AN OVERVIEW OF VENTILATION FOR THE CONTROL OF AIR QUALITY IN BUILDINGS

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Abstract

Ventilation is needed to satisfy the metabolic needs of occupants and to dilute and disperse pollutants generated within an occupied zone. This article provides an overview of the role of ventilation in providing for a good indoor climate. Particular emphasis is devoted to what ventilation can and cannot be expected to achieve. A review is also made of the generic approaches to ventilation and consequent design needs. Discussion is focused on ventilation needs in relation to occupants, occupant activities and pollutant emissions from internal sources. The energy implication of each of these needs is also discussed. Finally, proposals for future research activities in relation to ventilation are outlined. These include identifying the current position with regard to the magnitude and range of ventilation rates within the existing building stock, evaluating ventilation needs according to occupant requirements and pollution emissions, and formulating both energy and cost effective ventilation strategies for meeting ventilation needs.

INTRODUCTION

As the thermal performance of buildings continues to improve, air exchange will eventually become the dominant mechanism for building heating or cooling loss. Although, therefore, an essential parameter of the energy equation, ventilation is nevertheless vital for the dilution and removal of pollution generated within buildings. An inadequate supply of fresh air or poor air distribution may result in:

- **high levels of indoor contaminants**
- **discomfort and a poor living environment**
- **more serious health related problems**

As a consequence, reduced air change as a means to minimise energy demand has become inextricably linked to the problems associated with unhealthy buildings. Despite this apparent connection between indoor air quality and air change rate, it is, nevertheless important that the role that ventilation plays in controlling indoor air quality is fully understood. In many instances, ventilation may not be the most appropriate control mechanism. Furthermore, the need to increase the rate of ventilation, in order to control the concentration of pollutants introduced into occupied spaces, can be equated with an energy penalty. Often too there is a misconception about the role of ventilation and the role of building airtightness. Building `tightness' especially is sometimes used to describe many problems including the re-entry of exhaust air, poor ventilation, bad maintenance and the incorrect operation of ventilation systems. Equally the term 'inadequate ventilation' may be used to express conditions of discomfort and poor temperature control. It is important therefore, that a clear distinction is made between ventilation problems and other building health issues.

The purpose of this article is to review ventilation as an air quality control mechanism and to attempt to explain what ventilation can be expected and not expected to achieve. Some of the future research proposals of the Air Infiltration and Ventilation Centre are also outlined.

BACKGROUND

Minimum ventilation rates needed to secure adequate indoor air quality have been the subject of intensive investigation. In many instances, the control of pollution should arguably involve the restriction or elimination of the polluting source but often it falls upon ventilation to provide an answer. This can result in increased energy demand and in the need to provide extra ventilation capacity. The derivation of minimum ventilation rate is dependent on identifying the dominant pollutant, its source strength and its maximum acceptable indoor concentration. This approach is well documented as illustrated, for example, in **British Standard BS5925:1990.** Other recent assessments of needs include **ASHRAE Standard 62-1989** on *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 1989) and the results of **IEA Annex 9** on *Measures to Control Air Quality* (Trepte 1989). This latter report summarises the efforts of experts in 11 countries and at the EC ISPRA Research Establishment to focus on the sources and characteristics of common indoor pollutants and to evaluate the effects of such pollutants in relation to risk, annoyance and damage to building fabric. Control measures such as source control and ventilation needs are assessed for each pollutant.

In a review of indoor air quality problems (Ref. 6), a brief analysis of in excess of 90 technical papers revealed many suggestions as to the causes of such problems. These can essentially be categorised into the following three broad themes:

1) ventilation system performance

2) contaminants

3) other parameters

Ventilation System Performance

A summary is presented in Table 1. While insufficient or inadequate ventilation was widely cited as a cause, the measurement of air change is, as yet, not a common feature of air quality investigations. Unfortunately, without having routine knowledge of air change rates in buildings, it is to recommend any changes to ventilation rates in order to improve building air quality. A conclusion, therefore, would be that if ventilation is thought to be a problem, then indoor air quality investigations should include air change rate measurements. At the very least, efforts should be made to ensure that fresh air requirements as specified, for example, by **ASHRAE 62:1989** are being satisfied.

TABLE 1

Reasons for Sick Buildings - Ventilation Systems
Ventilation too low
Ventilation too high
Inoperative ventilation system
Air conditioning problems
Poor filtration
Poor maintenance

Contaminants

Some of the indoor contaminants investigated as part of indoor air quality studies are listed in Table 2. Those such as asbestos and formaldehyde, are specific to building components or choice of thermal insulation, others such as outdoor pollution and radon are more dependent on building location. The remainder tend to be contaminants which depend on building use and occupancy patterns. Since, over time, the pattern of building use can vary, the relative concentrations of occupant generated pollutants and hence ventilation needs may also be expected to vary.

TABLE 2

Reasons for Sick Buildings - Building Contaminants
Asbestos
Carbon Dioxide
Carbon Monoxide
Dust
Formaldehyde
Fungal Spores
Humidity (too high, too low)
Ions
Odour
Outdoor Pollution
Ozone
Radon
Smoke
Volatile Organic Compounds

Other Parameters

Other reasons cited in the literature as causes of *"sick buildings"* are indicated in Table 3. These tend to be linked to psychological or work related problems, the absence of user controls (eg openable windows), excessive noise and inadequate or inappropriate lighting.

TABLE 3

Reasons for Sick Buildings - Other Parameters
Lighting
No User Control
Noise
Psychological Factors
Stress

Since such a wide range of problems are associated with unhealthy buildings it is unlikely that a single common cause exists. However it is clear that ventilation is perceived to have an important role to play in the avoidance of such problems.

DEFINING OPTIMUM VENTILATION NEED

From the preceding discussion, it is possible to consider the following contributions to indoor pollution, each of which have an important bearing on ventilation needs and resultant energy impact:

(a) Metabolic Pollution (CO2 and Odour)

The need to ventilate to maintain metabolically produced carbon dioxide and odour to acceptable levels represents a minimum ventilation requirement and hence the minimum ventilation energy condition. A building or a zone within a building in which high concentrations of metabolically produced pollutants are measured clearly indicates insufficient ventilation. Furthermore, for a given occupancy pattern, the problem can only be solved by increasing the rate of ventilation.

(b) Pollutants Produced by the Activities of Occupants

Occupants produce pollution as a consequence of normal day to day activities. This could be tobacco smoke, moisture generation through cooking and washing, and contaminants generated by the use of unvented combustion appliances. Whether or at what level such pollutants are acceptable is largely a medical judgment but, if any of these contaminants or other occupant generated contaminants are found in a building in which the previous criteria set by (a) is satisfied, then either these activities must be reduced or further ventilation is needed. Any such additional ventilation requirements may also result in additional costs for installing and operating extra ventilation capacity.

(c) Pollutants Produced by Building Fixtures and Furnishings

These pollutants include volatile organic compounds, ozone and formaldehyde emissions. As with (b) acceptable concentrations must be based on medical judgment and the control strategy is either removal or increased ventilation. If the solution is increased ventilation, then the energy consequence is, again, clearly definable.

(d) Pollution Generated by the Ventilation System or through Poor Design

Some problems may be associated with poor ventilation design. These include air intakes being located too close to ventilation exhaust vents or too close to flues. In these examples, the rate of ventilation will not solve such problems and therefore increasing the rate of ventilation is not a viable control strategy.

(e) External pollution

External pollution could include soil gases, dust, industrial pollutants or traffic fumes. Again, ventilation of the internal space will not necessarily solve these problems. Strict airtightness controls and, in the case of external airborne pollutants, filtration systems are needed.

(f) "Unidentifiable" Air Quality Problems

Once identifiable sources of pollution have been eliminated, further indoor air quality problems may be apparent. This seems to be especially a problem with air conditioned spaces. Some evidence points to toxic microbiological or fungal infection of the ductwork. Again, it must be regarded as unlikely that the ventilation rate itself is too low and a different control measure (eg disinfection of the ductwork) is needed.

By undertaking an anlysis in such a structured way, the significance and implications of ventilation can begin to be identified and the consequent energy impact of ventilation can be evaluated. It is proposed, therefore, that such a study should take place.

SYSTEMS AND STRATEGIES

Once a ventilation need has been identified, then a system to achieve this must be designed. Overestimation of ventilation will influence heating or cooling losses as well as the energy needed to operate the system. Essentially, systems can be divided into two generic forms, these being 'dilution' systems and 'displacement' systems.

* **Dilution System** - incoming air is uniformly mixed with the interior air mass
* **Displacement System** - the interior air is displaced by incoming air with mixing kept to a minimum.

In practice some combination of the two approaches is common. While, from an air quality aspect, displacement approaches are generally preferred, very precise operating conditions are normally needed and their operation can be impaired by occupant activities, temperature fluctuations and door opening etc. Where air is conditioned, or warm air heating is used, high recirculation rates and resultant mixing ventilation may be necessary.

The motivating force for ventilation may be either natural or mechanical. This choice will influence the generic form of approach. Natural driving forces, for example, tend to be vary variable and therefore cannot normally be used to control a displacement ventilation system, although the use of passive ventilation stacks can provide some measure of flow control between zones in a building. A full account of developments in ventilation strategies is presented by Knoll (1991) (Ref. 5).

Integral to the selection of a ventilation strategy must be consideration of the building itself. In other words the building must be constructed to suit the ventilation system.

Mechanical Ventilation

Mechanically balanced supply/extract systems demand very airtight building shells for correct operation. Extract or supply only systems demand sufficient perimeter or envelope openings to avoid build up of excessive pressure differences across the building envelope. Such pressures can cause air quality or comfort problems, incorrect operation of the ventilation system and/or excessive operating energy demand.

Natural Ventilation

Natural ventilation systems cannot be expected to supply a constant flow rate and therefore user controllable perimeter openings are needed to ensure provision for adequate air flow under all operating conditions. Ideally, these should be openable windows for 'Summer' cooling purposes and air vents for 'Winter' air supply.

Building airtightness is therefore inevitably a vital part of the design strategy. It is only when a building is tightened without regard for ventilation that *'tight building'* problems will arise. The Swedish approach has been "Build tight - Ventilate right" (Elmroth 1980) (Ref. 3) Stringent airtightness with combined ventilation requirements are successfully enshrined in the **Swedish Building Code (1989).**

Demand Controlled Systems

Since buildings are frequently transiently occupied, ventilation needs may also be variable. Demand controlled systems are therefore becoming popular. At its most basic level odour is widely used as an indicator of air quality and ventilation may be controlled to minimise the intrusion of odour. However, the quantitative measurement of odour using instruments is not possible and therefore other indicators are needed for the automatic control of ventilation. One such indicator is Carbon Dioxide which is often used as a measure of occupancy and occupancy generated pollution. **ASHRAE Standard 62:1989** sets an upper concentration limit of 1000ppm for comfort (odour) although **British Standard 5925:1990** still uses 5000ppm. CO2 systems are used in commercial buildings, schools, shops and theatres. In the home, humidity controlled sensors may be found for the control of extract fans or systems in bathrooms and kitchens. Demand control is being investigated in detail by **IEA Annex 18** (Raatschen and Mansson 1990). The principal objective of this task is to develop guidelines for demand controlled ventilation systems based on the varying needs of domestic, office and other environments. While essentially focusing on Carbon Dioxide and humidity sensors for ventilation control, mixed gas, tobacco smoke and Carbon Monoxide sensors are also being considered. Additional work within **Annex 18** includes the development of guidelines for the implementation of demand controlled ventilation systems. A number of case studies have also been reviewed by this Annex.

The choice of ventilation system is therefore extremely wide and no single approach to ventilation can be expected to meet the requirements of all applications. Inevitably cost effectiveness as well as energy efficiency will be an important consideration in most instances. Ultimately the choice will be motivated by such considerations as:

*** capital costs * running costs * maintenance needs * reliability * heat loads and heat gains * building size and location * building purpose * climate * energy effectiveness * occupant needs ***

Whichever choice is made, however, it is thought that much more can be achieved in the design of efficient ventilation than is accomplished at present. Hence a proposal of the AIVC is to produce a *Guide to Ventilation* which would be aimed at policy makers, designers and other groups interested in promoting and developing energy efficient ventilation.

ENERGY IMPACT OF VENTILATION

In a global sense, the energy impact of ventilation is considerable and, in the future, may be expected to exceed that of building transmission heat or cooling loss. To offset this loss, there is, of course, considerable opportunity for ventilation heat recovery using air to air heat recovery systems and/or heat pumps. In capturing this return, however, consideration needs to be given to cost effectiveness, long term reliability and quality of building construction.

If it is assumed that air enters the building at the external air temperature and leaves the building at the internal air temperature, then the energy of ventilation is given by:

$$H = Q p c_p (T_{int} - T_{ext}) \quad (W)$$

where
Q = air flow rate (m^3/s)

p = air density (kg/m^3)

c_p = specific heat of air (J/kg/K)

T_{int} = internal temperature (K)

T_{ext} = external temperature (K)

Heat loss may conveniently be expressed in terms of Watts/m3 of enclosed space/°C temperature difference. Alternatively it may be expressed as a "ventilation heat loss coefficient" analogous to U-value, ie Watts/m2 of envelope surface/°C. Both of these measures provide a simple way of comparing the magnitude of ventilation heat loss with conduction losses from buildings.

Because the measurement of air change in buildings has, until recently, been both difficult and time consuming, there is little perception of actual ventilation rates and resultant heat loss in the overall building stock of Europe. A first step in any comprehensive ventilation analysis would therefore be to undertake a comprehensive evaluation of the existing building stock as outlined in the following section.

FUTURE RESEARCH

The Air Infitration and Ventilation Centre has recently prepared a strategy document identifying research needs for future ventilation and related energy research. The fundamental intention has been to identify the prime objectives and tasks needed to secure energy efficient ventilation. A strategy to determine the current energy consumed in buildings through ventilation is also proposed.

The principal objective of the future work programme is to understand, develop and promote the role of ventilation in indoor air quality and energy control (Figure 1). In order to achieve this the following tasks are proposed:

(i) Establish Indoor Air Quality Needs

Before ventilation requirements can be quantitatively identified, it is essential that indoor pollutants are understood. The purpose of this task, therefore, is to address this problem. Proposals include:

- **reviewing existing IAQ codes, standards, requiremnts and knowledge.**
- **classifying indoor pollutants, sources and sinks.**
- **assessing the interaction of pollutants.**
- **establishing acceptable pollutant concentrations.**

Many of these tasks are seen as falling within the domain of IAQ specialists.

(ii) To Identify the Role of Ventilation

The role of ventilation as an IAQ control mechanism must be clearly identified. In some instances, for example, ventilation may be essential while in others, ventilation control may be totally inappropriate. The suggested tasks include:

- **a review of existing knowledge and evidence.**
- **an analysis of the influence of flow rates, flow patterns and ventilation efficiency on the control of pollutants.**
- **field measurements to assess the role of ventilation.**
- **the specification of minimum ventilation rates and/or alternative control**

These tasks are principally seen as ventilation specialist activities.

(iii) To Evaluate Optimum Ventilation Needs and to Identify the Associated Energy Impact

The purpose of this exercise is to assess ventilation needs for both occupant and IAQ requirements in order to derive optimum air change rates.

Starting with the basic need for metabolic ventilation, the extra ventilation needed to cope with occupant activities and pollutant sources is identified. In each case, the resultant energy consequences need to be assessed. The tasks proposed include:

- **compiling requirements on metabolic needs.**
- **compiling requirements for occupant activities**
- **determining requirements to cope with pollution sources within buildings**
- **evaluating associated energy impact**

(iv) Assessing the (Global) Energy Impact of Ventilation

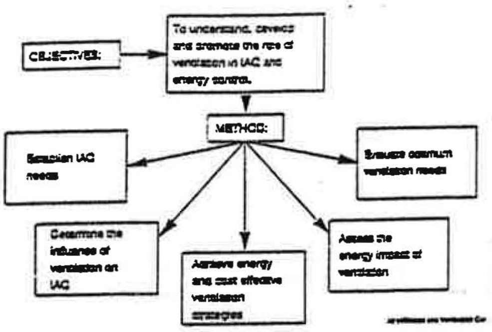
This task is seen as a major activity. The intention is first to assess the air change rates and resultant energy demand in the existing building stock (commercial buildings and dwellings), the second task is to evaluate the potential reduction in energy achievable by meeting basic ventilation needs. Both aspects of this study will help to provide information on the potential for energy reductions. The tasks include:

- **Evaluate the ventilation heat loss in the existing (occupied) building stock:**

(a) by analysis of building energy use statistics

(b) by sample simplified measurements in a statistically significant number of occupied buildings combined with supporting detailed measurements in selected buidings.

- **Evaluate theoretical minimum ventilation heat loss.**
- **Evaluate potential for energy reduction.**

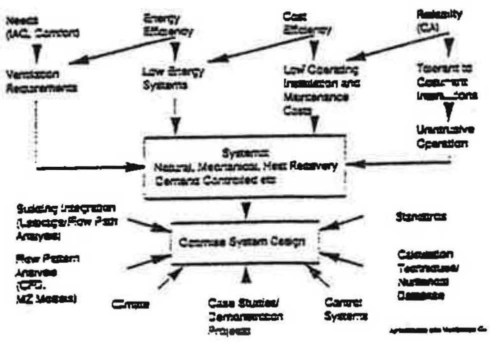


Strategy for IEA Ventilation Analysis

Figure 1

(v) Achieve Energy and Cost Effective Ventilation

Once the target for energy reduction has been determined, the final objective is to establish the strategy needed to achieve this goal. The necessary parameters is illustrated in Figure 2. The results of the preceding studies are combined with other factors such as climate, cost considerations, building integrity and occupant requirements in order to optimise system design and achieve reduced energy demand. From this analysis a realistic aim for optimum air change combined with energy efficiency may be set. In undertaking this analysis, input from other international activities covering air flow and multizone modelling techniques, database information and control systems will be essential.



Achieve Energy and Cost Effective Ventilation

Figure 2