A REVIEW OF VENTILATION AND THE QUALITY OF VENTILATION AIR

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ABSTRACT

Ventilation is pivotal both in terms of indoor air quality and environmental issues such as greenhouse gas emissions. It also has a major impact on energy use in buildings. It is important, therefore that the role and impact of ventilation is fully understood. The purpose of this paper is to review these aspects with particular reference to recent research and developments. Key aspects are concerned with the role of ventilation in maintaining good indoor air quality, ensuring the quality of the outdoor air and incorporating strategies to ensure good ventilation performance. References are particularly made to the development of standards and to examples of good case study buildings. Although good progress is being made, areas that still need to be addressed include maintaining good outdoor air quality and preventing contaminated outdoor air from entering buildings.

INTRODUCTION

Ventilation plays a fundamental role in maintaining good indoor air quality and thermal comfort in buildings. In fulfilling this need it touches on a wide range of topics associated with building design and services. Added to this, it is estimated that a third of all energy in OECD (and European) countries is consumed in buildings, and that a third of that is dissipated through ventilation and air infiltration. In investigating the impact of ventilation, it is important to consider various aspects including the role of ventilation, minimum ventilation need, ventilation mechanisms, climate, location, cooling need and the quality of ventilation air. The purpose of this paper is to provide a brief review to recent work aimed at achieving good ventilation performance.

THE ROLE OF VENTILATION

Ventilation is the process by which 'clean' air is intentionally provided to a space and 'stale' air is removed. In an occupied space, its fundamental purpose is to provide oxygen for metabolism and for the dilution of unavoidable pollutants, i.e. products of metabolism (carbon dioxide and odour) and for the essential activities of people (washing, clothes drying etc.). Ventilation is also used to maintain good indoor air quality by diluting and removing other pollutants in a space. Other roles include thermal distribution (i.e. pre-heated or pre-cooled supply air), 'passive' cooling of a building (e.g. 'night' cooling) and combustion air for 'open flue' appliances.

Too often, however, it falls upon ventilation to accomplish tasks for which it is not appropriate. As a rule, all but unavoidable pollutants should be controlled by elimination, substitution or source containment. Also ventilation cannot deal with contaminants that are introduced into the supply air at source or upstream of the location where fresh air is needed.

MINIMUM VENTILATION FOR OPTIMUM AIR QUALITY

There is currently considerable discussion on how much ventilation is needed. In essence this is coupled with the whole issue of indoor air quality. Too little ventilation has been demonstrated to be injurious to health and aids the spread of illness and infection. On the other hand, high rates of ventilation can cause discomfort through poor thermal control, draught and noise. The provision of high ventilation rates is also very costly in terms of energy and ventilation plant size. The prescription of a minimum acceptable ventilation rate (and its associated risk and health implications) has therefore become very difficult.

Throughout the world, considerable progress is being made in updating relevant standards to reflect current knowledge and concerns. 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[1]. While generally now being regarded as in need of revision, such is the public concern over defining minimum ventilation rates, that attempts to update this Standard have, so far, largely failed. In an attempt to overcome this difficulty, the AHRAE Standards Committee approved in 1998 separating the proposed revision of Standard 62 into two separate Standards [2], these being:

- Standard 62.1: Ventilation and Acceptable Indoor Air Quality in Commercial, Institutional, and High-Rise Residential Buildings

- Standard 62.2:Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

In both cases the scopes are aimed at defining the roles of and the minimum requirements for ventilation to provide acceptable indoor air quality. Also, while acceptable indoor air quality is the goal of these standards, it is recognised that such goals may not be achieved even if all requirements are met. To support this development, ASHRAE [2] has also produced a position paper on indoor air quality. This defines ASHRAE's responsibility with respect to indoor air quality.

In Europe, ventilation standards are being developed through CEN Technical Committee 156 "Ventilation for Buildings". Progress has recently been reviewed by Jackman [3]. In this review Jackman reports that the item causing most controversy is an attempt to standardise design criteria for the indoor environment. The criteria developed in this process have been published as a CEN Technical Report CR 1752. It specifies the levels of temperature, noise, and ventilation for occupied spaces.

VENTILATION MECHANISMS

Ventilation technology is rapidly expanding as improved control and monitoring systems are being developed. Essentially ventilation may be one of 'displacement', in which the 'clean' incoming air displaces 'room' or 'contaminated' air, or 'mixing' ventilation, in which the incoming air mixes with room air, thus, 'diluting' contaminant levels. Usually 'displacement' ventilation is seen as most efficient because a lower ventilation rate is normally needed to achieve equivalent acceptable air quality to building occupants than would normally be required by more conventional 'mixing' ventilation. However mixing ventilation (often with recirculation) is widely applied when the supply air is used to provide thermal conditioning to a space (i.e. as opposed to providing conditioning by separate means such as hydronic radiators and chilled beams etc.). In addition to the ventilation process itself, heat, cooling and latent load can be extracted from the exhaust air for pre-conditioning of the supply air. Advancing technology is improving the performance, reliability and cost effectiveness of such systems to the point where significant efficiency in cost and energy is possible.

Depending on the building, activities, location and climate, ventilation can be satisfied by either natural means, mechanical means or by a combination of both. Recent developments focusing on advanced natural and hybrid ventilation strategies include the European NatVent [4], TipVent [5] and AirLit-PV [6] programmes and the International Energy Agency 'Hybvent' [7], Evaluation and Demonstration of Domestic Ventilation Systems [8] and Low Energy Cooling [9] programmes.

OUTDOOR CLIMATE

The severity of climate influences the degree of heating and cooling that is necessary to provide comfort to a space. Greater potential exists for the use of complex ventilation systems (for example incorporating heat recovery and heat pump technology), when heating and cooling loads are high. A system that may be cost effective in one climate zone may not be effective in another.

Frequently the dominant pollutant is 'heat' itself. Particularly in large commercial offices, high heat loads are developed by the high concentration of lighting and other electrical appliances, as well as from occupants, solar radiation and high outdoor temperatures. These factors make cooling of the indoor air essential. The choice is either to introduce refigerative cooling or to introduce cooling by ventilation. In making this choice, it is also important to determine if comfort can be achieved by direct reduction in dry bulb temperature or if latent cooling (and hence refrigeration) is also needed. In either case, heat loads must be minimised by careful use of shading, daylighting and by the introduction of energy efficient appliances.

When climate and circumstances dictate the need for refrigerative cooling, then the ventilation rate should be controlled to that needed to meet optimum health needs. In other words, excessive ventilation and infiltration losses should be avoided to prevent the unnecessary loss of conditioned air. On the other hand, provision for substantially higher rates of ventilation are needed for non refrigerative cooling by air change. It is also essential for the ventilation air to be strongly coupled to thermal mass within the building otherwise the building itself can act like a fully charged capacitor and operate at excess air temperature rather than reduced temperature. Examples of good studies are published in the NatVent Case Study analysis [4] and in a recent IEA Innovative Cooling Case Study Report [9].

THE QUALITY OF VENTILATION AIR

To achieve successful ventilation, the ventilation air itself must be free of pollutants. Formally it was accepted that the 'outdoor' air largely met this requirement and that it could be regarded as suitably 'fresh'. Urbanisation, though, and the pollutants generated by a highly industrialised society, has resulted in localised contamination of the atmosphere. The quality of ventilation air is affected by several important factors including; the outdoor air quality, the proximity of the air intake to a pollutant source, the application of filtration, the cleanliness of the ventilation system.

Outdoor Air Quality: Good outdoor air quality is an essential pre-requisite for effective ventilation, yet increasing urbanisation and contaminant emissions into the atmosphere is presenting difficulty. Significant sources of local pollution include regional industrial pollution, pollution from vehicles and pollution emissions from adjacent buildings. In agricultural regions, pollen and chemical sprays can also be a problem. Pollution entry into buildings is widely documented (Limb [10]). Kukadia et al [11,12] 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 followed the daily external variation although at a lower concentration. Also Green et al [13] describe two separate experiments in which carbon monoxide (CO) from traffic is monitored inside buildings. Ajiboye et al [14] consider pollution at five sites in the UK. Preliminary measurements demonstrated that both PM10 and NO2 concentrations decrease with increasing height from a busy road, and that this could be a useful strategy for reducing the impact of contaminants derived from vehicle emissions.

***The Siting of Air Intakes*:** To minimise the risk of pollutant ingress through air intakes, the challenge is to position the intake away from local pollution sources. As buildings become more densely located and as traffic densities increase, this becomes even more of a problem. Examples of bad practice are vividly illustrated by Rock [15]. Guidelines based on dilution analysis are presented in the ASHRAE Fundamentals. Also, recently, Irving [16] has investigated intake location. In the Netherlands, the Dutch Code of Practice 1088 and Dutch Regulations NEN 1087, [17] has attempted to address the issue of siting air intakes in relation to building exhaust locations. To overcome problems associated with low level pollution, Gage [18] proposes practical examples of 'top-down' ventilation in which ventilation air is taken into the building at or above building height level.

Active Control of Intake Air: 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 [19], 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.

Filtration: Filtration is an obvious solution to dealing with external pollutants and is almost universally used in conjunction with the mechanical ventilation systems associated with fully air-conditioned buildings. In the UK, a typical 'design and build' air-conditioned building located in an urban environment would have main filtering to European 'EU6' or 'EU7' specification. Within the important respirable particle range, of 0.1 to 2.5 μm, the corresponding capture efficiency is greater than approximately 97% at 2.5μm for both specifications and between approximately 44% (EU6) and 55% (EU7) at 0.1μm . Subject to good design and building airtightness this filtration approach is therefore potentially effective at reducing respirable particle concentration. To reduce the penetration of gaseous components, however, high quality (gas adsorption and HEPA) filters must be used, this is an extremely expensive solution.

***Cleanliness of the Ventilation System*:** Duct contamination, especially of the supply system, must be avoided. 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. A review of this topic is covered by Lloyd [20].

CONCLUSIONS

The impact of ventilation on energy, IAQ and thermal comfort is considerable. In addition there is a diverse range of options, guidelines and standards covering all aspects of ventilation. The purpose of this review has been to focus on recent publications covering ventilation and IAQ. In undertaking ventilation design it is essential that the implications and consequences of each ventilation choice is clearly understood and analysed. Too often it falls upon ventilation to accomplish tasks for which it is not appropriate. The prime role of ventilation is to meet metabolic needs and remove pollutants from unavoidable sources i.e. pollutants generated by occupants themselves and their essential activities. All other pollutants should be controlled by elimination or source containment.

Fortunately there is a substantial range of innovative technique case studies (e.g. NatVent and IEA Annex 28 Low Energy Cooling). The results of these provide good guidance on the performance of new techniques. Despite good progress, much work is still needed, however, on introducing measures to avoid the ingress of outdoor contaminants into a space, especially where the siting of air inlets is concerned. This is particularly the case for highly urbanised areas in which there is a high risk of contamination of the ventilation air from vehicles and adjacent building exhausts.

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