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Occupant Impact on Ventilation

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Annex V Air Infiltration and Ventilation Centre

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Martin W. Liddament

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems (ECBCS)

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Twenty three countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date, the following projects have been initiated by the Executive Committee (completed projects are identified by *):

1. Load Energy Determination of Buildings *
2. Ekistics and Advanced Community Energy Systems *
3. Energy Conservation in Residential Buildings *
4. Glasgow Commercial Building Monitoring *
5. Air Infiltration and Ventilation Centre
6. Energy Systems and Design of Communities *
7. Local Government Energy Planning *
8. Inhabitant Behaviour with Regard to Ventilation *
9. Minimum Ventilation Rates *
10. Building HVAC Systems Simulation *
11. Energy Auditing *
12. Windows and Fenestration *
13. Energy Management in Hospitals *
14. Condensation *
15. Energy Efficiency in Schools *
16. BEMS - 1: Energy Management Procedures

17. BEMS - 2: Evaluation and Emulation Techniques *
18. Demand Controlled Ventilating Systems *
19. Low Slope Roof Systems *
20. Air Flow Patterns within Buildings *
21. Calculation of Energy and Environmental Performance of Buildings*
22. Energy Efficient Communities *
23. Multizone Air Flow Modelling (COMIS) *
24. Heat Air and Moisture Transfer in Envelopes *
25. Real Time HEVAC Simulation *
26. Energy Efficient Ventilation of Large Enclosures *
27. Evaluation and Demonstration of Domestic Ventilation Systems
28. Low Energy Cooling Systems *
29. Daylight in Buildings *
30. Bringing Simulation to Application *
31. Energy Related Environmental Impact of Buildings
32. Integral Building Envelope Performance Assessment *
33. Advanced Local Energy Planning *
34. Computer-aided Evaluation of HVAC System Performance
35. Design of Energy Efficient Hybrid Ventilation (HYBVENT)
36. Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures
37. Low Energy Systems for Heating and Cooling of Buildings
38. Solar Sustainable Housing.
39. High Performance Thermal Insulation (HiPTI)
40. Commissioning of Building HVAC Systems for Improved Energy Performance

Annex V Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre was established by the Executive Committee following unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The purpose of the Centre is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

The Participants in this task are Belgium, Denmark, Finland, France, Germany, Greece, Netherlands, New Zealand, Norway, Sweden, United Kingdom and the United States of America.

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1.0 Introduction

1.1 Background and Objectives

In recent years a substantial number of monitoring exercises have been made to determine the way in which occupants react to and/or are affected by the indoor environment. These cover a diverse range of aspects including:

- indoor air quality;
- moisture and condensation;
- radon ingress;
- the build up of pollutants;
- energy use;
- thermal comfort;
- draughts;
- the impact of airtightness and reduced ventilation rates;
- the actions of occupants in controlling their environment.

Many of these studies highlight the significance of, and the control of ventilation in securing a good indoor environment.

A comprehensive study on occupant behaviour with respect to ventilation involving Belgium, Germany, Switzerland, the Netherlands and the United Kingdom was initially established under the auspices of the International Energy Agency (IEA) through the Implementing Agreement on Energy Conservation in Buildings and Community Systems (ECBCS). This study (Annex 8, Dubrul 1988) focused on a combination of questionnaires and observations to determine what action is taken by occupants to ventilate their homes and to evaluate their reasons for these actions. It also went on to analyse the energy efficiency of these actions and to determine if occupants could adopt more efficient methods without adversely affecting indoor air quality and comfort. Since then, further IEA and other international activities have taken place to extend this area of activity. Important examples include IEA programmes such as ECBCS Annex 27 on 'The Evaluation and Demonstration of Domestic Ventilation Systems' (Månsson 2001), ECBCS Annex 28 ‘Innovative Low Energy Cooling’ (Zimmermann and Andersson 1998) and ECBCS Annex 35 on 'Hybrid Ventilation Systems' (Heiselberg 1998). In Europe, the Fourth Framework Joule project ‘NatVent’ (non-residential buildings) also included a detailed analysis of occupant perceptions about ventilation and the indoor climate of the buildings in which they work (Perera 1999). Coupled to these international studies have been various national studies focusing on occupants’ perceptions of building climate, indoor air quality and sick building syndrome. In France, for example, Lemaire and Trotignon (2000) have undertaken a comprehensive survey on ventilation behaviour involving participants in 10000 households.

A key consideration is the degree of control that occupants have over the indoor environment. This very much depends on the type of building and on the adequacy of control measures provided. In single-family homes, the occupant has virtually total access to the various mechanisms available (heating, ventilation controls, window-opening etc.). On the other hand, in multi-storey dwellings, offices, shops, public buildings and industrial premises, direct control may not be available to occupants or, if accessible to individual users, they may influence the environment for adjacent occupants. In these circumstances, much use has to be made of occupant feedback via surveys or even by direct health measurements to evolve optimum solutions.

This report aims to focus on some recent studies where general practical guidance can be obtained. Since it is not possible to provide a comprehensive analysis of all the relevant studies, an annotated bibliography of further related work is presented as an Appendix. Particular emphasis focuses on quantifying the effects of occupant interaction on:

- the influence that occupants have in controlling their environment;
- factors beyond the control of occupants;
- health;
- energy use;
- thermal comfort;
- draught.

Because the controls available to occupants and ventilation needs vary according to building type, this report is divided by building type.

1.2 Target Audience

This report is aimed at providing useable information. It concentrates on case study examples to emphasise occupant response and to show what has proved successful and where problems might occur. This study also looks at demonstrated problems and solutions. The intended audience, therefore, includes designers, architects, building owners and occupiers, and the information media.

1.3 Scope and Structure of Report

This report is aimed at summarising the key issues associated with occupants' use of ventilation systems. Wherever possible, it draws upon the results of occupant surveys and summarises occupants' perceptions about their environment and how it should be controlled. Both residential and non-residential buildings are considered. The contents include:

- a general review of occupant and building needs, including a summary of air quality control mechanisms and the sphere of influence over which occupants have control;
- an analysis of ventilation options including an outline of the occupant/control interface for each strategy;
- brief discussions on energy, indoor air quality and climate;
- factors influencing different building types;
- guidance and practical methods by which occupants can improve both their environment and energy efficiency;
- commissioning and maintenance issues;

- simple design measures proven to make buildings more occupant friendly;
- information on design tools and algorithms for design and evaluation as available;
- general conclusions;
- an Appendix of relevant annotated literature separated according to building type.

2.0 Meeting Health and Comfort Needs

2.1 Introduction

An essential need for building occupants is to live and work in a healthy and comfortable indoor environment. Unfortunately, detailed studies have shown that it is not possible to identify a unique set of conditions that will universally fulfil everyone's comfort needs. For this reason, it is necessary to design to achieve the highest likelihood of occupant satisfaction and then to provide the controls necessary to enable individuals to adjust their local environment to meet their particular specification i.e. an element of individual control is preferable.

Energy efficiency is also an essential need. Approximately 40% of primary energy in the developed world is used in buildings of which about half is dissipated through ventilation and air infiltration. Therefore, building energy use is of particular concern. With good design, energy efficiency should always complement healthy buildings.

The objective of this section is to summarise the elements that secure a healthy indoor environment and to identify and separate those elements that are under the control of the building occupants from those that are not.

2.2 Air Quality

To meet health and comfort needs, it is important to identify solutions to air quality problems and to assess the means available to the occupant to satisfy these needs. Key concerns relate to air quality since indoor air provides the medium in which pollutants that create discomfort and poor health propagate. In essence, this may be subdivided into pollutant ingress from outdoors and the production of pollution within buildings. These issues, and solutions for dealing with the problems that may arise, are considered separately below.

2.2.1 Outdoor Air Quality

Good outdoor air quality is essential for a healthy indoor environment, yet increasing urbanisation and contaminant emissions into the atmosphere present difficulties. Significant sources of pollution include industrial pollution, pollution from vehicles and pollution emissions from adjacent buildings. Various outdoor pollutants may also combine to develop wide-scale secondary pollution such as ozone and chemical smog. In agricultural regions, pollen and chemical sprays can also be a problem. The importance of achieving good outdoor air quality cannot be overstated. Stevenson (1999) at the London School of Hygiene, for example, reports on an epidemiological study linking respiratory related deaths to traffic fumes in urban areas. Respiratory problems related to urban pollution are additionally reported by Anderson et al (1997) and by the North American Six Cities Study (Lauerman 1999). The resultant pollution entry into buildings is also widely documented. Kukadia et al (1996, 1998), for example have undertaken extensive measurements and studies on the impact of urban pollution inside buildings. These studies note that the concentration of external pollutants found in monitored buildings follow the daily external variation although at a lower concentration. Similarly, as part of a hospital study, Basilico et al (1995) conclude that the quality of inside air is strongly dictated by outside pollutants, especially in relation to nearby motor traffic. The results of a major European study on the impact of pollution on health, based on observations in 5 cities, (Spix et al 1998 – the European (APHEA) Study) revealed that rises in outdoor 'low-level' ozone resulted in a significant increase of daily hospital admissions for respiratory diseases. The authors particularly noted that the finding was stronger in the elderly, had a rather immediate effect (same or next day) and was homogeneous over all cities. They further observed that these ozone results were in good agreement with the results of similar US studies. The same study showed that nitrogen dioxide was not, in itself, associated with hospital admissions but that significant associations were observed with PM10 particles, which were significantly stronger on days with high NO2 concentrations. Sulphur Dioxide was not associated consistently with an adverse effect.

The ingress of pollutants from underground may also present a risk to occupants. Examples include Methane and radon gas. These problems are usually confined to specific regions and solutions frequently involve using sealed foundations and extracting air from beneath the building.

Further examples of outdoor air quality problems and solutions are extensively reviewed by Limb (1999).

2.2.2 Outdoor Air Quality Control – What Can the Occupant Do?

The control of the quality of the outdoor air is an area in which individual occupants have, perhaps, the least control. As illustrated above, however, it is an aspect that can have a considerable impact on health and well-being. The hierarchical steps towards achieving good IAQ are illustrated in Figure 2.1

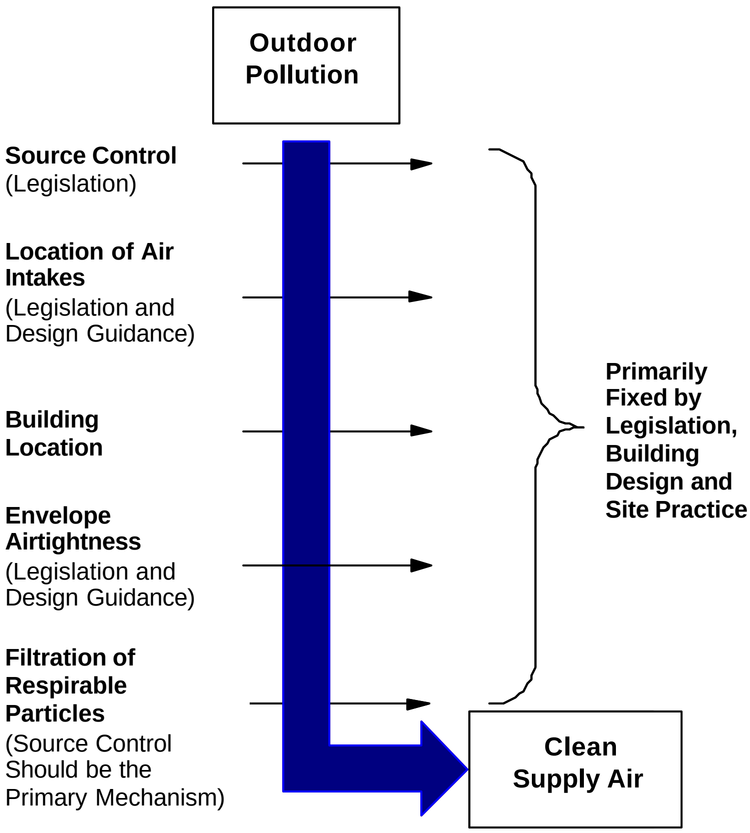

Figure 2.1 Steps for Achieving Clean Supply Air

In essence these steps are primarily within the domain of legislation and requirements imposed on the designer and builder to ensure that the occupant is protected. To secure clean outdoor air, therefore, the recourse of the occupier is to verify that requirements imposed by legislation, Codes of Practice and local building regulations have been fulfilled. Substantial progress in dealing with the outdoor environment is taking place. Recent developments include:

Emission Controls and Air Quality Standards:
Essentially the foremost need is to control the emission of pollutants into the atmosphere. Since airborne pollutants are not restricted by country boundary, much depends on international agreements and treaties. In the United States, for example, emissions are covered by the Clean Air Act, while, in Europe, it fits within the European Air Framework Directive (1999). Approaches within the legislation include emission caps, permits, offsets and target dates for reduced emissions. Because of the proven impact of adverse outdoor air quality on people, it is essential that governments continue to monitor and restrict the emission of pollutants into the atmosphere. Guidelines and goals for maximum acceptable outdoor pollutant concentrations are continuing to evolve. Current targets set for Europe for a selection of key outdoor pollutants are summarised in Table 2.1.

Building Location and Design:
This is an area in which there is probably least control. However, the building should be designed to suit its location in being able to offer the best protection against local sources of pollutants. The designer should state what measures have been introduced to maximise protection.

The Siting and Control of Air Intakes:
Many peaks in outdoor pollutant concentration are highly localised. These include exhaust outlets from other buildings and roadside pollutants from traffic. While regional monitoring, therefore might indicate acceptable pollutant concentrations, the concentration close to individual buildings may be unacceptably high. To overcome this, a survey of local sources must be made and then the air intakes for the building must be located away from the proximity of such sources. New guidance on the siting of air intakes has recently been published by Rock and Moylan (1999) as part of an ASHRAE sponsored research project and by Irving and Palmer (1997) as part of a UK (CIBSE) research project.

In the Netherlands a Code of Practice and Regulations (NPR1088) have been introduced covering the location and spacing between air inlets and outlets. These are based on an acceptable dilution factor depending on the type of pollutant emitted from nearby exhaust stacks. Examples are given in the code of practice of various configurations of exhaust and air inlet locations. In each case the minimum spacing is given according to the application of a dilution equation. The minimum dilution requirement is specified in the Regulations. This varies according to the type of exhaust emission such as stale air (ventilation exhaust) and gas and oil combustion exhaust (from heating systems).

Frequently, local urban air quality exhibits diurnal behaviour with peaks being associated with rush hour traffic. Where this is the case, the automatic control of air intake dampers has been attempted. Fletcher (1997), for example, illustrates this daily variation, with peaks occurring at rush hours. His paper presents potential control techniques for periods when outdoor air quality is poor based on pollutant monitoring combined with intake damper control. In general, a building should have a sufficient reservoir of fresh air to enable windows and dampers to be closed for the duration of short-term pollutant peaks.

Table 2.1 EU Target Values for Selected Outdoor Pollutants

Pollutant	**Averaging period**	**Limit value**	**Compliance Date**
EC Air Quality Framework Directive 96/62/EC			
Sulphur Dioxide			
One hour limit for the protection of health	1 Hour	350mg m^{-3} not to be exceeded more more than four times per calendar year	1 January 2005
Daily limit value for the protection of human health	24 hours	125mg m^{-3} not to be exceeded more than 3 times per calendar year	1 January 2005
Limit value for the protection of ecosystems	Calendar year and winter (1 October to 31 March)	20mg m^{-3}	Two years from entry into force of the Directive
Nitrogen Dioxide and Nitric Oxide			
One hour limit value for the protection of health	1 hour	200mg m^{-3} NO_2 not to be exceeded more than 8 times per calendar year	1 January 2010
Annual limit value for the protection of human health	Calendar year	40mg m^{-3} NO_2	1 January 2010
Annual limit value for the protection of vegetation	Calendar year	30mg m^{-3} NO + NO_2	Two years from entry into force of the Directive
PM10			
Stage 1			
24 hour limit value for the protection of human health	24 hours	50mg m^{-3} PM10 not to be exceeded more than 25 times per year	1 January 2005
2. annual limit value for the protection of human health	calendar year	30mg m^{-3} PM10	1 January 2005
Stage 2			
1. 24 hour limit value for the protection of human health	24 hours	50mg m^{-3} PM10 not to be exceeded more than 7 times per year	1 January 2010
2. annual limit value for the protection of human health	calendar year	20mg m^{-3} PM10	1 January 2010
OZONE: EC Directive on ozone - 92/72/EEC obliges Member States to establish ozone monitoring networks and inform the public when two out of four ozone thresholds are exceeded. These thresholds are:			
Health protection	55 ppb	110 mg m^{-3} (8 hour mean)	
Vegetation protection	100 ppb 32 ppb	200 mg m^{-3} (1 hour mean) 65 mg m^{-3} (24 hour mean)	
Population information	90 ppb	180 mg m^{-3} (1 hour mean)	
Population warning	180 ppb	360 mg m^{-3} (1 hour mean)	

Filtration:
Filtration is commonly applied in mechanically ventilated buildings and is an obvious solution to dealing with external pollutants. It is almost universally used in conjunction with mechanical ventilation systems associated with fully air-conditioned buildings. In the European Union, filtration performance is governed by a Standard 'EU' rating which categorises filtration performance by means of the efficiency with which it can trap particles of varying size. The classification system is presented in Figure 2.2.

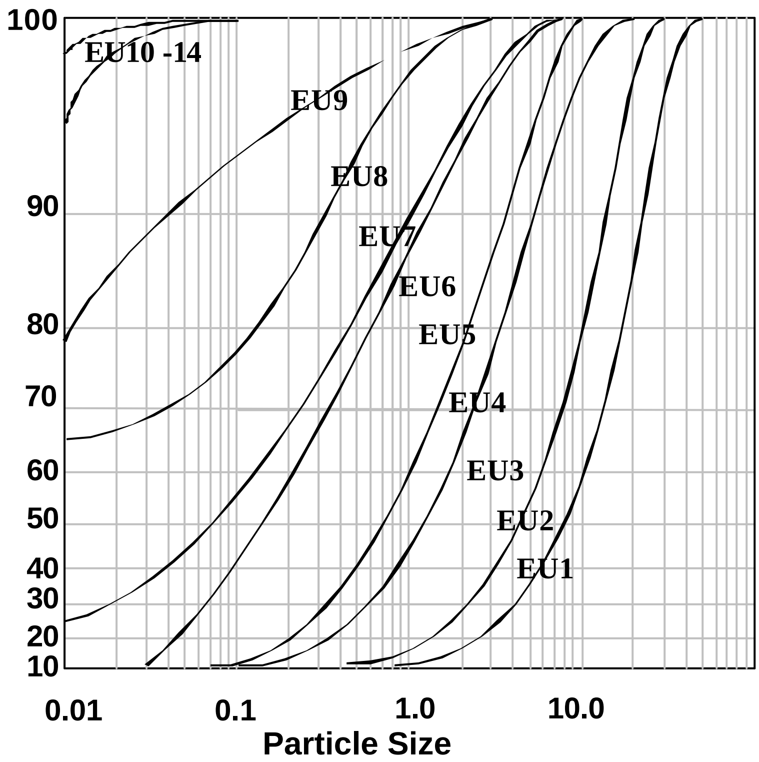

Figure 2.2 Typical EU Characteristics for Filter Efficiency

More detail is presented by Macdonald (1999). For a typical urban environment, an EU3 (or general 'G3)' filter would be used for pre-filtering, coupled to an EU6 or EU7 (or fine 'F6,F7) main filter. This gives approximately 97% efficiency down to 2.5µm and between 44% (EU6) and 55% (EU7) at 0.1µm.

In the United States, filtration is covered by ASHRAE Standard 52.2-1999. This classifies performance by particle removal efficiency using a standard Minimum Efficiency Reporting Value (MERV). There are a total of 16 performance ranges covering efficiency in three particle size ranges (i.e. range 1: 0.3-1.0 µm, range 2: 1.0 - 3.0 µm and range 3: 3.0 - 10.0 µm). A MERV value of 1 covers the lowest performance filters with an efficiency of < 20% for range 3 particles. A MERV value of 10, equates to a filter with a 50 - 65% efficiency for range 2 (>85% for range 3). A MERV value of 16 equates to a filter with > 95% performance in all three ranges.

Subject to good design and building airtightness, this filtration approach is therefore potentially effective at reducing respirable particle concentration, especially at the top end of the PM10 range. To reduce the penetration of gaseous components however, high quality (gas adsorption and HEPA) filters must be used; this is an extremely expensive solution. Despite the benefit of filters, they should not be seen as an excuse to accept poor outdoor air quality. Filtration solutions are expensive and cannot be applied to the many buildings that are naturally ventilated or excessively leaky. Also filtration performance is selective, has poor efficiencies for the finest of particles and will fail altogether unless the greatest of care is taken to ensure that the filtration system is correctly installed, maintained and operated.

Building Airtightness:
The tightness of the building shell is critical to the energy performance of the ventilation system. A tight shell also provides a barrier to transient outdoor pollution. The main difficulty with poor airtightness is that the rate of ingress of outdoor air becomes a function of the driving forces of wind and temperature. This is illustrated in Figure 2.3 for two levels of airtightness representing moderately tight and leaky.

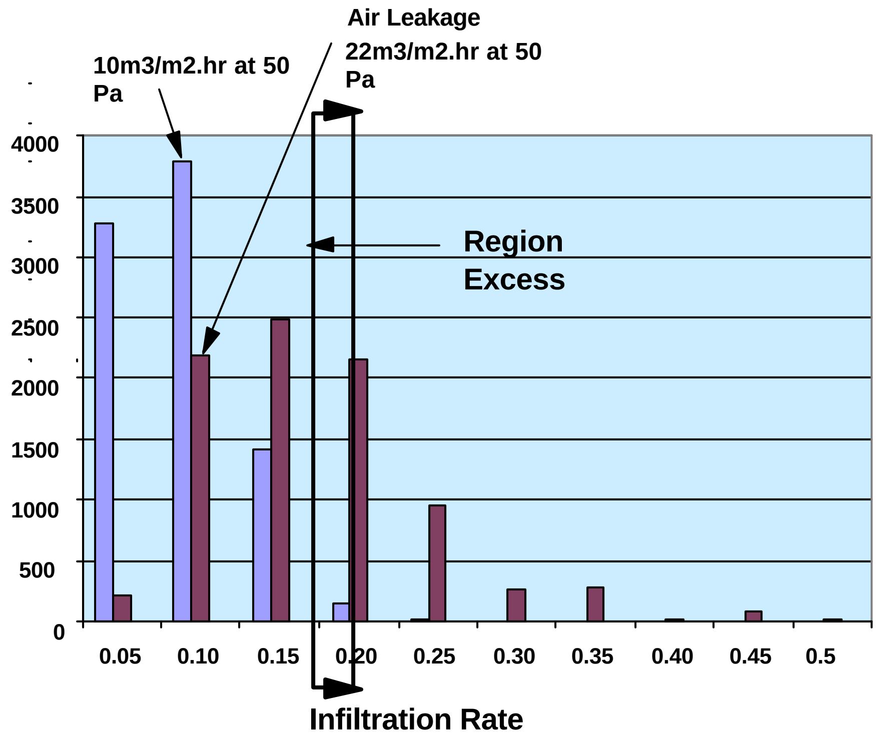

Figure 2.3 Example of the Range in Infiltration Rate for Fixed Airtightness Values Over a Full Weather Year (Birmingham, UK 1995 Data)

This Figure illustrates estimated distribution of air change rate, based on a year of real weather data. The key issue is that the occupant has no opportunity to control this infiltrating flow rate and, for much of the time it can exceed his ventilation need. Often infiltration rates peak in the coldest periods of weather when temperature (stack) driving forces are at their highest.

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. Many countries have introduced standards for airtightness. These cover not only the performance of individual components but also the construction as a whole and site practice. Before the level of airtightness is specified, it is paramount that the ventilation approach is understood.

OCCUPANT ACTIONS – OUTDOOR AIR QUALITY: If there is concern about outdoor air quality, occupants should undertake the following actions:

- Check and identify local pollutant sources e.g. from local traffic, adjacent building exhausts, etc. Relate times at which problems occur with suspect sources.
- If a source cannot be identified then check and identify any possible indoor sources.
- If a source still cannot be identified then check with a local urban monitoring station or commission measurements to ensure that national specifications are not being exceeded within the locality.
- Once a source has been identified, take action to secure its removal.

2.2.3. Indoor Pollutant Sources

A vast number of pollutants may be present within a space, many of which have largely unknown toxicological effects. Some pollutants can be tolerated at low concentrations while others are extremely toxic. Significant indoor pollutants include:

- **Non Toxic**

    - Carbon dioxide (metabolic and from unvented gas appliances (e.g. gas cooking). Carbon dioxide often provides an indicator of poor ventilation;
    - Moisture from cooking, washing, clothes drying and transpiration. However, condensation and high humidity promotes mould growth and damages the building fabric;
    - Odour (an indicator of poor ventilation and inadequate cleaning or hygiene);

- **Toxic**

    - Carbon monoxide (a product of incomplete combustion);
    - Formaldehyde (off-gassed from fibre boards, insulation and furniture);
    - Ozone (emitted from high voltage electrical equipment – printers , copiers etc.)
    - Particulate matter (fine particles up to 10 μm –pm_{10}'s). These can enter the building from outside or be generated by smoking and from printers and copiers);
    - VOC's (organic compounds emitted from furnishings, fabrics and household chemical products).

To ensure a satisfactory indoor climate, the concentration of indoor pollutants must be kept to safe, low risk levels. Ventilation provides one means for achieving this. However, for a healthy indoor climate this approach must be viewed in the context of the full range of control mechanisms as identified below.

2.2.4 Indoor Air Quality Control – What Can the Occupant Do?

The hierarchy of measures that must be applied to control indoor generated pollutants is summarised in Figure 2.4. For indoor generated pollutants, building owners and occupiers have substantially more control than for outdoor pollutants. A particular problem concerns the impact of environmental tobacco smoke. A simple solution that enables the co-existence of smokers and non-smokers in the same environment has proved to be elusive to achieve. Combined with this is growing concern about the health impact of tobacco smoke. For this reason, smoking is frequently discouraged in the work place, by the employer, for fear of future litigation. In the home there is no such control and future health problems could arise. The onus with tobacco smoke as with any other pollutant, therefore, is very much on the owner and occupier to resolve indoor generated pollutant problems.

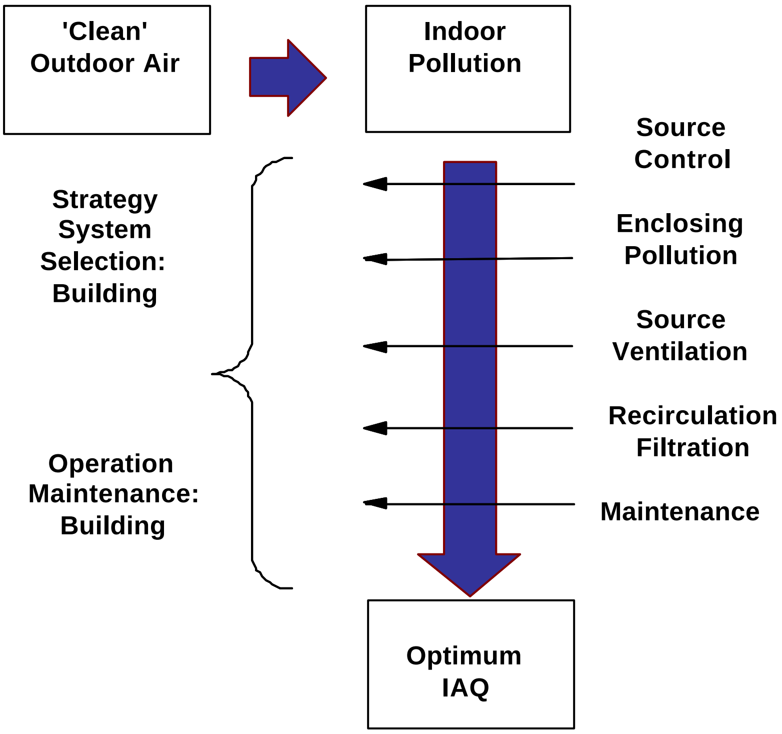

Figure 2.4 Measures to Control Indoor Pollutant Sources

Mitigation measures should primarily be within the control of building occupants since the pollutants are sourced from within the building. The primary mitigation steps are:

Source/Emission Control: The first approach to any indoor air emission must be to eliminate it or, at the very least, to restrict its discharge into occupied spaces.

Containing a Process: Failing elimination, all polluting activities should be contained. In the laboratory this means using a fume hood, or operating from within a depressurised enclosure. In the office and home, containment involves venting pollutants to the outside before they come into contact with the indoor air. Cooker/range hoods, direct exhausts and extract fans are used for this purpose. Pollutants that are likely to contaminate the outdoor air must be taken out of the exhaust air.

Ventilation: In recent times, the role of ventilation in securing a good indoor climate has undergone a radical re-assessment. Classically, ventilation is used to maintain air quality by dilution, this process is summarised in Figure 2.5.

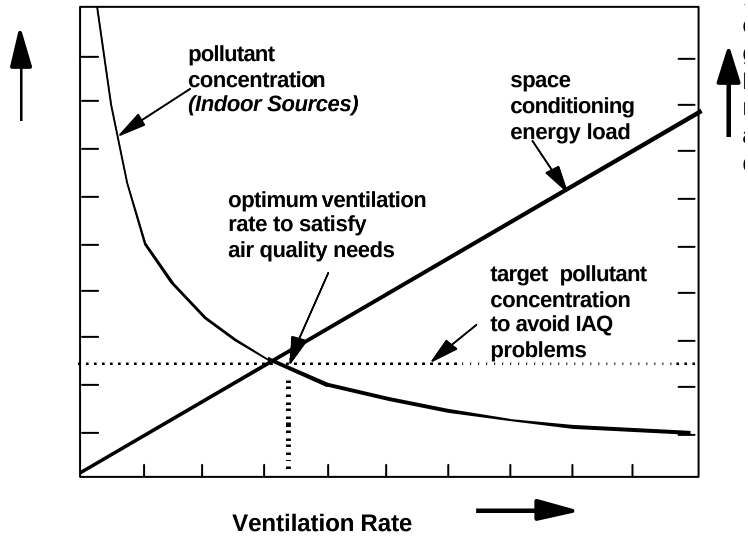

Figure 2.5 Characteristics of Dilution Ventilation

For a given pollutant emission rate, the steady concentration of pollutant within a space depends on the rate of ventilation. As the ventilation rate is increased, the ultimate steady state pollutant concentration is reduced. This, however, incurs an energy penalty, both in terms of the loss of 'thermally' conditioned air and in terms of electrical fan energy. It is usual, therefore, to identify the 'dominant' pollutant in a space, i.e. the pollutant needing the most ventilation to reduce the steady state concentration to at or below an acceptable 'comfort' and 'safe' concentration. Once this is determined, the ventilation needs of the lesser pollutants will also be satisfied. This dilution approach is described in more detail in the AIVC Guide to Energy Efficient Ventilation (Liddament 1996). In recent times, emphasise has been placed on 'displacement' ventilation in which incoming air enters the space without mixing. In theory, a displacement system could operate at a lower rate of air change but, for safety, and for added comfort, the ventilation rate for displacement systems should be based on the overall rate needed for the dilution approach. The amount of ventilation needed to remove or dilute a pollutant depends on source strength. Where the dominant pollutant is the occupant, a typical minimum ventilation rate is 8 –10 litres/second for each person (l/s.p).

In the United States, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in conjunction with the American National Standards Institute (ANSI) has been responsible for developing requirements for minimum ventilation especially in relation to the current Standard, ASHRAE 62 (1999).

In Europe, ventilation standards are being developed through CEN Technical Committee 156 "Ventilation for Buildings". Up to date accounts (1999) of current progress of both of these Standards have been published by Taylor (1999) for ASHRAE and Green (1999) for CEN.

Filtration: While it is possible to control internally generated particles by ventilation, if the generation rate is high and unavoidable, the amount of ventilation needed may become excessive. In these circumstances, particulate pollutants may be controlled with recirculatory air filters. Assuming 100% filter efficiency, a filtration rate equivalent to the ventilation rate halves the pollution concentration. This is further reduced to 25% of the level achievable by ventilation alone by increasing the filtration rate to three times the fresh air ventilation rate. To be successful, therefore, the air handling capacity of the filtration system and the filtration efficiency must be high to accomplish a worthwhile pollutant reduction. For this reason, desktop 'air purifiers' must be regarded as totally ineffective.

Maintenance: Ventilation systems must also be kept clean and be maintained, especially in the air supply network. Accumulation of dust within ductwork systems can provide a site for microbiological growth. This can result in bacterial and fungal spores being released into the occupied space as well as the emission of odour and other compounds. The control of dust contamination is improved by good filtration but provision in the system for cleaning is essential. Aspects of maintenance are described in Section 6.

2.3 Achieving Thermal Comfort

Acceptable thermal comfort conditions in which the majority of occupants will generally be satisfied is usually based on ranges of dry bulb (air) temperature, radiant temperature (from surfaces) local air speed (draught) and relative humidity. Such an example based on ASHRAE Standard 55 (1992) is illustrated in Figure 2.6. In the Figure, the 'operative temperature' is derived from the dry bulb temperature, mean radiant temperature and air speed. In its simplest form, this is measured using a 'pink' bulb thermometer. In any room, however, conditions are rarely uniform and therefore the challenge is to ensure that conditions are satisfied throughout a space.

OCCUPANT ACTIONS – INDOOR AIR QUALITY: If there is concern about indoor air quality, occupants should undertake the following actions:

- Verify the quality of the outdoor air;
- Check the supply air through the ventilation system to identify the possible location of system related pollutants (e.g. dust, mould, etc. in ventilation ductwork);
- Locate and eliminate or enclose all indoor pollutant sources;
- Check for odour and/or CO_2 concentration, if these peak with occupancy density, then the primary pollutant source is probably due to occupancy. Raise ventilation rates in all occupied zones to at least 8 – 10 l/s of outdoor air for each occupant;
- Eliminate smoking;
- Discourage indoor clothes drying unless the area is vented;
- Ensure all 'wet' zones have effective extract ventilation.

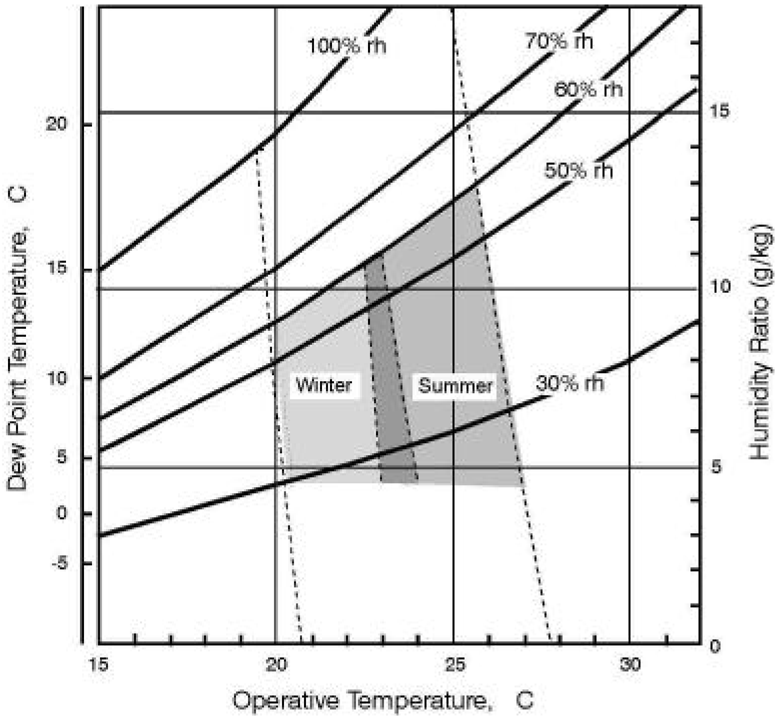

Figure 2.6 ASHRAE Thermal Comfort Envelope

2.3.1 Satisfying Cooling Needs

In all climates, large buildings are susceptible to overheating and thus cooling (often by mechanical refrigeration) becomes an important aspect of providing good thermal comfort. In addition, in hot and humid climates, mechanical cooling is also often necessary for small buildings and dwellings. From an energy and cost aspect, there is an advantage in avoiding or minimising the use of mechanical cooling. Developments in this area have been investigated as part of the European NatVent project (Perera 1999) and by Annex 28 of the IEA's Implementing Agreement on Energy Conservation in Buildings and Community Systems (Zimmerman 1998). Guidelines in satisfying cooling needs are summarised in Table 2.2. Simplified algorithms for identifying the most appropriate cooling strategy are summarised in the Annex 28 Synthesis Report (Liddament 2000).

Table 2.2 Meeting Cooling Needs

Climate Type	Cooling Strategy
Hot Humid	Refrigeration, with capacity reduced by minimising solar and indoor heat gains.
Hot Dry	Evaporative cooling with capacity reduced by minimising solar and indoor heat gains.
Moderate (average daily outdoor temperature 18°C – 22°C but daytime temperature might occasionally exceed 31°C).	'Passive' cooling aimed especially aimed at 'night' cooling of the thermal mass. Typically a high air change rate is needed (~10 air changes/hour and not less than 6 ach).

By the proper application of night cooling, shading, thermal mass and the avoidance of unnecessary heat gains, all of the above studies have shown that a 3 degree reduction in dry bulb peak day time temperature is easily achievable. This has substantial impact on energy efficiency and, in itself, even when mechanical cooling is still required, can result the worthwhile downsizing of such equipment.

OCCUPANT ACTIONS – THERMAL COMFORT: If thermal comfort is adequate, occupants should undertake the following actions:

Insufficient Warmth:

- Check heating system;
- Check and rectify sources of infiltration and cold draughts;
- Check for excess outdoor air from mechanical ventilation systems;

Overheating:

- Minimise indoor heat gains by shutting down all unnecessary electrical equipment;
- Apply external solar shading;
- Establish a night cooling strategy to cool the building fabric down at night (typically this should be between about 4-10 air changes/hour);
- Implement window opening or maximum ventilation at night **AND** in the morning, **BEFORE** the indoor temperature becomes unacceptable;
- Reduce the ventilation rate once the outdoor air temperature exceeds the indoor temperature. Note, however, that closing windows might exacerbate solar gain hence the need for external solar shading on sun facing windows).

2.4 Energy Impact of Ventilation

Approximately 40% of primary energy is used in buildings (residential and non-residential combined). Of this, approximately two thirds is used in dwellings with the remainder being used in non-residential buildings. Approximately half of this energy is dissipated from buildings through ventilation and air infiltration. Unnecessary energy losses occur when a space is conditioned for thermal comfort but excess loss of air occurs through uncontrolled air infiltration or when ventilation is at a higher rate than it needs to be. Orme (1998) has undertaken a study of the energy impact of ventilation. Based on information from a wide range of sources, he estimates that the total annual delivered energy dissipated from buildings in 13 major countries through air flow amounts to approximately 9.3 EJ. On the other hand, based on the constant provision of 10 l/s.p, the total energy need would be in the region of 3.1 EJ (Figure 2.7). This would indicate that there is potential for a considerable reduction in energy need should ventilation be provided efficiently. In addition other reduction measures such as exhaust air heat recover and ‘passive’ or ‘low’ energy cooling provide a further means to reduce energy use. Heat recovery methods especially, however, require a careful net gain assessment to determine the impact of electrical fan energy on primary energy use.

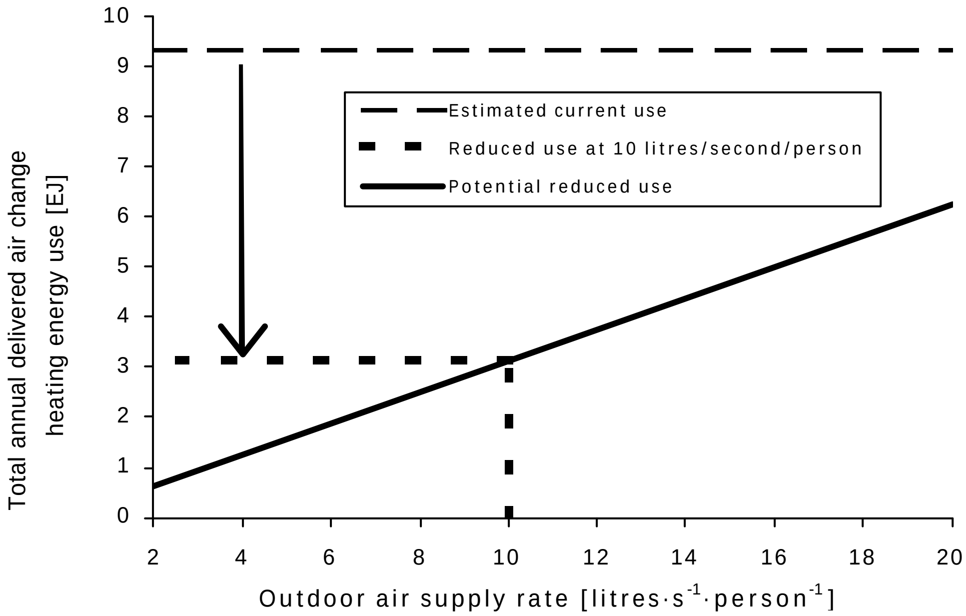

Figure 2.7 Total Space Conditioning Delivered Energy Need for Belgium, Canada, Denmark, Finland, France, Germany, Netherlands, New Zealand, Norway, Sweden, Switzerland, UK and USA

2.5 Identifying Responsibilities – The Roles of Legislation, Designers, Builders, Owners and Occupiers

Before reviewing the role of occupants in influencing their indoor environment it is important to identify the tools and actions open to occupants. Against the hierarchical measures illustrated in Figure 2.1 and 2.4 is the source of responsibility for achieving each measure. This is summarised in further detail in Figure 2.8. Key aspects include:

- ***Legislation and Standards:*** Outdoor air quality control and the basic requirements of building design must be incorporated into regulation and standards since the occupant is not able to influence these aspects.

- ***Design and Construction:*** The designer must implement the requirements of regulations and standards and take responsibility for ensuring that the building envelope and the ventilation, heating and cooling systems will perform correctly.

- ***Occupants and Building Owner:*** Occupants and owners must understand the operational controls and systems and use them correctly. Evidence of occupant surveys reveal that occupants do not use devices correctly because instructions are inadequate or too complicated. Occupants and owners must also ensure that maintenance schedules are followed and they must not interfere with the systems or functional parts of the building structure.

In essence, therefore, although occupants have the final ability to thwart the intention of any air quality or ventilation measure, without good control of the outdoor air and of building design and construction, occupants have virtually no control over the indoor environment. The fact that many of the parameters influencing the indoor environment are well beyond the control of the building occupant is possibly often not considered.

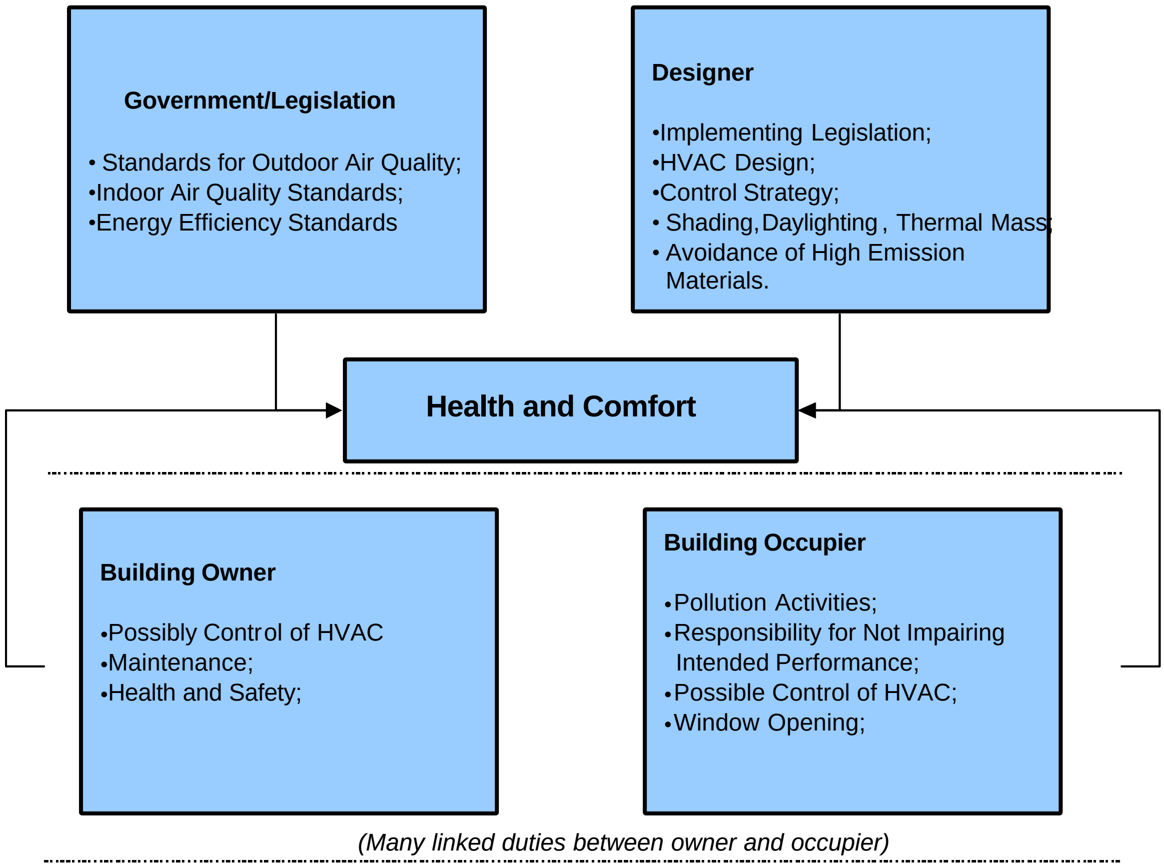

Figure 2.8 The Roles of Legislation, Designers, Builders, Occupants and Building Owners in Achieving a Good Building Environment

2.6 Differences in Philosophy ‘Tight’ Buildings or ‘Less Tight’ Buildings

It is clear that there are philosophical differences between countries and individuals about how airtight a building should be. Each philosophy has advantages and disadvantages. Furthermore the reasoning will vary according to building use. In Figure 2.9 below are presented some generalisations concerning the advantages and disadvantages of each approach. It should be understood, however, that there is little advantage in buildings which are excessively leaky. Occupants in such buildings may be faced with uncontrollable draughts, excessive heating and cooling costs and no possibility of achieving thermal comfort.

Possible considerations and/or points of attention

‘Tight’ Building

Ventilation Strategy

•Mechanical extract and balanced ventilation systems can be dimensioned to perform reliably with minimum interference from prevailing weather conditions.

Advantages

•Heat recovery systems can be effective.

•Uncontrollable draughts energy loss avoided;

Disadvantage

•Severe risk of inadequate ventilation if occupant seals air supply’return terminals or switches system off.

•Fan energy needed, either to overcome high underpressure (e.g. 10-20Pa room + 200Pa Duct) with an extract system or to operate two fans (balanced system (e.g. 200Pa for each duct network).

Control Strategy

(People are not capable of correctly managing ventilation devices)

•Method of purging needed, either by substantial ventilation boost or by openable windows;

•Adjustable ventilation grilles should not close completely since these represent the only significant source of air supply.

Applications

Cooler climates where high infiltration losses lead to discomfort and energy loss and where the benefit of heat recovery can be maximised.

‘Less Tight’ Building

Ventilation Strategy

•Basic ventilation may be dominated by air infiltration.

•‘Passive’ stacks and/or local extract fans, combined with user controllable trickle ventilators may be used to ‘top-up’ ventilation need.

Advantages

•A measure of ‘safe’ background’ ventilation is provided by airflow through the natural porosity of the building.

Disadvantage

•Mechanical systems and heat recovery will perform unreliably because of interference from fabric leakage;

• Risk of excessive air change especially when driving forces are high (e.g. high temperature difference (winter) and high wind speeds.

Control Strategy

•User can control trickle ventilators, fans andopenable windows as needed;

•Adjustable openings needed otherwise, if fixed, the occupant might permanently seal them. Air infiltration provides a measure of safety.

Applications

Milder climates where cold draughts are less of a problem and heat recovery is economically difficult to justify.

OUTCOME

By good design and with a thorough understanding of the interaction of airtightness and climate with ventilation both approaches could lead to good air quality and energy efficient solutions

Figure 2.9 Factors Affecting the Choice of ‘Tight’ and ‘Less Tight’ Buildings

3.0 Ventilation

Ultimately, it is ventilation that plays the key role in how an occupant reacts to accomplish an optimum indoor environment. Important aspects cover:

Ventilation need;

- controls;
- the type of ventilation system;
- energy efficiency;
- the outdoor climate;
- lessons learnt.

The key functions of ventilation are summarised in Table 3.1 and a summary of the main ventilation strategies, identifying the occupant's role in controlling each of these systems is outlined in Table 3.2.

Table 3.1 Ventilation – The Need

Application	**Comment**
Metabolic need (unavoidable need/pollutant)	Less than 1 l/s of air is needed to provide oxygen for metabolism. To avoid odour and discomfort, though, ventilation of approximately 8-10 l/s for each occupant (l/s.p) may be required.
Removing other pollutants by dilution and displacement	Ventilation rate will depend on the amount of dilution needed to dilute the pollutant to a 'safe' threshold concentration. Conventionally pollutants generated in a space are identified and the ventilation rate needed to dilute each of them is separately calculated. The actual ventilation rate is then set at the highest calculated rate (i.e. that needed to dilute the 'dominant' pollutant). [See AIVC Guide to Ventilation - Liddament 1996]. The ventilation rate needed to remove moisture in a dwelling, for example, could be substantially higher than that needed to meet occupancy needs albeit only for transient periods.
Combustion air	In dwellings especially, room air may be used to support combustion appliances. Sometimes combustion appliances do not have external flues (e.g. gas cooking appliances), therefore additional ventilation is needed to cope with this need. Comprehensive ventilation guidelines and dilution equations are presented in BS5925(1990).
Cooling	In Summer, ventilation air is widely used (in moderate to mild climatic regions) to assist in meeting cooling demand as an alternative to mechanical refrigerative cooling. Provision then needs to be made for high rates of ventilation (typically in the region of 8 – 10 building air changes/hour (ach). Successful ventilation cooling needs a good control strategy and well designed integration with the thermal mass of the building [See Annex 28 case studies, Zimmermann and Andersson 1998, and the Nat Vent Case Studies, Perera 1999]. Reduced indoor heat gains and outdoor solar shading is also essential.

Table 3.2 A Summary of Ventilation Methods

Strategy	Method	Occupant Control/Comments
Natural		
Adventitious	Building porosity and window opening.	Window opening. Poor control, especially in a 'leaky' building.
Controlled Natural	Combination of controllable vents, passive stacks and/or wind towers.	Adjust vent openings and dampers to control air flow. Moderately airtight structure is preferable to avoid draughts.
Fan Assisted	The addition of extract fans in 'wet' rooms. Combined with the use of passive air inlets in other rooms.	Control fans either manually or by PIR's or humidistats.
Mechanical		
Extract	Ducted central extract to 'wet' rooms. Passive air inlets in other rooms.	Control by fan boost, PIR's or humidistats. Typically for dwellings. Moderately air tight structure needed. Passive inlets sized to give 10-20 Pa under-pressure.
Supply	Ducted central supply combined with passive air outlets.	Control by fan boost, PIR's or thermostats. Filtration possible. Typically for simple office. Moderately air tight structure needed. Passive outlets sized to give 10-20 Pa over-pressure.
Balanced	Separate ducted supply and extract system, usually combined with air to air heat recovery.	Control by fan boost, PIR's or thermostats. Filtration possible and recirculatory heating and cooling. Used in homes (usually in severe climates) and in offices. A tight building is essential since infiltration adds directly to the system ventilation rate.
'Mixed' Mode		
NV+MV	Natural Ventilation combined with simplified mechanical ventilation.	Adjust vents and mechanical system typically to maximise night cooling in summer and avoid over ventilation in winter.
Ventilation 'Modes'		
'Single' Pass	Air enters through air inlets, passes through the building or zone and is then extracted.	Often the preferred approach but a separate heating and/or cooling system is needed (e.g. hydronic radiators and chilled ceilings).
Recirculatory	Incoming air is blended with an air stream of up to 90% existing room/building air. This usually forms part of the heating or cooling system.	Widely used in buildings with air heating and cooling.
Mixing	Incoming air is mixed uniformly with indoor air.	Forms the idealised basis of natural ventilation and recirculatory mechanical systems.
Displacement	Incoming air displaced room air with the minimum of mixing. This is a single pass approach.	Little direct occupant control. With good design, air in the breathing zone can be less polluted than with mixing systems.

4.0 Occupant Impact on Ventilation - Dwellings

4.1 Introduction

The characteristics of residential buildings differ widely. Issues include:

- outdoor climate and season of year;
- building size and type (e.g. single family, high rise);
- location (e.g. city, urban, rural);
- ventilation, heating (and cooling) strategy;
- occupancy patterns.

In this section, ventilation and occupant interaction with the ventilation system is considered in terms of:

- basic statistics on housing occupation and ventilation systems;
- basic ventilation and indoor climate needs;
- observed occupancy interaction with ventilation systems and controls;
- occupant impact on the total ventilation/air change rate;
- occupant impact on energy consumption;
- lessons learnt and procedures for optimising occupant interaction.

Many of the results presented in this Section are based on the following reports:

IEA ECBCS Annex 8 Inhabitant Behaviour with Respect to Ventilation (Dubrul 1988): This international work involved Belgium, Germany, Switzerland, the Netherlands and the United Kingdom. Its purpose was to assess whether and how ventilation behaviour could be modified in order to save energy while taking into account indoor air quality. Key tasks included:

- determine the behaviour of occupants and to correlate it to the outdoor and indoor climate;
- to estimate the amount of energy lost through such behaviour;
- to study the motivation behind inhabitants' behaviour;
- to study whether such behaviour could be modified and, if so, assess the potential energy saving.

IEA ECBCS Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems M◇nsson (2001): The main purpose of this Annex was to develop tools for the analysis and operation of efficient ventilation systems. This included an analysis of existing and new ventilation systems within the participating countries (Canada, France, Italy, Japan, the Netherlands, Sweden, the United Kingdom and the USA), and the modelling of behaviour and systems.

1992 Swedish Energy and Indoor Climate Survey (the ELIB) study: The indoor climate in a random sample of 1200 single- and multi-family houses from the Swedish housing stock were investigated as part of a major study on the Swedish housing stock. Among different parameters the ventilation and the air-tightness of the houses were measured. The ventilation measurements were performed during one month in each house/flat by means of the PFT (passive tracer gas) method and the air tightness of a sub-sample of 90 buildings were measured by means of pressurisation technique. (Full details are reported by Kronvall and Boman 1993.)

French Study: "Ventilation in the home: survey of the attitudes and behaviour of Private Citizens" (Lemaire and Trotignon 2000): The purpose of this study was to take stock of changing attitudes in households with regard to their use of energy and to assess the impact of French policies relating to energy efficiency. This study involved a preliminary survey of 10,000 households covering energy/ventilation features, appliances and their use etc., followed by a smaller second survey of those who responded in the first survey that they had carried out energy efficiency work in their homes.

4.2 Basic Statistics on Housing Occupation and Ventilation Systems

DWELLINGS - BASIC DETAILS (Based on ECBCS Annex 27 Study):

Occupancy Patterns:

- Occupancy approaches 100% between 18.00 – 06.00;
- Occupancy falls to an average of approximately 25% (men) and 50%(women) during the working day (highly country dependent see Section 4.4.2);
- The amount of time spent inside the home increases with the age of the occupants.

Ventilation Strategy:

- Natural ventilation (often with mechanically assisted extract fans) is still the most overwhelmingly used approach in dwellings in many countries (Table 4.2). The exception is Scandinavia and Canada where balanced mechanical systems with heat recovery is being introduced in large numbers of new dwellings

Smoking:

- Window opening was found to be twice as frequent in 'smoking' homes compared to 'non smoking' homes (Dubrul 1988);

Moisture:

- Water consumption in the home averages between 140 – 250 litres/day;
- A 10-minute shower produces up to half a litre of water vapour. Even with a bathroom exhaust fan, the relative humidity can reach 100% in a bathroom within 5 minutes of showering;
- A well-designed mechanically extracting cooker hood can remove up to 70% of the moisture generated during cooking.

Dwellings are subjected to a wide range of occupancy patterns and pollutant emissions. General commonality though includes:

- Up to 24 hour a day occupancy including full occupancy at night;
- Moisture generation from cooking, clothes washing and bathing;
- Often a supply air need for fossil fuel heating appliances;
- Unvented combustion products from gas cooking appliances;
- Tobacco smoke in a significant number of households.

In general ventilation must be sized to deal with these pollution loads, whereas occupant density can be relatively low (when compared with offices and school etc.).

Occupancy Density: Details of occupancy density (based on Annex 27) for various countries are summarised in Table 4.1(a) and (b). This shows significant percentages of occupancy in households, varying from single occupancy to households of five or more. It also highlights the wide variation in building size between countries.

Table 4.1(a) Persons/dwellings

Country	Persons/ dwelling	Area, m^2/person
Belgium	2.7	
Denmark	2.2	49
Finland	2.5	30
France	2.7	32
Germany	2.5	35
Italy	3.2	29
Japan	3.2	28
Netherlands	2.6	
Norway	2.5	43
Sweden	2.1	47
Switzerland	2.2	39
United Kingdom	2.7	27
Canada	2.7	50
U.S.A	2.3	61

Table 4.1(b) Number of persons/house-hold.

Country	Number of persons/household (distribution %)				
	1	2	3	4	5
Belgium	26	30	18	16	9
Denmark	34	33	15	13	5
Finland	31	29	17	15	8
France	25	28	19	16	12
Germany	33	29	18	14	6
Italy	22	24	23	21	10
Japan	18	20	18	23	21
Netherlands	27	30	15	19	9
Norway	35	26	15	15	8
Sweden	40	31	12	12	5
Switzerland					
United Kingdom	24	33	17	17	9
Canada	21	30	18	19	12
U.S.A.	25	33	16	17	9

Ventilation Systems: An approximate split of ventilation systems installed in single family and multi-family houses in ECBCS Annex 27 countries for (a) existing and (b) recent housing is summarised in Table 4.2 (a) and (b). This shows that, among the countries listed, natural, adventitious and mechanically assisted natural ventilation are still overwhelmingly used approaches in dwellings. The exception is Scandinavia and Canada, where balanced systems with heat recovery are being introduced in large numbers in new dwellings.

Table 4.2(a) Distribution of Ventilation Systems in the Existing Dwelling Stock

Country	Single family homes					Multi family homes				
	Natural			**Mechanical**		**Natural**			**Mechanical**	
	Ad-ventitious	Stack (S)	Stack + Kitchen hood	Ex-haust	SE	Ad-ventitious	Stack (S)	Stack + Kit-chen hood	Ex-haust	SE
Belgium	100					95	5			
Canada		15	85							
Denmark	50[1]			48	2	50[1]			50	
Finland										
France	40	15	20	22	3	40	20	10	30	
Germany										
Italy	80		10	10		75			25	
Japan										
Nether-lands	62[1]			38		37[1]			63	
Norway			80	15	5		60		30	10
Sweden		12	63	14	11		40		44	16
Switzerland	70		30			40		60		
UK	95[1]		5			100[1]				
USA	60			40						

(1) Includes all natural systems

Table 4.2(b) Distribution of Ventilation Systems in Newly Constructed Dwellings

ountry	Single family houses				Multi family houses			
	Natural		**Mechanical**		**Natural**		**Mechanical**	
	Local Exhaust	S+local exhaust	E	SE	Local Exhaust	S+local exhaust	E	SE
Belgium								
Canada				100				
Denmark								
Finland								
France		20	75	5	1		99	
Germany								
Italy	80		20		90		10	
Japan								
Nether-lands		20	80			20	80	
Norway								
Sweden			80	20			20	80
Switzerland								
UK	100				100			
USA	90	10			90	10		

4.3 Basic Ventilation and Indoor Climate Needs

The main roles of ventilation in dwellings are to:

- provide air for metabolism;
- dilute and remove pollutants;
- provide combustion air for fuel burning appliances such as gas cookers and open flued heating systems.

Indoor pollution loads include:

- metabolic CO_2 and odour;
- combustion products (CO_2, NO_x, water vapour) from gas cooking or, possibly, open-flued heating appliances;
- moisture from bathing, clothes washing and drying, cooking and cooking appliances;
- tobacco products including particles.

Approximate ventilation rates needed to reduce the concentration of these moisture and carbon dioxide sources to acceptable threshold levels are summarised in Figure 4.1.

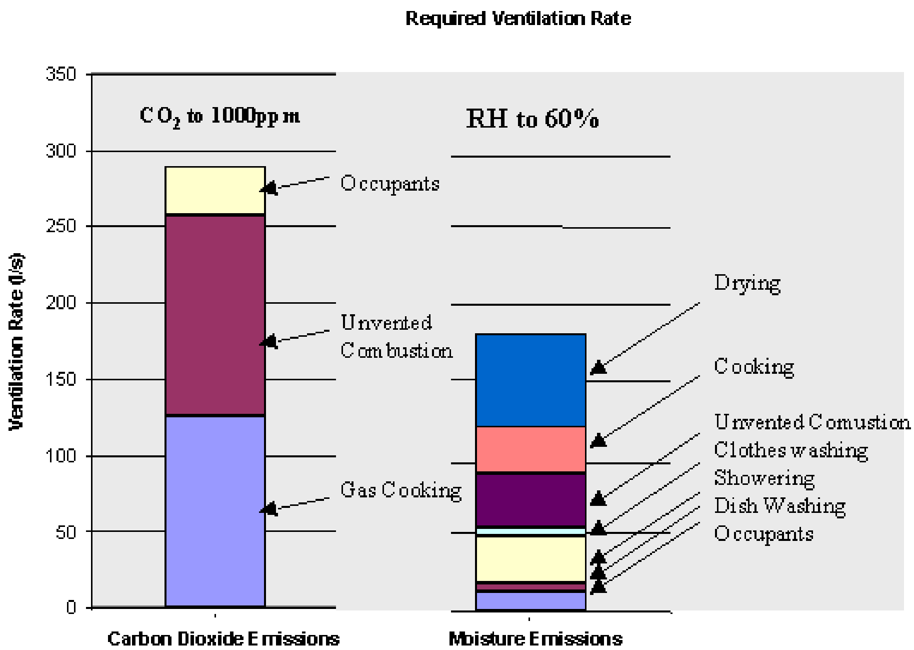

Figure 4.1 Typical Ventilation Rates Needed to Deal with Various Household Activities

In addition to these pollutants, the home might also be subject to contaminants from outside including:

- urban and industrial pollution (e.g. chemical pollutants and pollution from traffic);
- rural pollution (pollen, fugal spores, agricultural chemicals);

- insects;
- ground contaminants (radon gas, methane, moisture);
- transient pollution from neighbouring activities (e.g. smoke) and from adjacent buildings.

For these reasons the envelope needs to be airtight to provide good protection against the ingress of unwanted outdoor pollutants. Especially, it must be possible to protect the indoor environment from harmful transient pollutants by being able to close ventilation openings (e.g. from rush hour urban traffic).

4.4 Observed Occupancy Interaction with Ventilation Systems and Controls

All of the references investigated have identified aspects of occupant behaviour and need that impact on ventilation requirements; these observations are summarised below:

Observed Occupancy Patterns: Studies from Annex 27 revealed the following occupant characteristics:

- The amount of time spent in a dwelling increases with age;
- Occupancy approaches 100% of the time between 18.00 and 06.00;
- During weekdays (industrialised countries), occupancy falls to a mean of about 25% (men) and 50% (women), peaking in the middle of the day (highly country and location dependent) to between 40%-70%;

Observed Occupancy Interaction with Ventilation System: The observation of the way that occupants interacted with ventilation provisions formed a major part of Annex 8. Aspects were covered in terms of:

- Reasons for ventilation (as reported by occupants);
- Strategies as inferred from objective recording and self reporting;
- Impact of life style (e.g. smoking, occupancy patterns etc.);
- Building fabric factors.

In total, measurements and observations were made in over 9000 dwellings as part of this study. Dwelling types included the full range from single family to high-rise apartments. In addition to postal questionnaires and self-reporting, detailed measurements included:

- The continuous monitoring of door and window opening;
- Photographic monitoring (of window opening);
- Weather monitoring (temperature, solar radiation, wind velocity and precipitation);
- Indoor climate.

Reasons for Ventilation and not Ventilating Given by Occupants: The participating countries conducted enquiries and interviews in order to assess the reasons for ventilation and not ventilating. The key reasons are summarised in Figure 4.2.

ECBCS Annex 8 Survey

Reasons for Ventilation

- **To get fresh air into bedrooms and the living room;**
- **To remove odour;**
- **To remove stale air and condensation;**
- **To 'air' the dwelling during domestic activities;**
- **To remove tobacco smoke.**

Reasons for Not Ventilation (Primarily by Window Opening)

- **To prevent draughts;**
- **To maintain a prefered temperature level in the home;**
- **To protect inhabitants from adverse climate (i.e. cold and rain);**
- **To preserve privacy and safety;**
- **To reduce outside noise and pollution.**

Figure 4.2 Reasons Given by Occupants for Ventilating and Not Ventilating Their Homes

4.5 Observed Use of Specific Ventilation Components

Through all the studies reviewed it has been possible to develop a comprehensive picture of the use, by occupants of specific ventilation components. The results are summarised in the following sections.

Observed Use of Windows: Window opening is one of the most basic of occupant controls and the surveys of Annex 8 revealed the wide use of window opening to control the indoor environment. Observations of window opening trends is summarised in Figures 4.3 to 4.6.

Factor			Observed Trend
(i)	**Occupant Density**	→	Window opening increases with the number of occupants present.
(ii)	**Occupant's Age**	→	The amount of window opening and ventilation reduces with the increasing age of the occupant.
(iii)	**Outdoor Air Temperature** (Figure 4.4)	→	Window opening decreases with decreasing outdoor temperature, although a significant number are still opened at temperatures as low as -5°C (~7%).
(iv)	**Sunshine** (Figure 4.4)	→	More windows tend to be open on the sunny side of buildings than the on the opposite side.
(v)	**Windspeed** (Figure 4.5)	→	Window opening decreases with increasing wind speed.
(vi)	**Daytime Opening** (Figure 4.6)	→	Windows are usually closed when the building is unoccupied during the day.
(vii)	**Night Time Opening** (Figure 4.6)	→	A significant number of windows are kept open in bedrooms at night, even in cold weather.
(viii)	**Weekend Opening**	→	Windows are opened more frequently at weekends than during the rest of the week.
(ix)	**Thermostat Setting**	→	The higher a householder sets his heating thermostat, the less often windows are opened.
(x)	**Domestic Activities**	→	Reasons given for window opening include: vacuum cleaning, and airing of bed -clothes, cooking, cooking odour, and moisture problems.
(xi)	**Smoking**	→	Windows are opened twice as frequently in smoking households than in non -smoking households.
(xii)	**Energy Use**	→	There is only a weak correlation between energy saving intentions and window opening. More window opening tends to take place in buildings in which heating energy is not separately metered to occupants.

Figure 4.3 Observations of Window Opening Trends

Figure 4.4 illustrates that window opening is observed to decrease as the outdoor temperature falls but that there is still window opening, even if the outdoor temperature fall to below freezing point. The figure also illustrates that window opening is more likely on sunny days (irrespective of air temperature) than on cloudy days.

Figure 4.5 illustrates that window opening decreases as the wind speed increases.

Figure 4.6 shows the use of windows throughout a typical day. Windows are usually closed when the building is unoccupied. Bedroom windows are often open at night.

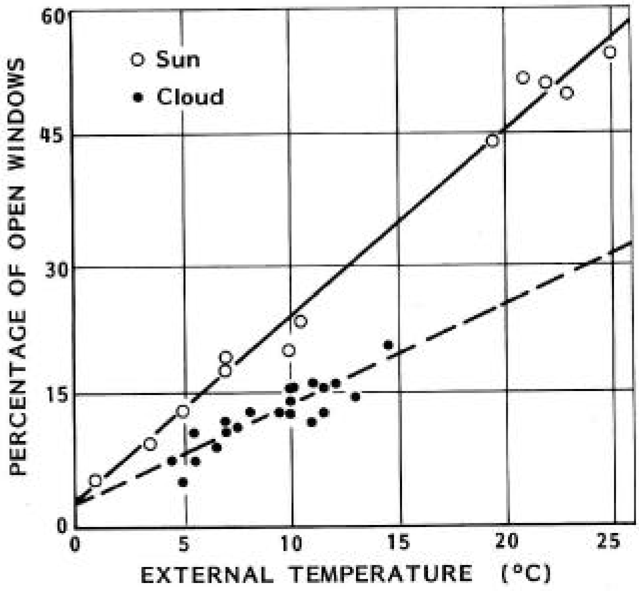

Figure 4.4 Window Opening in Relation to Outside Temperature and Sunshine

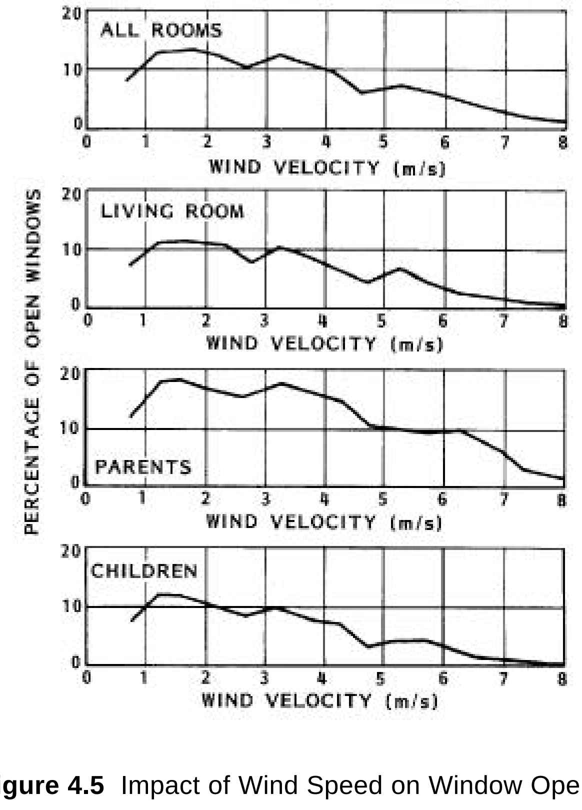

Figure 4.5 Impact of Wind Speed on Window Opening

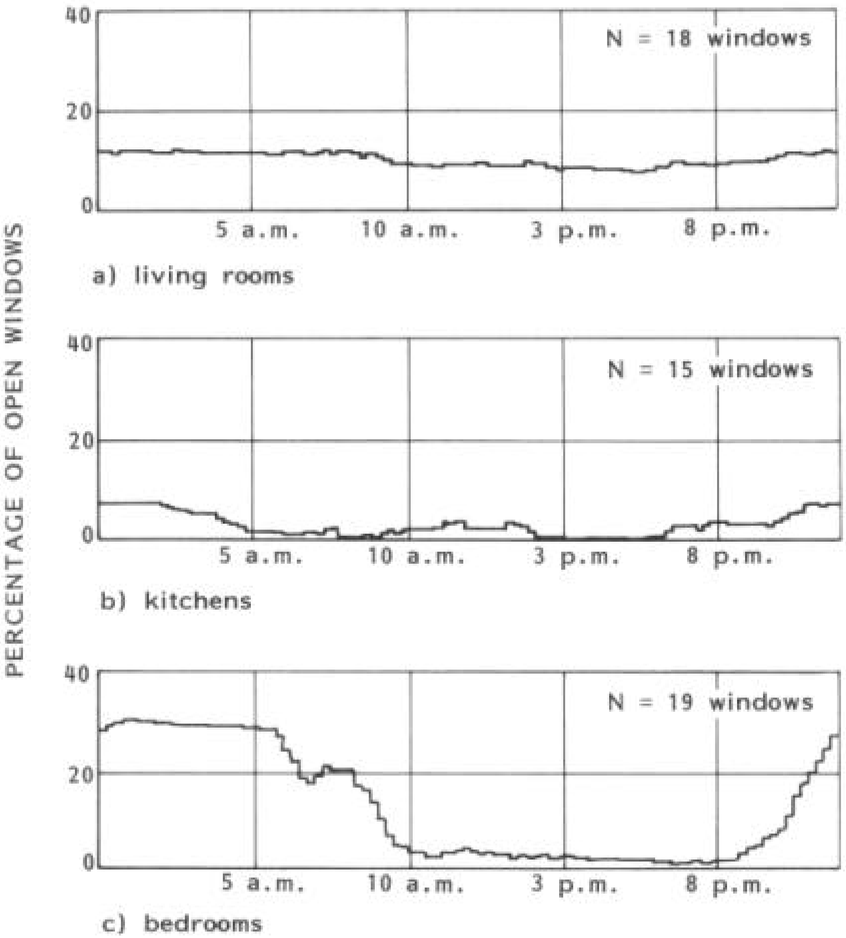

Figure 4.6 Observed Window Opening Throughout a 24 Hour Period
(from Annex 8 Dubrul 1988)

Observed Use of Trickle Ventilators: Trickle ventilators are those fitted to provide background ventilation into rooms. In some countries they may be required by Building Regulations or may be specified to meet the needs of combustion appliances. Some authorities may require permanently opened vents while others allow for manually or automatically adjustable openings. In the Dutch contribution to Annex 8, observations showed that trickle ventilators and grilles were generally left open. In the French Study 13% of occupants reported that they had sealed all or some of their vents. This was reduced to 7% or less for houses constructed after 1982.

Observed Use of Extract Fans: Oseland (1995) describes the results of a large occupant survey of the use of both mechanical extractor fans (MEF) and passive (natural) stack ventilation (PSV) in UK dwellings. New build and refurbished homes with PSV and MEF were identified and questionnaires were posted to 3000 households of which 1223 were returned. The survey showed that there were only a few cases in which the MEF was blocked up or disconnected i.e. 1.5% in kitchens and about 5% in bathrooms. However, less than a half (40%) of the respondents usually or always used their MEFs. The respondents were asked to rate how problematic condensation, mould and noise were in their home. Approximately one-third of the respondents had at least a moderate problem with condensation in winter (34%) and noise from extract fans (36%) and one-fifth (19%) had moderate problems with mould.

Observed Use of Venting/Non Venting Cooker Hoods: The French study reported that 54% of French homes are fitted with cooker hoods of which 2/3 expel air. Annex 27 reported that moisture extraction efficiency for venting cooker hoods could reach 70%.

Observed Use of Passive Stack Systems: In the same study to the above, Oseland (1995) found that in homes installed with a PSV system, only 7% of those in the kitchen and only 8% of those in the bathroom were reported as blocked up. Unlike the relative low use of MEF's, most (93%) of the PSV systems were in constant use. Fewer occupants reported problems in homes installed with a PSV system than homes fitted with a MEF, whether manually operated or humidistat-controlled.

Observed Use of 'Automatic' Controls: Various systems are used in the home to modulate the ventilation system. Observed use of various approaches are summarised below:

- ***Humidistats:*** These are often coupled to extract fans located in the 'wet' rooms of dwellings. Their purpose is to provide an automatic control in which a rise in humidity is detected resulting in fan operation. As the humidity level falls, the fan switches off. This automatic system therefore reduces the need for occupant interaction. Several occupant surveys have been carried out to establish their effectiveness. A detailed analysis of the performance of sensors was undertaken as part of ECBCS Annex 18 (Månsson and Svennberg 1997). The most basic sensor is based on the dimensional change characteristics of fibres such as hair, plastic or wood. Although inexpensive, this device was found to require frequent re-calibration and can have substantial hysterisis. More accurate sensors are based on the electrical impedance characteristics of various materials or on the measurement of dew point temperature. Annex 18 case study results, based on humidity control systems, found that performance was variable. Analysis showed that humidistats of the type that were commonly employed for relative humidity control in dwellings were often grossly inaccurate, subject to drift over time and were lacking in any convenient means of calibration. Various systems, however, that were based on humidity controlled air supply and exhaust showed considerable promise.

  In a UK study on the effectiveness of domestic kitchen fans, Boyd and Cooper (1989) describe a field study and computer modelling work aimed at providing quantitative information for fan specification. This work concluded that low rate fans are unable to prevent condensation and that condensation is difficult to remove once present even with extended running from humidistat control. Equally, moisture migration through open doors cannot be prevented because of thermally induced air movement. A full transient analysis is recommended as being essential in assessing mould risk.

  In Canada, Buchan et al (1986) report on the effectiveness of low-cost ventilation systems in reducing moisture problems in houses in Maritime climates. A six-unit row house block in Dartmouth, Nova Scotia was the subject of the study. Three different ventilation systems that were installed in separate interior units and were based on: a humidistat controlled bathroom exhaust fan; a humidistat controlled through-the-wall fan mounted in the kitchen; and a whole house fan, also controlled by a humidistat. All houses had evidence of moisture problems that could be associated with high interior moisture levels. These included mould growth on window frames and in some areas of the ceilings. The findings of the project were that all three fan installations were somewhat effective in limiting exposure of the house to high internal humidity levels. There was not a clear link, however, between the control of humidity and a reduction of those moisture problems evident in the houses.

- ***Presence Infra Red (PIR) Controls:*** A relatively new control system for domestic ventilation is the Presence Infra Red or occupant detector (PIR). This is configured to operate a fan when someone is detected in the room in which the fan is installed. Normally an over-run time will be included so that the fan can continue operation for a short time after the occupant has left. This has the advantages of being very inexpensive and reliable and can be effective in bathrooms and kitchens. Such an approach for dwellings is proposed by Ducarme et al (1996) who argue that such demand controlled ventilation in dwellings is potentially an interesting way to achieve energy consumption reduction.

- ***Advanced Control Systems:*** Advanced 'domotic' controls are also being proposed. Knabe et al (1997) investigate the development of a new indoor air condition control strategy for domestic buildings with a conventional heating system, non-central ventilation and outdoor blinds. The control uses information about the indoor and outdoor climate, user specific behaviour and solar energy gains.

Observed Use of Mechanical Ventilation Systems: The French study indicated that simple (extract) ventilation was installed in about 17% of all homes and less than 3% had balanced displacement systems. The remaining homes predominantly had some form of purpose provided natural ventilation, although 27% were adventitiously ventilated (see Table 4.2). Almost a quarter of households fitted with mechanical systems reported that they often or fairly often switched them off. Systems in 23% of mechanically ventilated dwellings could not be switched off by the occupant.

Almost all mechanical systems investigated by Annex 8 were found to have shortcomings to some degree; these included:

- unacceptable noise level;
- severe draught effects;
- high auxiliary energy consumption;
- design air flow rates not established;
- odour transmission;
- deficient installation;
- poor instructions;
- restricted user access.

Observed Use of Balanced Mechanical Ventilation Systems: Air to air heat recovery systems have become popular across a wide range of climates, although maximum energy benefit comes from the more severe climatic regions. Not only do such systems provide a measure of energy recovery but they also enable pre-heat of the incoming air supply, thus substantially reducing the risk of cold draughts or icing. Hill (1998) outlines occupant surveys undertaken in Canada to evaluate the effectiveness of mechanical ventilation heat recovery in dwellings. Aspects covered:

- mechanical ventilation system design;
- installation practices;
- occupant use and maintenance of ventilation systems.

This project involved the inspection of 60 homes with heat recovery ventilator (HRV) ventilation systems, a survey of the occupants to determine their understanding and usage of their ventilation system, telephone surveys of a further 15 households and intensive performance testing of 20 conventional and four experimental ventilation systems. The methodology for the testing involved the use of a tracer gas to assess air change rates. Based on an assessment of the air change rates, evaluations were made of the fresh air distribution in the homes with and without the operation of the mechanical systems. The common types of HRV installations investigated under this study (fully ducted, simplified and extended) were capable of performing well. The majority of the HRV ventilation systems were operating and the occupants believed the use of their HRV was beneficial. Potential existed for far greater benefits, however, and considerable improvements were possible in installation practice, system performance, occupant understanding and occupant interaction with their system.

Other Observations

Water Use and Moisture Generation: The use of water and consequent moisture and mould risk is a significant problem in many dwellings. Aspects cover:

- ***Water Consumption:*** Water consumption contributes, through washing, showering, clothes drying etc., to potential moisture related problems such as condensation and mould growth. From the Annex 27 study, water consumption is estimated at between approximately 140 – 250 litres/day.

- ***Clothes Washing and Drying:*** Clothes washing is undertaken several times a week in family dwellings, reducing to less frequently among older people. As part of a study based on 1000 questionnaires (Annex 27) ‘air’ drying was most common at approximately 70% with 30% using drying machines or cupboards. Moisture becomes a problem when clothes drying takes place indoors or when clothes dryers vent within the building.

- ***Bathing and Showering:*** Approximately 70 – 85% of people take regular showers (depending on age) while the remainder use baths. The typical shower time is 10 minutes and, even with an exhaust fan, the relative humidity can reach 100% within 5 minutes (M◇nsson 2001). The water vapour production rate is estimated by at 2600 g/hour (43 g/minute) thus approximately half a litre of water turns to vapour during a typical shower.

- ***Cooking:*** Water vapour is produced by cooking and, if gas is used, by combustion. Cooking time varies between about 1 - 2 hours each day and is predicted to gradually reduce. Mechanically extracted cooker hoods are estimated to capture and remove up to 70% of the moisture generated.

Smoking: Approximately 30% of the adult population are smokers and much additional ventilation is needed to minimise the risks associated with tobacco smoke.

Cleaning of Vents: The French study reported that 2/3rds of occupants said that they cleaned ventilation vents and systems at least once a year.

System Satisfaction: The French study also reported that overall satisfaction of the ventilation system amounted to more than 73% of occupants in apartment buildings and 87% in dwellings. Factors that resulted in improved satisfaction with ventilation in the home included:

- age of householder;
- newer buildings;
- household income;
- number of rooms;

- surface area;
- ability to control ventilation system;
- type of system;

Adverse factors included:

- noise from mechanical ventilation;
- increased occupancy;
- tenancy.

Ventilation Relationship with Health: In the French study, of those who complained of poor health, over 59% were either dissatisfied or completely dissatisfied with their ventilation system.

4.6 Occupant Impact on the Total Ventilation and Air Change Rate

Annex 8 considered the additional seasonal ventilation rate (i.e. that which occurs above air infiltration) and background air change due to window use. This they defined as:

Low window use:	$\longrightarrow$	0.0 – 0.1 ach
Average window use:	$\longrightarrow$	0.1 – 0.5 ach
High window use:	$\longrightarrow$	0.5 – 0.8 ach

The Swedish study showed that the ventilation rate in occupied buildings is, on average, lower than 0.35/(l.s.m^2) or 0.5 ach in more than 80% of all the single-family houses and more than 50% of all the multi-family houses. Expressed in 1/s.inhabitant only approximately 50% of all, both single- and multi-family houses, have a ventilation rate higher than 10 l/(s, inhabitant). The influence of age, construction year, ventilation system, renovation status and geographical region can be traced by means of a scheme of relative-differences correction factors. The investigation of the air tightness of the houses showed mainly that newer houses are less leaky than older ones and that the prescribed maximum n50-leakage value, as stated in the Swedish Building Code, is reached only by the newest multi-family houses.

Iwashita and Akasaka (1997) conducted a residential survey assessing indoor environment and residents' behaviour (i.e. when they opened windows/doors, when they operated air conditioners, and so on) during the period of ventilation measurement. The purpose of this study was to measure the ventilation rate in occupied dwellings in Kagoshima City, located in the southern part of Japan. Actual air change measurements were made using tracer gas method to investigate the relationship between the occupants' behaviour in each dwelling and the energy consumption for air conditioning during the summer. Based on the continuous measurement of the ventilation rate in eight dwellings, the proportion between the total ventilation rates (ventilation rate during occupancy of the dwellings) and the basic ventilation rate (ventilation rate during non-occupancy and with door/windows closed) was evaluated. The main conclusion is that there is a large difference between the mean basic ventilation rate and the mean total ventilation rate. If the size of the basic ventilation rate and the user-influenced ventilation rate in the investigated dwellings are compared, it is found that 87% of the total air change rate is caused by the behaviour of the occupants.

4.7 Occupant Impact on Energy Consumption

A major component of the Annex 8 study was to evaluate the energy impact of ventilation in dwellings and to assess the benefit of avoiding excessive air change. Table 4.3 summarises the increase in space heating demand for mild and severe climates for each unit flow of ventilation air. Based on the Annex 8 study, 'average' window use is estimated to result in an increase in air change rate (over ambient) levels of between 0.1 – 0.5 ach whereas high window use results in an increase in air change rate between 0.5 – 0.8 ach. The average increase in air change rate due to occupancy was found to be 0.32 ach for naturally ventilated dwellings and 0.34 for mechanically ventilated dwellings. In energy terms, for a moderate (heating) climate excessive window opening revealed that energy use could rise by up to 17,000 MJ / 250 m^3 dwelling during the heating season compared to a 'normal' rate (for good air quality) of 11000 MJ.

Shorrock et al (1992) describe a comprehensive analysis of energy consumption in the UK housing stock. From this, the total annual air change energy demand is estimated at 0.285 EJ. These data are supported by a subsequent analysis by Liddament (1996) and approximate to an average air change rate of 0.92 ach. Based on a minimum average (continuous) ventilation need of 0.5 – 0.6 ach, the order of potential energy saving by providing efficient ventilation with the minimum of occupant window opening is similar to that observed by the Annex 8 study.

Table 4.3 Approximate Annual Energy Need for Increments in Air Flow Rate.

Climate	MJ / yr for each dm^3/s of air flow	MJ / year for each m^3/hr of air flow
Mild (1800 – 2600 Degree Days)	190 - 280	53 - 76
Severe (2100 – 3500 Degree Days)	220 - 370	62 - 103

4.8 Lessons Learnt and Procedures for Optimising Occupant Interaction

A key part of the Annex 8 study was to determine if ventilation habits could be improved by educating occupants to operate ventilation controls more efficiently, i.e. to 'modify' behaviour. To achieve this a specific set of ventilation instructions was developed for ventilation control in one of the monitored buildings. The use of these instructions showed some reduced use of unnecessary ventilation window opening. Other conclusions common to many of the investigated studies were that:

- Designers and regulators should provide the occupant with the means to adjust indoor climate to meet their individual needs, and more control is needed over ventilation openings (e.g. by using small windows and vents for winter ventilation).
- Information campaigns are needed to explain how to use ventilation openings and to avoid the contamination of indoor air. It is especially important to explain the operation of mechanical systems.
- Regulators must understand the background to ventilation, especially in relation to health. It is important, therefore, that ventilation guidance is specified.

GUIDELINES FOR EFFICIENT RESIDENTIAL VENTILATION

(These guidelines are based on the original Annex 8 proposals but are updated to cover developments in ventilation technology.)

Whole House Mechanical Systems

- Understand the system and its purpose;
- Do not seal or obstruct air grilles, or disconnect the system;
- Apply boost to meet high moisture loads etc.;
- Avoid excessive window opening during periods of heating (or mechanical cooling);
- Ensure the system is regularly cleaned and maintained.

Purpose Provided Natural Ventilation with Vents, Stacks and/or Local Extract, etc.

- Maintain background ventilation in all rooms each day, ensuring vents, etc. are kept open;
- Air bedrooms and living rooms daily by window opening for 10 – 20 minutes each day (e.g. while cleaning);
- Operate extract fans, set passive stacks to maximum or open a window while cooking. Maintain maximum airing for 10 - 20 minutes after cooking;
- Operate extract fans, windows, etc. during and after showering. Vents should be left open for some hours.

Do not allow indoor temperatures to fall below 16ºC since the capacity of the air to absorb moisture becomes drastically reduced, thus increasing the risk of condensation.

5.0 Occupant Impact on Ventilation: Non-Residential Buildings

5.1 Introduction

In non-residential buildings, occupants generally have less opportunity for direct control over their climate conditions. In addition, occupants sharing the same space may need different conditions to meet their preferred comfort requirement. Providing an environment that meets everyone's satisfaction is therefore often a difficult challenge. In attempting to understand comfort and health needs, much emphasis has been placed on occupancy surveys and health studies. Recent examples and conclusions are summarised in this section.

NON RESIDENTIAL BUILDINGS – KEY FEATURES

Offices, Libraries:

- Moderate occupancy density (approximately 1 person / 7 - 10 m^2);
- Mainly occupied in daytime and weekdays only;
- High heat loads from electrical equipment, solar gains and urban location;

Hospitals, Call Centres:

- Moderate occupancy density
- 24 Hour occupancy;
- High heat loads from electrical equipment;

Schools:

- High occupancy density (> 3 people / 10 m^2);
- Not occupied at night or at weekends;
- Often not occupied over the hottest summer months.

Recreational/Entertainment:

- High but very transient occupancy density (>4 people / 10 m^2);
- Potentially high heat loads (e.g. from people and activities);
- Large single enclosed spaces;

Manufacturing/Industrial:

- Low occupancy density (<1 person / 10 m^2)
- High polluting and thermal loads from processes;
- Large single enclosed spaces.

Buildings within the non-residential sector include:

- offices;
- shops and malls;
- recreational buildings such as theatres and cinemas;
- public buildings (hospital, libraries courts etc);
- educational buildings;
- manufacturing premises and warehouses.

To a first approximation these can be divided into:

- buildings with low to medium occupancy densities (e.g. offices, libraries and warehouses etc.);
- those with high and/or fluctuating occupancy densities (e.g. schools, airport lounges, shopping malls, lecture theatres and concert halls etc.);
- those with potentially high pollution loads (e.g. manufacturing industry).

Industrial applications are beyond the scope of this report and therefore discussion is restricted to the first two generic building types.

Special issues relating to non-residential buildings cover:

- indoor environment and productivity;
- ventilation strategies;
- urban climate;
- building type;
- occupant perceptions;
- occupant impact on energy consumption;
- lessons learnt and procedures for optimising occupant interaction.

5.2 Indoor Environment and Productivity

An area of importance in non-residential buildings is the impact of the environment on productivity. Woods et al (1993), for example, consider the system of relationships presented in Figure 5.1. This provides a conceptual relationship between human responses, exposures, systems, sources and economics. Sensharma et al (1998) have undertaken an extensive literature review of productivity in relation to the indoor environment. Aspects cover:

- How is occupant performance in non-industrial environments defined and measured?
- What are the factors that influence occupant performance and productivity in the non-industrial environment?

From this they conclude that much more standardisation of terminology and methods is needed to quantify links across the broad range of influencing parameters.

Wyon (1994) also looks at the economic benefit of a healthy indoor environment. His results include:

- Poor thermal conditions can reduce key aspects of human efficiency such as reading, logical thought and performing arithmetic by 5-15%;

- Poor air quality gives rise to subjective symptoms such as headache and fatigue and is estimated to reduce efficiency also by 5-15%;
- Poor air quality is strongly affected by temperature and temperature gradient;
- Payback time, in terms of productivity, for improved ventilation is estimated to be as low as 1.6 years.

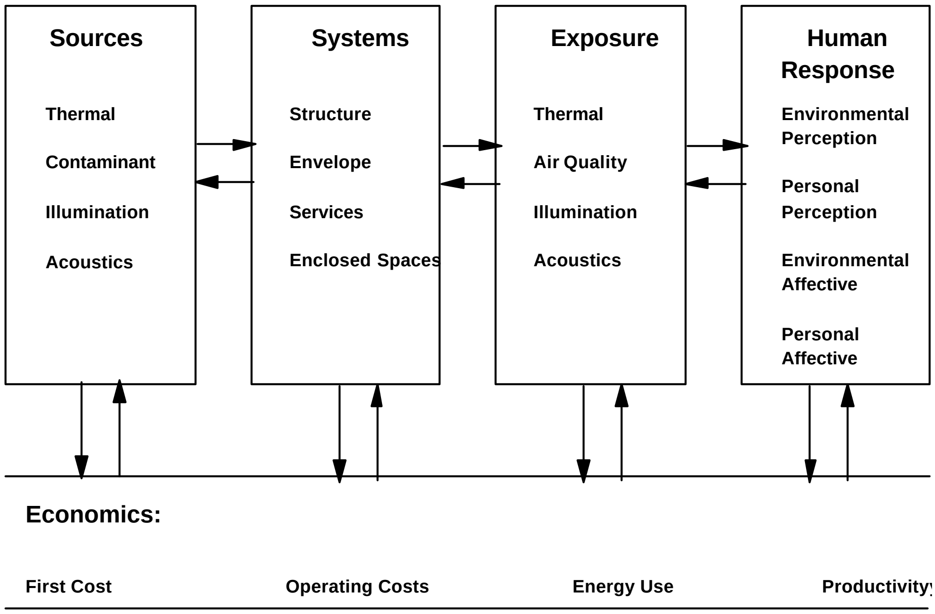

Figure 5.1 Rationale Model of System Relationships (Woods et al 1993)

5.3 Ventilation Strategies for Non-Residential Buildings

Depending on climate, building size and use, ventilation options include:

- natural;
- hybrid (mixed mode);
- mechanical (mixing with recirculation, displacement, 'task' ventilation).

In general, natural ventilation is applied to smaller buildings in mild climates. There has been much renewed growth in this area, especially for fabric (night) cooling as covered by the European NatVent Project (Perera 1999) and IEA Innovative Cooling (Zimmerman et al 1998). Where natural ventilation is not appropriate, hybrid ventilation is seen as a means of avoiding the need for fully mechanically ventilating and air conditioning spaces. This approach is especially applicable in climates where cooling need is primarily derived from internal heat gains, rather than from high outdoor temperature and humidity. This type of ventilation is currently being researched by the IEA ECBCS Annex 35 'HybVent' research project (Delsante and Vik 2000).

Mechanical mixing (usually with full air conditioning) is most common in severe climate regions (cold winters, hot and or humid summers) where a significant amount of thermal conditioning of the space is needed. Displacement ventilation has become increasingly popular in buildings in milder climatic regions in which the relatively low air flow rates of this type of system can accommodate the cooling or heating load, or such loads can be satisfied with hydronic radiators and/or chilled ceilings and beams. Task ventilation provides an element of individual occupant control and, therefore, serves to address the individual preferences of occupants.

Urban Climate: A particular problem associated with many non-residential buildings is that they are located in urban environments. This means that they are especially susceptible to problems associated with both industrial and traffic pollution. Local sources including stationary traffic, car parks and emissions from adjacent buildings can be a serious problem. Other aspects include the additional (external thermal load) created by heat island effects and noise.

5.4 'Low' and 'Medium' Occupancy Density Buildings (e.g. Offices, Warehouses, Libraries)

The key features of 'low' and 'medium' occupancy density buildings are:

- Occupancy density is approximately 1 person for each 7 - 10 m² of floor area.
- The enclosed volume of the space is relatively large compared its to surface area (i.e. a 'large' volume building in relation to dwellings).
- Occupancy and occupancy activity generated pollution can be relatively low (especially where smoking is banned).
- There is 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 and electrical equipment may be a concern;
- May be mechanically ventilated and air conditioned.
- In some countries these buildings can be very 'leaky'. This means that heating and cooling systems either don't provide 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.
- Occupants usually do not have direct access to climate and ventilation controls.
- Typically, concentrated heat and pollution loads are generally larger than for dwellings. This can change the balance, even for fairly cold climates, from the need to avoid excessive heat loss to preventing over-heating, even in winter.

In low to medium 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.

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 (for outdoor air) vary from about 8 – 10 litres/second.person (l/s.p). To reflect the different sources of pollutant (i.e. people, fabric and furnishings etc.) there is increasing emphasis on area weighted ventilation (e.g. litres/m^2 of floor area). The setting of such standards is still largely on-going (see also Section 2.3.2).

5.4.1 Monitoring Programmes

A wide range of occupancy surveys have been undertaken in office type buildings. Many examples are included in the Appendix. Surveys commonly investigate:

- building sickness;
- comfort;
- thermal climate;
- indoor air quality;
- work efficiency.

An attempt is made in this section to review some of the surveys and draw conclusions about occupant perceptions and needs for controls.

European Audit Project - Study in 56 Office Buildings: This study involved 15 institutes from 11 countries (The Netherlands, Denmark, France, Belgium, United Kingdom, Greece, Switzerland, Finland, Norway, Germany and Portugal) and took place in the heating season of 1993-94 (Bluyssen et al 1996). The main aim of this audit was to develop assessment procedures and guidance on ventilation and source control in occupied office buildings. A standard procedure was developed involving physical measurements (ventilation rate, thermal conditions and odour) and questionnaire response of occupants. Fifty-six buildings were selected in nine of the participating countries for audit. Key conclusions were:

- There is no contradiction between low energy consumption and good indoor air quality.
- There were no systematic regional differences in Europe concerning IAQ parameters, occupant responses or energy consumption.
- The average outdoor airflow rate was 1.9 l/s.m² or 25 l/s.person.
- 27% of the building occupants found the indoor air quality was not acceptable at the time of the building audit.
- 32% of the building occupants found that the IAQ was not acceptable during the month preceding the audit.
- In all buildings the air was found to be ‘dry’ by the occupants.
- The mean perceived odour intensity, as measured by a trained panel, was 6 decipol for outdoor air, 4 decipol for supply air and 2 decipol for outdoor air.
- No relationship was found between sensory and chemical pollutant loads or perceived air quality and TVOC levels.
- Identified pollution sources comprised emissions from materials and furnishings, ventilation system, occupants, tobacco smoking, cleaning agents and outdoor pollution.
- The mean perceived air quality showed significant correlation with the measured ventilation rates (i.e. buildings with higher ventilation rates tended to have better perceived indoor air). The mean operative temperature was 22.5 °C and mean air velocity was 0.08m/s. This was within comfort standards but, in general, occupants felt slightly warmer than neutral.
- The mean energy consumption was 1100 MJ/m² of heated floor area, with the range from lowest to highest varying by a factor of seven. Energy data were difficult to obtain and not known in detail. This probably accounts for the difficulty experienced in this project in correlating ventilation and (other sources of heat-loss) with energy consumption.

- Outside some of the audited buildings the perceived outdoor air quality was found to be poor and, in some cases, even poorer than the perceived indoor air quality.
- The ventilation system itself was often found to be a significant pollution source itself, especially from the filters.
- Views of occupants: Large variations between the occupants' perceptions within the same building were observed. The control of the office environment, especially the ventilation, was generally rated as low. In approximately half of the audited buildings, the occupants could not or were not permitted to open windows.

The average energy consumption of 1100 MJ/m² of heated floor area was well above best practice levels. Thus there is certainly indication that substantial opportunity for energy efficiency improvement. In terms of ventilation rate, the average monitored value of 25 l/s.p is comparable to the energy impact results illustrated in Figure 2.5 and is substantially above the minimum level set by many Standards. The study does note, however, that these higher rates give improved perceived indoor air quality. A major problem seems to arise from indoor pollutant sources which, apart from emissions from furnishings etc., included tobacco smoke. Source control seems to be the required remedy rather than excessive ventilation. This European report makes the point that considerable improvement to the office environment could be achieved by allowing occupants ventilation control, either by window opening or by task ventilation.

Swedish Audit on 200 Office Buildings: Sundell (1994) reports on numerous observations in Sweden involving occupant perceptions, tracer gas ventilation rate measurements and indoor air quality monitoring. Approximately 5000 occupants in over 200 office buildings were involved covering natural, mechanical and air conditioned buildings. His general conclusions were that:

- Indoor air is typically characterised by its constituents (mostly pollutants) or by human environmental perceptions (odour, "stuffy air", "dry" air) or body perceptions.
- Airflow rates were generally larger than those prescribed by current standards with a mean value of 16.9 litres/second.person (l/s.p) and a median of 13.6 l/s.p.
- No association was demonstrated between the type of ventilation system and reports of sick building syndrome (SBS).
- Ventilation running time of <10h/workday was associated with an increased risk of sbs.
- No increased risk was associated with rotary heat exchangers or recirculation.
- An association between increased risk of SBS and low ventilation rates (measured in l/s.p) was found (see Figure 5.2). This association was less pronounced for airflow rates measured in air changes/hour (ach).
- All reported results were tested, retested and compared in simple, stratified and multivariate analyses.

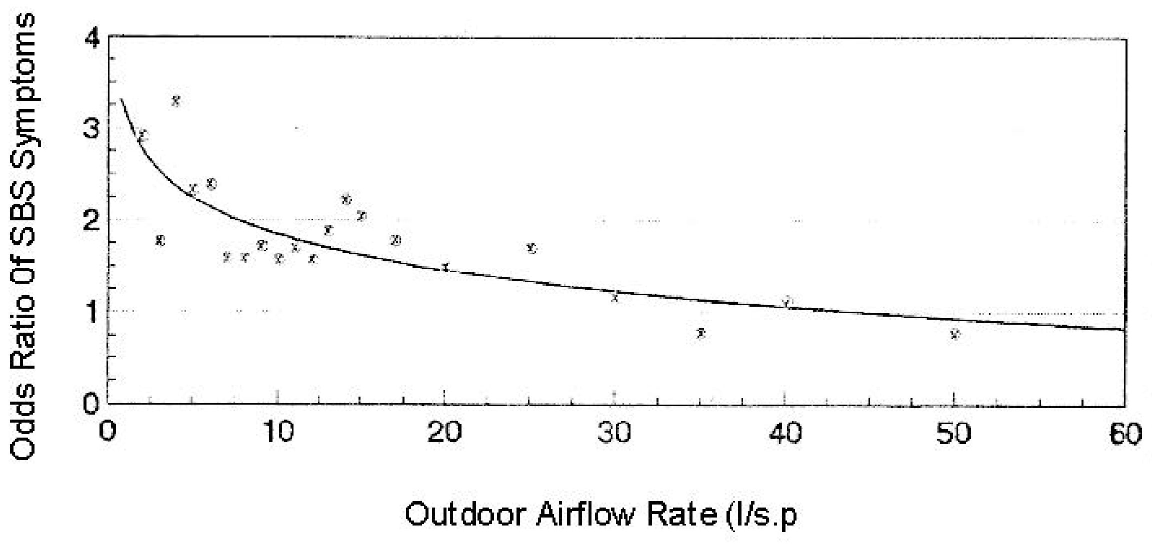

Figure 5.2 Relationship Between Symptoms of Sick Building Syndrome and Ventilation Rate (Sundell 1994)

Canadian Occupant Study on Offices with Mechanical Ventilation with Air Conditioning: In Canada, Haghighat and Donnini (1999) present results of environmental studies in twelve office buildings. These varied greatly in surface area, number of floors, occupant density, and building use. The indoor air quality, thermal comfort, energy consumption, and perception of occupants were investigated in these buildings. A total of 877 subjects participated in the questionnaire survey during the hot summer months of June, July and August, and during the cold winter months of January, February, and March. The questionnaire dealt with health, environmental sensitivity, personal control and the workstation's environment, and job satisfaction. Measured parameters concerning the quality of indoor air included ventilation rate, concentration of TVOC, CO_2, CO, RH, and formaldehyde. Thermal comfort parameters included room air, mean radiant, plane radiant asymmetry, and dew point temperatures, as well as air velocity and turbulence intensity. Monthly energy consumption data were also gathered for each building. Ventilation performance, in terms of air flow rate and indoor air quality, was compared with the ASHRAE Standard 62-89R. The measured and calculated thermal environmental results were also compared with the ASHRAE Standard 55-92 (Thermal Environmental Conditions for Human Occupancy). Measurement results showed that the outdoor airflow rate was half that recommended in only one building. The formaldehyde and TVOC levels were moderately higher than suggested comfort levels. Only 63% of the indoor climatic observations fell within the ASHRAE Standard 55-92 summer comfort zone and 27% in the winter. In terms of occupant perceptions, the following was observed:

- 56% of the occupants rated dissatisfaction with the indoor air quality.
- However, only 69% of those surveyed agreed with the comfort zones.
- More symptoms were reported by workers who perceived IAQ to be poor.
- Positive relationships were observed between the job satisfaction and satisfaction with office air quality, ventilation, work area temperature, and ratings of work area environment.
- Job dissatisfaction did not correlate with symptom reports.
- Occupants were more dissatisfied with IAQ when they preferred more air movement. In other words, the higher the perceived air movement, the greater the satisfaction with IAQ.

Displacement Ventilation: Dickson and Collins (1992) report on occupant surveys in an air conditioned energy efficient office building. It has three stories with overhanging canopies providing solar shading and 21% solar control glazing. The open plan interior is ventilated by a displacement system with three twist outlets in the floor to each desk position. A detailed questionnaire survey showed this to be one of the 'healthiest' buildings tested, with a very low 'building sickness symptom score'. Air temperature, humidity, air speed, fresh air, noise, dust and lighting were monitored and found to lie within accepted guidelines. Fine dust levels were lower than outside. Energy costs monitored over three years proved to be low for a building of this type. The achievement of good indoor air quality combined with energy efficiency is attributed to good passive design features, the displacement ventilation system, a limited smoking policy and active participation of the end user at all stages of the design, construction and management of the building.

Task Ventilation Monitoring: Bauman et al (1998) report on a field study of the impact of a desktop task/ambient conditioning system in office buildings. This was based on 42 selected workstations within three San Francisco office buildings occupied by a large financial institution. In this study, field measurements, including subjective surveys and physical monitoring were performed both before and after system installation to evaluate the impact of task ventilation on occupant satisfaction and thermal comfort, as well as the thermal environments within the office buildings. For comparative purposes a control group within each building, consisting of workers who did not receive task ventilation units, was studied concurrently. During the follow up field tests, performed three months after the task system installation, measurements were repeated under three different room temperature set point conditions (normal set-up and set down) to investigate the ability of the occupants to use the system. Survey results show that among six building assessment categories investigated, installation of the desktop task system provided the largest increases in overall occupant satisfaction for thermal quality, acoustical quality and air quality. A large majority of the workers in the control group indicated a preference for higher air movement at operative temperatures of 23°C and above. The percentage preferring higher air movement within the task ventilation group was significantly lower. Workers in the task unit group had the ability to adjust the air movement in their workstations in response to changes in the ambient temperature. Over the range of operative temperatures covered by this field study, air movement preference and thermal sensation votes by workers in the control group indicated that they were more than twice as sensitive to changes in temperature than those in the task unit group.

Natural Ventilation - the European NatVent Study: As part of the European NatVent study involving participants in the Belgium, Denmark, Netherlands, Norway, Sweden, Switzerland and the United Kingdom (Perera 1999), occupants in nineteen case study buildings were questioned over their environmental conditions during summer and winter. This was supported by a 7-day period of continuous climate monitoring in summer and winter. Monitored parameters included:

- air temperature;
- air movement;
- air quality;
- odour intensity;
- acceptability of climate;
- lighting;
- noise;
- overall comfort

For each of the two seasons, occupants were asked to rate these parameters in a range of ‘0’ satisfactory to ‘100’ wholly unacceptable. An example result is illustrated in Figure 5.3 below:

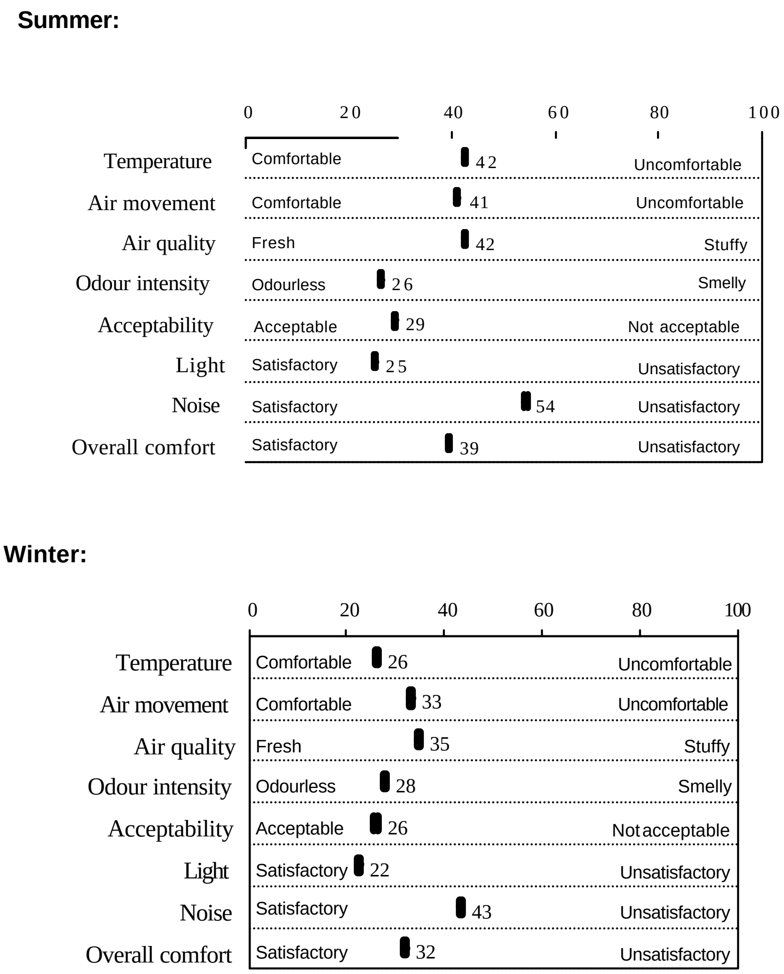

Figure 5.3 Example of NatVent Occupancy Rating

The case study buildings represented a ‘snap-shot’ of typical buildings, some of which incorporated specific natural ventilation features while others (relying primarily on window opening) incorporated no specific design. Results and conclusions included:

- Common problems, highlighted by occupants, in buildings in which there was no specific natural ventilation design included:
  - noise;
  - high indoor temperature and lack of air movement in summer resulting in unacceptable air quality;
  - cold draughts in winter.

- Benefits of buildings with integrated natural ventilation design (i.e. in which there was good integration of the thermal mass, night ventilation, solar shading and minimisation of internal heat gains). These generally performed well and usually achieved a reduction in peak (Summer) daytime dry bulb temperature of approximately 3K compared to the outdoor peak.

- Practical conclusions of the NatVent study include:

- Natural ventilation openings such as trickle ventilators, air intakes and exhausts should have individual control, accessible overrides and visual dampers. This need is demonstrated by one of the NatVent Case Study buildings in which an exhaust flow is controlled via an inaccessible damper located in the duct system. The damper system proved unreliable and, in cold weather, a reverse flow pattern could establish itself, in which much denser and colder outdoor air would back flow down the ventilation shafts. The only action available to the occupants was to tape cardboard over the grille as illustrated in Figure 5.4 below.

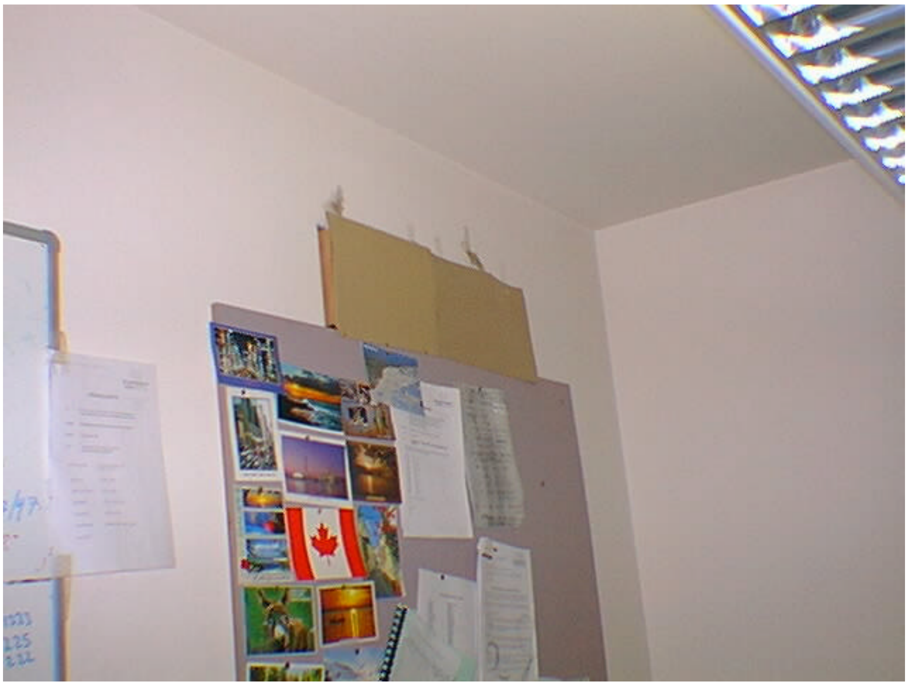

Figure 5.4 Uncontrollable and Back-Draughting Extract Grille is Taped Over by Occupants.

- Clear integration between thermal mass, ventilation air, shading and indoor heat sources. Natural ventilation designs do not work unless all these aspects are properly understood and applied.

Natural Ventilation vs Mechanical Ventilation with Air Conditioning: The UK Building Research Establishment has undertaken various studies to compare the occupants; perception of naturally versus air-conditioned buildings (Oseland et al 1996, 1997). Over a three-year period, winter and summer occupant surveys were carried out on the satisfaction with environmental conditions in 23 buildings. These were a mixture of naturally ventilated and air conditioned buildings. The results were based on an analysis of 5136 completed questionnaires. The aim was to determine the effect of ventilation type and season on occupant satisfaction with key environmental parameters including:

- thermal sensation;
- thermal comfort;
- humidity;
- air movement;
- stuffiness;
- air quality;
- lighting;

- noise.

General conclusions were that:

- Occupants considered the NV offices to be comfortable across a wider range of temperatures than AC offices in winter, but the range was similar in summer.
- Although 3% more occupants were satisfied with the environment in air-conditioned offices than in naturally ventilated ones, this difference does not justify the 60% extra energy consumption and the additional installation and maintenance costs associated with the air-conditioned offices.

Bordass et al (1997) also discuss occupancy comparisons between natural and air-conditioned buildings. Eight published post occupancy surveys focused on building services and energy performance, management and occupant satisfaction. Results showed that:

- All the buildings were relatively good and two of them had unusually high occupant satisfaction. These were a sophisticated deep-plan air conditioned office which demanded (and received) a high level of management; and a simple, low energy, largely naturally-ventilated medical centre, in which occupants were prepared to forgive some of the inefficiencies in lighting, ventilation and summertime temperatures.
- Very good energy performance was delivered in three of the naturally-ventilated buildings, but in the more advanced of them, difficulties with control, commissioning, usability and management - problems which also afflict air-conditioned buildings - had affected occupant satisfaction.
- The results indicate the need for better briefing; more recognition and discussion of the demands buildings are likely to make on their occupants and management; more robust and sometimes simpler solutions. Also, risks should be considered and minimised; intrinsically efficient systems with more usable controls and feedback; and better industry support to occupiers after hand-over are needed.

5.5 Non-Residential Buildings (‘High’ Occupancy Density e.g. School Classrooms)

While ‘high’ occupancy 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. Various studies have shown that schools, in particular, can be prone to very low rates of air change and, hence, high levels of CO_2. By dilution analysis and assuming sedentary activity, the relationship between the steady state metabolic CO_2 concentration and the ventilation rate is illustrated in Figure 5.5. This is confirmed in practice by the results of Myhrvold et al (1996) (shown in Figure 5.6) who undertook an analysis of pupils' health and performance following the renovation of schools Norway. The Figure illustrates the monitored air change rate and CO_2 concentration for 374 school hours in several schools. Based on a classroom volume of 162m³ and a class size of 30, the 1000 ppm limit set by the Norwegian Authorities equates to a minimum ventilation rate of 9 l/s.p. To test improvements resulting from renovation, schools were divided into ‘good’ with assumed good indoor environments, ‘bad’ waiting to renovated and experimental schools which had just been renovated. Apart from pupils expressing a view on their environment, they also undertook a reaction time test based on a Swedish Performance evaluation system. Results showed substantial improvements in perceived climate and reaction time of pupils in the renovated schools. Other examples include Sundell in Sweden (1994) who reports on CO_2 concentrations in schools of up to 5000 ppm while, in the UK, Lugg et al (1999), illustrate rapid rises in CO_2 concentration due to lack of sufficient ventilation.

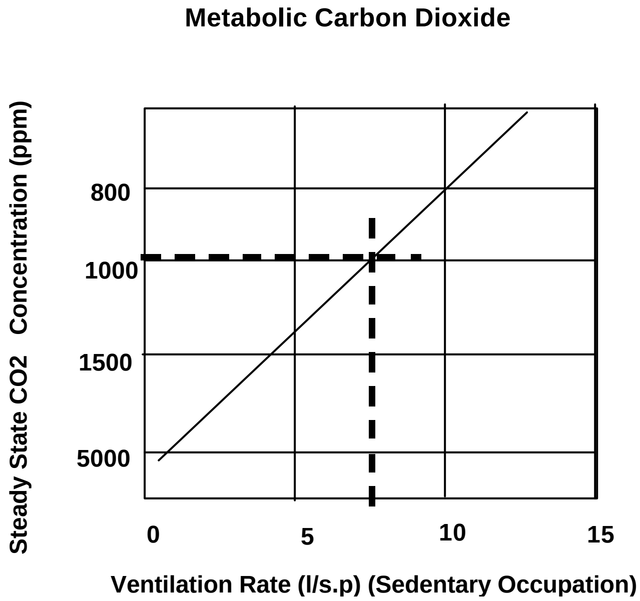

Figure 5.5 Relationship Between Steady State Metabolic CO_2 Concentration and Ventilation Rate (Assuming an Outside CO_2 Concentration of 350 ppm)

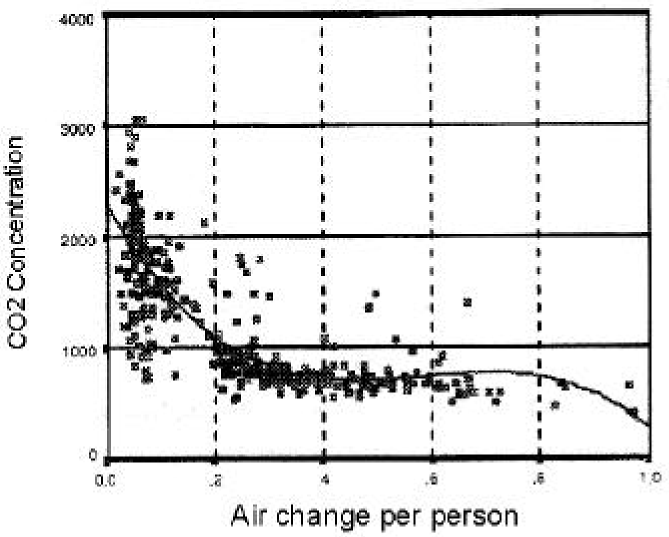

Figure 5.6 CO2 Concentrations Monitored in Schools

5.6 Energy Impact – Non Residential Buildings

The energy impact due to occupancy and ventilation is largely consistent across the studies reviewed. From Orme (1998), approximately 40% of energy in key industrialised countries is consumed in buildings and about one third of this is consumed in non-residential buildings. Of this, about half is dissipated through ventilation and air infiltration. Actual heat loss equates very approximately with a ventilation rate of 25 l/s.p. Since typical standards and norms for minimum ventilation are in the region of 10 l/s.p, there is scope for radical energy reduction. This is dependent, however, on providing efficient ventilation and on eliminating indoor pollutant sources.

5.7 Lessons Learnt

Lessons learnt from the non-residential sector include:

- Outdoor air quality and air intake location have been outlined as problems, especially in the European Framework project.
- There is a strong correlation between ventilation rate and perceived IAQ and sick building syndrome. Sundell, for example, (Figure 5.1) illustrates the potential for increased risk of SBS at ventilation rates below approximately 10 l/s.p Further improvements are achievable at higher rates.
- Pollution emissions from furnishings, fabrics and activities such as smoking, often dominate the need for ventilation. Health, comfort and energy efficient performance depends on minimising these emissions.
- Ventilation systems themselves can become very contaminated and cause pollution - regular maintenance is essential.
- Several of the studies illustrated the benefit of providing user controls to improve occupant satisfaction. Generally, occupants having access to openable windows or task ventilation systems were more content with the environment.
- Schools in many countries appear to be under-ventilated in relation to current norms. This is demonstrated by the reporting of high concentrations of metabolic CO_2. Because schools, theatres, restaurants etc. have a relative high (and transient) density of occupation in relation to the enclosed volume, metabolic CO_2 rises rapidly, hence they may benefit from CO_2 demand controlled ventilation systems.
- Typical ventilation flow rates (as measured in the European study) were more than twice that of many standards. Provided the causes of indoor air pollution are minimised, a substantial reduction in ventilation rate, resulting in the halving of ventilation energy dissipation, is achievable.

6.0 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, for example, has given comprehensive guidelines (NKB 1991).

In Sweden, the Swedish Parliament decided in 1991 that ventilation systems in all non-industrial buildings should be regularly inspected at intervals from 2 to 9 years (shortest for schools, hospitals, etc and longest for naturally ventilated apartments) (Månsson 1998). The systems are checked to fulfil the requirements given when installed. The goals of the evaluation were to give estimated rates for how many systems were approved by the end of 1997 and the cause of the faults that led to the system either not being approved or being remedied before the next inspection. The evaluation was made in three steps:

1. A questionnaire was sent out to a selected number of municipal authorities.
2. A questionnaire was sent out to housing organisations representing more than 60% of all apartments in Sweden.
3. In total 10,300 inspections were completed.

Results showed the estimated approved rate at the end of 1997 to be:

- schools 85-90%,
- day nurseries 90-95%,
- hospitals 40%,
- offices 40%,
- dwellings 65-70% (condos 85-90%, publicly owned 75-80%, private <50%).

Stack ventilation was found to have far more faults than any other system. Repeated inspections decreased the number of faults and increased the approved rate. The most frequent fault was insufficient flow rate. These results illustrate that without wide scale testing and remedial work, there is a risk that many buildings will not be functioning correctly.

A review of this topic is covered by Lloyd (1996).

7.0 Modelling Occupant Behaviour

An area of growing significance is the modelling of occupant behaviour. In other words, it is important to be able to simulate, in numerical terms, both the way in which occupants will react to their environment and the impact that occupant actions will have on their local environment (e.g. increased air change).

Early algorithms devised by Annex 8, focused on determining the additional impact that window opening would have on the natural air change rate derived from leaks in the building. Thus, an algorithm was devised that could add the impact of window opening on to that of air leakage, where the air leakage parameter was based on the tightness of the building at 50 Pa induced pressure. The resultant algorithm is presented in Figure 7.1

This activity was further developed by Roulet and Vandaele (1991) as part of ECBCS Annex 20 (Airflow Patterns Within Buildings). In this study he outlines a stochastic model of inhabitant behaviour. This begins with an assessment of driving variables (Table 7.1).

Table 7.1 Driving Variables and Parameters for Inclusion in a Stochastic Model

External Variables	Internal Variables	'Human' Parameters
Outdoor Temperature	Indoor Temperature	Time of Day
Solar Radiation	Odours	Type of Day
Wind Velocity	Contaminants	Type of Building
Rain	Moisture	Habits etc.
Noise		
Odours and Pollutants		

The purpose of the model is to generate opening sequences for doors and windows (including angle of opening and period of opening) which give results similar to measurement sequences but using only a small amount of measurement data. A Markov chain approach is used in which the state at one time step depends only on the preceding state. This has proved a suitable model for simulating window-opening angles. The models developed include:

- an internal door model (including activity level such as work hours, breaks etc.);
- a window opening (and angle of opening model);
- an external door model.

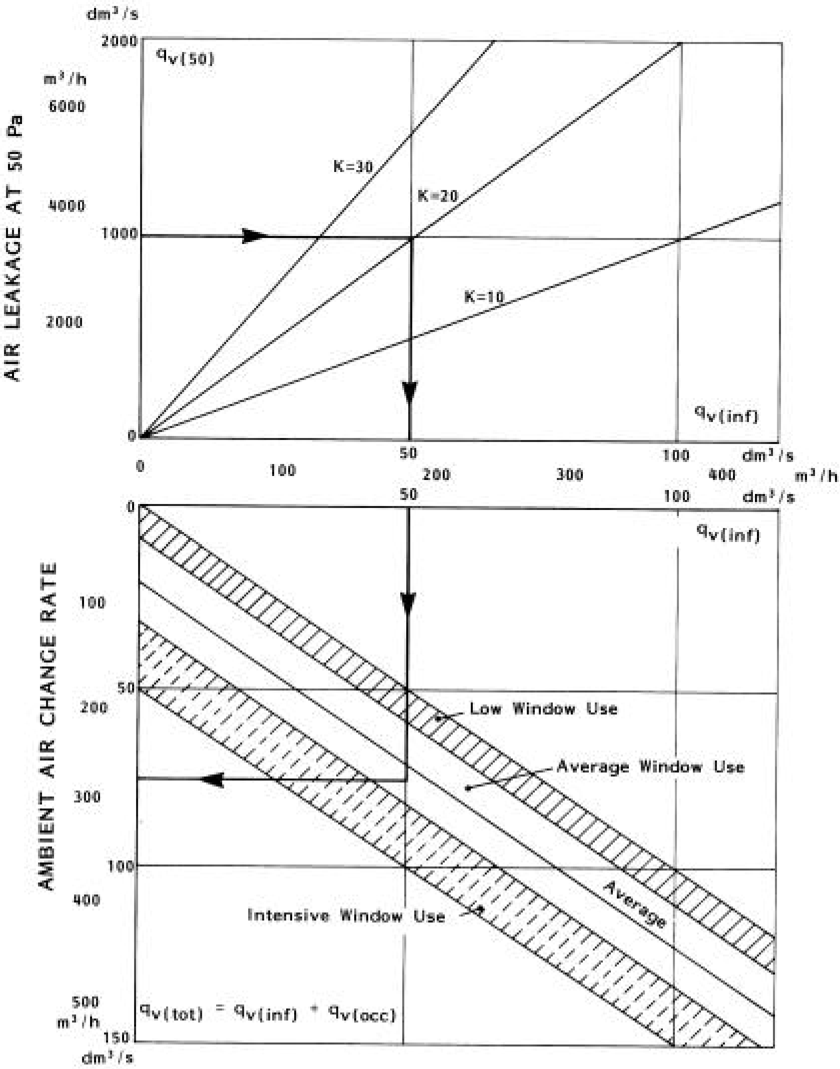

Figure 7.1 Nomograph for Determining Typical Heating Season Ventilation Rates in Dwellings (Annex 8, Dubrul 1988)

Applicable Ventilation Models: To obtain information on the impact of occupants, it is necessary to incorporate the results of occupant behaviour into a time dependent ventilation (and thermal) model. A compendium of applicable models has been published by Orme (1999).

A recent design tool (*ENERVENT*) for analysing the impact of ventilation systems and occupant interaction has been developed as part of the Annex 27 evaluation of domestic ventilation systems (Månsson 2001). An example for a passive stack ventilation system is illustrated in Figure 7.2.

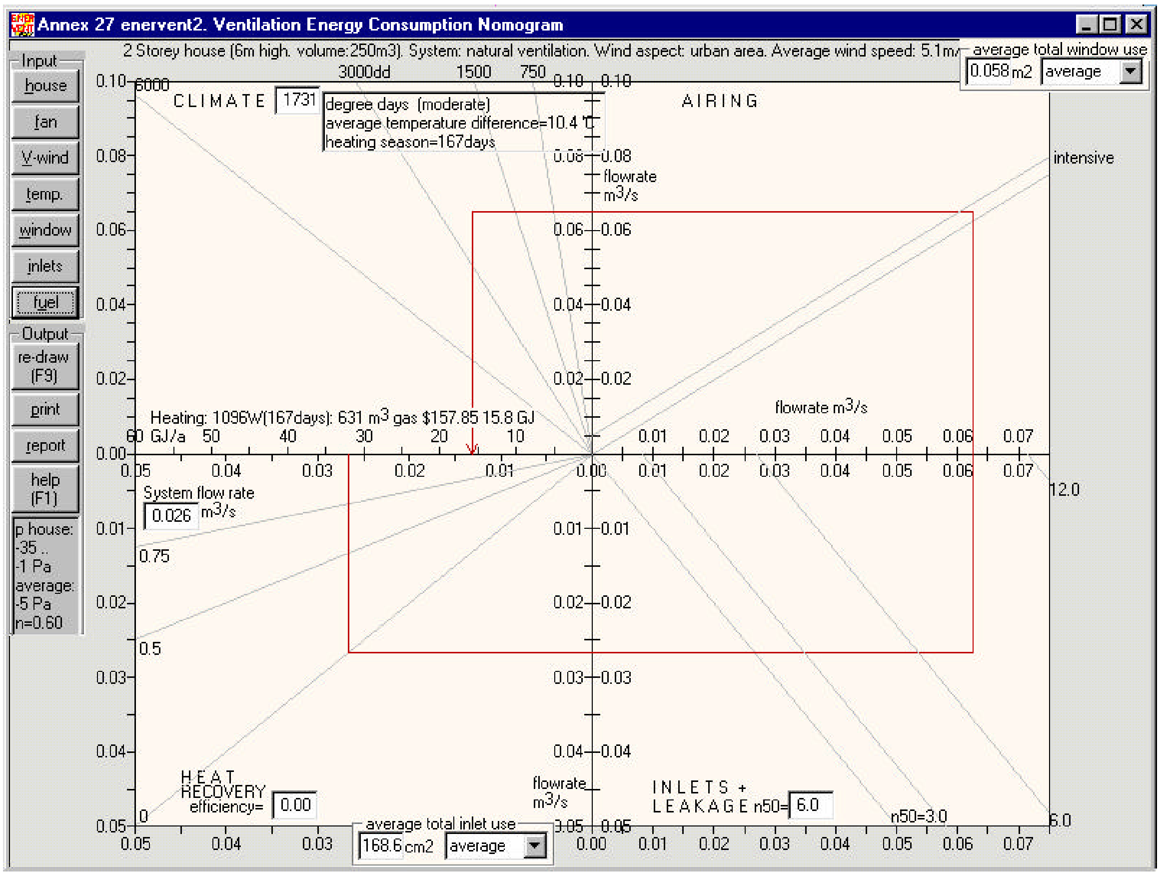

Figure 7.2 Ventilation Energy Consumption Nomogram

Behind this nomogram is a single zone ventilation model that takes into account key parameters including:

- climate conditions;
- occupant 'airing' (e.g. by window opening);
- system flow rate;
- building air leakage;
- heat recovery efficiency.

This approach enables an integrated ventilation system to be optimised according to the various loads imposed on it. Above all it enables the energy and economic performance of different ventilation systems to be analysed when confronted with dealing with identical performance requirements.

The final output is given as:

- the average heating power needed in W;
- the amount of fuel used, expressed in user-defined units;
- the annual cost in user-defined units;
- the annual energy consumption in GJ;
- net present value for the energy cost over 30 years;
- flow rate and fan pressure;
- fan efficiency;
- time for which the system is in use.

8.0 Conclusions

Occupancy case studies and surveys easily highlight both successful solutions to ventilation and simple mistakes that lead to failure. Summarised below are some of the key lessons:

Successful solutions include:

- Accessible and finely adjustable controls which have an immediate impact;
- Automatic controls (with over-ride) to give overall control;
- The building design should accommodate the varying needs of occupants so that occupants can do the fine-tuning themselves;
- Good integration of the ventilation system with the building design. Use should be made of existing knowledge, especially in relation to shading, daylighting, thermal mass and ventilation needs;
- The building and its controls must be adaptable to meet the varying requirements of occupants;
- The outdoor air must be free of contaminants. Air intakes must be placed away from pollution sources such as adjacent stacks, vehicles or other polluting processes. Practical and quantitative guidelines are needed for the placement of air intakes.
- The system must be easy to maintain. All parts must be accessible for dismantling, cleaning and replacement;
- Good documentation.

Poor solutions include:

- Inadequate research into good design;
- Failure to understand how the strategy operates and integrates with the rest of the building;
- Improper sizing of openings, systems etc.;
- Complex controls with meaningless or confusing symbols;
- Inaccessible, unreliable and leaky dampers;
- Poor documentation;
- Lack of design especially in coupling ventilation with the heating and cooling strategy and with thermal mass etc.;
- Inadequate building airtightness.

The numerous studies that have been undertaken in recent years provide good direction for providing occupant friendly buildings that are energy efficient, healthy and comfortable.

9.0 References

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Appendix - Bibliography of Occupant Surveys

OFFICES

#NO 11794 Impact of psychosocial factors on perception of the indoor air environment studies in 12 office buildings.
AUTHOR Haghighat F, Donnini G
BIBINF UK, Building and Environment, No 34, 1999.
ABSTRACT The main function of a mechanically ventilated office building is to provide a healthy and comfortable working environment for occupants, while maintaining minimum energy consumption. Twelve mechanically ventilated buildings were selected. They varied greatly in surface area, number of floors, occupant density, and building use. The indoor air quality, thermal comfort, energy consumption, and perception of occupants were investigated in these buildings. A total of 877 subjects participated in the questionnaire survey during the hot summer months of June, July and August, and during the cold winter months of January, February, and March. The questions included in the questionnaire dealt with health, environmental sensitivity, work area satisfaction, personal control and the workstation's environment, and job satisfaction. Measured parameters concerning the quality of indoor air included ventilation rate, concentration of TVOC, CO2, CO, RH, and formaldehyde. The thermal comfort parameters included room air, mean radiant, plane radiant asymmetry, and dew point temperatures, as well as air velocity and turbulence intensity. Monthly energy consumption data was also gathered for each building. Ventilation performance, in terms of air flow rate and indoor air quality, was compared with the ASHRAE Standard 6289R (Ventilation for Acceptable Indoor Air Quality, Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. U.S.A. [1]). The measured and calculated thermal environmental results were also compared with the ASHRAE Standard 5592 (Thermal Environmental Conditions for Human Occupancy, Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. U.S.A. [2]). CO2 and CO levels satisfied the recommended limits. The outdoor airflow rate was half that recommended in only one building. The formaldehyde and TVOC levels were moderately higher than suggested comfort levels. However, more that 56% of the occupants rated dissatisfaction with the indoor air quality. Only 63% of the indoor climatic observations fell within the ASHRAE Standard 5592 summer comfort zone; 27% in the winter. However, only 69% of those surveyed agreed with the comfort zones. More symptoms were reported by workers who perceived IAQ to be poor. Positive relationships were observed between the job satisfaction and satisfaction with office air quality, ventilation, work area temperature, and ratings of work area environment. However, job dissatisfaction did not correlate with symptom reports. The occupants were more dissatisfied with IAQ when they preferred more air movement. In other words, the higher the perceived air movement, the greater the satisfaction with IAQ.

#NO 11775 The environmental protection agency's research program on total human exposure.
AUTHOR Ott W, Wallace L, Mage D, et al
BIBINF Environment International, Vol 12, 1986.
ABSTRACT The U.S. Environmental Protection Agency's (U.S. EPA) research program on total human exposure to environmental pollution seeks to develop a newly emerging concept in the environmental sciences. Instead of focusing purely on the sources of pollution or their transport and movement through the environment, this

research focuses on human beings as the receptors of these pollutants. People and daily activities become the center of attention. The methodology measures and models the pollutant concentrations found at the physical boundaries of people, regardless of whether the pollutants arrive through the air, water, food, or skin. It seeks to characterize quantitatively the impact of pollution on people by determining if an environmental problem exists at the human interface and, if so, by determining the new sources, nature, extent, and severity of this environmental problem. By exploiting an emerging new arsenal of miniaturized instruments and by developing statistically representative survey designs for sampling the population of cities, significant progress has been made in recent years in providing previously unavailable human exposure field data needed for making valid risk assessments. The U.S. EPA total human exposure research program includes: development of measurement methods and instruments, development of exposure models and statistical protocols, microenvironmental field studies, total human exposure studies, validation of human exposure models with empirical data, and dosage research investigations.

#NO 11428 Modelling people.
AUTHOR Riordan P
BIBINF UK, Building Performance, No 1, Spring 1998, pp 1415, 2 figs, 3 tabs.
ABSTRACT Describes results of work on occupants' heating and cooling behaviour in temperate climates. Explains the difficulties of building simulation in relation to occupant behaviour. The underlying assumption in most thermal simulations is that building occupants seek "thermal comfort". These assumptions have a crucial effect on energy consumption predictions and design messages. Key facts about occupant behaviour are observed. People have a variety of ways of dealing with being too hot or cold, and thermal neutrality is not necessarily the desired state: they apparently often alter controls in order to feel the change. Results of a survey are tabulated.

#NO 11124 Occupant satisfaction with environmental conditions in naturally ventilated and air conditioned offices.
AUTHOR Oseland N A, Brown D K, Aizlewood C E
BIBINF UK, Chartered Institution of Building Services Engineers, 1997, proceedings.
ABSTRACT During the past three years, BRE has conducted winter and summer occupant surveys on satisfaction with environmental conditions in 23 buildings. These were a mixture of naturally ventilated and air conditioned buildings. The results presented in this paper are based on a secondary analysis of 5136 completed questionnaires. The aim of the analysis was to determine the effect of ventilation type and season on occupant satisfaction with key environmental parameters: thermal sensation, thermal comfort, humidity, air movement, stuffiness, air quality, lighting and noise. Although 3% more occupants were satisfied with the environment in air conditioned offices than in naturally ventilated ones, this difference does not justify the 60% extra energy consumption and the additional installation and maintenance costs associated with the air conditioned offices.

#NO 11114 Probe: some lessons learned from the first eight buildings.
AUTHOR Bordass W, Bunn R, Cohen R, Standeven M, Leaman A
BIBINF UK, Chartered Institution of Building Services Engineers, 1997, proceedings
ABSTRACT Eight published post occupancy surveys have focused on building services and energy performance, management and occupant satisfaction in buildings of technical interest. All the buildings are relatively good; and two of them had unusually high occupant satisfaction: a sophisticated deepplan air conditioned office which demanded (and received) a high level of management; and a simple, low energy, largely naturally ventilated medical centre, in which occupants were prepared to forgive

some of the inefficiencies in lighting, ventilation and summertime temperatures. Very good energy performance was delivered in three of the naturally ventilated buildings, but in the more advanced of them, difficulties with control, commissioning, usability and management problems which also afflict airconditioned buildings had affected occupant satisfaction. The results indicate the need for better briefing; more recognition and discussion of the demands buildings are likely to make on their occupants and management; more robust and sometimes simpler solutions with downside risks considered and minimised; intrinsically efficient systems with more usable controls and feedback; and better industry support to occupiers after handover.

#NO 11098 Field study of the impact of a desktop task/ambient conditioning system in office buildings.
AUTHOR Bauman F S, Carter T G, Baughman A V, Arens E A
BIBINF USA, Ashrae Transactions, Vol 104, Pt 1, 1998.
ABSTRACT A field study was carried out to assess the impact of installing a desktop task/ambient conditioning (TAC) system at 42 selected workstation within three San Francisco office buildings occupied by a large financial institution. In this study, field measurements, including subjective surveys and physical monitoring were performed both before and after the TAC system installation to evaluate the impact of the TAC system on occupant satisfaction and thermal comfort, as well as the thermal environments within the office buildings. For comparative purposed within each building, a control group consisting of workers who did not receive and desktop TAC unit, was studies concurrently. During the follow up field tests, performed three months after the TAC system installation, measurements were repeated under three different room temperature setpoint conditions (normal setup and setdown) to investigate the ability of the occupants to use the desktop TAC units to control their local environment in response to a wider range or ambient temperatures. Survey results show that among the six building assessment categories investigate, installation of the desktop TAC system provided the largest increases in overall occupant satisfaction for thermal quality, acoustical quality and air quality. In terms of specific environmental factors, increased occupant satisfaction levels among the TAC group were strongly significant in comparison to changes within the control group for both temperature and temperature control. A large majority of the workers in the control group indicated a preference for higher air movement at operative temperatures of 73oF (23oC) and above. The percentage preferring higher air movement with the TAC group was significantly lower. Workers in the TAC group had the ability to use their TAC units to adjust the air movement in their workstations in response to changes in the ambient temperature. Over the range of operative temperatures covered by this field study, air movement preference and thermal sensation votes by workers in the control group indicated that they were more than twice as sensitive to changes in temperature than those in the TAC group.

#NO 10625 A method for assessing indoor air quality in office buildings.
AUTHOR Kirchner S, Derangere D, Riberon J, et al
BIBINF France, Centre Scientifique et Technique du Batiment, proceedings of the Second International Conference on Buildings and the Environment, held Paris, June 912 1997, Volume 1.
ABSTRACT Health complaints related to indoor air quality are increasingly common. Hence, it is well known that environmental factors act on the emergence of certain illnesses. Today, many people consider that their health problems are due to a specific building environment. Chemical, microbiological and particulate pollutants are of interest, but only a one category of potential factors. Other risk factors have been identified ranging from the individual's sex and health status to psychosociological issues and buildings characteristics. Based

on French and international research experiences, work is being conducted in order to produce a multidisciplinary audit method in order to classify office buildings in terms of indoor air quality on given criteria. The investigation protocol uses walk through survey, questionnaires, measurements of indoor climate factors and comparison with threshold values. In addition, the protocol gives a strategy when solving indoor air problems. The visual inspection list is used to collect information on the building, its equipments, its operation conditions and potential pollutant sources. The aim of the questionnaire is to know the prevalence of health and comfort problem as well as environmental conditions and other aspects of the office environment of the building occupants.

#NO 10531 Field study of occupant comfort and office thermal environments in a cold climate.
AUTHOR Donnini G, Molina J, Martello C, et al
BIBINF USA, Ashrae Transactions, Vol 103, Part 2, 1997.
ABSTRACT This paper presents the findings of ASHRAE research project RP821, a field study of occupant comfort and office thermal environments in 12 mechanically ventilated office buildings in southern Quebec. A total of 877 subjects were surveyed during hot and cold months. Each interview provided a set of responses to a questionnaire and a set of physical indoor climatic measurements. The incremental effect of chairs was included in the estimates of clo values.

#NO 10471 Variable air volume air conditioning system under reduced static pressure control.
AUTHOR Tung D S L, Deng S
BIBINF UK, Building Serv Eng Res Technol, Vol 18, No 2, 1997.
ABSTRACT Claims that despite its fall from favour, air conditioning will continue to be essential in high density urban areas, but that there will be many cases where there is no clear distinction as to which mode of environmental control, natural or mechanical, should be adopted. Describes the results of a study conducted by the Welsh School of Architecture and the Bartlett, which set out to determine what it was about hvac systems and their operation that accounted for the notes ill health of occupants. The study of each building included a detailed examination of the hvac system, a survey of the occupants' utilisation of space; monitoring of the workspace environmental conditions throughout the building over a period of at least one week in the summer and winter; and a questionnaire survey of over 2190 occupants and the completion of daily diaries to determine the occupants' health, comfort, detailed occupation and overall attitudes and behaviours at work. The final range of building sickness scores suggested that there was nothing inherently unhealthy about air-conditioned buildings. However, poor maintenance was implicated in occupant ill health.

#NO 10314 BRE office environment survey: comfort and health in naturally ventilated versus air conditioned offices.
AUTHOR Oseland N A, Aizlewood C E
BIBINF UK, CIBSE, 1996, proceedings of CIBSE/ASHRAE Joint National Conference PROC. 1996.
ABSTRACT The thermal environment was continuously monitored for one week in winter and one week in summer in four naturally ventilated (NV) and four air conditioned (AC) UK offices. Occupants considered the NV offices to be comfortable across a wider range of temperatures than AC offices in winter, but the range was similar in summer. The neutral temperature in NV offices was 1.3 Deg C lower in winter and 2.2 Deg. C lower in summer than in AC offices. However, there was only a marginal difference in clothing insulation and activity levels between the two types of office. Discrepancies of up to 4 Deg. C were found between the observed neutral temperatures and those predicted by international standard ISO 7730. Health questionnaires were completed in the same buildings, and sensory panel evaluations of air quality were made.

#NO 9669 Occupant questionnaire on interior environmental conditions: initial results.
AUTHOR Levermore G J
BIBINF UK, Building Serv Eng Res Technol, Vol 17, No 1, 1996.
ABSTRACT An initial survey has been conducted to assess a selfadministered questionnaire, fingerprint and liking score which are aimed at quantifying, in a simple manner, occupants perceptions of their interior environments, 450 questionnaires have been analysed. The average liking scores for groups of occupants range between 14% and +19%. The questionnaire responses have been found to be consistent in two testretests and in agreement with an earlier independent survey. The results from four groups of occupants in four different buildings, (208 responses), naturally ventilated and air conditioned, are discussed in detail. In general there was agreement etween the liking scores and building sickness scores but two buildings, each with a Building Sickness Score of 1.7, had liking scores of +19% and +1%. The questionnaire also revealed that office temperature, occupant health, and daylight were important factors. Although minor modifications to the questionnaire are considered, and have been implemented in the PROBE project, it is hoped that the questionnaire will become a useful management and design tool.

#NO 9668 Freshness, ventilation and temperature in offices.
AUTHOR ClementsCroome T D J
BIBINF UK, Building Serv Eng Res Technol, Vol 17, No 1, 1996.
ABSTRACT An environment survey has been undertaken of environmental conditions in 23 office spaces. This paper focuses on the responses of 228 occupants who voted on a fresh to stale sevenpoint scale. The most significant factors found in this survey for judging freshness were air temperature and fresh air supply rate. Current standards for fresh air are questioned and there is certainly a need for fresh air ventilation controls to be more sensitive to changes to indoor temperature of only 1 degree C steps which may occur throughout the day.

#NO 9585 Organisational and job factors in sick building syndrome: a critique and some suggestions for future research.
AUTHOR Whitley T D R, Makin P J, Dickson D J
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings 1995.
ABSTRACT The office environment survey (Wilson and Hedge, 1987) indicated that sick building syndrome was higher in all types of public sector buildings compared to their private sector counterparts. However, when public and private sectors occupied different floors of the same building similar sickness rates were recorded. A public sector organisation which occupied difference buildings, one naturally ventilated, the other deep plan air conditioned had very different sickness rates. In summary the authors (Wilson and Hedge, 1987) concluded (Section 4.4) that: Further study on organisational factors is certainly warranted...ultimately the quality of our office stock reflects the policies and priorities of the organisations occupying it .

#NO 9583 The impact of outdoor air intake rate on the indoor air quality of office buildings located in metropolitan areas.
AUTHOR Sohn JY, Yee JJ, Moon HJ, Song K D
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 1014 September 1995, pp 14011406, 6 figs, 3 tabs, 5 refs.
ABSTRACT Recent rapid increases in global atmospheric contamination levels, especially in metropolitan areas, lead to high attention to indoor air qualities in commercial buildings located in the polluted areas. One of the most common methods to provide office workers with a clean and comfortable indoor air environment is ventilation, in which a certain portion of the return air from the interior spaces is replaced by outdoor air in the air handling unit (AHU). Indeed, ventilation is the most effective method of maintaining a high quality indoor air

environment when the outdoor air is fresher than the indoor air. However, ventilation usually causes higher energy consumption in HVAC system due to the temperature and humidity controls with the raw outdoor air. Therefore, it is a key objective of this field study to identify the impact of outdoor air intake rates at the air handling units on the indoor air contaminant levels in commercial office buildings especially located in metropolitan areas. A total of four commercial office buildings located in Seoul, Korea and Tokyo, Japan were selected for field measurements. The concentration levels of the indoor air pollutants were monitored at different outdoor intake rates and the odor and discomfort ratings were made by the occupants through questionnaire surveys.

#NO 9578 Developing baseline information on buildings and indoor air quality (BASE 94): Part I study design, building selection, and building descriptions.
AUTHOR Womble S E, Girman J R, Ronca E L, Axelrad R, Brightman H S, McCarthy J F
BIBINF Healthy Buildings 95, edited by M Maroni, proc. 1995.
ABSTRACT The U.S. EPA s Office of Radiation and Indoor Air (ORIA) has initiated a major study of indoor air quality (IAQ) to fill a significant data gap that exists regarding baseline IAQ in public and commercial office buildings. The goal of the study is to define the status of the existing building stock with respect to IAQ and occupant perception. The ongoing crosssectional study, entitled Building Assessment Survey and Evaluation (BASE) Program, is collecting baseline data characterizing public and commercial office buildings. The study buildings are randomly selected without regard to IAQ complaints. Core parameters and measured in a representative space in each building. This paper discusses the study design and the building and study space selection. Summaries of building descriptions and the results of measurements related to thermal comfort and ventilation for the first thirteen buildings are also included. The building descriptions include information about building age; size; study area location within the building; heating, airconditioning and ventilation (HVAC) system type; occupant activities; smoking policy; and percent outdoor air. The measurements related to thermal comfort include indoor and outdoor temperatures and relative humidities. The data collected are coded for confidentiality and are in a publiclyaccessible database. A separate paper (Part II) presents the results of pollutant measurements and occupant perceptions.

#NO 9577 Ventilation performance and energy consumption in European office buildings.
AUTHOR Roulet CA, Bluyssen M, Ducarme D, et al
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 1014 September 1995, pp 12991304, 4 figs, 6 refs.
ABSTRACT Fifty six office buildings, selected in nine European countries for being as far as possible representative of the building stock, were audited between December 1993 and March 1994. These audits were performed according to a standard procedure, within the frame of the European Audit Project to Optimise Indoor Air Quality and Energy Consumption in Office Buildings , part of the JOULE Programme (CECDG XII). The main purpose of office buildings is to provide a comfortable working environment for occupants. This includes, among others, thermal, visual and acoustical comfort as well as indoor air quality. One of the objectives of the survey was hence to assess the actual quality of the indoor environment in office buildings. Measured parameters concerning the quality of indoor environment included occupant satisfaction, sick building symptoms and concentration of contaminants. Yearly energy consumption data were also gathered for each building. Ventilation performance in terms of air flow rate and indoor air quality was compared to a proposed European prestandard and related to occupant satisfaction and energy consumption. Theoretically, energy is required to control the indoor climate and indoor air quality. Therefore, it is a common

perception that energy savings will result in a poorer quality indoor environment. It was interesting therefore to relate energy consumption to various parameters describing the indoor environment. The results show that good indoor environment is compatible with low energy consumption. Good quality energy services do not necessarily incur a high energy use.

#NO 8755 Individual and occupational correlates of the sick building
AUTHOR Hedge A, Erickson W A, Rubin G.
BIBINF Denmark, Indoor Air No 5, 1995.
ABSTRACT Results of a questionnaire survey of 939 workers from 5 airconditioned offices where smoking was prohibited are reported. Levels of carbon monoxide, carbon dioxide, formaldehyde, respirable particulates, and temperature, relative humidity, and illuminance were measured in these buildings, but these did not correlate with symptom reports. The number of sick building syndrome symptoms per worker was related linearly to perceived indoor air quality, job stress, job satisfaction, allergies, eyewear, and seasonal affective disorder. Two hundred and fifty five of these workers also completed a battery of psychological measures. Measures of depression, personality variables, situational stress, vulnerability to stress, and individual differences in circadian rhythms did not correlate with the numbers of sick building syndrome symptoms per worker, although depression did correlate with the number of symptoms when these were weighted for their frequency of occurrence in the previous month. Job stress and perceptions of indoor air quality correlated with both the unweighted and weighted indices of sick building syndrome.

#NO 8625 The impact of the building indoor enviroment on occupant productivity Part I: recent studies, measures, and costs.
AUTHOR Lorsch H G, Ossama A A
BIBINF USA, ASHRAE Transactions, Vol 99, Part 2, 1993, pp 741749. This paper is one in a series of three that summarize the results of a survey undertaken by the authors for an industrial client. The purpose was to collect and systematize information on quantitative relations between the indoor air environment and worker productivity. No independent research was to be performed. This paper describes three large studies of officeworker productivity, discusses protuctivity measurements, and relates productivity to building costs. Companion papers deal with the effects of temperature and indoor air quality. . There is general agreement that improved working conditions and the office environment is certainly one of the more important working conditionst end to increase productivity However, determining a quantitative relationship between environment and productivity proved to be highly controversial. While some researchers claimed they reliably measured improvements of 10% or more, others pesented data showing that no such relationships exist. Since the cost of the people in an office is an orderof magnitude higher than the cost of maintaining and operating the building, spending money on improving the work environment may be the most costeffective way to improve worker productivity.

#NO 8489 The use of breathingzone filtration (BZF) to indoor air quality and office worker comfort and health.
AUTHOR Hedge A
BIBINF Italy, proceedings of Healthy Indoor Air '94, held Anacapri, Italy, 68 October 1994, pp 353359.
ABSTRACT Breathingzone filtration (BZF) is a new technology which locally treats the air within an office space. It is not a part of the mechanical ventilation system, although it increases ventilation efficiency because it improves air movement and local air mixing at each workstation where it is installed. A BZF system benefits indoor air quality because it continuously filters office air to remove volatile organic compounds, microorganisms, and other particulates. A BZF system can be integrated into new office furniture, where these benefits are optimized, or fitted to existing office furniture. The benefits of a BZF system remain with

workers whenever the layout of the office furniture is changed. A study of the effects of a furnitureintegrated BZF system on indoor air quality and employee comfort, health, and productivity will be described. New office furniture with an integrated BZF system was installed as part of an office renovation project for one entire floor (1,200 m2) of a large office building. Preinstallation and 3 month postinstallation surveys of indoor air quality and occupant reactions were conducted on the remodelled BZF floor, and on a matched control floor and results were compared. the furnitureintegrated BZF produced a significant reduction in submicronic diameter airborne particles and it also reduced the concentration of volatile organic compounds. The furnitureintegrated BZF system produced a dramatic reduction in indoor air quality complaints, and improvements in worker comfort, workrelated health, and productivity. BZF systems can offer a costeffective way to improve indoor air quality and health in offices.

#NO 8457 Sick building syndrome: is it an environmental or a psychosocial phenomenon?
AUTHOR Hedge A
BIBINF Italy, proceedings of Healthy Indoor Air '94, held Anacapri, Italy, 68 October 1994.
ABSTRACT This paper summarizes current knowledge n the "sick building syndrome" (SBS) and its association with poor indoor air quality in offices. Results from 3 recent research studies which have been conducted are described. In these studies, indoor air quality data have been collected concurrent with questionnaire surveys of occupants. Questionnaires have included questions on perceived indoor air quality (PIAQ) and on sick building syndrome (SBS) symptoms. When individual symptoms are analysed only a few significant associations have been found. Also results show that traditional industrial hygiene measures are not good indicators of the number of SBS symptoms per worker. Personal, occupational, and psychological factors are significantly associated with the total number of symptoms reported, and global seasonality is weakly associated with symptoms. Symptoms are not associated with personality, depression, life stressors, or vulnerability to stress. The implications of these results fro the diagnosis, cure, and prevention of SBS in offices are summarized.

#NO 7329 The use of standardized questionnaires in buildingrelated illness (BRI) and sick building syndrome(SBS) survey.
AUTHOR Andersson K, Stridh G.
BIBINF NATO/CCMS Pilot Study on Indoor Air Quality. 4th Plenary Meeting: Epidemiology and Medical Management of Building Related Complaints and Illnesses, report on a meeting held in Oslo, Norway, 1921 August 1991.
ABSTRACT Many occupants in modern buildings are complaining of deteriorated air quality and of subtle medical symptoms that may be related to the indoor climate. The symptoms reported are common in the general population and have many causes apart from factors in problem buildings. Technical investigations of the indoor climate in thesebuildings mostly show concentrations of chemicals well below levels one would expect to produce any health effects and thermal and ventilation parameters which are within acceptable ranges of the national codes. Therefore, at present, the frequencies of reported symptoms are often the best source when establishing an index of the sickness (or health status) of a building. The occupants perception of the environment can be used as well to describe theindoor climate in terms of odours, perception of dry air, high temperatures etc. The problem is therefore to provide an unbiased estimate of the prevalences of symptoms and environmental perceptions with good reproducibility.

#NO 7079 The development of a questionnaire suitable for the surveillance of office buildings to assess the building symptom index a measure of the sick building syndrome.
AUTHOR Burge P S, Robertson A S, Hedge A

BIBINF Finland, Helsinki, Indoor Air '93, proceedings of the 6th International Conference on Indoor Air Quality and Climate, 1993.
ABSTRACT Questionnaires used in the assessment of the sick building syndrome vary in their complexity, many being too cumbersome for non research use. We have tried to develop a questionnaire with the minimum number of questions which can reliably estimate the building symptom index, the average number of workrelated symptoms per occupant per building. We started with the ten symptoms used in the British Office Environment Survey, and investigated the effect of leaving out successive questions of the ranking on 47 buildings, when the building symptom index was recalculated with the small data set. The building symptom index calculated from 5 questions produced the best balance between brevity and reliability, correlating highly with the ten symptom index. The 95% confidence intervals for the ranking of the 47 buildings using just 5 questions were less than +3.8 ranks.

#NO 5984 Demand controlled ventilation: a case study.
AUTHOR Fleury B
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, 1992.
ABSTRACT Good indoor air quality in buildings becomes such a major concern that new design recommendations emerge in many countries (USA, Nordic Countries,...). Improvement of the interior environment should not beat the expense of higher energy consumption. Heat recovery systems are one appropriate answer to this challenge. However, additional energy savings could be achieved by applying demand controlled ventilation when the internal loads vary significantly. A CO2 controlled ventilation system has been installed in a conference room with high variable occupancy in mid 91. In this paper, we present the survey of 6 months of use, the limits and the benefits of such a system. We focus on the practical aspects to offer the optimum air quality and to integrate the occupants and building owner's requirements.

#NO 5608 A comparison of two methods of evaluating the relationship between fungal spores and respiratory symptoms among office workers in mechanically ventilated buildings.
AUTHOR Tamblyn R M, Menzies R I, Comtois P, Hanley J, Tamblyn R T, Farant J P, Marcotte P
BIBINF USA, Ashrae, "IAQ 91 Healthy Buildings", proceedings of a conference held September 48, 1991.
ABSTRACT Respiratory symptoms are among the most common symptoms reported by workers in mechanically ventilated office buildings. In different studies, the prevalence of nasal problems has been reported in the range of 22%62% and cough, 18%41%. Fungal spore exposure has been identified as one possible explanation of these respiratory complaints, exposure arising either as a result of humidification system contamination with fungalspecies or through local contamination of office carpets,plants, and furnishings. In this study, we compared two approaches to the investigation of this hypothesized association: a repeated measures crosssectional survey of exposure levels and symptoms under two different ventilation conditions and a nested casecontrol design within a defined cohort of office workers. The first approach is best suited to the detection of associations attributable to HVAC sources of fungal spore exposure, whereas the latter is best suited toassociations related to local fungal spore contamination. In the four buildings studied, average fungal spore counts were low, in the range of 7.7 to 97.0 ns/m3. The highest value observed was 289 ns/m3. At these low levels of contamination, there was no difference in fungal spore measurements with the two methodologies. Despite a high prevalence of weekly respiratory and mucosal irritation symptoms among the 1,627 participating building occupants (24%47%), there was no association between fungal spore count and symptom occurrence.

#NO 5603 Effect of ventilation rate in a healthy building.
AUTHOR Nagda N L, Koontz M D, Albrecht R J
BIBINF USA, Ashrae, "IAQ 91 Healthy Buildings", proceedings of a conference held September 48, 1991.
ABSTRACT A study was conducted in a 20story government office building to quantitatively assess the effect of ventilation rate on measured and perceived indoor air quality (IAQ) and comfort. The building has not experienced occupant complaints and, therefore, is thought to be healthy. IAQ/comfort monitoring was conducted and occupant surveys were administered during two separate weeksone with the building at a ventilation rate near 20 cfm/person and the other near 35 cfm/personwithin both the summer and winter seasons. Monitored pollutant levels at either ventilation rate were well within existing guidelines or standards. The IAQ parameter most affected by ventilation was CO2, for which concentrations were lower at the higher ventilation rate. For most other IAQ parameters, monitored levels were either uniformly low or highly variable. Measured comfort parameters were similar for the two ventilation rates, and occupant perceptions of IAQ and comfort were largely unaffected by the ventilation rate. Despite these limited differences in measured and perceived IAQ/comfort, occupants consistently reported fewer health symptoms in the presence of higher ventilation.

#NO 4785 A field measurement system for the study of thermal comfort.
AUTHOR Benton C C, Bauman F S, Fountain M E
BIBINF USA, ASHRAE Transactions, Vol 96, Part 1, 1990, pp 623633, 4 figs, refs. #DATE 00:00:1990 in English
ABSTRACT This paper describes the instrumentation and measurement protocol used in ASHRAE research project RP462, a field study of environmental conditions and occupant comfort in 10 office buildings located in the San Francisco Bay region. During this study, we made a total of 2342 visits to 304 participants during two seasons, collecting a full set of physical measurements and subjective responses at each visit. In this paper we describe the design of equipment and techniques for gathering physical measurements with the detail and accuracy required by both ASHRAE Standard 5581 (ASHRAE 1981) and ISO Standard 7726 (ISO 1985). In addition, the project developed a laptop microcomputerbased thermal assessment survey that collected a substantial subjective data set in machinereadable form. These components performed reliably during nine months of field use, providing a detailed description of the monitored workstation environments with a concurrent portrait of subjective occupant response. The system is recommended for further use.

#NO 4773 Thermal responses to the Thai office environment.
AUTHOR Busch J F
BIBINF USA, ASHRAE Transactions, Vol 96, Part 1, 1990
ABSTRACT This paper reports on a field study of more than 1100 Thai office workers in which a questionnaire survey and simultaneous physical measurements were taken. Both airconditioned and nonairconditioned buildings were included. The data are compared to those from other field studies from both temperate and tropical climates. Thai subjective responses were analyzed on the ASHRAE McIntyre, and other rating scales, relating them to effective temperature, demographics, and to rational indices of warmth such as PMV and TSENS. Selected results are as follows: the neutral temperature of the whole sample was 25 Deg C and in rough agreement with several empirical model predictions; the ASHRAE Scale category widths, determined through probit analysis, exceed by several degrees previously published findings; Thai conditions of thermal acceptability exist over a broad range of effective temperature, from 22 Deg C to 30.5 Deg C, pushing the summer comfort zone outward by 4 Deg C. These findings suggest that, without sacrificing comfort, significant energy conservation

opportunities exist through the relaxation of upper space temperature limits.

#NO 4467 An indoor air quality survey of twentysix Swiss office buildings.
AUTHOR Turner S, Binnie P W H
BIBINF Canada, Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, 29 July 3 August 1990.
ABSTRACT In an effort to characterize the major factors influencing air quality in buildings in Switzerland, 26 representative buildings were selected for this study. Each building was subjected to the same indoor air quality survey methodology. The most significant cause of air quality problems was found to be poor ventilation, followed by inadequate filtration and poor hygiene. Control of Legionella bacteria and asbestoscontaining materials may also require high priority in order to prevent immediate and long term hazards to building occupants.

#NO 4412 Sick building syndrome environmental comparisons of sick and healthy buildings.
AUTHOR Burge P S, Jones P, Robertson A S
BIBINF Canada, Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, 29 July 3 August 1990
ABSTRACT Environmental measurements and plant surveys were made over two week periods in the winter heating season in six office buildings. The offices were chosen from a large group which had been selected without knowledge of health problems amongst theworkforce. The original buildings were grouped according to ventilation category, buildings were studied with natural ventilation, air conditioning with induction units, and air conditioning with all air systems. Within each ventilation category two buildings were surveyed, one whose occupants had a high prevalence of symptoms suggestive of building sickness, and one with a lower prevalence. The environmental measurements of temperature, air change rate and humidity did not differentiate between the pairs of buildings with high and low building sickness prevalences, suggesting that these were not in themselves major causes of the sick building syndrome. There was a correlation between standards of maintenance, and of knowledge of the plant and the prevalence of building sickness suggestingthat inadequate standards of maintenance are an important risk factor for the sick building syndrome.

#NO 4036 Sick building syndrome traced to excessive total suspended particulates (TSP).
AUTHOR Armstrong C W, Sherertz P C, Llewellyn G C
BIBINF in: The human equation: health and comfort, proceedings IAQ 89.
ABSTRACT An epidemiological and environmental investigation into the air quality of a highrise public office building was conducted in July 1988. A walkthrough inspection revealed particulate (dust) soiling of ceiling and work surfaces in occupied sections of theservice floor. Building air samples obtained by highvolume air pumps and cassette filters revealed elevated concentrations of total suspended particulates (TSP) which ranged up to 1.07 mg/m3 (more than 17 times the Building Officials and Code Administrators [BOCA] standard). In 17 (59%) of the 29 areas tested, TSP levels exceeded the BOCA standard of <0.06 mg/m3(annual average). Recorded temperatures, relative humidity readings, and supply of outside air were within acceptable limits. Testing for volatile organic compounds, combustion products, formaldehyde, ozone and fungal spores revealed no levels of concern. A survey of occupants in selected units was conducted with 94% participation. Fiftyfive percent indicated that they had experienced symptoms that appeared or worsened during their working hours. Of these, 47% indicated that they had missed work because of their symptoms. Common symptoms were headache and sinus/upper respiratory congestion compatible with air contamination by TSP or other irritants. In multivariate

analysis, illness was found to be significantly associated with air TSP concentration ($P<0.002$), CO_2 concentration, average number of hours worked per week, gender, and smoking status. This is one of very few outbreaks of buildingrelated illnesswhere occupant illness has been associated with exposure to elevated levels of an environmental contaminant (TSP).

#NO 3075 User manual tenant questionnaire survey.
AUTHOR Dillon R, Vischer J C
BIBINF Canada, Public Works, November 1987.
ABSTRACT This manual describes the Tenant Questionnaire Survey, a simple approach to assessing occupants' ratings of office building performance. It is based on taking occupant surveys using a standard questionnaire. Occupants are asked torate how certain apsects of the building interior affect their comfort and satisfaction at work. The ratings are compared to a norm that is derived from average ratings from previous building surveys, which are stored in a computer database. The result of the comparison indicates whether the building is performing within the same range as other office buildings or whether there are any aspects that require further investigation or action. The manual provides complete instructions for performing a Tenant Survey. All necessary documents are provided, including the questionnaire and sample letters. Users may perform the tabulation and analysis of ratings themselves using the worksheet and lookup charts provided, or can send completed questionnaires to Public Works Canada Headquarters for input to the Tenant Survey database.

#NO 3074 Derivation of the tenant questionnaire survey assessment method: office building occupant survey data analysis.
AUTHOR Dillon R, Vischer J C
BIBINF Canada, Public Works, November 1987.
ABSTRACT This report describes the development of the Tenant Survey Assessment Method, a simple approach to assessing occupants' ratings of office building performance. It is based on taking occupant surveys using a standard questionnaire. Occupants are asked to rate how certain aspects of the building interior affect their comfort and satisfaction at work. The ratings are compared to a norm that is derived from average ratings from previous building surveys, which are stored in a computer database. The result of the comparison indicates whether the building is performing within the same range as other office buildings or whether there are any aspects that require further investigation or action. The report outlines the history of the building surveys and compilation of the Tenant Survey database. It goes on to describe the various types of statistical analysis that were performed on the database in an effort to find systematic associations between survey results and instrument measurements of building performance. Some recommendations are made for applying the Tenant Survey method to building evaluation.

#NO 2897 Relating health and environmental studies in a tight building syndrome investigation.
AUTHOR Bernard J M. et al
BIBINF in: Indoor air quality in cold climates: hazards and abatement measures. APCA Specialty Conference 1986.
ABSTRACT A twophased study was undertaken to investigate health and environmental complaints in a large, modern, sealed office complex.The health surveys of present and past employees were conducted to fully characterize the nature and magnitude of the complaints. Preliminary analyses of the current employee questionnaire data were used in establishing the environmental sampling protocol. A limited environmental study was conducted to identify environmental factors which might be responsible for the complaints of thecomplex's occupants.

#NO 2543 Identifying and avoiding indoor air quality problems.
AUTHOR Turner W A, Bearg D

BIBINF Heat Pip Air Condit, February 1987.
ABSTRACT This article outlines a methodology that has proved useful for building evaluations where there is no identifiable suspected source of air contaminants causing complaints or situations where there is an identifiable suspected source but unknown pathways of transmission. It draws upon illustrative case studies to show how the parameters discussed have contributed to various cases of degraded indoor air quality. Lists some of the typically more important indoor air contaminants to be considered, eg particles, combustion gases, ozone, biological sources, organic chemicals, fibres. Also lists outside building sources (radon, loading docks, parking lots, cooling towers, localized exhaust systems), and mechanical system sources (location of air intakes, humidity control, location of supply and exhaust registers). If the evaluation of ventilation rates and the determination of air movement pathways are not sufficient to deduce the source of air contaminants, further specific sensitive measurements of source and contaminant concentrations can be employed. The techniques and procedures described have been used by the authors to investigate several buildings with histories of occupant complaints. These buildings had "passed" OSHA type surveys with flying colours, and yet when looked at very closely as 'office buildings' they had situations occurring that were causing irritation and discomfort to the occupants. Solutions have been developed from these investigations that have eliminated or minimized both the problems and complaints.

#NO 1595 Baseline data: health and comfort in modern office buildings.
AUTHOR Sterling E M, Sterling T D.
BIBINF 5th AIC Conference 'The implementation and effectiveness of air infiltration standards in buildings' Reno, Nevada, 14 October 1984, pp17.117.13, 13 tabs, 11 refs. #DATE 00:10:1984 in English
ABSTRACT Reduction of fresh air ventilation is becoming the major means of energy conservation in office buildings. Simultaneously, health and comfort problems experienced by occupants are often suspected to be a direct result of reduced fresh air ventilation. However, there is little data available on health and comfort problems experienced by occupants of buildings operated under normal ventilation rates. Baseline data needed to compare occupant health and comfort complaints in buildings with reduced ventilation to complaints in 'normal buildings' was provided by a survey of 1106 members of the New York local of the Office and Professional Employees International Union in nine office buildings with no prior history of complaints from occupants of health and comfort problems. Buildings were screened for energy conserving retrofits and architectural and ventilation factors.

SCHOOLS/EDUCATIONAL

#NO 7956 Ventilation by the windows in classrooms: a case study.
AUTHOR Richalet V, Beheregaray B, Guarracino G, Dornier C, Janvier L
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference.
ABSTRACT Four classrooms of two secondary schools located around Lyon in France have been monitored, The objectives are to analyse the quality of the indoor air and the thermal comfort and also the behaviour of the occupants towards opening of windows. This paper briefly describes the context and the nature of the monitoring campaign, and presents the results of the measurements with direct interpretation of the ventilation needs. Then, we try to make a statistical analysis of the influencing factors that lead to the opening of windows, but our study is limited because of the small number of collected data. Results from this study show that allowable CO2 levels are over passed several times in a school day. The presence of a mechanical ventilation system leads tolower peaks but the fresh airflow is too small to prevent an indoor confining, that is also revealed by the aerobiological analysis. These measurements confirm a

certain illbeing of the surveyed people, not in relation with thermal comfort. This feeling leads people to open windows provided that outdoor conditions are favourable (temperature, wind speed, noise, outside odours,...)

#NO 7076 Sick building survey of seven noncomplaint university buildings.
AUTHOR Godish T, Dittmer J
BIBINF Finland, Helsinki, Indoor Air '93, proceedings of the 6th International Conference on Indoor Air Quality and Climate, 1993
ABSTRACT A self-administered questionnaire survey of occupants of seven non-complaint university buildings was conducted with an overall response rate of 44% (range 3661%). Symptom prevalence rates were summarised based on two classification criteria. Significantly higher prevalence rates were observed when building/workrelated symptoms were summarized on a sometimes/often/always basis as compared to often/always. Using both classifications, criteria symptom prevalence rates were generally lower than those reported in other studies. The most prevalent symptoms which appeared to be associated with the building/work environment using the often always classification were headache (12%), suffy nose (9%), eye irritation (9%), fatigue(7%), runny nose (6%), and dry/itchy skin (6%). A relatively large percentage of respondents (2040%) were dissatisfied with building temperature, humidity, air movement and dustiness.

#NO 4209 Indoor air quality in 12 schools: a case study.
AUTHOR Cousins D M, Collett C W
BIBINF in: The human equation: health and comfort proceedings IAQ 89, 1989.
ABSTRACT An investigation of indoor air quality in 12 schools in Alberta was conducted to evaluate the relationship between type of ventilation system, occupant health and comfort, and levels of specific indoor pollutants. Three categories of schools were investigated: (1) schools constructed prior to 1960 with no modification to mechanical systems, (2) schools constructed prior to 1960 which have been upgraded to meet current building codes, and (3) schools constructed since 1960. A questionnaire survey was administered to teachers, administrators and custodial staff. Common health and comfort complaints reported by occupants of all school types included: headache, fatigue, eye irritation, sore throat, too little air movement, stuffiness andpoor temperature control. The highest prevalence of health and comfort complaints were reported by occupants of schools constructed since 1960. Based on the results of thequestionnaire, three schools (one from each category) were selected for further evaluation of air quality parameters by physical measurement. Carbon monoxide, respirable particles, temperature, relative humidity, and airborne microbial levels were similar in all three schools and were far below established air quality guidelines. However, carbon dioxide (CO_2) concentrations varied substantially within and between schools,exceeding, at times, 1000 ppm in classrooms of each school. The highest CO_2 concentrations (200 to 2800 ppm) were measured in portable classrooms. The elevated CO_2 concentrations indicate that the ventilation systems, as operated, were ineffective in meeting the outside air requirements. Total outside air requirements in classrooms are greater than for other areas within the schools because of the high density of students. Recommendations to improve indoor environmental conditions in the three schools included an overhaul of outside air dampers, relocation of supply air registers, and continuous operation of ventilation systems during occupancy of portable classrooms.

#NO 4066 Stochastic study of occupant behaviour.
Etude stochastique du comportement de l'occupant.
AUTHOR Scartezzini J L, et al
BIBINF Switzerland, Laboratoire d'Energie Solaire et de Physique du Batiment, Institut de Technique du Batiment, [1990], in French.

ABSTRACT The feasibility of stochastic models of occupant behaviour with regard to ventilation was established. Both the angle of window opening and the number of doors opened were modelled. The models were based on an experimental survey of four parts of the LESO building.

THEATRE / AUDITORIA

#NO 6970 Indoor air quality and energy consumption with demand controlled ventilation in an auditorium.
AUTHOR Fehlmann J, Wanner HU, Zamboni M
BIBINF Finland, Helsinki, Proceedings of 'Indoor Air '93', The 6th International Conference on Indoor Air Quality and Climate, July 48, 1993.
ABSTRACT The ventilation system of an auditorium was regulated in response to continuously measured CO2 concentrations in the room, or according to the timetable of the occupancy. The running time, the energy consumption and several climatic parameters as well as the CO2 concentrations were measured under winter and summer conditions. Furthermore, the occupants' judgment of the indoor air quality was surveyed with aquestionnaire. It was shown that during the monitored periods the ventilation controlled by measured CO2 concentrations consumes 80% less energy during summer and 30% less during winter than the ventilation operating on a fixed timeschedule. If all the avoidable sources of odour in the room would be eliminated, the indoor quality would still remain within an acceptable range.

DWELLINGS

#NO 12147 The energy and indoor climate performances of the recent housing stock in Belgium: outcome of the VlietSenvivv study.
AUTHOR Bossaer A, Demeester J, Vandaele L, Wouters P, et al
BIBINF EPIC '98, Proc 1998, Lyon, France.
ABSTRACT A systematic analysis of recently constructed dwellings in the Flemish Region has been undertaken within the SENVIVVproject (19951998). In total 200 dwellings have been examined in detail. The study involved various aspects: energy related building data (thermal insulation level, net heating demand, installed heating power,..), indoor climate (temperature levels in winter and summer), building airtightness, ventilation, appreciation of the occupants,... This paper especially focuses on the results for thermal insulation, airtightness and ventilation. In the field of the thermal insulation several calculations were performed with great care, indicating that a large number of the investigated dwellings does not comply with the Flemish requirements, although it should be no problem from the technical point of view to obtain even much better performances. With respect to the indoor air quality, the presence and performance of ventilation devices was evaluated in all 200 dwellings. A comparison was made with the requirements of the Belgian ventilation standard. The results seem to be rather disappointing. Measurements of the airtightness were performed in 50 dwellings, revealing that the global airtightness is often very bad, while some rooms are very airtight.

#NO 12016 Field survey of heat recovery ventilation systems.
AUTHOR Hill D
BIBINF Canada Mortgage and Housing Corporation, December 1998.
ABSTRACT This research study was undertaken to assess the effectiveness of ventilation in dwellings in relation to:
* mechanical ventilation system design,
* installation practices, and,
* occupant use and maintenance of ventilation systems.
The project involved the inspection of 60 homes with heat recovery ventilator (HRV) ventilation systems, a survey of the occupants to determine their understanding and usage of their ventilation system, telephone surveys of a further 15 households and intensive performance testing of 20 conventional and four experimental ventilation systems

The methodology for the testing involved the use of a trace of concentration of gas (Sulphur Hexafluoride) to assess air change rates. A tracer gas decay methodology was used to calculate the natural, combined apparent natural and mechanical, and mechanical air change rates in representative areas of each house. Based on an assessment of the air change rates, evaluations were made of the fresh air distribution in the homes with and without the operation of the mechanical systems.
The common types of HRV installations investigated under this study (fully ducted, simplified and extended) were capable of performing well. The majority of the HRV ventilation systems were operating and the occupants believed the use of their HRV was beneficial. Potential existed for far greater benefits, however, and considerable improvements were possible in installation practice, system performance, occupant understanding and occupant interaction with their system.

NO 11790 Energy audits.
AUTHOR Anon
BIBINF USA, Home Energy, July/August, 1998.
ABSTRACT Describes a project carried out by Massachusetts Division of Energy Resources to find out if its home energy audit program was effective. A survey carried out found that customers wanted the audits, but that few were using the results to improve energy efficiency in their homes. The project concluded that by installing only 16% of the recommended measures (and tending to install the cheaper measures), customers had realized only 10% of potential energy savings from the audit recommendations.

#NO 11717 A comparison of passive stack ventilation and mechanical extract fans in reducing condensation problems in homes.
AUTHOR Aizlewood C, Brown D, Oseland N
BIBINF UK, Chartered Institute of Building Services Engineers, (CIBSE), "Harnessing Technology for Sustainable Development", PROC, 1998.
ABSTRACT A study comparing the effectiveness (as reported by occupants) of passive stack ventilation (PSV) and mechanical extract fans (MEFs) was carried out during the winter of 1996. This involved a facetoface survey of 437 homes in England. More than 50% of the homes in the study had MEFs, 14% had PSV and 8% had humidistatcontrolled MEFs (HMEFs). About 25% of the homes had either a kitchen or a bathroom with no ventilation device, and 16% had no ventilation device in the home.
Four measures of condensation problems were analysed: condensation overall in the home, in the kitchen and in the bathroom, and a combined index of condensation and mould. For the measures analysed, the reported effectiveness of PSV and MEFs was not significantly different. The effectiveness of both, however, was reported to be better than HMEFs.
This report concludes that allowing the use of PSV for dwellings is supported by these results. HMEFs may save energy, but are reported by occupants to be less effective. However, this may be due to problems with their acceptance and use by occupants, rather than any technical failing.

#NO 11564 Improvement of indoor climate and ventilation system in a renovated multistoried residential building.
AUTHOR Palonen J
BIBINF UK, Air Infiltration and Ventilation Centre, proceedings of "Ventilation Technologies in Urban Areas", 19th Annual Conference, 1998.
ABSTRACT The goal of this project was to improve the quality of indoor air in a multistoried residential building of 81 flats built in 1960. The building is located in a heavily built urban area of Helsinki. The building had a mechanical exhaust ventilation system without outdoor air inlets. A questionnaire was sent to occupants and a condition survey was made prior to renovation. The main indoor climate problem was draught with a prevalence of 60%. Other almost as common problems were traffic noise also during nights and dust coming from the street. The ventilation system was

fully unbalanced with reduced exhaust air flows partly due to uncleaned exhaust air vents. A new type of fresh air window with air filtration (EU 5) and good acoustic performance was developed. The sound insulation value measured in field was 42 dB(A). When these new windows were installed in the dwellings a new questionnaire was sent to occupants. The results showed clear improvement in all indoor climate related factors. The habitants were much more satisfied with the performance of ventilation system after the renovation measures.

#NO 10810 Indoor air quality in homes: Part 1. The Building Research Establishment Indoor Environment Study.
AUTHOR Berry R W, Brown V M, Coward S K D, et al
BIBINF UK, Building Research Establishment, 1996.
ABSTRACT The UK Government White Paper published in 1990 recognised the importance of indoor air pollution for public health. It described the major part of the research work undertaken for DOE on indoor air quality as being directed to monitoring levels of indoor pollutants to assess risks to people's health and the need for action. As part of this work, DOE commissioned the UK Building research Establishment (BRE) to undertake a study of levels of specific pollutants in a sample of normally occupied homes. This was carried out in collaboration with the University of Bristol project team responsible for the Avon Longitudinal Study of Pregnancy and Childhood, and has involved the monitoring or concentrations of nitrogen dioxide, organic compounds and biological particulates in 174 homes over a 12 month period. The main aims of the work, known as the Indoor Environment Study, were to provide data on the range and concentrations of pollutants occurring in UK homes and to identify the factors such as household characteristics and occupant activities, which influence the levels of pollutants. The study concentrated on pollutants, exposure to which indoors was likely to be an important contributor to total personal exposure. These were: formaldehyde, total volatile organic compounds and selected individual compounds, nitrogen dioxide, airborne bacteria, airborne fungi, and house dust mites in furnishings. The study has generated a large volume of data about pollution in homes, some of which is detailed here and in the accompanying volume.

#NO 10723 The effects of human behaviour on natural ventilation rate and indoor air environment in summer a field study in southern Japan.
AUTHOR Iwashita G, Akasaka H
BIBINF UK, Energy and Buildings, No 25, 1997.
ABSTRACT Residents completed a questionnaire survey assessing indoor environment and residents' behaviour (i.e. when they opened windows/doors, when they operated air conditioners, and so on) during the period of ventilation measurement. The purpose of this study is to measure the ventilation rate in occupied dwellings in Kagoshima City, located in the southern part of Japan, using the tracer gas method and to investigate the relationship between the occupants' behaviour in each dwelling and the energy consumption for air conditioning during the summer period. Based on the continuous measurement of the ventilation rate in eight dwellings, the proportion between the total ventilation rate (ventilation rate during occupancy of the dwellings) and the basic ventilation rate (ventilation rate during nonoccupancy and with door/windows closed) is discussed. The measuring principle applied is the constant tracer gas method. The main conclusion is that there is a large difference between the mean basic ventilation rate and the mean total ventilation rate. If the size of the basic ventilation rate and the userinfluenced ventilation rate in the investigated dwellings are compared, it can be seen that 87% of the total air change rate is caused by the behaviour of the occupants.

#NO 10649 SEED Agenda 2000. Measurement based, "person centred" field

data on the real building performance of public housing.
AUTHOR Walsh C J
BIBINF France, Centre Scientifique et Technique du Batiment, proceedings of the Second International Conference on Buildings and the Environment, held Paris, June 912 1997.
ABSTRACT `SEED' Sustainable Energyefficient Environment friendly Development is a concept which has brought together for the first time three separate areas of concern and crystallizes the single idea that building energy performance cannot be evaluated in isolation from interrelated human and environmental factors. Allied to this working concept, the construction of a coherent philosophy, based on first principles are derived from interactive consultation with building users and the detailed observation / measurement of real building performance, has been a large factor in achieving effective results from a recent major study of public housing in Dublin, Ireland. This paper shows the resultant range / quality of the project observations and thermal comfort measurements in accordance with EN ISO 7730 : 1995 (1). Infrared thermography (8 to 12 micron band) was of critical importance in understanding the real performance of each building and in suggesting new lines of investigation. Also illustrated are the results of an indepth questionnaire survey with tenants on their own `comfort'. Finally, a strong linkage between energy efficiency, socioeconomic status and health is demonstrated.

#NO 10291 User satisfaction with innovative cooling retrofits in Sacramento public housing.
AUTHOR Diamond R, Remus J, Vincent B
BIBINF USA, Washington DC, American Council for an Energy Efficient Economy (ACEEE), Proceedings of the 1996 Summer Study on Energy Efficiency in Buildings, "Profiting from Energy Efficiency"
ABSTRACT How do tenants of public housing respond to retrofits to improve their comfort and energy use during the cooling season? In contrast to retrofits to improve heating or lighting, cooling retrofits have been little studied, despite extensive programs by utilities and housing authorities to reduce this end use. A local utility and a housing authority have been retrofitting their buildings with evaporative coolers, groundsource heatpumps and other cooling measures. As part of an overall evaluation of the project we have conducted interviews with the residents, building managers and project staff to determine satisfaction with the performance of the systems. The initial evaluation revealed glaring defects in the design and installation of the systems, and not surprisingly, there was great dissatisfaction by the tenants and staff with their performance. Subsequent interventions and improvements to the equipment solved the technical problems, but tenant satisfaction was mixed. Further surveys revealed misunderstandings by the tenants on the nature of the evaporative coolers, their control and operation_often due to poor thermostat design_and expectations for comfort and familiarity with the technology. A significant finding from the study has been that despite the technical potential for these retrofit measures, the improper implementation of the systems, maintenance requirements and user behavior can all greatly impact the projected energy savings.

#NO 9078 Occupant response to passive stack ventilation: a UK postal survey.
AUTHOR Oseland N
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research, Proc. 1995.
ABSTRACT A study was set up to compare the effectiveness of passive stack ventilators (PSV) with mechanical extract fans (MEF) in providing adequate ventilation in UK homes. New build and refurbished homes with PSV and MEF were identified and questionnaires posted to 3000 households of which 1223 were returned. The survey showed that in homes installed with a PSV system, only 7% of those in the kitchen and only 8% of those in the bathroom were reported as blocked up. There were also few cases in which the

MEF was blocked up or disconnected: 1.5% in kitchens and about 5% in bathrooms. However, less than a half (40%) of the respondents usually or always used their MEFs whereas most (93%) of the PSV systems were in constant use. The respondents were asked to rate how problematic condensation, mould and noise were in their home. Approximately onethird of the respondents had at least a moderate problem with condensation in winter (34%) and noise from extract fans (36%) and onefifth (19%) had moderate problems with mould. Fewer occupants had problems in homes installed with a PSV system than homes fitted with a MEF, whether manually operated or humidistatcontrolled.

#NO 9067 Field survey of heat recovery ventilation systems: occupant interactions.
AUTHOR Hill D
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research, 1995 Proceedings.
ABSTRACT The installation of packaged heat recovery ventilation (HRV) systems has recently become common practice in new homes in Canada. Despite improvements in product quality and reliability, HRV systems are only capable of providing safe, continuous, efficient and effective ventilation if homeholders have an understanding of the basic operation and maintenance procedures and the system s interaction with other house systems. Furthermore, homeholders must be able to perceive the value of HRV systems if they are expected to operate them. Canada Mortgage and Housing Corporation initiated a research project to determine the degree to which homeholders are capable, or willing, to interact the HRV systems. HRV systems within fiftyeight, regionally representative houses of various ages were inspected to characterize the condition and performance of the systems as found. Interviews were conducted with the occupants to determine their understanding of the operation and maintenance requirements of their HRV systems and their perceptions of system value, effectiveness and efficiency. While most occupants reported an understanding of the operation and maintenance needs of their HRV systems certain disparities exist. For instance, more than half of the systems surveyed had immediate service requirements such as filter, heat recovery core and intake grille cleaning. More that half of the systems had unbalanced supply and exhaust air flows. Ventilation rates were found to be substandard in 60% of the homes surveyed. The occupants of tract built homes demonstrated the least appreciation of the operating and maintenance requirements of HRV systems. The configuration of the HRV systems ductwork and the availability of controls also was found to have an influence on occupant interactions. This investigation demonstrated that most homeholders appear willing and able to interact with HRV systems. More consumer education and refined (userfriendly) control and maintenance strategies are required to ensure the successful adoption of HRV systems within Canadian homes.

#NO 8116 A comparison of the predicted and reported thermal sensation vote in homes during winter and summer.
AUTHOR Oseland N A
BIBINF UK, Energy and Buildings, No 21, 1994.
ABSTRACT The results from a BRE survey, conducted in new homes during winter and summer, are presented. The occupants' reported thermal sensation (TS) was obtained using the ASHRAE scale and sufficient physical measurements were made to allow their predicted mean thermal sensation vote(PMV) to be computed. The neutral (comfortable) temperatures based on reported and predicted votes were compared. The neutral temperature calculated from TS was 5 C lower than that calculated from PMV in winter and 3 C lower in summer. The respondents rated themselveswarmer in winter than in summer even though room temperatures were lower. The respondents appear to maintain thermal comfort in summer, relatively independently

of room temperature, indicating that they may have more control over their environment. The respondents prefer to be slightly warm in winter and be of a neutral thermal sensation in summer.

#NO 7791 Efficient air heating for lowenergy apartment housing with timber frame construction and glazed atrium
AUTHOR Schiphouwer H, Snoek R Vander
BIBINF France, International Energy Agency, proceedings of a conference held Dortmund, Germany, 79 April 1992
ABSTRACT The Haringkavel housing project consisting of 47 apartments is situated in the town of Boskoop, The Netherlands. This project, completed in 1989, consists of two parallel, threefloor apartment blocks with the areain between enclosed by a glass roof and glass walls (atrium). This glasscovered central area is used as an entrance to the apartments and as a meeting place for the occupants. To ensure an agreeable indoor climate the central area is fitted with automatic shading, mechanical ventilation and ventilation panels to fend off excessive heat. The apartment buildings are mainly of timberwood construction with a low heat accumulation, and are heavily insulated and extra airtight. The indoor climate is controlled by a newlydeveloped, high efficiency air heating system, one unit in each apartment. This unit incorporates mechanical ventilation, 2zone air heating, hot domestic water supply and heat recovery from flue gas and ventilation air. This housing project has been evaluated over a period of two years regarding energy consumption, indoor climate and air quality, both in the glasscovered central area and in the apartments, together with the functioning of the heating systems. Furthermore a survey was carried out into the way the occupants experienced their apartments and the other aspects of this project The overall result of this project are very positive

#NO 7418 Analysis of innovative ventilation systems in multifamily buildings : RCDP Cycle 3.
AUTHOR Heller J.
BIBINF USA, Bonneville Power Administration, Super Good Cents, Residential Construction Demonstration Project, March 1993.
ABSTRACT The purpose of this study was to examine th effectiveness of ventilation systems installed in Super Good Cents multifamily buildings. Extensive field testing was done inseven case study buildings to collect information on envelope tightness, ventilation system capacity and runtime, inter-apartment air leakage, occupant effects, system costs, and other factors to evaluate the ventilation systems. Field testing included: blower door tightness testing, short term sulfur hexafluoride tracer gas testing (SF6), long term perfluorocarbon tracer gastesting (PFT), flowhood measurements, sound level measurements, smokestick analysis, differential pressure measurements, and occupant surveys. The ventilation systems were also evaluated for quality of installationand cost effectiveness.

#NO 6681 Experience in low energy living.
AUTHOR Brundrett G W
BIBINF Proceedings of the Third International Congress on Building Energy Management ICBEM'87, held in Lausanne, Switzerland, September 28 October 2, 1987.
ABSTRACT Customer satisfaction with four low energy houses was high. This satisfaction was based on the freedom to choose high comfort standards at low cost without worry. The mechanical ventilation system was particularly appreciated. The heating system was responsible to complement the uncertainties of the free heat from occupancy and solar gains. The heater sizing was based on dynamic response rather than steady state losses in rooms of multiuse. The benefits of regular intermittent operation of the heating system are minimal. Economic surveys show that people spend 5% of their expenditure on domestic energy and this should be the basis of the design.

#NO 6632 The indoor climate in 3000 Swedish houses. Inomhusklimat i 3000 svenska bostadshus.

AUTHOR Andersson K, Norlen U, Fagerlund I, Hogberg H, Larsson B
BIBINF Sweden, Statens institut for byggnads/forskning, TN:26, 1991, 59pp.
#DATE 00:00:1991 in Swedish
ABSTRACT This report intends to describe the indoor climate in Swedish residences based on results from a nationwide questionnaire survey in slightly more than 3000 singlefamily and multifamily houses. More than 17,000 residents have reported their experience about the indoor climate. The study showed that both the perception of the indoor climate and symptoms were related to: The characteristics of the building (type, size, year of construction and in some cases geographical location). Individual factors (sex, age and atopic constitution). For the 3000 buildings: Complaints and symptoms were more frequent inthe multifamily houses than in the singlefamily houses and most frequent in the bigger multifamily houses. Every tenth resident in the multifamily houses were complaining about stuffy air, dry air, noise, dust and dirt. Dry air and varying temperature were the dominating complaints in the singlefamily houses. For the 17,000 residents: Complaints and symptoms were more frequent among females than males, most frequent in the ages of 1854 years and more frequent among allergics than nonallergics. The most frequent complaints are dry air,stuffy air, dust and dirt, draught and noise. The most frequent symptom was fatigue which affected 17% of the females and 12% of the males.

#NO 6624 The householder as energy manager: a survey of user attitudes in low energy housing.
AUTHOR Jesch L F, Pollock A, Jankovic L
BIBINF Proceedings of the Third International Congress on Building Energy Management ICBEM'87, held in Lausanne, Switzerland, September 28 October 2, 1987.
ABSTRACT This study concerns the thermal performance of 50 low energy houses and the attitudes and behaviour of the householders as energy managers. Actual energy consumption for one year is compared with simulation. Information from interviews with all householders provide feedback to architects and builders regarding design and components. Areas where education of householders may be beneficial are identified.

#NO 6450 Moisture damage in South Carolina housing.
AUTHOR Gardner L L, DeWitt C A
BIBINF UK, Building Research and Information, Vol 20, No 3, 1992.
ABSTRACT In the results of a 6000 homeowner/occupant survey in 16 South Carolina counties in January 1989, 69% of respondents reported moisture problems in their home. The results obtained by Professor Gardner's team are particularly significant in relation to the correct use of insulation and ventilation, similar results have been found in the UK.

#NO 5973 Occupant's behavior with respect to window opening: a technical and sociological study.
AUTHOR Fleury B, Nicolas C
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, 1992.
ABSTRACT The occupant's behavior with respect to window opening may greatly affect the ventilation system, the energy consumption or/and the indoor air quality. In order to quantify the magnitude of opening times, many surveys have focused on climatic parameters and concluded to thetemporal correlation between the timelength of opening and the outside temperature or the solar irradiation. In this paper, we study the influence of sociological and technical parameters on the average time of opening during the winter. The research is based on a sociological survey and a two year monitoring of thirty houses with recording sensors on every window. The wife at home or not, the size and age distribution of the family are key variables in the kitchen, bathroom, children's bedroom. The orientation of the living room related to the sun explainsthe occupant's behavior in this room. For the parent's bedroom, none of

the selected parameters emerges, the distribution and frequency of opening time are so erratic. The type of ventilation systems, natural versus mechanical, is not the main explainable variable, as well as the degree of equipment of the family.

#NO 5492 A cross sectional survey of indoor radon concentrations in 966 housing units at the Canadian forces base in Winnipeg, Manitoba.
AUTHOR Figley D A, Makohon J T
BIBINF USA, Environmental Protection Agency, "1991 International Symposium on Radon and Radon Reduction Technology", Volume 6: Radon Surveys, paper from a conference held in Philadelphia, Pennsylvania, April 1991. #DATE 00:04:1991 in English
ABSTRACT This paper summarizes the results of a crosssectional survey of indoor radon concentrations in a total group of 966 housing units at the Canadian Forces Base (CFB) in Winnipeg, Manitoba. The major objective of the study was to characterize the distribution of indoor radon levels in the housing group as the first step in developing a radon control strategy. Subsequent investigations on subgroups of these houses (not reported here) were conducted to examine the building factors associated with the indoor concentrations and the efficacy of postconstruction control measures. Measurements were obtained from 670 of the 966 housing units (69% participation). The study group was composed of large numbers of nominally identical housing units of several different building styles. The twoday average measurements were taken using charcoal canisters during extremely cold weather, 28 Deg C to 35 Deg C. A short questionnaire administered to the occupants by the field workers who installed and removed the canisters recorded basic data on occupant activi ties and building factors. For the entire group, the geometric mean concentration was 112 Bq/m3 (3.0 pCi/L), approximately twice as high as the geometric mean obtained by an earlier summertime study of 563 Winnipeg houses. Data was subgrouped based on geog raphic location within the city, and the subgroup geometric mean concentrations varied between 25 and 206 Bq/m3 (0.7 and 5.6 pCi/L). Individual house measurements ranged from Bq/m3 to 5400 Bq/m3 (pCi/L to 146.0 pCi/L). No building or occupant factors were initially identifiedas being associated with the variation in levels.

#NO 5028 Northwest residential infiltration survey: analysis and results.
AUTHOR Palmiter L, Brown I
BIBINF USA, Seattle, Ecotope, August 15 1989, 52pp, refs. #DATE 00:08: 1989 in English
ABSTRACT The primary goal of the Northwest Residential Infiltration Survey (NORIS) was to provide an estimate of the average heatingseason infiltration rate of new electricheat singlefamily homes in the Bonneville Power Administration (BPA) service area. Special emphasis was placed on the scientific and statistical defensibility of the infiltration estimates. In particular, the sample of homes was to be statistically representative for the purpose of estimating the population mean values of the measured infiltration parameters. Secondary goals of the survey included comparison of two different techniques for estimating infiltration, and, to the extent possible, assessing the influence of physical characteristics of the home and occupant behavior on infiltration rates. Two infiltration estimation techniques were employed. The first used blowerdoor leakage tests combined with the infiltration model developed at Lawrence Berkeley Laboratories (LBL) and hence referred to as the LBL model [Sherman and Grimsrud 1980]. The second used the timeaveraged perfluorocarbon tracer (PFT) method [Dietz et al. 1986]. The target population for the survey was all singlefamily electricheat homes completed after Jan. 1, 1980. Multifamily units, mobile homes, homes with airtoair heat exchangers, and homes participating in BPA incentive programs were excluded. The homes were restricted to the BPA service area of Washington, Oregon, Idaho, and western Montana.

#NO 5030 Northwest residential infiltration survey cycle 2: study design and sample selection.
AUTHOR Heller J, Baylon D, Palmiter L
BIBINF USA, Seattle, Ecotope, June 9 1989
ABSTRACT Battelle Pacific Northwest Laboratories, working under contract with Bonneville Power Administration (BPA) and the State of Idaho's Department of Water Resources, conducted the Northwest Residential Infiltration Survey (NORIS) to shed light on theimpacts of air infiltration and ventilation on heat loss in residential buildings. The study was carried out during the 1987/1988 (Cycle 1) and 1988/1989 (Cycle 2) heating seasons. Cycle 1 evaluated homes built since 1979 to establish a baseline for studying infiltration rates. Cycle 2 studied homes withnonheat recovery ventilation (NHRV) systems which met Super Good Cents (SGC) specifications.

#NO 5048 Relationships among indoor NO2, air exchange rate and house characteristics of residential houses in Boston.
AUTHOR Yanagisawa Y, Spengler J D, Ryan P B, Billick I H
BIBINF Canada, Indoor Air '90, proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, 29 July 3 August 1990
ABSTRACT Relationships of indoor NO2 concentrations monitored with Palmes tubes, air exchange rates measured by a PFT method, and house characteristics were sought by selecting 501 house units from the Greater Boston area in the winter of 1985. The air infiltration rates ranged from 114 m3/hr to 1096 m3/hr with the mean and standard deviation being 325 m3/hr and 168 m3/hr. The mean and standard deviation of air exchange rates were 1.47 (1/hr) and 1.16 (1/hr) respectively. Fifteen factors were extracted by a factor analysis to characterize the house units. Building type, height of housing unit, extent of implemented energy conservation measures such as double pane window and window caulking, and number of adult occupants were significantly influenced on the air infiltration and exchange rates. Results of the NO2 survey were not included here due to the limitation of space.

#NO 5421 Buildings and health. Indoor climate and effective energy use.
AUTHOR Johnson B G, Kronvall J, Lindvall T, Wallin A, Lindencrona H W
BIBINF Sweden, Swedish Council for Building Research, Document D20: 1991.
ABSTRACT The indoor climate in our dwellings, offices, schools and other premises is of decisive importance for the health and wellbeing of their occupants. Health and comfort problems associated with the indoor climate have, however, come to constitute a major problem in recent years. A conclusion is that the hygienic and climatic requirements frequently are neglected, and that they must reassume a central position in the building and building management process. Greater demands must be made on the quality of materials, on responsibility and competence in the building process and on the overall strategy for energy conservation in conjunction with both new construction and modernization. Presentday knowledge of health problems associated with the indoor climate and an overview of the possibilities of solving these problems are presented in this knowledge survey.

#NO 5439 Exposure to nitrogen dioxide in homes in the UK: a pilot study.
AUTHOR Raw G J, Coward S K D
BIBINF UK, University of Warwick, Legal Research Institute, conference, "Unhealthy Housing: The Public Health Response", 1820 December 1991
ABSTRACT The purpose of this study was to pilot a method for investigating typical levels of nitrogen dioxide (NO2) in homes, and the factors which influence personal exposure to NO2, in the UK. The pilot was also used to conduct an analysis of thefactors which influence indoor levels of NO2 and personal exposure. 72 homes were selected on the basis of type of area (inner city, suburban or rural) and cooking fuel (gas o relectricity). Passive sampling diffusion tubes (Palmes tubes) were used to measure NO2 concentrations in the bedroom, living

room, kitchen and immediately outside the home. In addition, personal exposure was measured by diffusion tubes worn by the occupants. Data on the dwelling and occupants (particularly those undergoing personal monitoring) were obtained using questionnaires and diaries. The survey was carried out in the summer.

#NO 4983 Northwest residential infiltration survey (NORIS) project protocol.
AUTHOR Parker G B, Hadley D L, Lee R N
BIBINF USA, Battelle Pacific Northwest Laboratories, April 1988.
ABSTRACT This document describes the Battelle project team, the design and selection of the sample of homes to be studied, field data collection training and procedures, data recording and reporting procedures, the quality assurance plan and the schedule for conducting the study. This document also briefly discusses the background and previous relevant studies in the Northwest region.

#NO 5499 New Jersey radon program, 1991.
AUTHOR Anon
BIBINF USA, Environmental Protection Agency, "1991 International Symposium on Radon and Radon Reduction Technology", Volume 7: State Programs and Policies Relating to Radon, paper from a conference held in Philadelphia, Pennsylvania, April 1991.
ABSTRACT Describes the radon mitigation programme set up by the New Jersey Department of Environmental Protection (NJDEP), in response to calls from enquiries resulting from an article in the New York Times. The resulting survey of potential sites for radon and action taken are documented here.

#NO 4982 Northwest residential infiltration survey (NORIS) recruitment plan.
AUTHOR Parker G B, Hadley D L, Morrow P A
BIBINF USA, Battelle Pacific Northwest Laboratories, April 1988.
ABSTRACT This document describes the systematic approach to be used to recruit the residents to participate in the NORIS field study. Qualified homes for the first heating season's study will beselected from a random telephone survey conducted by the Washington State Energy Office. A sample of approximately 290 candidate homes will then be drawn from the survey by Ecotope, Inc. for recruitment. Of this sample of 190 homes, 160 homes will be selected for the field measurements. Qualified homes for the second heating season's study will be selected from a list of MCS homes supplied by the Bonneville Power Administration. A sample of approximately 150 of these homes will be drawn by Ecotope, Inc. for recruitment. Battelle will be responsible for recruitment and for obtaining a cooperative agreement from residents willing to participate in the study. Participation inthe field measurements will be voluntary. The study will last anywhere from 2 to 24 weeks in a home.

#NO 4976 Northwest residential infiltration survey (NORIS) technical reference field manual.
AUTHOR Parker G B, Hadley D L
BIBINF USA, Battelle Pacific Northwest Laboratories, July 1988
ABSTRACT This document is intended to serve as a standard technical reference manual for field specialists performing data collection for the Northwest Residential Infiltration Survey (NORIS). It is also intended as a training aid and as project documentation of data collection principles, procedures, and protocols for the field measurements portion of the project. The primary purpose of this manual is to ensure that the data collected in NORIS participant homes is meaningful and defensible, and that it is collected efficiently, with minimal disturbance to the occupants of those homes. The procedures documented in this manual include those for acquiring data on structure leakage using a onetime fan pressurization (blower door) measurement, information on structure and occupant characteristics, a two to threeweek ventilation measurement using a perfluorocarbon tracer (PFT) technique, temperature andwind speed

data, and records of significant occupant activities during the PFT measurement period.

#NO 4770 Moisture and mould in blocks of flats. Stage 1: a survey of damage and the present state of knowledge.
Fukt och mogel i flerbostadshus. Etapp 1: Inventering av skador och kunskapslage.
AUTHOR Karpe J
BIBINF Sweden, Stockholm, Swedish Council for Building Research, report R78:1990.
ABSTRACT The report describes investigations of the extent and nature of moisture and mould damage in blocks of flats. A survey of the present state of knowledge in this area has also been carried out. The aim of the survey was to analyse the problem situation, primarily in order to control thefurther orientation of the project. It is clear from the report that there is a lot of moisture damage in residential buildings. This is particularly the case as regards facades, windows, balconies and wetareas (bathrooms, laundry rooms) etc. The nature of damage is also shown in detail, as well as the frequency of occurrence of each type of damage. The report also sets out what, in the opinion of SABO (Federation of Swedish Nonprofitmaking Housing Enterprises), the present damage situation is due to. Shortcomings in the housing loan regulations, changes in living habits, and also defects in theorganisation and state of knowledge of the enterprises, are pointed out as important causes of such damage. The report ends with a description of what property management firms are asking for. What they mainly want are descriptions of remedial measures to eliminate moisture damage, aswell as information and training for not only the management personnel of the firms but also the occupants and their representatives. Further work in the project will therefore concentrate on satisfying this demand.

#NO 4563 Indoor air quality test protocol for highrise residential buildings.
AUTHOR Rousseau J
BIBINF Canada, Canada Mortgage and Housing Corporation, April 1990, 49pp.
#DATE 00:04:1990 in English
ABSTRACT This manual provides a protocol for the assessment of air quality in highrise residential buildings. The protocol is based on a three stage process: a preliminary assessment, simple contaminant measurements and, where warranted, complex measurements. The preliminary assessment consists primarily of site inspections and occupant surveys. The second stage involves simple, usually inexpensive, contaminant measurements which, in most cases, identify the majority of problems. The final stage of the investigative process is required only when careful evaluation during the first two stages has not identified both the causes and probable solutions to any detected problems.

#NO 4304 Survey of the medical impact on environmentally hypersensitive people of a change in habitat.
AUTHOR Barron S R
BIBINF Canada Mortgage and Housing Corporation, April 1990.
ABSTRACT This report summarizes the medical histories of 29 people with environmental hypersensitivity disorder (multiple chemical sensitivities) who have made modifications to their homes toimprove indoor air quality for health purposes. It also reviews literature on environmental illness and the medical discipline of clinical ecology. The literature review supports the existence of environmental hypersensitivity disorder as a real and serious health problem. Ongoing professional controversy over etiology and treatment prevents many affected people from obtaining appropriate medical treatment. 29 respondents completed detailed medical questionnaires, documenting a variety of symptoms associated with this chronic disorder. All respondents report improvement in health following modifications to their homes to reduce chemical exposure. The population surveyed is not statistically random and the results of the medical survey are not

statistically useful since a bias already exists in the source of the candidates.

#NO 3212 Predicting the contributing effects of occupants on the total air changes in houses.
AUTHOR Stum K R
BIBINF USA, Utah, Orem, Envirosun, April 1988
ABSTRACT The paper aims to do the following: 1. Describe a survey (and its results), which was performed to obtain more information about the habits of occupants as they relate to air change. 2. Quantify the air change associated with occupants' habits. 3. Develop a model to predict the air change caused by occupants that will be useful to the practitioner. 4. Outline the applications of the model.

#NO 2483 What do the occupants think? Vad tycker de boende?
AUTHOR Engvall K
BIBINF VVS & energi, No 10, 1986, in Swedish.
ABSTRACT Reports on social survey interviews being carried out with the purpose of assessing what occupants think of different energysaving methods. Parameters include: the occupants' opinion of the ventilation during the winter and summer; the occupants' opinion of the temperature during the winter andsummer; what are the occupants' reactions to noise in apartments and its sources; comparison with previous apartment. Considers that not only heating and ventilation are important factors. Project continues and further interviews with occupants will be carried out in Spring 1987.

#NO 2446 The Pennyland and Linford low energy housing projects.
AUTHOR Everett R C
BIBINF Int J Amb Energy, Vol 7, No 2, April 1986, p7587, 10 figs, 5 refs. #DATE 00:04:1986 in English
ABSTRACT This paper is a summary of the results of two complementary low energy housing projects that have been monitored by the Open University Energy Research Group. Over the past nine years these have involved the design, monitoring and evaluation of nearly two hundred new houses. The results have clearly shown the benefits of simple energy saving measures. The largescale Pennyland field trial has demonstrated a halving of gas heating energy consumption, worth about _115/yr per house at 1984 prices for an estimated extra construction cost of _440, giving an overall payback time of under five years. A social survey showed that the measures were also well liked by the occupants. The companion eighthouse Linford project has allowed detailed study on the various measures involved: Insulation to Danish BR77 standards,Use of low thermal capacity gas boilers, Airtight construction, Direct gain passive solar design. Detailed costings of the projects have also given a full breakdown of their relative cost effectiveness.

#NO 2308 Inhabitant behaviour with regard to mechanical ventilation in France.
AUTHOR Bienfait D, Moye Cl
BIBINF 7th AIVC Conference,"Occupant interaction with ventilation systems", 29 September 2 October 1986.
ABSTRACT In France, most of the ventilation systems in dwellings now consist of exhaust vents linked up with a fan, and air inlets. A survey conducted by the CSTB shows that actual ventilation rates are frequently different from prescribed values and that a lot of problems encountered are related to occupant behaviour. The duration of exhaust flowrate peak value was measured; it was shown that this duration was dependent on the kind of command and its location in the room. Draughts through air inlets were a major concern. A lot of air vents did not operate correctly because of fouling. Reasons were that theinhabitants had not always a high consciousness of the necessity of cleaning, and that, moreover, a lot of air vents were not easily dismountable. Among conclusions of the survey, are the following: air vents should be easily dismountable for cleaning and recommendations for it should be given to the inhabitants; air inlets, exhaust vents and fan command should be correctly located.

#NO 2307 Ventilation and occupant behaviour in two apartment buildings.
AUTHOR Diamond R C, Modera M P, Feustel H E
BIBINF 7th AIVC Conference,"Occupant interaction with ventilation systems", 29 September 2 October 1986.
ABSTRACT In this paper we approach the subject of ventilation and occupant behavior in multifamily buildings by asking three questions: 1) why and how do occupants interact with ventilation in an apartment building, 2) how does the physical environment (i.e., building characteristics and climate) affect theventilation in an apartment, and 3) what methods can be used to answer the first two questions. To investigate these and other questions, two apartment buildings in Chicago were monitored during the 1985 1986 heating season. In addition to collecting data on energy consumption, outdoor temperature, wind speed, and indoor apartment temperatures we conducted diagnostic measurements and occupant surveys in both buildings. This paper describes each of the research methods utilized, the results of these efforts, and conclusions that can be drawn about ventilationoccupant interactions in these apartment buildings. The major conclusion of this work is that a multidisciplinary approach is required to understand or predict occupantventilation interactions. Such an approach must take into account the physical characteristics of the building and the climate, as well as the preferences and available options of the occupants.

#NO 2303 Ventilation air infiltration and building occupant behaviour.
AUTHOR Harrje D T, Kempton W M
BIBINF 7th AIVC Conference, "Occupant interaction with ventilation systems", 29 September 20 October 1986,
ABSTRACT This paper describes work at Princeton which measured occupant ventilation behaviour, and which provided feedback in an attempt to modify behaviour. Experiments have been conducted about the effect of informing the occupant as to when outdoor temperature is low enough that window opening would be the better choice than employing mechanical cooling methods. A small blue lightvisible to the occupants was used to supply this guidance, in conjunction with feedback to the occupants about cost. In a large multifamily building, regular visual inspection of window openings, sometimes supplemented with infrared scanning, were used to identify the prevalence of these actions. Fan pressurization tests in the apartments indicated very tight construction with the windows closed. When comfort and perceived ventilation needs conflict with energy conservation, poor temperature regulation can be the culprit. In another study, data were collected through openended interviews and a survey in the same multifamily building.

#NO 1818 Basic material for the instruction of occupants of homes. How, when and where to use your windows.
AUTHOR De Gids W F
BIBINF 6th AIC Conference "Ventilation Strategies and Measurement Techniques", Het Meerdal Park, Netherlands, 1619 September 1985. Air Infiltration Centre.
ABSTRACT Airtightness measurements were carried out in ten typical Dutch dwelling complexes. In each complex four homes were measured. The IMG calculation model was used to calculate expected ventilation for these dwellings. Results of a survey of 1500 occupants on use of ventilation are given. The ventilating behaviour in 610 homes was studied in greater detail. 210 of these had some form of mechanical ventilation. Ventilation requirements are given for individual rooms. To provide efficient ventilation, the system must be welldesigned, of adequate dimensions, easily controllable and adjustable, within reach of the inhabitant and easy to handle. It should cause no draught or noise nuisance. Occupant education is also important.

#NO 1666 Survey of occupants in dwellings with an air heating and ventilation system.
AUTHOR Van Dongen J E F.

BIBINF IMGTNO Instituut voor milieuhygiene en gezondheidstechniek, January 1984, pub. no 11566. Rapport D79, 188pp, 7 figs, 12 tabs, and Supplement, May 1984, 28pp, 2 tabs. #DATE 00:05:1984 in Dutch
ABSTRACT 50 occupants of terraced houses, divided into 4 groups, were surveyed three times in October 1981, February 1983 and March 1983. The first group had Isolair air heating and ventilating systems, and were well insulated with double glazing. The second group was heated by radiators and had the same insulation as group 1. Groups 3 and 4 had normal insulation. Results of the surveys are given. The air heating and ventilating system did not provide the level of satisfaction hoped for. The group with the air heating and ventilating system was surveyed again in March 1984.

#NO 1647 Residential indoor air quality, structural leakage and occupant activities for 50 Wisconsin homes.
AUTHOR Quackenboss J J. et al.
BIBINF Indoor Air. Vol 5. Buildings, Ventilation and Thermal Climate. Edited by B Berglund, T Lindvall, J Sundell. Swedish Council for Building Research, 1984. 411420, 2 tabs, 23 refs. #DATE 00:00:1984 in English AIVC bk
ABSTRACT As part of an investigation into the influence of a residential weatherization program on indoor air quality and energy efficiency, a multipollutant survey of the air inside 50 Wisconsin homes was conducted three times during the heating season of 19821983. Air infiltration, structural leakiness, and thepresence and use patterns of indoor air pollutant sources during the same time period were also measured. Indoor air quality measurements included integrated sampling for nitrogen dioxide, respirable sized particulates, radon, formaldehyde, and carbon monoxide. Air infiltration rates were measured using a constant emission Sulfur Hexafluoride method: structural leakage area was determined using the fan pressurization ("blower door") technique. Household residents kept a stove and exhaust fan usage diary during each sampling period. Occupant activities related to the use of other pollutant sources or to intentional ventilation were also recorded.

#NO 809 Indoor climate problems in Danish dwellings Complaints and diseases referred to the type and materials of dwellings and the living habits.
AUTHOR Valbjorn O. Nielsen P.A. Kjaer J.
BIBINF In "Building Energy Management" E.de.O.Fernandes, J.E.Woods, A.P.Faist (eds.) Proceedings, International Congress Povoa de Varzim 1216 May 1981 p.717726 5refs. Pergamon 1981 #DATE 13:05:1980 in English
ABSTRACT Reports survey of indoor climate problems in dwellings. Questionnaires were distributed to 424 families who had complained of indoor climate problems and 240 replies were received. The questionnaires dealt with complaints relating to the dwellings and the age, profession, health and smoking habits of theoccupants. The dwellings are described by type, age, material of outer and interior walls, ceiling and floor. There are questions on ventilating habits, cleaning habits and occupants' views on dust, noise, odour, temperature, humidity and draughts. Gives results of survey and discusses the incidence of dry upper airways, headaches and eye irritation.

#NO 627 Airtightness of buildings: Results from airtightness measurements in new Norwegian houses. Boligers lufttethet: Resultater fra lufttethetsmalinger av nyere norske boliger.
AUTHOR Brunsell J.T. Uvslokk S.
BIBINF Norges Byggforskningsinstitutt report no.31 1980 ISBN:8253601255< =A.I.C. translation no.7 #DATE 01:01:1980 in english, norwegian #AIC 278
ABSTRACT Presents the results from a major airtightness survey carried out in Norwegian dwellings. 61 detached houses and 34 flats were pressure tested. In 14 of the detached houses and 6 of the flats, leakage paths were traced using thermography. Gives tables of results. Lists most common leakage paths located by thermography. Occupants of the dwellings

were interviewed about draught problems, but there was no clear correlation between occupant dissatisfaction and leakage rate. Notes a considerable variation in leakage between the houses.

VARIOUS BUILDING TYPES

#NO 9221 Survey on the indoor environment of enclosed car parks in Hong Kong.
AUTHOR Chow W K, Fung W Y
BIBINF Tunelling Underground Space Technol., April 1995.
ABSTRACT Results of an indoor environment survey of 19 underground car parks in Hong Kong are reported. The indoor air temperature, relative humidity and air speed were measured. Subjective feelings of the occupants and their views on the indoor environment were surveyed by questionnaire. The design and operation of the installed ventilation systems and the number of occupants staying at the car parks were also investigated. Finds that studies of this kind are very important in providing design data. Goes on to propose a fourpoint assessment system to quantify the indoor thermal environment of the car parks.

#NO 8374 Pascool thermal comfort studies
AUTHOR Baker N, Stadeven M.
BIBINF France, Ecole Nationale des Travaux Publics de l'Etat, November 1994, proceedings of the European Conference on Energy Performance and Indoor Climate in Buildings.
ABSTRACT This paper summarises the studies of the PASCOOL comfort task whose aim is to develop revised comfort criteria for assessing predicted conditions in freerunning buildings. The studies have been used to try to quantify some of the nonrandom "errors" that can lead to a discrepancy between conventional comfort predictions and observed comfort conditions. Occupant adaptation and interaction with the building environment, such as movement, clothing change and metabolic rate adjustment have been surveyed for occupants in a number of buildings in southern Europe. A record of the spatial and temporal variation of conditions is obtained using a novel personal sensor array.

#NO 4978 Air infiltration and building factors: comparison of measurement methods.
AUTHOR Nagda N L, Fortmann R C, Koontz M D, Rector H E
BIBINF USA, proceedings of the 79th Annual Meeting of the Air Pollution Control Association, Pittsburgh, Pennsylvania, June 2227, 1986
ABSTRACT As part of an indoor air quality survey that GEOMET Technologies, Inc., conducted in Texas during the 19841985 heating season, air exchange was measured in residences using a pressurization technique and two different tracergas techniques. Selected questions were posed to occupants to quantify building factors and ventilation practices. In this paper, the measurement methods are described and empirical relationships derived from measurement results are presented.

#NO 4264 Design and protocol for monitoring indoor air quality.
AUTHOR Nagda N L, Harper J P (eds)
BIBINF USA, Philadelphia, ASTM publication STP 1002, 1989.
ABSTRACT Papers presented at the Symposium on Design and Protocol for Monitoring Indoor Air Quality, held in Cincinnati, Ohio, April 2627, 1987. The focus of the symposium was on the design and protocols for investigating, sampling, analyzing, and characterizing building, occupant, and environmental factors, and other aspects of indoor air measurements. The book groupspaper in three major sections: Commercial and Office Buildings, Residential Buildings, and Instrumentation and Methods. The 21 papers include four papers on using tracer gas measurements to characterize ventilation. There are two papers on instrumentation for measuring volatile organic compounds: one for investigating buildings, the other for characterizing emissions from building materials. The papers on commercial and

office buildings include several on considerations in designing investigations. Others offer some case studies and discussions of general investigation methods. There is also a report from a workshop on data collection aspects of building investigations. The aspects include general building problem areas, bioaerosol sampling considerations, and tracer gas techniques for measuring air exchange rates. The residential building papers include largescale studies, testhouse studies, and reports from workshops on survey needs and survey questionnaire design.

#NO 1880 Systematic development of survey instruments for indoor air quality studies.
AUTHOR Koontz M D, Nagda N L
BIBINF 78th Annual Meeting, Air Pollution Control Association, Detroit, USA, June 1621 1985. 16p. 1 fig, 4 tabs, 7 refs. #DATE 00:06:1985 in English

ABSTRACT This paper describes a framework and methodology for developing and evaluating surveys of occupants for indoor air quality studies. Factors to be studied, and how they can be classified, are addressed. How the often substantial information can be obtained in a stepwise fashion without burdening theparticipant unduly, and ways of judging the efficacy of the questions are also discussed.

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