Start-up (AP#3)
- 8. Operations & Maintenance (AP#3)

Meanwhile…

- SSPC 62 and Standards Committee votes to split Standard 62 into two Standards:
  - **Standard 62.1 applies to...**
    - Commercial and institutional spaces
    - High-rise residential spaces
  - **Standard 62.2 applies to…**
    - Residential spaces in low-rise buildings
    - Single-family dwellings

And…

- Multidisciplinary Standards Committee votes to split Standard 62.1 into three:
  - **Standard 62.1**
    - Code-intended document
  - **User's Manual**
    - To assist users of the code
  - **Guideline**
    - State-of-the-art guidance for advanced users

ASHRAE Standard 62-89 ...

What is Continuous Maintenance?

- **Until June 1997: "Periodic Maintenance"**
  - Revise entire document at one time
  - Plan to issue entire standard every 5 to 10 years (was reissued in 1973, 1981, 1989)
  - Revision was planned to be published in 1998 or 1999
- **After June 1997: "Continuous Maintenance"**
  - Revise incrementally by addenda
  - Plan to issue addenda every 6 months to 1 year
  - Plan to republish revised Standard and User Manual every 3 years (as per model building codes)

Continuous Maintenance ...

Why Change to CM?

- **Reduce controversy?**
  - Evolution rather than Revolution
  - Divide and conquer
- **Retain ANSI status?**
  - ANSI status threatened if Standard not republished by 1999
- **Simplify the review process?**
  - 8500 comments...

What is Acceptable IAQ?

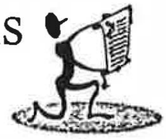
- Standard 62-1989: "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."
- Probable Revision: "Air in an occupied space toward which a substantial majority of occupants express no dissatisfaction with respect to odor and sensory irritation, and in which there are no known contaminants at concentrations leading to exposures determined by cognizant authorities to be harmful."

Addenda Package 1 Proposals

(Expected Publication: March, 1999)

- Addendum 62b:
  - Add to scope: This standard applies to new buildings, additions to existing buildings, and some changes to existing buildings as identified in the standard.
- Addendum 62c:
  - Thermal comfort requirements are not included in this standard.
  - Delete requirement to comply with Standard 55

Addenda Package #1 Proposals



Continued

(Expected Publication: March, 1999)

- Addendum 62d:
  - Add caveats to scope: acceptable indoor air quality will not necessarily be achieved even if all requirements are met because of the:
    - diversity of sources and contaminants in indoor air.;
    - many other factors that may affect occupant perception and acceptance of indoor air quality, such as air temperature, humidity, noise, lighting and psychological stress; and
    - range of susceptibility in the population.

Addenda Package #1 Proposals

Continued

(Expected Publication: March, 1999)

- Addendum 62e:
  - Delete the statement in Ventilation Rate table that rates accommodate a "moderate amount of smoking"
- Addendum 62f:
  - Makes it clear that CO2 is not a contaminant of concern; it is an indicator of body odor
  - 1000 ppm reference deleted and replaced with 650 ppm indoor/outdoor differential as indicator of odor acceptability by "visitors"

Addenda Package #2 Proposals

PR: 11/98 to 1/99.
Expected Publication: Jan. 2000)

- **Addendum 62g:**
  - Establishes requirements for separation of areas where smoking is permitted
- **Addendum 62h:**
  - Revises the IAQ Procedure in code language.
  - Removes explicit references to contaminant concentrations
  - Eliminates subjective panel

Addenda Package #2 Proposals

PR: 11/98 to 1/99.
Expected Publication: Jan. 2000)

- **Addendum 62i:**
  - Establishes when the VRP and IAQ Procedures can and must be used.
- **Addendum 62j: :**
  - Eliminates performance test for Natural Ventilation systems
  - Adds prescriptive openable area similar to Model Codes

Addenda Package #2 Proposals

PR: 11/98 to 1/99.
Expected Publication: Jan. 2000)

- Addendum 62k:
  - Replaces section 4 with new application and compliance requirements.
  - Geared toward code applications

Addenda Package #3 Proposals

Expected PR: 3/99 to 5/99.
Expected Publication: March, 2000)

- Addendum 62-3A:
  - Codifies outdoor air quality assessment and cleaning section.
  - Eliminates gas-phase air cleaning; retains particle filtering

Addenda Package #3 Proposals

Expected PR: 3/99 to 5/99.
Expected Publication: March, 2000)

- Addendum 62-3B:
  - New section on construction and system start-up
- Addendum 62-3C:
  - New section on operating and maintenance procedures

Addenda Package #4

- Classifications of air
  - Adds 4 classes of air
  - Limits recirculation of poor quality air to areas of better quality air
- Ventilation Rate changes
  - Adds building component
  - Makes Ventilation Efficiency calculation requirements clearer, simpler

Possible Revised Ventilation Rate Procedure (from 62R)

People Component

Building Component

Design Outdoor Air Ventilation Rate CFM

$$DVR = R_P P_D D + R_B A_B$$

- R_P: Minimum CFM/Person
- P_D: Number of People
- D: Diversity Factor
- A_B: Building Area
- R_B: Minimum CFM/sqft

Addenda Package #5

- VAV Systems
  - Minimum volume setpoints
  - OA rate control
- Equipment requirements
  - Drain pans
  - Access
  - Water management
  - Minimum filtration

Building Regulations & Ventilation

Dr L Fothergill

Department of the Environment, Transport & the Regions (DETR)

Building Regulations and Ventilation

By Les Fothergill BSc MSc PhD FIoA, Department of Environment Transport and the Regions

1. INTRODUCTION

Building Regulations are concerned mainly with the health and safety of people in and around buildings, and we are interested in ventilation because of the way it affects indoor air quality, and therefore the health of the occupants. Ventilation also accounts for a significant part of a building's energy consumption, and so we need to find a balance between sufficient ventilation for health without excessive energy consumption. This paper will consider the requirements for good indoor air quality, the Building Regulations and guidance on ventilation strategies needed to achieve it, and how the requirements and guidance may develop in the future.

2. INDOOR AIR QUALITY

2.1 The problem

Air quality is a major subject in its own right, so I can only give a brief overview here. Indoor air comes from outdoors and, therefore, contains most of the pollutants found in outdoor air, plus the pollutants added by the materials and activities indoors. We have to consider the following questions:

- What are the pollutants in indoor air?
- Are they harmful, and if so what are acceptable exposure levels?
- What are appropriate ventilation strategies?

2.2 The pollutants

The best-documented pollutants are probably asbestos and radon, but these are treated as hazards in their own right - rather than as aspects of air quality. The other pollutants can be classified in several ways, and I will adopt three simple categories: particulate, gaseous, and biological.

Particulate matter is characterised by size. For example, PM_{10} means particles having an aerodynamic diameter of 10 microns or less. The main sources of particles are vehicle exhaust and tobacco smoke, and it is the larger of these particles that are normally filtered out in mechanical supply systems, but not naturally ventilated systems. Epidemiological studies have shown that day-to-day variations in concentrations of particles are associated with adverse effects on health. The effects depend on the size of the particles, as smaller particles are able to penetrate deeper into the lungs.

The largest group of gaseous pollutants comprises volatile organic compounds (VOCs). The Department has funded studies in people's homes, which have identified several hundred of these compounds. They are found in furniture, carpets, paint, cleaning materials, and air fresheners (limonene), for example. Generally, indoor levels are higher than outdoor levels, and levels in new buildings are higher than in older buildings. The best known are probably formaldehyde and benzene. Formaldehyde is found in many wood based products, carpet backing, and other consumer products, while benzene is present in petrol, tobacco smoke, plastics, and many consumer products.

Apart from VOCs, there are many other chemicals in buildings. The most common include carbon monoxide, nitrogen dioxide, sulphur dioxide, carbon dioxide, and water vapour. Carbon dioxide and water vapour are associated with household and metabolic activity, while nitrogen dioxide and carbon monoxide are particularly associated with gas cookers, and indoor sulphur dioxide is mainly associated with appliances that burn paraffin.

Biological pollutants include fungi, bacteria, and allergens - such as those associated with pets (particularly cats) and house dust mite faeces. Fungi and bacteria generally come from outside, and may form colonies on damp walls and in air distribution ductwork systems. Their removal is the main objective of ductwork cleaning. The allergens are thought to trigger allergic reactions in susceptible individuals, and may be associated with asthma attacks.

2.3 Acceptable exposure levels

Exposure limits have mainly been set for occupational situations. Arguably, target limits should be more stringent in homes because the occupants are likely to spend more time there, and will include vulnerable groups such as the young, the elderly, and the infirm. Unlike the occupational situation, it is impractical to control levels of specific pollutants in homes, as the levels will be influenced by factors such as the presence of a smoker, the method of cooking, and choice of decorating and cleaning materials. However, in spite of these difficulties, the Department of Health has set up a committee to review the situation.

Surveys of exposure have indicated that levels of most of the pollutants commonly encountered in buildings present a low risk to health [1], and because of this we concentrate on controlling water vapour in dwellings, and carbon dioxide in commercial buildings. We control water vapour to reduce the risk of mould growth, and we control carbon dioxide because it is related to the number of people in the building and so can be used as a proxy for the ventilation rate needed to control odour. The assumption is that the ventilation rates necessary to control these two pollutants will also be sufficient to dilute any other pollutants present. BRE are currently looking into the validity of this assumption.

2.4 Ventilation strategies

Pollutant levels are not uniform throughout the building. Levels are initially high near the source of production, and slowly diffuse throughout the space. During this process, many pollutants can be adsorbed by soft furniture and furnishings, and are slowly desorbed over a period of hours when the rate of production has diminished. This mechanism has an averaging affect on the pollutant level.

The ventilation system is therefore required to:
(a) deal with high levels of pollutants produced in designated places, for example in a kitchen during cooking;
(b) quickly dilute high levels of pollutants produced in a less predictable way, for example during cleaning and decorating; and
(c) provide a steady flow of fresh air to dilute the pollutants produced by normal living activities.

3. BUILDING REGULATIONS

For Building Regulations purposes, the United Kingdom is divided into three territories: England & Wales; Scotland; and Northern Ireland. The Building Regulations in the three territories have generally similar technical requirements, although the administrative procedures are different. My comments will refer specifically to the ventilation requirements in England and Wales, but the technical aspects will also apply broadly to Scotland and Northern Ireland as well.

3.1 The Building Regulation system in England and Wales

To keep the system flexible, all the legal requirements are set out in functional form, with little or no technical detail in the Regulations themselves [2]. A builder can demonstrate that he has complied with a requirement by showing that he has followed guidance which is set out in an authoritative document such as an Approved Document published by the Department, or a British or European Standard. Alternatively, he can show that the method he has chosen will provide a similar performance to a solution shown in a guidance document.

Usually, small builders adopt solutions shown in the Approved Documents, because it is the simplest way of gaining approval from the building control body, but I emphasise that following the Approved Documents is not mandatory.

3.2 The requirement for ventilation

The legal requirement is as follows:

Means of ventilation
F1. There shall be adequate means of ventilation provided for people in the building.

3.3 The guidance in Approved Document F - Ventilation

The Approved Document [3] says that to meet the requirement, ventilation should restrict the accumulation of moisture (which could lead to mould growth) and pollutants originating within a building that would otherwise become a hazard to the health of the people in the building.

The Approved Document goes onto say that this could be achieved by providing all of the following:

extract ventilation to remove water vapour and hazardous pollutants from the areas where they are produced;
rapid ventilation to dilute, when necessary, pollutants and water vapour produced in habitable rooms; and
background ventilation to supply over long periods a minimum supply of fresh air for the occupants, and to disperse residual water vapour.

Extract ventilation can be provided by a fan or passive stack ventilator (PSV); rapid ventilation by an open window; and background ventilation by trickle ventilators.

Rapid ventilation can also aid thermal comfort in hot weather.

The guidance gives separate detailed recommendations for domestic and non-domestic buildings.

3.3.1 Domestic Buildings

The main guidance is restricted to natural ventilation, and is summarised in the following table, which is based on Table 1 of Approved Document F.

Domestic buildings			
Table 1 Ventilation of rooms containing openable windows (located on an external wall)			
Type of room	**Rapid ventilation** (e.g. open window area)	**Background ventilation** [1]	**Extract ventilation:** intermittent fan rate, or PSV [2]
Habitable room	1/20 floor area	8000 mm^2	
Kitchen	Any size window	4000 mm^2	30 l/s by hob; 60 l/s away from hob; or PSV
Utility room	Any size window	4000 mm^2	30 l/s or PSV
Bathroom (& WC)	Any size window	4000 mm^2	15 l/s or PSV
WC (Sanitary accommodation)	1/20 floor area or fan extract of 6 l/s	4000 mm^2	

1. Alternatively, the overall provision for ventilation should be 6000 mm^2 per room, with minimum of 4000 mm^2.
2. Passive Stack Ventilator.

Guidance is also given on other topics, including: ventilation of non-habitable rooms without windows; ventilation of habitable rooms through other rooms and spaces; and the interaction of mechanical extract ventilation and open-flued combustion appliances (spillage). The approved document also gives references to British Standards and BRE digests to cover alternative approaches, such as continuous mechanical ventilation of dwellings.

3.3.2 Non-domestic buildings

Again, the main guidance is restricted to natural ventilation, and is summarised in the following table, which is based on Table 2 of Approved Document F.

Non-domestic buildings			
Table 2 Ventilation of rooms containing openable windows (located on an external wall)			
Type of room	**Rapid ventilation** (e.g. open window area)	**Background ventilation**	**Extract ventilation**[1]**:** intermittent fan rate
Occupiable room	1/20 floor area	Floor area $\leq 10\ m^2$ – 4000 mm^2; $>10\ m^2$ - 400 mm^2 per m^2 of floor area	
Kitchen (domestic type)	Any size window	4000 mm^2	30 l/s by hob, or 60 l/s away from hob, or PSV
Bath/shower room	Any size window	4000 mm^2 per bath or shower	15 l/s per bath or shower or PSV
Washing facilities and/or sanitary accommodation	1/20 floor area; or extract fan at 6 l/s per WC; or 3 ac/h	4000 mm^2 per WC	

1. In domestic type facilities, a PSV can be used instead of a mechanical fan.

The guidance also covers ventilation of common spaces in non-domestic buildings and mechanical ventilation of rooms. Ventilation strategies for more specialised buildings, such as schools, hospitals, and other workplaces, are covered by reference to other documents.

3.4 Enforcement of Building Regulations

The building control function of checking plans and/or site visits may be carried out by local authorities or private Approved Inspectors. It is the builder's responsibility to comply with the Building Regulations, and legal action can be taken to enforce compliance where negotiation has failed.

4. CURRENT ISSUES

Clearly, ventilation system design should be firmly based on the air quality needs of the building occupants, and we need to know a lot more about these needs and how they can be met in an energy efficient way. The two main issues that I see are the need to gain a better understanding of the connection between air quality and health, and the need to raise awareness of the importance of reducing infiltration. The Department is supporting research on the first topic at BRE.

As well as improving air quality, ventilation also consumes energy. It is therefore important to minimise air leakage (or infiltration) so that the ventilation system can work properly and efficiently. Energy conservation is covered by Part L of the Building Regulations, and so Approved Document L, rather than F, gives guidance on limiting infiltration. It includes advice on: sealing the gaps between dry lining and masonry walls at the edges of openings; sealing of vapour control membranes in frame construction; fitting draft stripping to windows, door frames and loft hatches; and ensuring that pipe penetrations and boxing for concealed services are sealed (see Diagram 1).

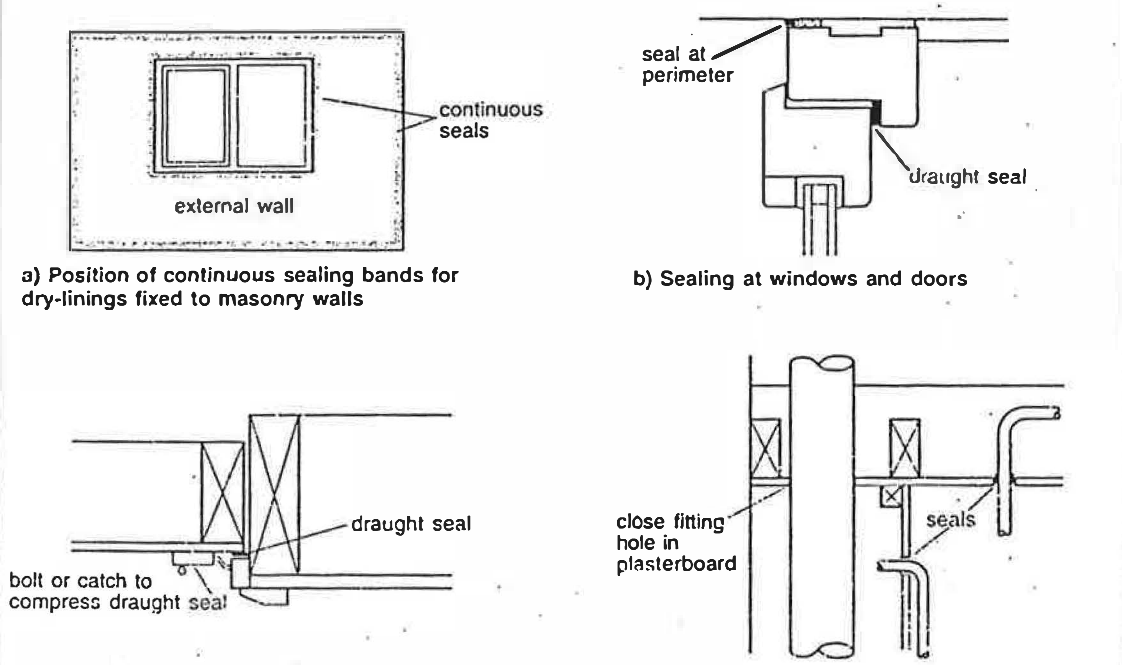
The Department has commissioned BRE to see how well this guidance is being followed. They have looked at plans for both domestic and non-domestic buildings to see what measures have been specified to control infiltration, and they have also measured leakage in completed buildings to see how effective the measures have been. The work is not completed yet, but the provisional results have been disappointing. They show that often very little attention has been paid to controlling infiltration either at the design or building stage, with the result that modern dwellings have about the same leakage rates as those built before 1995 (when the guidance was introduced). This is an area where we may need to be more proactive.

If buildings are made more airtight, it will increase the importance of design decisions. If the air is entering only through the intended inlets, it will be even more important to ensure that they are located away from sources of pollution to ensure the air quality is as good as it can be [4]. In mechanical systems, the air quality can be improved by filtering, and we need to know more about the health benefit, if any, of using finer filters. Fungi and bacteria can form colonies in ductwork and be distributed around the building with the air. Regular, and effective, cleaning is therefore important, and systems should be designed with cleaning in mind.

References

1. IEH Assessment on Indoor Air Quality in the Home. Assessment A2. MRC Institute for Environment and Health, Leicester 1996, ISBN 1 899110 05 4.
2. The Building Regulations 1991 (as amended), Statutory Instrument 1991 No 2768, HMSO London.
3. Approved Document F - Ventilation, 1995 edition, HMSO 1994, ISBN 0-11-752932-X.
4. Minimising pollution at air intakes. TM 21:1999. CIBSE, 222 Balham High Road, London, SW12 9BS.

Diagram 1 **Limiting infiltration in dwellings**

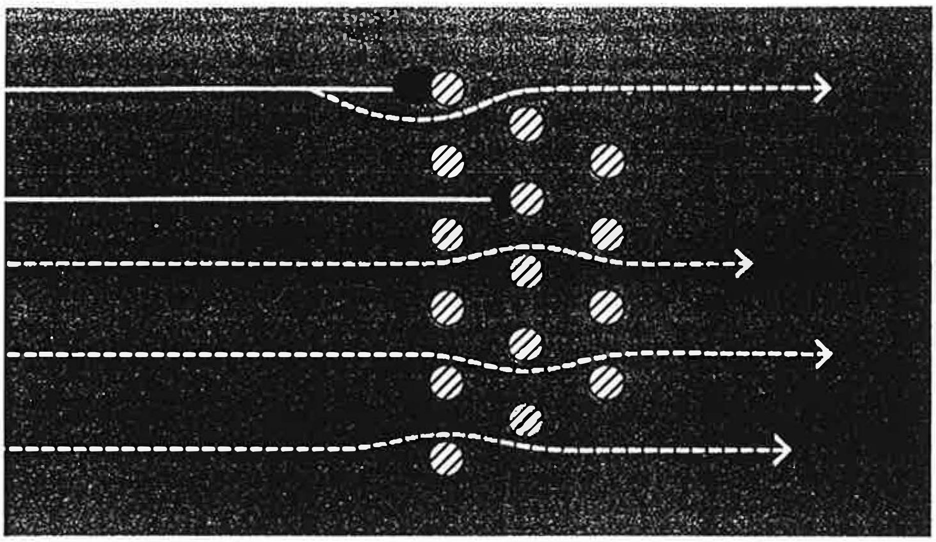


a) Position of continuous sealing bands for dry-linings fixed to masonry walls

b) Sealing at windows and doors

c) Sealing of loft hatch

d) Sealing around service pipes

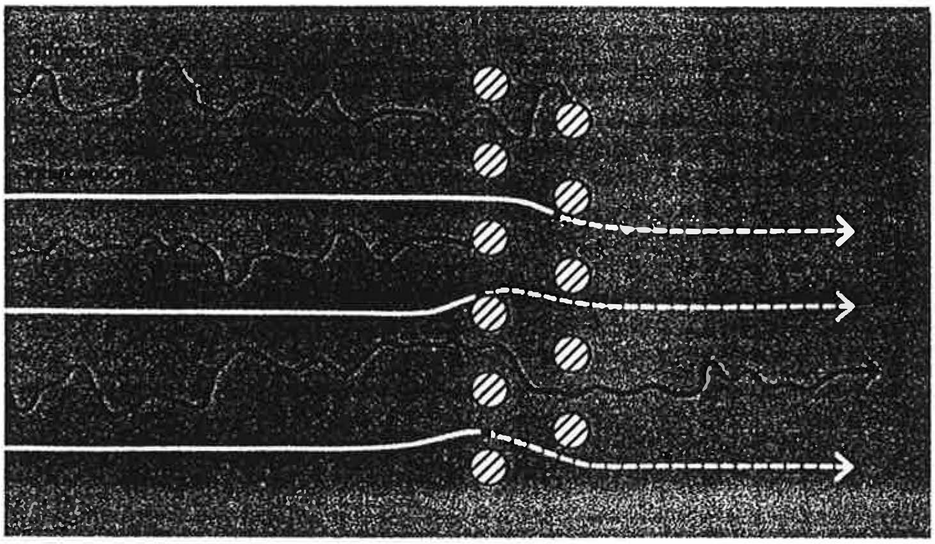


· **Inertial impaction principle**

reducing the overall efficiency. As a consequence, filters relying on inertial impaction ineffective at velocities through the filter medium above 3m/s. On the other hand, m/s their efficiency starts to drop due to the reduction in inertia. They are also only t the larger particle sizes - those above 5µm diameter – which whilst accounting for e total mass of typical atmospheric contamination, only account for a tiny percentage ber of particles present in the air.

er can typically remove 85% of 5µm particles from the airstream, but its efficiency only 15% for 1µm particles. Put another way, 85% of the 1µm particles will pass netrate this type of filter.

N/INTERCEPTION



I Interception/diffusion principle

Small, very light particles follow the airstream but are, under certain cor molecular attraction forces between the particles and the filter fibres. This is principle.

Furthermore, all extremely small particles (<1μm) are subject to erratic mc motion, which is caused by colliding air molecules, so that they move in ran fluid flowlines. It is possible to trap these small, randomly moving partic packed ultra-fine fibres in their path. As the particles diffuse through the principle) they are trapped. See Figure 4 for a depiction of the diffusion/interc

All medium/high/ultra-high efficiency air filters, including bag, cartridge and Particulate Air) filters employ the diffusion/interception principle. To help the through the filter is reduced to between 0.1 and 0.2m/s in the case of mediur either by fashioning the medium into the form of deep pockets (bag filte (cartridge filters). The velocity through the filter medium and its fibre diamet efficiency – the lower the velocity and the finer the diameter the higher tl against the smaller particles. Typically the fibres used are less than 1μm d from Figure 5, a highly magnified, electron microscope photograph of a hum: trapped in a bag filter.

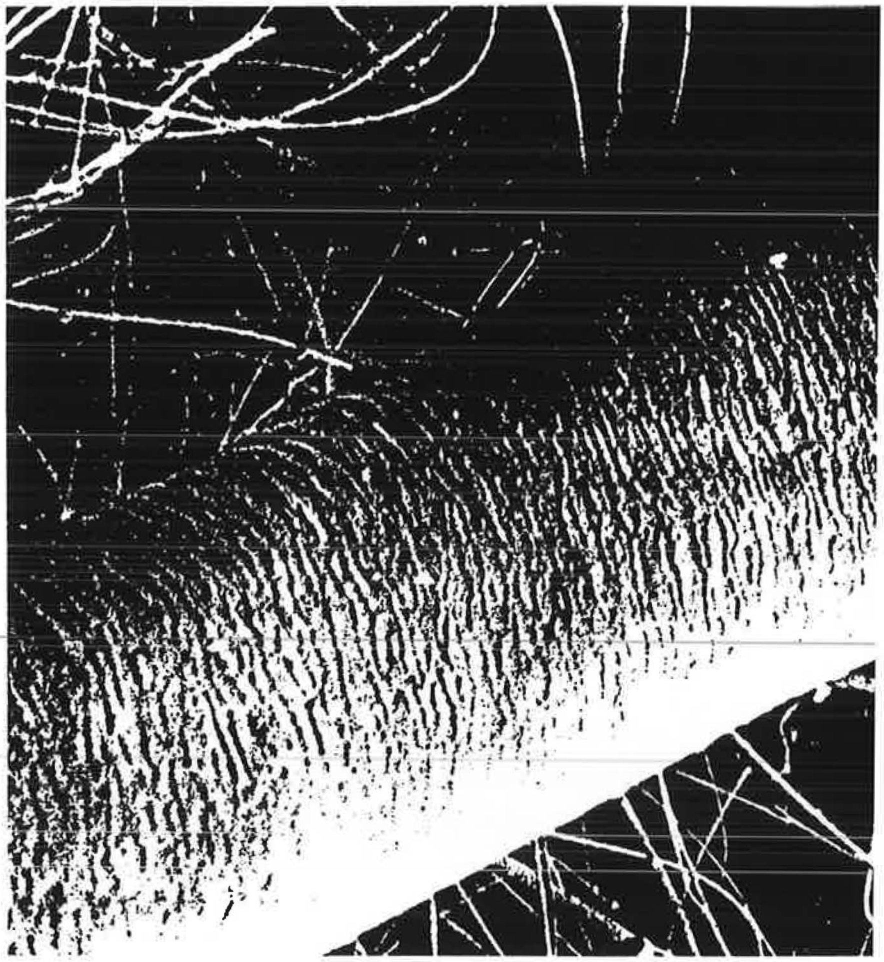


Figure 5 Human hair caught in bag filter medium

IAQ Standard

—

The Present Position

Mr A Green

TROX (UK) Ltd

IAQ STANDARD - THE PRESENT POSITION

1. INTRODUCTION

The opportunity has been taken in this presentation to describe a little bit of the history of TC156. The various stages through which the indoor air quality proposals have gone; a review of what happened at the various stages of voting on draft documentation culminating in the present situation.

2. CENTC156

CENTC 156, the Technical Committee dealing with ventilation in buildings was initiated in 1989 with 4 working groups dealing with terminology, domestic ventilation, duct work and air distribution. In 1990 the activities were extended to cover air handling units, indoor air quality, system performance - procedures and measuring methods for handing over installations. Finally, in 1994 further activity was added concerning fire protection of air distribution systems.

3. WORKING GROUP 6

This was the group dealing with indoor air quality, under the convenorship of Professor Ole Fanger.

Terms of Reference:

To specify how the quality of the indoor environment be expressed for the design and operation of ventilation and air conditioning of spaces. The indoor environment comprises the thermal and acoustic environments and the air quality. Different levels of environmental quality should be available.

During the activities of this working group there was an active membership from the following countries:

UK	**Netherlands**	**Germany**	**Norway**	
Sweden	**Switzerland**	**Austria**	**France**	**Finland**

Their first working group meeting took place in Zurich in September 1990.

4. DOCUMENT DEVELOPMENT

The scope of the document indicated that it was to cover the specification of how the quality of the indoor environment could be expressed for the design, commissioning operation and control of ventilation and air conditioned systems. It considered the major features of the indoor environment which comprised:

- A) thermal environment
- B) air quality
- C) acoustic environment

The applicability of the draft standard was intended to be indoor environments where a major concern was the human occupation. It was not applicable to dwellings, i.e. domestic situation or industrial process plant areas and similar environments.
Finally, in terms of the requirement for different levels of environmental quality the draft standard would include three categories, namely:-

- A high level of expectation
- Medium level of expectation
- Moderate level of expectation

The contents of the proposed draft standard are shown in table 1.

Table 1 of this Presentation

CONTENTS

Table 1 of this presentation Cont'd. ....

5. THERMAL COMFORT

Previous work by Professor Ole Fanger, part of which has been incorporated in ISO 7730, has been used including the procedure for draught ratings.
The principle features affecting thermal comfort are the local air temperature; the local mean air velocity and a function called turbulence intensity. Turbulence intensity is a measure of the fluctuation in the local air velocity as a function of time.

For the mathematically minded it can be defined as a standard deviation divided by the mean value. Taking the three categories mentioned above permissible relationships between the above factors have been presented - see figure 1 (A3) of this document.

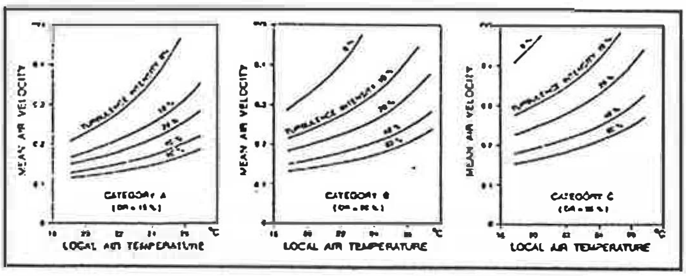


Figure 1.1 Permissible mean air velocity as a function of local air temperature and turbulence intensity for the three categories of the thermal environment (Figure A3 of prENV 1752:1997)

It is interesting to note that in category 'A' High Level of Expectation (draught risk of 15%) typically a mixed flow air distribution system will result in turbulence levels between 30 and 40%. Taking a local air temperature of 24°C this means that maximum value of local air velocity is less than 0.15m/s in the occupied zone. With a mixed flow system this would be difficult to achieve and could drive the designer towards displacement flow systems, possibly in combination with Chilled Ceilings and Chilled Beam elements.

6. INDOOR AIR QUALITY

The draft standard developed the concept of perceived air quality in conjunction with the 'olf' and 'decipol' concepts. It also recommends the need to consider both the building and people in terms of the pollution rating.

The annexes to the draft standard has demonstrated how these pollution rated assessments could be used to determined ventilation rate. Other alternative strategies considering carbon dioxide, the human bioeffluent and chemical pollution loads are also demonstrated as a means of determining ventilation rates. This resulted table 2 which is extracted from the draft Standard.

Table 2 of this presentation:
Design Criteria for spaces in different types of buildings. Insert Table 1 1996a.xls and 1996b.xls

Table A10: Permissible A-weighted sound pressure level generated and/or transmitted by the ventilation or air-conditioning system in different types of spaces for three categories

Type of Building	Type of Space	Category [1] dB(A) A	B	C
Child Care Institutions	Nursery Schools	30	40	45
	Day nurseries			45
Places of assembly	Auditoriums	30	33	35
	Libraries	30	33	35
	Cinemas	30	33	35
	Court rooms	30	35	40
Commercial	Retail Shops	35	40	50
	Department stores	40	45	50
	Supermarkets	40	45	50
	Computer rooms, large	40	50	60
	Computer rooms, small	40	45	50
Hospitals	Corridors	35	40	45
	Operating theatres	35	40	45
	Wards	25	30	35
Hotels	Lobbies	35	40	45
	Reception rooms	35	40	45
	Hotel rooms (during night-time	25	30	35
	Hotel rooms (during daytime)	30	35	40
Offices	Small offices	30	35	40
	Conference rooms	30	35	40
	Landscaped offices	35	40	45
	Office cubicles	35	40	45
Restaurants	Cafeterias	35	40	50
	Restaurants	35	45	50
	Kitchens	40	55	60
Schools	Classrooms	30	35	40
	Corridors	40	45	50
	Gymnasiums	35	40	45
	Teachers' rooms	30	35	40
Sport	Covered sports stadiums	35	45	50
	Swimming baths	40	45	50
General	Toilets	40	45	50
	Locker rooms	40	45	50

[1] The letters A, B and C define merely one of the three categories and they have no relation to the weighting curves like dB(A)

Table 3: A10 1997

7. ACOUSTIC ENVIRONMENT

Again, recommendations were made in terms of suitable noise levels for a wide range of applications for category 'A', 'B' and 'C' levels of expectation. The most important feature of this is the use of dB(A). These recommendations are detailed in table 3.

Table 3 of this presentation:

Insert Table A10 1997

8. prENV 1752 MILESTONES

As the proposed draft standard was breaking a certain amount of new ground in applying research work to standardisation of design criteria, particularly in the field of ventilation rates, it was decided that the draft standard should be a pre-standard. This allows the procedures in the standard to be reviewed after a 3 year period with a view to introducing appropriate modifications, determined from experience, to make the document subsequently a full standard. The development of the draft pre-standard passed through a number of stages of European review. These are detailed below:-

prENV 1752 Milestones

- ENV is a pre-standard with 3 year life time.

- **December 1994**
  1st document which was prepared by Working Group 6, circulated for National Votes and comments.

- **March 1995**
  Vote rejected document.
  Countries rejecting indicated reasons

- **July 1996**
  2nd document prepared by Working Group 6 (based on March 1995 comments) and circulated for National Votes and comments.

- **September 1996**
  Vote on 2nd document at TC156 Plenary deferred to review comments from UK, France and other comments at meeting.

- **March 1997**
  Working Group 6 finalises 3rd document

- **June 1997**
  Revised document, i.e. 3rd version issued for postal vote.

- **September 1997**
  Postal vote rejects document

9. MAIN UK ISSUES - PRE-DECEMBER 1994

As a result of discussions with the various trade associations and professional bodies in the UK, BSI charged the UK representatives to CENTC156 to raise a number of issues. Briefly, these can be summarised as follows:-

a) Thermal Comfort Criteria:
Concern was expressed in relation to the use of turbulence intensity. Whilst laboratory instrumentation existed to enable turbulence intensity to be determined it was felt that robust instrumentation of the sort required to be used in a site environment was not available.

Also, more basically, all catalogue performance data for grilles, diffusers etc., which were currently available, did not present information on turbulence intensity and hence there did not appear to be available suitable tools for use by consultants at the design stage of the system.

b) Acoustic Criteria:
For many years the UK has used NC and NR for noise specification of internal environments - dB(A) is only used in control of the external environment.

c) Indoor Air Quality and Ventilation Rate
As a result of other research work carried out it was felt that there were questions over the use of the 'olf' as a means of evaluating the pollution load and hence determination of ventilation rates.

With regard to turbulence intensity and dB(A), the UK were unsuccessful in presenting the above mentioned points of view as all other European countries considered the proposals acceptable. However, in connection with indoor air quality there were a number of countries who had similar views to the UK.

10. UK PROPOSALS - JULY 1996

As can be seen from paragraph 8, the second draft document was prepared by Working Group 6 and circulated for national voting. This voting was planned to take place at the CENTC156 Plenary meeting in September 1996. The UK, again in consultation with the appropriate agencies, submitted through BSI their main concerns in relation to the latest draft. These were:-

a) Table 1 of the Document: (see table 2 of this presentation)
This table should contain one column only to specify the minimum ventilation rate which should take account of all currently recognised and agreed design criteria. The last three columns shall be deleted.

b) Annex A2
The clauses in A2 should be edited to ensure a more equal balance between the various methods of ascertaining ventilation rates currently available and those described in this Annex.

11. SEPTEMBER 1996

At the Plenary meeting of TC156, there was considerable discussion concerning the second draft document prepared by Working Group 6. It became clear that a number of countries had some concerns, particularly in relation to the indoor air quality issues.

Table 1: Design Criteria for spaces in different types of buildings. This table applies for the occupancy listed in the table and for a ventilation effectiveness of one.

Type of Building/ space	Activity met	Occupancy person/ (m2)	Category	Operative temperature 3) Co		Maximum mean air velocity 1) m/s		Sound pressure	Ventilation rate l/s m²	Additional ventilation when smoking is allowed²)
				Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)	dB(A)		l/s(m²)
Single office (cellular office)	1.2	0.1	A	2,45+1,0	22.0+1.0	0.18	0.15	30	2	0
			B	24.5+1.5	22.0+2.0	0.22	0.18	35	1.4	0
			C	24.5+2.5	22.0+3.0	0.25	0.21	40	0.8	0
Landscaped office	1.2	0.07	A	24.5+1.0	22.0+1.0	0.18	0.15	35	1.7	0.7
			B	24.5+1.0	22.0+2.0	0.22	0.18	40	1.2	0.5
			C	24.5+2.5	22.0+3.0	0.25	0.21	45	0.7	0.3
Conference Room	1.2	0.5	A	24.5+1.0	22.0+1.0	0.18	0.1 5	30	6	5
			B	24.5+1.5	22.0+2.0	0.22	0.18	35	4.2	3.6
			C	24.5+2.5	22.0+3.0	0.25	0.21	40	2.4	2
Auditorium	1.2	1.5	A	24.5+1.0	22.0+1.0	0.18	0.15	30	16[1]	-
			B	24.5+1.5	22.0+2.0	0.22	0.18	33	11.2	0
			C	24.5+2.5	22.0+3.0	0.25	0.21	35	6.4	0
Cafeteria/Restaurant	1.2	0.7	A	24.5+1.0	22.0+1.0	0.18	0.15	35	8	0
			B	24.5+2.0	22.0+2.5	0.22	0.18	45	5.6	5
			C	24.5+2.5	22.0+3.5	0.25	0.21	50	3.2	2.8

Table 4: 1997a

Table 1: Design Criteria for spaces in different types of buildings. This table applies for low polluting building materials and furnishing, for the occupancy listed in the table and for a ventilation effectiveness of one

Type of Building/ space	Activity met	Occupancy person/ (m2 floor)	Category	Operative temperature 3) C°		Maximum mean air velocity 1) m/s		Sound pressure	Minimum Ventilaton rate, i.e. for occupants only l/s m²	Additional ventilation for building (add only one)		Additional ventilation when smoking is allowed²)
				Summer	Winter	Summer	Winter	dB(A)		low polluting building l/s m²	not low polluting building l/s m²	l/s(m² floor)
Single office (cellular office)	1.2	0.1	A	2.45+1,0	22.0+1.0	0.18	0.15	30	1	1	2	0
			B	24.5+1.5	22.0+2.0	0.22	0.18	35	0.7	0.7	1.4	0
			C	24.5+2.5	22.0+3.0	0.25	0.21	40	0.4	0.4	0.8	0
Landscaped office	1.2	0.07	A	24.5+1.0	22.0+1.0	0.18	0.15	35	0.7	1	2	0.7
			B	24.5+1.5	22.0+2.0	0.22	0.18	40	0.5	0.7	1.4	0.5
			C	24.5+2.5	22.0+3.0	0.25	0.21	45	0.3	0.4	0.8	0.3
Conference Room	1.2	0.5	A	24.5+1.0	22.0+1.0	0.18	0.1 5	30	5	1	2	5
			B	24.5+1.5	22.0+2.0	0.22	0.18	35	3.5	0.7	1.4	3.6
			C	24.5+2.5	22.0+3.0	0.25	0.21	40	2	0.4	0.8	2
Auditorium	1.2	1.5	A	24.5+1.0	22.0+1.0	0.18	0.15	30	15 1)	1	2	-
			B	24.5+1.5	22.0+2.0	0.22	0.18	33	10.5	0.7	1.4	0
			C	24.5+2.5	22.0+3.0	0.25	0.21	35	6	0.4	0.8	0
Cafeteria/Restaurant	1.2	0.7	A	24.5+1.0	22.0+1.0	0.18	0.15	35	7	1	2	0
			B	24.5+2.0	22.0+2.5	0.22	0.18	45	4.9	0.7	1.4	5
			C	24.5+2.5	22.0+3.5	0.25	0.21	50	2.8	0.4	0.8	2.8

1) It may be difficult to meet the Category A draught criteria

2) Additional ventilation required for comfort when 20% of the occupants are smokers. The health risk of passive smoking should be considered separately

3) For many types of buildings and spaces with moderate heating or cooling loads the air temperature will be approximately equal to the operative temperature. For design, the upper end of the temperature range can be used during summer and the lower end during winter.

4) It is recommended to design for a low-polluting building by using low-polluting materials etc. (see Annex G: Guidleines for low-polluting buildings)

Table 2: 1996a

Continued

The Committee decided to give Working Group 6 a further opportunity to consider the points raised during the meeting. On this basis there was to be a further meeting of Working Group 6 who would then prepare a finalised document which would be circulated for a postal vote.

12. FINAL DOCUMENT

The UK submitted a number of detailed comments and proposed changes to the document. These were considered at the Working Group 6 meeting in Copenhagen on 14th March 1997. As a result of this table 1 of the document was revised as shown in table 4 of this presentation.

Table 4 of this presentation:
Insert Tables 1997a.xls and 1997b.xls

This shows that the required ventilation rate had now been consolidated into a single column with no reference to low or high polluting buildings as requested by the UK submission to Working Group 6.

13. BRE/BUILDING SERVICES JOURNAL INVESTIGATION

In order to evaluate the use of the current draft pre-standard a Group of leading consultants in the UK were asked to apply the draft standard to the design of 3 selected buildings. Details of the buildings were supplied and an evaluation undertaken.

The results of this were discussed at a meeting at BRE and also reported in the Building Services Journal of September 1997. The two significant features are demonstrated by the enclosed tables extracted from the Building Services Journal.

Table 5 of this presentation:

Table 2: Spread of Results for the three Buildings designed using prENV 1752

Calculation	Building A	Building B	Building C
Winter Temp.(°C)	21±2, 21±2	21±2, 21.5±2, 22±2	22±2, 22±2
Summer Temp. (°C)	24±2, 22±2	22±2, 22±2, 23±2	25±1.5, 23±1.8, 24±1.8, 23±1.5
Sensory pollution load (occupants, olf/m²)	0.1, 0.04	0.12, 0.12, 0.12	0.08, 0.08, 0.07, 0.07
Sensory pollution load (building, olf/m²)	0.3, 0.6	0.4, 0.3, 0.3	0.1, 0.6, 0.3, 0.3
Sensory pollution load (total, olf/m²)	0.4, 0.64	0.52, 0.42, 0.42	0.18, 0.62, 0.37, 0.37
Outdoor air quality (decipol)	0, 0.1	0.3,>0.5, >0.5	0, 0, 0, 0,
Ventilation effectiveness (nd)	0.95, 0.8	0.8, 0.5, 0.9	0.9, 1.0, 0.8, 0.8
Required ventilation rate (l/s/m²)	3.0, 6.1	5.9, 9.3, 5.0	1.5, 4.9, 3.3, 3.3
Required ventilation rate (l/s/person)	87.5, 178.0	98.0, 164.0, 83.0	17.5, 59.0, 47.1, 47.1
Noise levels (dBA)	40 not available	40, 45, 40	40, 35, 40, 40
Original Specification	Winter 20+2°C, Summer 22+2°C 40-70% rh, 22 l/s/ person, 35 NR	Winter 20°C, Summer 22°C 50-60% rh(ventilation rate not recorded but assumed to be orthodox	Winter 18-21°C, Summer 28°C<1% year and 25°C<5%, 40-70% rh, 8 l/s/person

Note that the prENV 1752 pre-standard assumes a ventilation effectiveness at various operative temperatures, and all three designers in this exercise were conservative in their estimations.

Table 6 of this presentation:

Table 3: Different Ventilation Rates for Test Building C Depending on Different Estimates Of Internal Pollution

Occupant density (per m^2)	Occupant pollution load (olf/m^2)	Building pollution load (olf/m^2)	Total Load (olf/m^2)	Outside decipol	Ventilation rate (l/s/m^2)	l/s/person)
0.8	0.08	0.2	0.28	0.1	2.1	26.3
0.08	0.08	0.2	0.28	0.5	3.1	38.8
0.08	0.08	0.6	0.68	0.1	5.2	65.0
0.08	0.08	0.6	0.68	0.5	7.6	95.0

The BRE's Nigel Oseland drew up a matrix showing the sensitivity of assessing a building's sensory pollution load. The data for Building C reveals that even when designing to a building pollution load of 0.2 olf/m^2, ventilation rates can be 26 l/s/person, three times the current recommended rate. With a building regarded as being high polluting under the standard, ventilation rates could rise as high as 95 l/s/person. Ventilation rates for the other buildings rose as high as 122 l/s/person.

Table 5 shows a range of ventilation rates which were determined by various experts.

There was a wide variation on each building, on one building there was a ratio of up to approximately 3:1. In addition, table 6 shows on building 'C' the variation in ventilation rate depending upon the estimated internal pollution load. This also indicates ventilation rates per person which could be approximately three times those currently recommended.

There was also concern expressed at the meeting as to how the level of pollution rates could be determined. Again, there was at this time, a lack of design data on this subject.

Final conclusions of the meeting were that, at the present time, the indoor air quality aspects in proposed pre-standard could not be used effectively.

14. VOTING SEPTEMBER 1997

Again, after having taken the views of trade associations and professional bodies, it was decided at BSI to submit a negative UK vote. The specific reasons for the UK vote were as follows:-

- Need to remove the distinction between low and high polluting buildings from normative part of pre-standard. Relevant section of draft pre-standard refers to Annex C in this context, hence making it normative.
- Prospective users express concern of over practicality of draft pre-standard and the potential for costly litigation.
- Draft pre-standard too descriptive with insufficient normative statement.

As a result of the UK vote and number of negative votes, the proposed pre-standard was rejected.

15. Current Situation

At the Plenary meeting of TC156 during September 1996, the issue was addressed as to the possibility of a non-acceptance of the proposed pre-standard. It was agreed with one dissent (Denmark) that the draft pre-standard should be edited and issued as a CEN Technical Report as it did represent a considerable amount of work that needed to be considered in future developments in this area. It was also agreed at the Plenary meeting, again with the exception of Denmark, in the event of a negative vote that there would be an ad-hoc group called together within CEN TC156 by the Chairman to meet later this year to consider what future actions should be taken.

Subsequently, the work has been issued as a Technical Report – CR 1752.

The Ad hoc Group met on 28th October 1998 and put forward recommendations to the Plenary Committee. These have now been accepted by the voting process and are as follows:-

1. Two new work items are to be undertaken –

   a) **Ventilation for Buildings**: Design Criteria for the Indoor Thermal Environment.
   b) **Ventilation for Buildings:** Design Criteria for the Indoor Acoustic Environment.

2. To consider the work on Ventilation for Buildings – Design Criteria for Indoor Air Quality at a later date recognising that ISO/TC 205 has now initiated work in this area.

The next meeting of CEN 156 Plenary is in October of this year when it will decide how to implement part 1 of the above recommendations.

Within some European countries there is a view that thermal comfort and acoustic environment proposals in prEN 1752 were not that contentious and that it should be a relatively simple matter to produce draft standards to cover these two topics.

As far as ISO/TC 205 activities is concerned their activities are at an early stage. Consideration is being given to the following topics for Building Environment Design:-

1. The Indoor Environment - General principles
   Scope - The general principles of building environment design for new construction and the retrofit of existing buildings as relating to the indoor environment.

2. Indoor Air Quality
   Scope - Building environment design for new construction and the retrofit of existing buildings as relating to indoor air quality.

3. Indoor Thermal Environment
   Scope - Building environment design as relating to the indoor thermal environment for new construction and the retrofit of existing buildings, excluding the scope of ISO 7730

4. Indoor Acoustic Environment
   Scope - Building environment design for new construction and the retrofit of existing buildings as relating to indoor acoustic environment.

5. Indoor Visual Environment
   Scope – Building environment design for new construction and the retrofit of existing buildings as relating to indoor visual environment.

As with all ISO Committee activities it will be a few years before final draft documents become available. The current situation can therefore be summarised as follows:-

1. There is a CEN report on Indoor Environment covering Indoor Air Quality Thermal Comfort and Noise.

2. CEN TC 156 has to decide how to deal with thermal comfort and the acoustic environment and the associated time scales to draft standard availability.

3. As far as IAQ is concerned the next potential standard input will be in a few years from ISO, subject to a successful work programme.

Minimising pollution at air intakes

S J Irving

Oscar Faber, Marlborough House, Upper Marlborough Road, St Albans, Herts, AL1 3UT

There has been a significant increase in interest in air quality issues over recent years. This has been brought about through a number of factors.

- An increased understanding of the effects of pollutants on human health and well being
- A recognition that there can be conflicts between energy conservation and indoor air quality. Ventilation rates for adequate indoor air quality have been the subject of considerable debate within the framework of both European and ASHRAE standards.
- The resurgence of interest in engineered natural ventilation as a design strategy. External noise and pollution are arguably the main factors that limit the application for such buildings in urban areas.

Pollution in the outdoor air can have a significant effect on the quality of ventilation air, and thereby influence indoor air quality (IAQ). External pollution sources include

- General background pollution from industrial processes etc remote from the building location
- Local but widespread pollution sources, especially exhausts from vehicular traffic
- Specific local sources like boiler flues and ventilation exhausts.

There is an increasing body of knowledge about how pollution in urban areas is generated and dispersed and this has been summarised in a recently published CIBSE Technical Memoranda (*Minimising pollution at air intakes*, TM21, CIBSE, 1999).

The document gives general guidance on how to locate ventilation inlets to minimise the effects of external pollution on the intake air. Methods outlined in that document provide a basis for estimating the concentration of the pollutant at the ventilation intake(s) from known sources.

In most cases, the building designer is concerned with indoor air quality, and so a method is needed to combine the effects of external pollution, air treatment in the HVAC plant and internal pollution sources. The analysis described in this paper allows the effects of varying external pollution levels to be estimated for any configuration of ventilation system, natural or mechanical. The analysis takes into account filter efficiency and position, internal pollutant sources, degree of re-circulation and varying fresh air rates. By developing simplified dynamic equations rather than steady state formulations, the effects of varying "fresh" air rates based on the external pollution level can also be examined.

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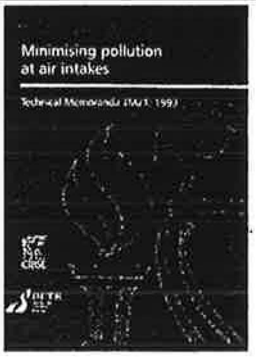
Minimising Pollution at Air Intakes

Steve Irving
Oscar Faber Applied Research

OSCAR FABER



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External pollution & IAQ

- How fresh is "fresh" air?
  - Application of natural ventilation in urban areas
  - Siting of ventilation inlets for mechanical ventilation systems
  - Application of air quality controlled fresh air rates during (e.g.) rush hour periods.
- Pollutant concentrations at intake
- Impact on indoor air quality

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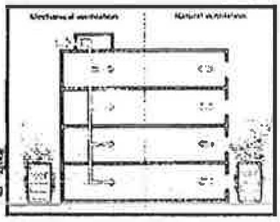
Intake types and locations

- Building scale
  - centralised ducted mechanical ventilation or air conditioning systems
- Room scale
  - through the wall units for fan convectors or local air conditioning units
- Window scale
  - trickle vents and opening windows in nat vent



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Pollution sources

- Background pollution
- Traffic pollution
- Building sources
  - ventilation exhausts, plumbing or oil tank vents
  - Standby generators, CHP engines, boiler flues
  - Loading bays, underground carpark exhausts
  - Cooling towers, stagnant water (flat roofs), roosting ledges ....

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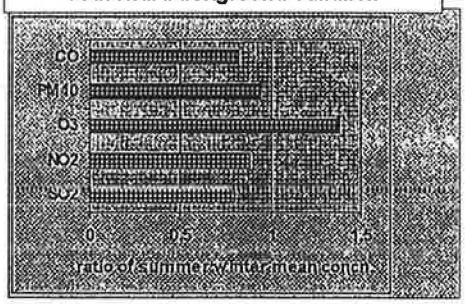
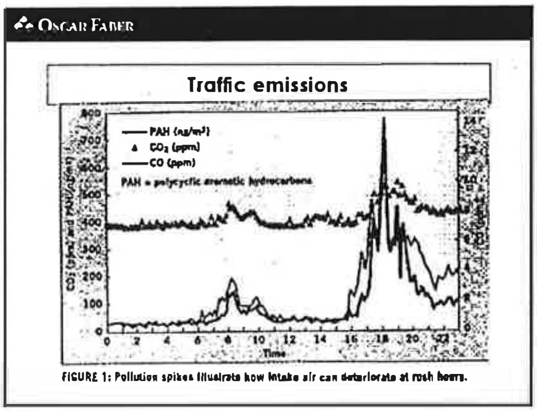
Seasonal background variation

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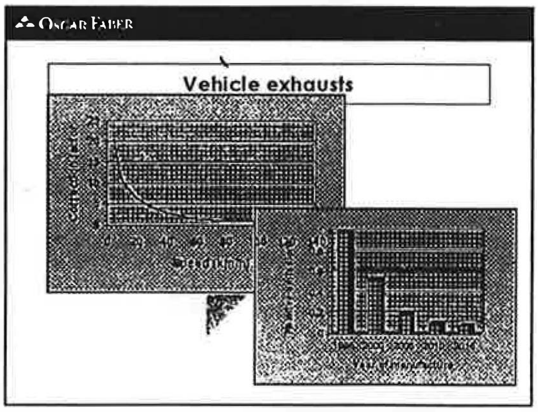
Traffic emissions
PAH (ng/m³)
CO₂ (ppm)
CO (ppm)
PAH = polycyclic aromatic hydrocarbons
Time
FIGURE 1: Pollution spikes illustrate how intake air can deteriorate at rush hours.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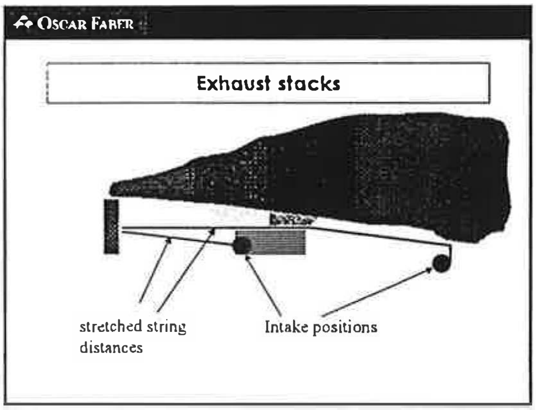
Vehicle exhausts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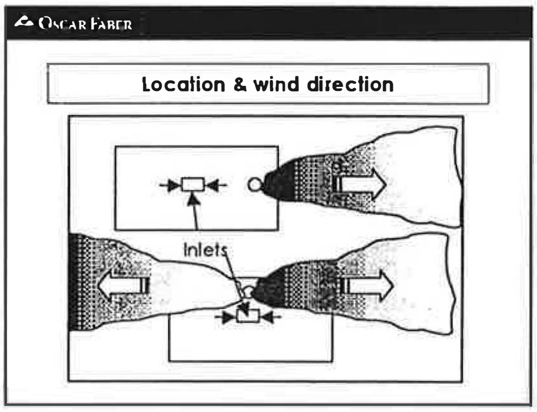
Exhaust stacks
stretched string
distances
Intake positions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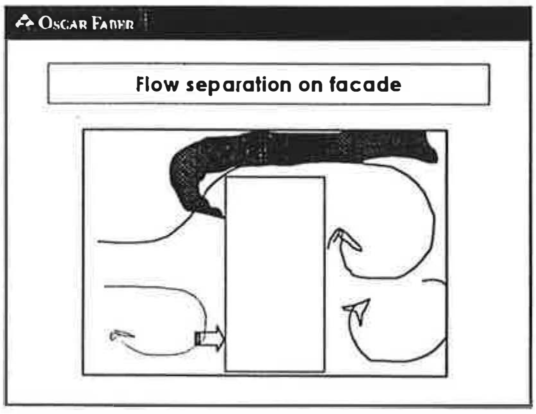
Location & wind direction
Inlets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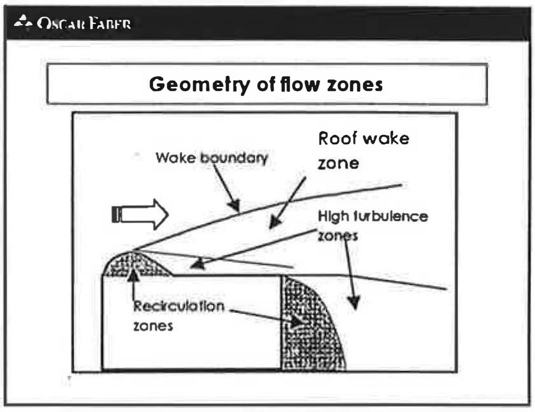
Flow separation on facade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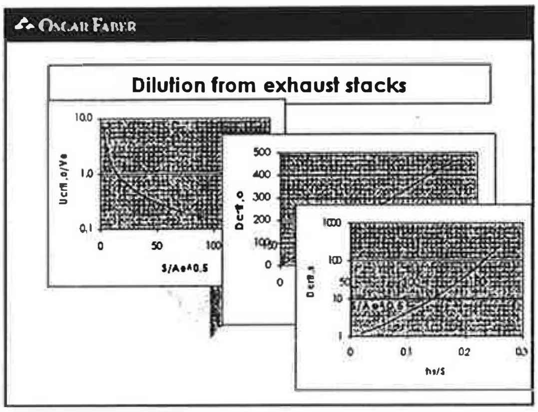
Geometry of flow zones
Wake boundary
Roof wake
zone
High turbulence
zones
Recirculation
zones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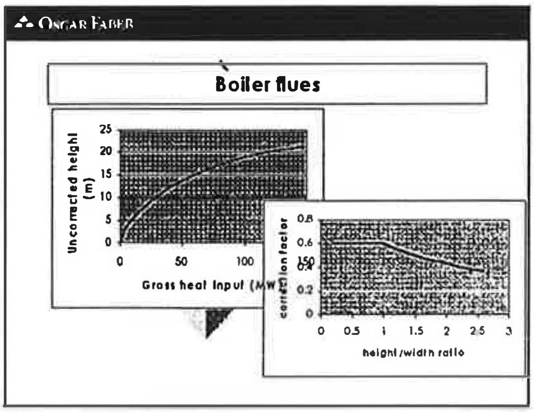
Dilution from exhaust stacks
Ucrit,o/Ve
S/Ae^0.5
Dcrit,o
Dcrit,s
hs/S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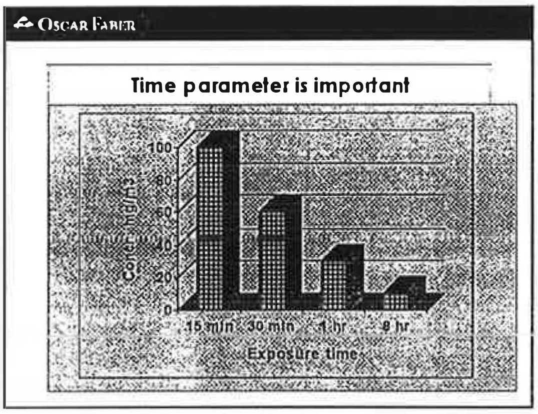
Boiler flues
Uncorrected height (m)
Gross heat input (MW)
correction factor
height/width ratio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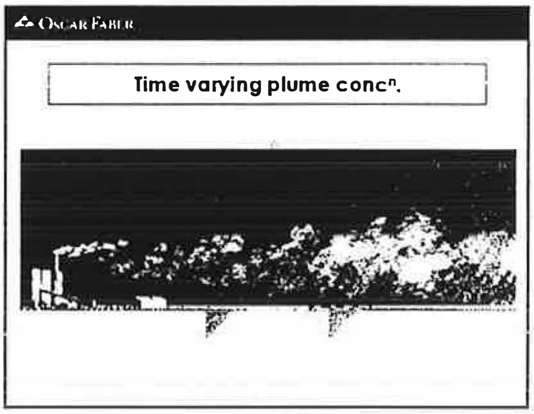
Time parameter is important
15 min
30 min
1 hr
8 hr
Exposure time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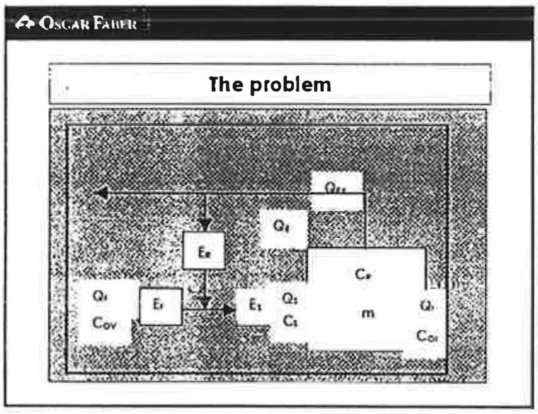
Time varying plume concn.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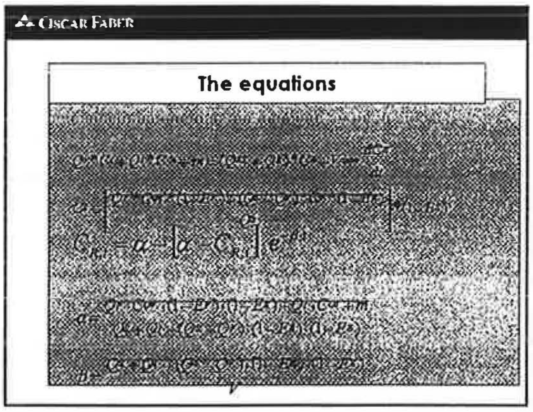
The problem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The equations

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Example application

- **Naturally ventilated scheme**
  - background trickle ventilation
  - rapid ventilation around midday
- **Mechanically ventilated**
  - Infiltration for 24 hrs
  - Constant mech vent between 7:00 and 18:00
    - pollutant 15%< than background

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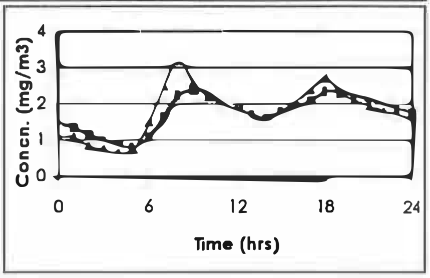
Naturally ventilated



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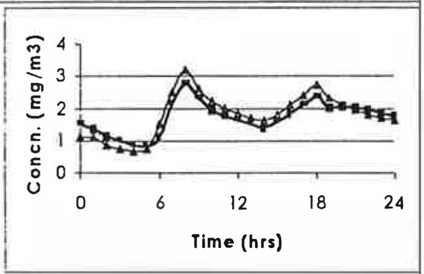
Mechanically ventilated



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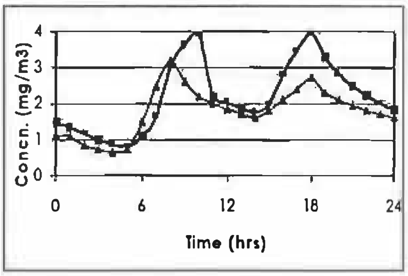
Nat vent + internal source



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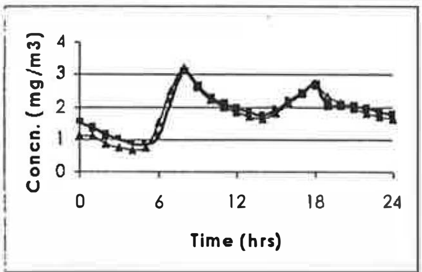
Mech vent + internal source



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Conclusions

- Acknowledge support of DETR and CIBSE in preparing TM
- Summarises available information on estimating external pollution levels
- Assessment method for predicting IAQ based on external & internal pollution, ventilation & filtration
- Internal & external effects are important
- Considerable work is underway to further develop understanding.

Filter Application for Decent Air Quality

Mr P MacDonald

Filter Applications for Decent Air Quality

By Peter MacDonald BSc CEng MIMechE, formerly AAF McQuay

1. INTRODUCTION

Much publicity has been given to the potential health risks posed by buildings, particularly those with mechanical ventilation or air conditioning. There have been concerns over the possible effects of the VOCs given off by the furnishings and finishes, of fungal spores shed from dirty ducting, of legionella distributed by wet cooling towers, etc., etc. The list of concerns is long. But what about the effects on the building occupants of the air that comes in from the outside, naturally or otherwise, the so-called 'fresh air'?

Compared with when domestic coal fires and 'smoke stack' industries were prevalent, present day pollution levels are low. Despite this though, researchers recently have begun to find startling evidence that outdoor air can be positively harmful to health and that the biggest threat is the fine particles which are semi-permanently suspended in it. These don't just make people feel off-colour. They can kill.

2. THE HARVARD STUDY

The most comprehensive study into the effect of air pollution has been that conducted by Dockery *et al* of the Harvard School of Public Health, which was published in 1993.

The research team took a random sample from six cities of 8111 white adults aged 25 through to 74 years and over a 14-16 year period, compared their mortality rate with the pollution levels in their cities. All the subjects in the study had undergone lung function testing and had completed a standardised questionnaire which included questions about age, sex, weight, education level, smoking history, occupational exposures and medical history. So this allowed control for individual smoking status, sex, age, and other risk factors.

Concentrations of particulate matter, sulphur dioxide, ozone, suspended sulphates and hydrogen ions (for aerosol acidity) were monitored at a central location in each of the six cities. As well as measuring the total suspended particulate matter, they measured the concentration of inhalable particles (aerodynamic diameter <10μm, commonly referred to as PM_{10} particles) and fine particles (aerodynamic diameter <2.5μm, referred to as $PM_{2.5}$ particles).

Mortality was most strongly associated with cigarette smoking and increased mortality was also associated with having less than a high-school education and with increased body-mass index. But after simultaneous adjustments for these risk factors, the differences in mortality among the six cities remained significant.

What was found was that the city-specific mortality rates were associated with the annual average levels of air pollutants in the cities. Mortality was more strongly associated with the levels of inhalable, fine and sulphate particles than with the levels of the total suspended particles, the nitrogen dioxide levels or the acidity of the aerosol. Figure 1 shows the scatter of the latter.

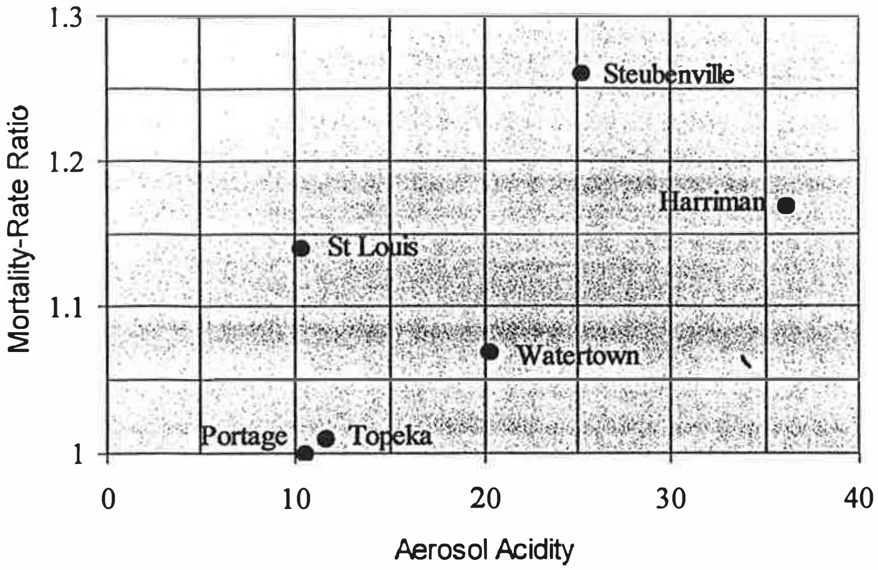

Figure 1 Relationship between mortality-rate ratio and annual aerosol acidity

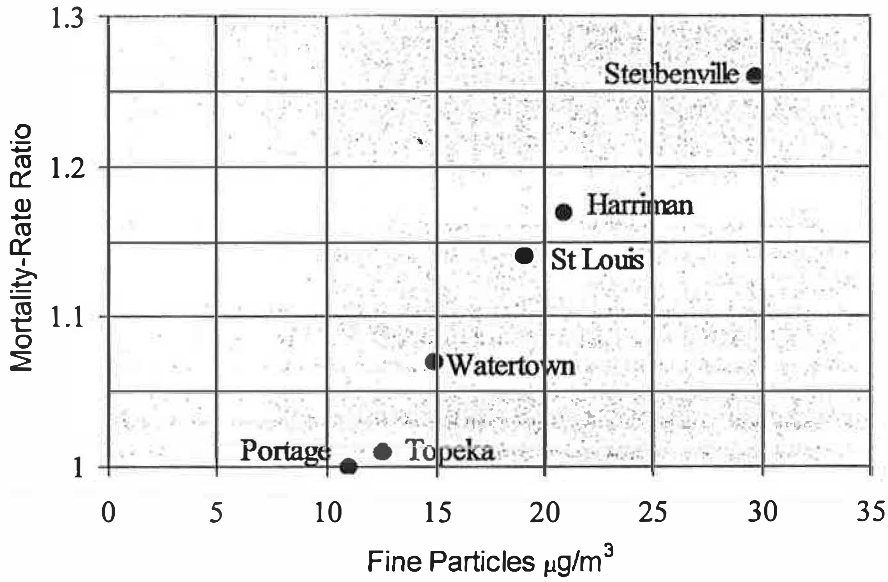

Figure 2 Relationship between mortality-rate ratio and annual average concentration of fine ($PM_{2.5}$) particles

However, as Figure 2 indicates, there was found to be virtually a straight-line relationship between the levels of the fine $PM_{2.5}$ particles and the mortality rate. The difference in mortality rate between the most and least polluted cities was an amazing 27%. But the most worrying aspect is that the increased risk of death occurred at concentrations well below those currently considered acceptable, as the annual average level of the inhalable PM_{10} particulate was only 46.5µg/m^3 in the most polluted city in the study.

3. OTHER STUDIES

This decade, following the revelations of the Dockery report, there has been a flurry of research activity into the harmful effects of air pollution. A recent UK study by Poloniecki *et al* has reported a statistically significant association between the daily incidence of myocardial infarction (the medical term for a heart attack) and daily concentrations of pollutants, especially particulate matter. The authors suggest that in the UK some 6000 myocardial infarctions may each year be related to exposure to air pollutants.

This work on the immediate, short-term effects of pollution has been taken further. The department of Health asked the Committee on the Medical Effect of Air Pollutants (COMEAP) to advise on the effects on air pollutants on health in the UK, including an estimate of the numbers of people affected. Their report estimated that in the UK, 8100 deaths of vulnerable people were brought forward by particulate air pollution. It was also associated with 10500 hospital admissions, brought forward or additional, of vulnerable people suffering from respiratory problems.

For every 10$\mu g/m^3$ increase in concentration of PM_{10} particles it has been estimated that there will be a 1% increase in the total death rate, a 3.4% increase in respiratory deaths and a 1.4% increase in cardiovascular deaths (see Table 1).

	% change in health indicators
Increase in daily mortality	
Total deaths	1.0
Respiratory deaths	3.4
Cardiovascular deaths	1.4
Increase in hospital usage	
All respiratory admissions	0.8
Emergency department admissions	1.0
Exacerbation of asthma	
Asthmatic attacks	3.0
Bronchodilator use	2.9
Hospital admissions	1.9
Increase in respiratory symptoms reports	
Lower respiratory	3.0
Upper respiratory	0.7
Cough	1.2

Table 1 Effects of each 10$\mu g/m^3$ increase in PM_{10} on indicators of ill-health

4. WHY ARE PARTICULATES SO HAZARDOUS?

It is not clear yet as to why fine particles are so dangerous, although a recent paper in the Lancet suggests that the immune system may be reacting to them as if they were invading organisms. This immune response causes inflammation of the tissues in a similar manner to the allergic reaction of a hay-fever sufferer, but with the ultra-fine particles the inflammation is deep in the lungs. The finer the particle size, the deeper it will penetrate. That is why many experts are calling for the monitoring and control of $PM_{2.5}$ particles (2.5μm diameter) instead of PM_{10} particles. It is even being suggested that ultra-fine particles (<0.05μm diameter) may play a role.

5. WHERE DO THE PARTICLES COME FROM?

The primary source of fine particles is old coal fired power stations, industry and especially, road vehicles. By far the worse culprits are diesel engined vehicles – it is estimated that 90% of fine particles in the urban atmosphere are from this source.

Diesels use 20-25% less fuel than petrol engines, so have been trumpeted as being environmentally friendly and have rapidly become popular. However, since combusting one litre of diesel oil produces about 15% more carbon dioxide than one litre of petrol, emissions of the 'greenhouse gas' carbon dioxide are only slightly less than from diesel cars. Emissions from new diesel cars are estimated to be 3-4 times more carcinogenic than emissions from petrol cars. A modern diesel, even when it is correctly set up, emits 10-15 times more particles than a modern petrol engined car. Worse still, the particle sizes emitted by a diesel are considerably finer, so are more damaging to health.

Unless there are technological advances which will enable the cleaning up of diesel exhausts (one promising advance has just been reported in the IMechE's Journal), or the Government takes steps to curb the growth in sales of diesel engined vehicles, the concentration of fine particles in the atmosphere of our cities will not decrease. It will probably increase.

6. THE SOLUTION

Whilst the wearing of personal face masks, as favoured by some of our Japanese cousins, may provide a degree of apparent protection in the street, our buildings can be made relatively safe havens from the dangers of particulate pollution. How? By making sure that the 'fresh air' from outdoors is admitted in a controlled fashion via an air filtration system.

This effectively means that a mechanical ventilation or air conditioning system is needed. A naturally ventilated city building can seriously damage its occupants' health is the message!

7. AIR FILTRATION TECHNIQUES

Contrary to what many might believe, air filters in ventilation systems do not work by straining or sieving the particulate matter out of the air. Instead they rely on three major collection mechanisms: inertial impaction, diffusion/interception and electrostatic precipitation. The last mechanism is not commonly employed for ventilation systems, due to certain problems and drawbacks, not the least cost, so will not be covered in this Paper.

8. INERTIAL IMPACTION

Particles in an airstream have mass and velocity, hence have a momentum associated with them. As the air and entrained particles pass through the filter medium the air takes the path of least resistance to flow and diverts round the fibres of the filter medium. The particles, because of their inertia, tend to travel in a straight line and as a result, those particles located at or near the centre of the flow line, impact on the fibre and are removed (see figure 3).

Filters employing the inertial impaction mechanism are humble panel filters. These comprise a matt of fibres which is between 13 to 50mm thick, the thicker the better to provide as many obstacles as possible in order to produce sufficient deviations of the airstream. Typically the fibres are around 35μm diameter.

The larger the particle and the faster the airstream the greater the particle's inertia, so the higher the likelihood of impaction taking place. However, if the velocity is too high, the particle can be blown

10. THE CORRECT FILTER TYPE

There is a great number of filters to choose from, each characterised by its efficiency, initial pressure drop, final pressure drop, dust holding capacity, size, cost, ease or otherwise of maintenance, to name but a few characteristics. But probably the most important characteristic of a filter is its efficiency.

Filter Class	Arrestance	Average efficiency
G1	$A \leq 65$	
G2	$65 < A \leq 80$	
G3	$80 < A \leq 90$	
G4	$A > 90$	
F5		$40 < E \leq 60$
F6		$60 < E \leq 80$
F7		$80 < E \leq 90$
F8		$90 < E \leq 95$
F9		$E > 95$

Table 2 Filter classification according to BS EN 779

A high efficiency filter, class F8 to European filter standard EN 779, will remove 99.5% plus of 5µm particles from the airstream, and will only let 10% or so of 0.5µm particles penetrate. Figure 6 shows the comparative performance of three differing classes of filter against 0.5, 1 and 5µm particles.

It is unfortunate that with air filters it is almost axiomatic that as their efficiency increases, so does their cost and operating resistance. Possibly that is why so many installations have nothing better than panel filters, often poor ones at that - G3 or worse - which as Figure 6 indicates, do virtually nothing to stop the dangerous, fine particles from entering the building. They are there to protect the items of plant, such as heat exchangers, from becoming clogged. They are certainly not there to protect the occupants.

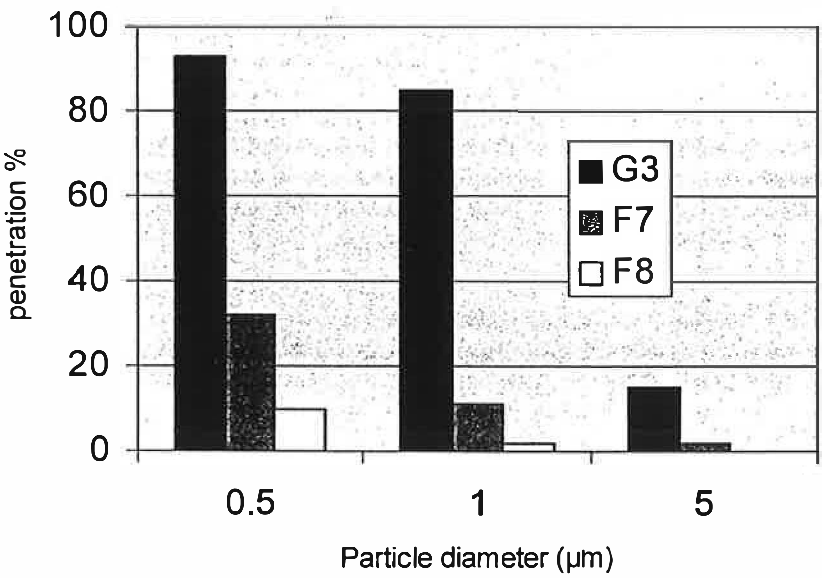

Figure 6 Penetration of a filter as a function of particle size and filter class

At the other extreme, it would be completely unwarranted to install HEPA filters, which are capable of intercepting between 99.5 and 99.999995% (depending upon the filter grade) of even the most penetrating particles, which are approximately 0.2μm in size. Unwarranted, that is, unless there are special requirements such as within a laboratory handling health-hazardous material. Using HEPA filters (which are tested to a different standard - EN 1822) for general applications cannot be justified, due to their high cost and high pressure drop.

The common recommendation for offices and commercial buildings is class F6 or F7 filters, the former for normal offices, and the latter for executive offices. However, in the light of what has been revealed in the earlier part of this paper, this needs to be revised upwards. Most suitable for protecting occupants within the served space are class F7 or F8 filters. Certainly an F7 filter is very effective against $PM_{2.5}$ particles, typically allowing only 5% or so to penetrate. But if the suspicion were substantiated that it is the ultra-fine particles that are the real health risk, then F8 filters would have to become the norm, as their performance when challenged by sub-micron sized particles is several orders better than that of the next grade lower filter.

The other great advantage of using an F8 filter is the reduction in staining of the décor. As Table 2 indicates, although the sub-micron sized particles only account for typically 3% by weight of the particulate in urban air, by number they account for around 98.5%. These small particles, mainly hydrocarbon in composition, have a tremendous staining power. Just a thimble full of carbon black can stain an area the size of a tennis court! Using a filter with good effectiveness against sub-micron particles, by reducing the staining of the décor, can therefore increase the interval between redecorating. So particularly for high quality interiors, better quality filtration can pay for itself.

Particle size range (μm)	Number of particles	% by number	% by weight
0 – 0.5	18 340 000	91.7	1.0
0.5 – 1.0	1 300 000	6.8	2
1.0 – 2.5	200 000	1.1	6
2.5 – 5	50 000	0.25	11
5 – 10	35 000	0.145	52
10 – 30	1 000	0.005	26

Table 2 Particulate content of 0.05m^3 urban air

No matter how effective a filter is at removing particulates from the airstream, it will not take out gaseous contamination. An F8 filter will take out virtually 100% of tobacco smoke, for example, but it will not remove the gaseous products of smoking. So whilst the filter will clear the fug it will not stop eyes watering. An adsorber such as a carbon filter is needed to deal with this. It is also worth knowing that specially impregnated carbons are available to protect paintings and fabrics from the harmful effects of sulphur dioxide and even for dealing with cooking smells.

11. CORRECT INSTALLATION

Air cannot be allowed to come through random holes in the building. The building must be sealed and slightly pressurised, so that air is only drawn in through the ventilation inlets, from where it is forced to pass through filters.

Very obvious, but often overlooked, is the siting of the inlets. These should be as high as possible, certainly away from street level and from car parking, from where vehicle emissions can be directly drawn in.

Through-the-wall and unitary ventilation or air conditioning equipment rarely has other than a minimal panel filter, often so thin as to be of dubious efficiency, so is not to be recommended. All fresh air, even for decentralised systems, should be introduced into the building by air handling units, which can be fitted with effective filters of the required efficiency.

Within the air handling unit should be two stages of filtration (three for those special applications where an adsorber is required). The first stage should be a roughing filter to class G3, placed at the inlet in order to protect the heat exchangers and other components. Downstream, normally just before the fan, should be the high efficiency secondary, F6 to F8 filter. The reason for siting it close to the fan is that any leakage of air through the casing between the secondary filter and fan will result in the ingress of unfiltered air, so reducing the overall effectiveness of the filtration system. The other benefit of using a prefilter is that it can double the life of the more expensive second stage filter.

One factor frequently overlooked is the effect of mist and fog on filters. Even the lowest efficiency filter, a class G1 filter, is a highly effective mist stripper. So, very quickly a pool of water collects under the first stage of filters. Cardboard-framed filters collapse and are drawn into the unit. If the unit is anywhere near the coast, the saline solution drawn off the sea mists soon corrodes the bottom of the unit. The solution is to have the area around the first stage filter completely tanked out, to use metal framed roughing filters, or to fit coalescers as is the normal practice for off-shore air handlers.

Often ignored is the axiom that a filter is only as good as its installation. There is no point in fitting high efficiency filters into holding frames that allow bypass of unfiltered air. There is a very simple and quick test for this in the recent air handling standard BS EN 1886:1998. Performed at the same time as the casing air leakage test the air bypassing the filter cells and coming in through the casing is measured and compared against a pass/fail criterion that is directly related to the filter's efficiency. The higher the efficiency, the lower the allowable leakage rate.

Another aspect of the installation is the size of the air handling unit. Large air handlers, 2m or more in height, may well be economic in terms of lower capital cost per m^3/s and reduced footprint size, but thought should be given as to how easy or otherwise it is to replace filters which are over 2m above the deck, especially when the access space is inadequate. Too often the maintenance staff, when faced with such difficulties, just do not bother to change the upper rows of filters!

The effect of velocity on filter pressure drop and performance must not be overlooked. In the quest for reducing costs, air handling units are often sold which are designed to operate at unacceptably high velocities through components such as the filters. Not only do excessive velocities lead to higher energy consumption, they also reduce the filter efficiency and filter life. From a life cycle cost point of view the face velocity across general ventilation filters should not be allowed to exceed 2.5m/s. Only if there are space restrictions should higher velocities be accepted, up to a top limit of 3m/s.

12. CORRECT MAINTENANCE

Filters should be maintained and changed frequently. Seals need to be checked/replaced to prevent the by-pass of unfiltered air. The pressure drop across each filter bank should be frequently monitored and the filter cells replaced as soon as the recommended resistance has been reached. The maximum pressure drops should not be allowed to exceed those tabulated in Table 3. These are taken from the forthcoming CEN standard covering the ratings and performance of air handling units and their components: EN 13053. The maximum pressure drop figures are lower than those used in EN 779 for filter classification purposes, for very good reasons of energy saving.

Filter class	Final pressure drop
G1 – G4	150 Pa
F5 – F7	250 Pa
F8 – F9	350 Pa

Table 3 Maximum final pressure drop for filters

Filters that are left in too long can severely reduce the volumetric performance of the air handling unit due to the adverse effect of excessive air resistance. This can destroy the balance of flows, badly affecting the ventilation rate without anyone being consciously aware of it. Just as importantly, filters can themselves become a potential hazard to IAQ if left too long between changes or if allowed to become wet. They can become a source of odours and support the growth of mildew, fungi and bacteria. However there are now filters that have an antimicrobial applied to them during manufacture, which helps to considerably reduce the effect of this.

13. DECENT INDOOR AIR QUALITY MEANS DEMANDS GOOD AIR FILTRATION

Within a sealed building, air filters can protect the occupants from the now-known dangers of the particulates in the outdoor air. But protection is only possible if the filters are correctly selected, correctly installed and correctly maintained. They are often overlooked and too frequently are the first items to suffer when costs are being cut. Decent air quality demands good air filtration!

The Performance of Building Ventilation Systems in Practice: Findings from the Probe Project

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The Performance of Building Ventilation Systems in Practice: Findings from the Probe Project

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SYNOPSIS

The Probe project has undertaken post-occupancy evaluations of sixteen buildings. The studies reviewed the buildings' services, energy performance, management and occupant satisfaction. Ventilation strategy was a key factor for all these aspects and this paper reviews and compares the success of the many approaches found, ranging from simple and advanced natural ventilation through mechanical displacement ventilation to traditional full air-conditioning systems.

1. BACKGROUND

Probe (Post-occupancy Review Of Buildings and their Engineering) is a unique collaboration between a journal publisher, an independent multidisciplinary research team and government. It obtains feedback on the performance of recently completed buildings and publishes it rapidly study by study in BSJ - the *Building Services Journal.* Following the success of Probe 1 in 1995-96, funding was obtained for Probe 2 which was undertaken in 1997-99. A major strategic review[1] of findings from the sixteen buildings studied during this time has recently been completed and has provided the source for many of the conclusions in this paper. Further funding has recently been confirmed to continue the work under Probe 3 until 2001.

Probe examines a building, and particularly its building services and internal environment, from four main standpoints:

1. The experience of the occupier, by informal and structured discussions.
2. The perceptions of the individual occupants, by questionnaire.
3. Energy performance, using the EARM™ Office Assessment Method procedure.
4. Technical performance, from discussion, survey results, observations and spot measurements.

The buildings studied date from the early to mid-1990s. When first completed, the editor of BSJ had regarded them as being of special technical interest to readers, and made them the subject of extended articles in the Journal. Most Probe surveys were undertaken 2-3 years later, to allow the building, its occupants, and its pattern of energy consumption to have time to settle down. Table 1 gives basic details of these buildings, in order of publication of the studies. It also gives three letter codes, used to refer to the buildings throughout this paper.

The buildings are not necessarily representative of their genre as they have been through three levels of selection:

1. Their original interest to the editor of the BSJ, which means they tend to represent leading edge buildings (although generally not architectural icons)
2. The project team's perceptions of their value as published studies, which generally meant that they had a low-energy agenda in their brief (promotion of sustainability through low energy design is a key factor in the government's support for the project)
3. The occupier's assent to the exercise, which typically is an indicator that they are better managed.

[1] The author would like to acknowledge that much of the material presented here has been extracted from the Probe Strategic Review 1999 produced by the Probe Team (Bill Bordass of William Bordass Associates, Adrian Leaman of Building Use Studies and Robert Cohen, Mark Standeven and Paul Ruyssevelt of Energy for Sustainable Development).

Most are also owner-occupied, partly because speculative buildings are rarely covered in BSJ and partly because access to rented buildings, support to an investigation, and approval for the publication of results is much more difficult when both landlord and tenants are involved.

Each building's ventilation strategy is placed into one of four categories in the HVAC column of Table 1 (although in practice parts of some of the buildings fall into other categories). It can be seen that in total there are 5 air conditioned (AC), 4 mixed mode (MM), 2 naturally ventilated (NV) and 5 with advanced natural ventilation (ANV). This set of buildings therefore includes examples of many of the ventilation systems being installed today and the results of the project offer a valuable opportunity to compare and contrast their virtues and shortcomings.

Code	Name	Function	HVAC type	TFA (m^2)	Date
TAN	Tanfield House	Very deep plan admin centre	AC	19800	Sep 95
ALD	1 Aldermanbury Square	Narrow plan speculative office	AC	7000	Dec 95
C&G	Cheltenham & Gloucester Building Society	Deep plan headquarters	AC	17400	Feb 96
DMQ	de Montfort University, Queen's Building	Engineering department	ANV	8400	Apr 96
C&W	Cable & Wireless Training College	Residential training centre	ANV	11400	Jun 96
WMC	Woodhouse Medical Centre	Doctors' & dentists' surgeries	NV	640	Aug 96
HFS	HFS Gardner House	Headquarters office	AC	3800	Oct 96
APU	Anglia Polytechnic University	Learning resource centre	ANV	5650	Dec 96
CAB	John Cabot City Technology College	Secondary school	ANV	8800	Oct 97
RMC	Rotherham Magistrates Courts	Courtrooms and offices	MM	4350	Dec 97
CAF	Charities Aid Foundation	Principal office (pre-let)	MM	3700	Feb 98
FRY	Elizabeth Fry Building	University teaching	MM	3130	Apr 98
MBO	Marston Book Services Office	Principal office (pre-let)	ANV	960	Aug 98
MBW	Marston Book Services Warehouse	Warehouse (pre-let)	NV	5030	Aug 98
CRS	Co-operative Retail Services	Large head office	AC	17300	Oct 98
POR	The Portland Building	University teaching	MM	6000	Jan 99

Table 1 The buildings studied in Probe to date

2. REVIEW OF SYSTEMS

2.1 The NV Buildings

Only two of the Probe buildings were NV and neither of these was a typical example. One, WMC, initially had a domestic mechanical ventilation system with heat recovery. By the time of the Probe survey this was no longer used and ventilation relied on the openable windows and doors. Unfortunately, provision in the design for stack ventilation via openable rooflights was thwarted by their 4m height above floor level and either ignorance or inertia preventing the purchase of the pole necessary to open them; the consequence was that in two rooms comfort cooling had been added. The other NV building, MBW, was a warehouse which relied on the reservoir provided by its large volume, open delivery doors and infiltration for normal ventilation requirements. In hot weather the doors were permanently open but there was a tendency for hot air to build up beneath the roof: motorised opening rooflights or ventilators would have alleviated this, but at some risk of rain ingress, which the occupier was keen to preclude.

Three fairly obvious but surprisingly widespread problems with openable windows in the Probe NV, ANV and MM buildings were: unreachable handles, insufficient fine control and not enough friction to avoid falling or blowing shut.

2.2 The ANV Buildings

ANV buildings are naturally ventilated typically using a full repertoire of wind and stack driving forces. They are distinguished from NV because their openings for ventilation include manually switched or BMS controlled *motorised* windows or dampers as well as ordinary windows and trickle ventilators. In many ways the Probe ANV buildings were pioneers of this genre (their designs were often developed with the aid of modelling, including CFD (computational fluid dynamics) and salt baths) and post occupancy evaluations revealed that these promising developments were proving less satisfactory than had been hoped in terms of performance, reliability and occupant satisfaction. Many design lessons have become apparent:

- Difficulty in getting controls to work as intended. Control problems are endemic to buildings, but as ANV is less standard, there is more of a learning curve for designers, manufacturers, suppliers, and building managers.
- Poor reliability of components, with drive and connection failures and air leakage. Inaccessible mechanisms need to be particularly robust and maintenance free. Openings for summertime ventilation must also perform acceptably in winter (finer control, airtight when shut) and be able to cope with sudden changes in the weather. Equally clashes with internal or external blinds have to be pre-empted. Many of these issues are being addressed by a current PII project[2].
- Insufficient understanding of occupant perceptions and provision for their requirements. In particular, there were instances of:
  - no local over-rides so people could shut the windows if there were draughts, noise, fumes or insects; or automation which usurped the over-ride a few minutes later
  - a lack of feedback at remote controls (manual or automatic) on the window position
  - security, external noise or blackout requirements making it impossible to use openable windows for ventilation.

The main message from the Probe ANV buildings is that the approach is encouraging but needs consolidating, taking heed of the lessons learned.

2.3 The MM Buildings

These buildings have both natural and mechanical ventilation systems, either in different zones of the building or in the same zone where they can be operated concurrently or alternately. The four Probe MM buildings included examples of each of these:

- RMC had displacement-ventilated courtrooms with cooling available, mechanical plus automated natural ventilation in public areas, NV in magistrates' rooms, and offices with openable windows, background mechanical ventilation, and added comfort cooling units.
- CAF had displacement ventilation with heat recovery and indirect evaporative cooling, plus openable windows and fanlights.
- FRY was designed as a highly insulated thermal flywheel, with trickle-charge ventilation through the Termodeck hollow core floorslabs, and the windows openable essentially as safety-valves.
- POR, although the majority of the space is ANV, can be classified as a zoned MM: the main lecture theatre has mechanical displacement ventilation with comfort cooling, seminar rooms are comfort cooled and internal offices have mechanical ventilation supply.

By definition, the MM buildings employed many of the components used in ANV and AC buildings and shared the same problems, but generally the less intensive nature of the services made the consequences less severe. In the Probe MM buildings, there was a tendency to achieve the best of both worlds rather than the worst, though there was substantial scope for improvement in windows, controls, and greater energy efficiency of mechanical ventilation systems. MM can limit the application of mechanical ventilation and cooling in a building to spaces and times where and when it is necessary and overall shows great promise in its ability to deliver both occupant satisfaction and lower energy consumption.

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[2] Specification of Automatic Ventilation Opening Devices, Brian Ford & Associates for DETR, 1998 – 2000.

2.4 The AC Buildings

Probe 1 included four AC offices, three with variable air volume (VAV) systems: C&G's a conventional ceiling installation with plenum return, ALD with fan assisted terminals - also in the ceiling; and TAN a 100% fresh air system from the floor, with free return through the atria. The fourth, HFS, was one of the first UK buildings with chilled beams and displacement ventilation. Sadly, this approach's claimed energy savings had not materialised, for three main reasons: high preheating and humidification loads from a full-fresh-air system with no heat recovery; extended running owing to high air infiltration through the fabric; and no on-site engineers in this relatively small building. Probe 2 therefore visited a second building of this type, CRS, which had exposed ceilings and heat recovery. CRS had lower HVAC energy consumption, but operational and comfort problems plus some air infiltration made overall success difficult to judge.

TAN and CRS were nominally mixed-mode, with openable windows at the perimeter. However, these deep-plan buildings essentially worked as fully AC, with the windows offering little benefit to anyone not immediately beside them; and their use being discouraged by the facilities managers. Table 2 summarises the key characteristics of the AC buildings' ventilation systems.

	TAN	ALD	C&G	HFS	CRS
Office ventilation system	VAV	Fan-assisted variable temp VAV	VAV	Displacement ventilation	Displacement ventilation
Office specific fan power (W/l.s): max	5.0	4.6	5.0	4.0	4.0
Office specific fan power (W/l.s): avge	1.7	3.0	2.5	4.0	4.0
Fan speed control method	Eddy current drives	VAV inverter plus 2-speed fan terminals	Variable frequency inverters	Constant volume	Constant volume with inverter trim
Supply from	Raised floor duct	Suspended ceiling	Suspended ceiling	Raised floor plenum	Raised floor plenum
Return via	Atria	Luminaires	Ceiling void	Ceiling void	Atria
Typical air change rate (ac/h)	Maximum 12, Typical 5	Pri max 9, Recirc 18	Maximum 8, typical 5	Constant 3	3.5, trimmable
Fresh air proportion	100%	Variable	Variable	100%	100%
Heat recovery	Restaurant only	Recirc only	Recirc only	None	Cross-flow
Typical vent hrs/year	4500	3500	3500	4200	3100
Humidification fitted	Cent gas steam	AHU elec steam	Cent gas steam	AHU elec steam	AHU elec steam
Humidity control	Liberal	Fair	Reasonable	Liberal	Liberal
Night cooling	Not used	Not used	Not used	Not used	Not used
Ventilation and air conditioning issues and problems	Floor diffusers moved to avoid draughts. Eddy current drives inefficient for VAV, and low power factor.	Temp control initially difficult.	Reported draughts or air shortages from VAV. 2 multizone plants need LPHW reheat but boilers now off in summer	Draughts from floor diffusers. Room stats shielded from warm and cool air.	Gets hot overnight.
Actions taken in respect of above	VAV range cut to avoid local discomfort. VAV supply temp compensated to avoid re-cooling.	Software modified.	VAV range cut to 30-70%.	Floor diffusers moved away from desks and dampers removed. Air supply temp raised and compensated.	Smoke vents opened overnight in hot weather.
Result of changes	Comfort improved.	Better, not perfect.	Comfort improved.	Problems still persist	Problems still persist

Table 2 Key characteristics of the ventilation systems in the Probe AC buildings

3. OPERATION AND MANAGEMENT

While the facilities and engineering staff at two of the large AC buildings (TAN and C&G) were able to look after their buildings and equipment and respond rapidly and effectively to problems and occupant complaints, the other AC buildings demanded more than their occupiers or the contractors they employed were able to provide, or regarded as affordable.

Although ANV buildings should have lower plant maintenance costs simply by virtue of having less installed HVAC plant, often air-conditioning plant is replaced by sophisticated ventilation, shading and control devices which can themselves have significant maintenance and management requirements, exacerbated by poor accessibility. Typically this need was underestimated by occupiers and often compounded by contractual arrangements which delayed the resolution of teething problems during the defects liability period and by a lack of information about how the building was intended to function.

Buildings maintained as part of their Universities' estates seemed particularly prone to such problems because the site teams had insufficient resources to understand and fine tune new buildings at the same time as maintaining their older buildings. However, there was one notable exception (FRY), which can be considered an exemplar of how to hand over and then manage and operate a novel building. Three key success factors were:

- Commitment and motivation of the O&M staff.
- Careful and persistent commissioning and handover during the first two years of occupation, including quarterly review meetings on site.
- A user-friendly BMS developed by the controls specialists in co-operation with the design team and O&M staff.

In nearly all the buildings apart from FRY, Probe found shortcomings in the controls and their usability (including for ventilation), leading to occupant dissatisfaction, management frustration, and often energy wastage. Typically, controls must be more user-friendly, occupants need to be involved in choices where appropriate and if complex technical systems must be incorporated they should be supported by an appropriate building management resource.

4. ENERGY PERFORMANCE

4.1 Overall

As a general rule, ventilation strategy has a dramatic impact on both overall building energy use and CO_2 emissions per square metre of treated floor area: the NV buildings have the lowest consumption and emissions, followed by ANV, MM and AC. This is effect as well as cause, as the intensity of use also tends to increase. However, the more highly-serviced buildings are more inclined to wastefulness. If heating in a NV building runs all the time, gas consumption will rise by perhaps 25%. In an AC building, not only does gas consumption rise much faster owing to the extra ventilation load; but fans, pumps, chillers and humidifiers run too. Figure 1 is a bar chart of CO_2 emissions per unit treated floor area. The emissions from the energy use of just the normal building services varies by a factor of six between 30 and 175 kg CO_2/m^2.

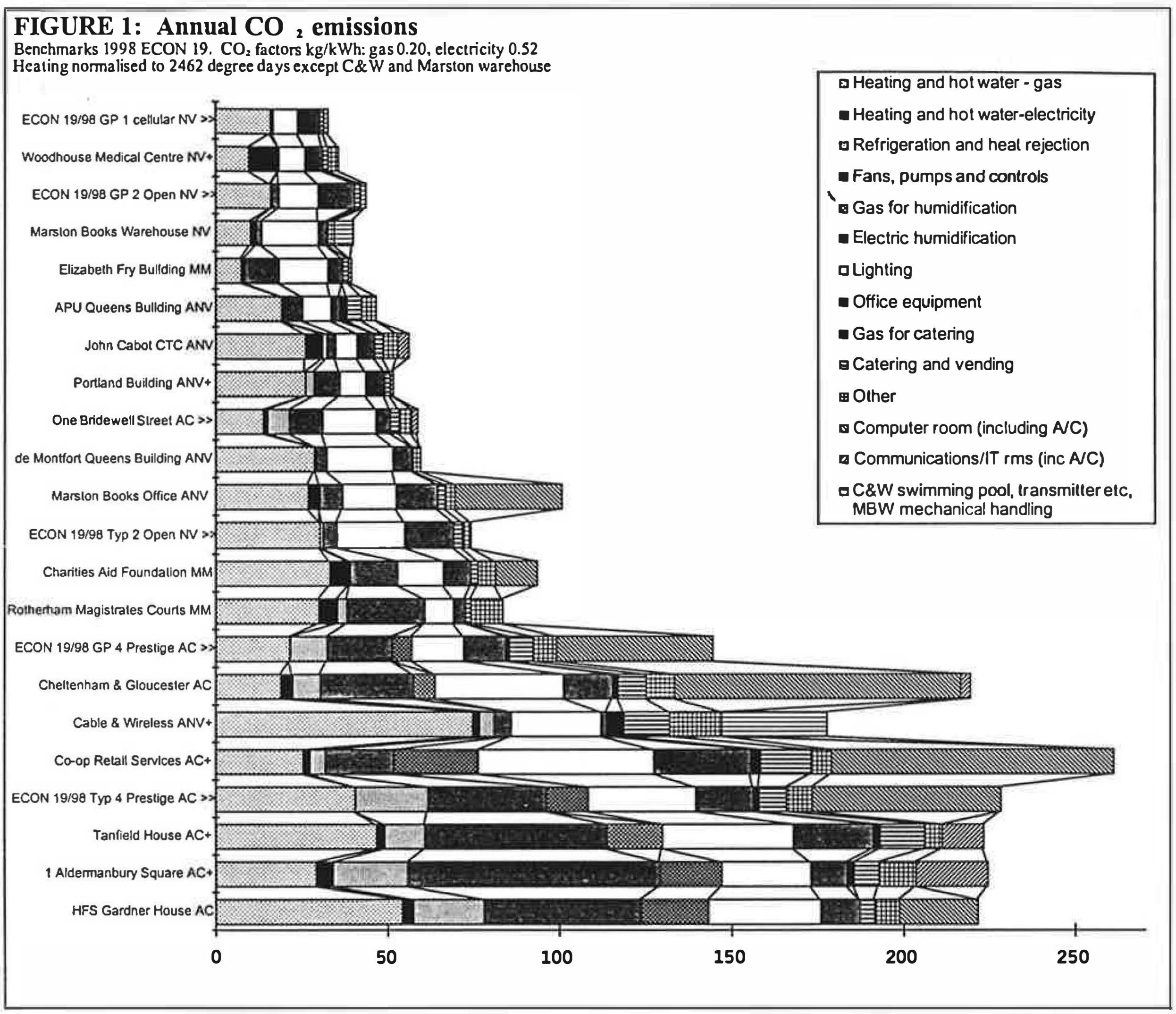

Figure 1 Annual CO_2 emissions from the Probe buildings

4.2 Infiltration

Energy losses due to infiltration in all the building types were frequently high. The main causes were:

- gaps in the fabric, particularly at eaves, cills and reveals of window and door frames, at junctions between structure and infill, and between light and heavyweight cladding. In traditional construction, such gaps were often filled by formless materials: mortar, plaster, insitu concrete and mastics. Now well-designed, carefully-engineered and quality-assured techniques are necessary.
- motorised windows and particularly dampers intended for summer ventilation which did not seal well enough when shut.

Building pressure tests undertaken for Probe 2 quantified incontrovertibly the scale of the problem. Two of the ANV buildings were particularly leaky suggesting that some builders may not appreciate the rational for air tightness in a naturally ventilated space. The other two ANV buildings and the only AC building tested were all leakier than even a mediocre benchmark (see Figure 2). Reception areas often suffered especially high infiltration (not only through the doors). With inadequate heating and sometimes glare and solar gains, remedial action had been required in many of the buildings.

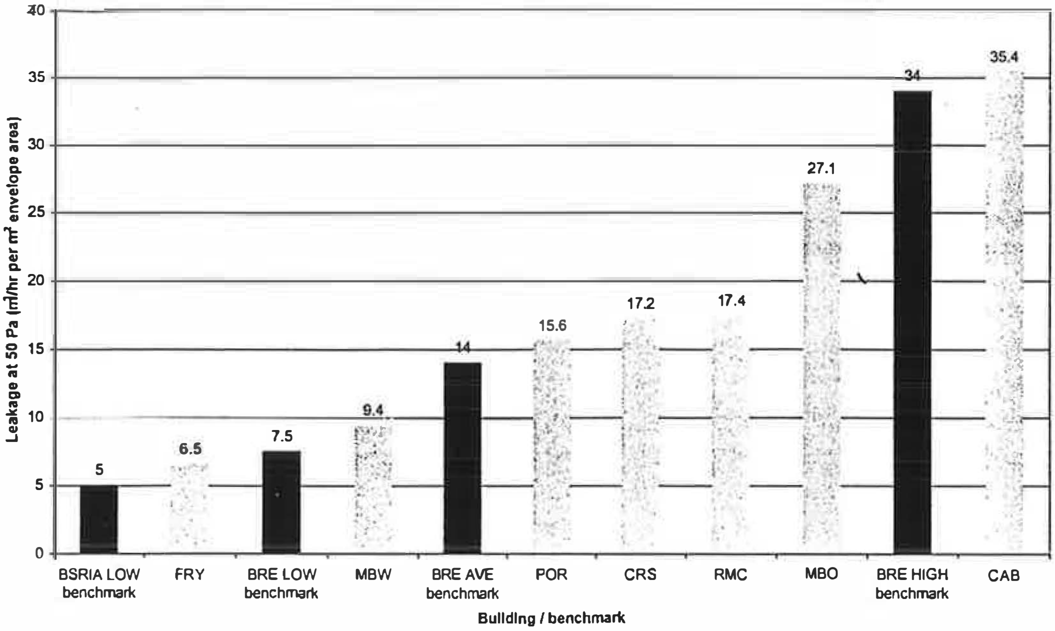

Figure 2 Pressure test results for seven of the eight Probe 2 buildings

4.3 Ventilation

In the AC buildings the mechanical ventilation was often running with unnecessarily high volumes and long hours, mostly without heat recovery, generating high gas use for heating and high electricity use for fans. Significant fan (and refrigeration) energy consumption also occurred in some of the non-AC buildings, particularly:

- C&W, where a local chilled water system ran constantly for a few classrooms which were expected to have high heat gains (in practice most did not owing to altered requirements). This system was not interlocked with the heating or the natural ventilation.
- The same applied in a conference room at CAB and the lecture rooms at POR.
- RMC, with high ventilation rates in relation to its relatively low occupancy; partly to recover heat from the sunspaces which was much less valuable than the fan energy used.
- CAF, where the contractor had installed more powerful fans than the designer had anticipated.
- MBO/MBW, where the shared toilet supply/extract ventilation plant ran for extended hours. Its air preheating was often the sole load on the boilers, significantly increasing gas consumption.

Only at FRY was the specific fan power reasonably efficient (2 W/l/s), and even here the designers said that if they were to do it again they could have reduced it still further.

There was in general much less energy management than might have been anticipated in these leading buildings. Hence strategies requiring management input were fragile and simple, robust, "fit and forget" measures would have been preferable, with the emphasis on intrinsically efficient plant and waste avoidance. Although most of the AC buildings in Probe used large amounts of energy, particularly electricity, AC should not be demonised: there is much scope for better energy performance through improved efficiency, control and management.

5 OCCUPANT SATISFACTION

Occupants rate buildings as most comfortable when:

- conditions are stable (and reasonably predictable so that people know what to wear); and fall for most of the time within acceptable (not necessarily ideal) comfort thresholds; but

- if necessary, conditions can be quickly altered in response to perceived fluctuations (like the weather) or unpredictable events (like glare, draughts, or noises outside); and
- if conflicts or unsatisfactory conditions occur, occupants can decide for themselves how to resolve them, by over-riding default settings rather than having conditions chosen for them.

Furthermore, occupants who perceive that they are comfortable also tend to say that they are healthy and productive at work, so responses to questions on health, comfort and productivity can often be surrogates for each other. For the Probe dataset, uncomfortable staff overall report productivity losses of minus 8.8% and comfortable staff productivity gains of plus 4.0%, a difference of 12.8 percentage points.

It is tempting to focus on design and technical features for explanations of good occupant satisfaction, but the real reasons may be more connected with how design and management factors interact to create a total system. Buildings which are quicker on their feet in meeting occupant needs - irrespective of their plan form, office type or ventilation design - tend to be rated more highly by occupants for comfort, health and productivity. Good ratings for perceived quickness of response can have several origins, all of which are desirable but they do not all have to be present in any one building. These include:

- usable controls which are easy for occupants to understand, deliver acceptable performance and can be seen to be obviously working;
- a diligent facilities management team backed up by a proactive help desk which deals with complaints sensitively and rapidly;

So, although high levels of perceived control are frequently associated with better comfort, health and productivity scores, this is not invariably so: low perceived control may not matter much if conditions are good, management is good, and problems seldom occur, as at TAN.

Figure 3 shows overall occupant survey scores for comfort by ventilation type in the Probe buildings and the BUS reference database. It can be seen that the Probe buildings generally tend to be above average, and the top 15% contain two Probe examples of AC, MM and NV buildings, confirming that all of these technical solutions have their place. For reasons already discussed, the ANV buildings have fared less well but have the potential to do much better.

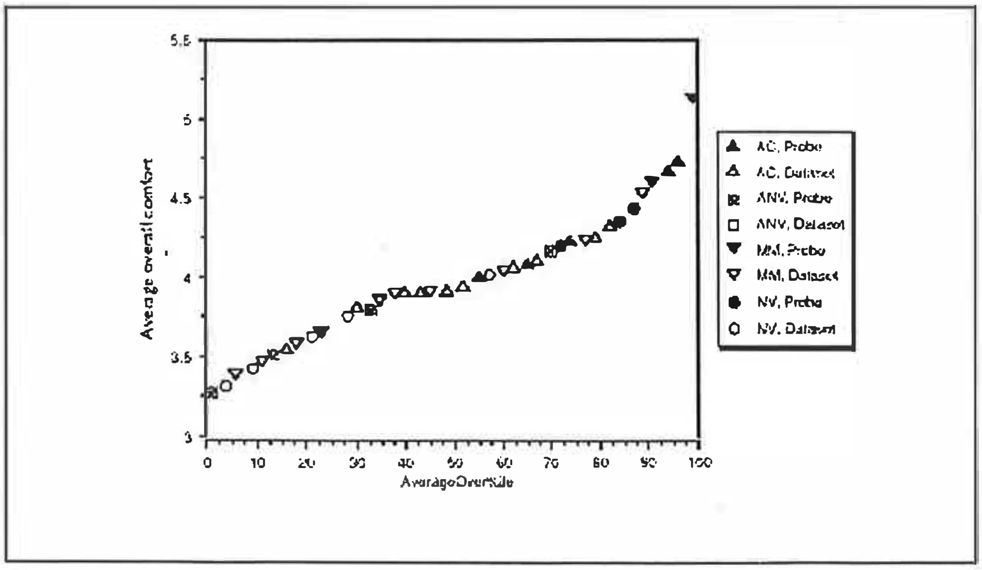

Figure 3 Overall occupant survey scores for comfort by ventilation type