VENTILATION, IAQ AND ENERGY EFFICIENCY IN HOT HUMID CLIMATES

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ABSTRACT

At the conceptual design stage, one needs to pay considerable attention to both the energy as well as indoor air quality (IAQ) requirements. Often, designers tend to overlook ventilation and IAQ issues and conceptualise the HVAC design more from energy considerations. An energy efficient design of air-conditioning system in hot and humid climates is quite challenging in view of the high humidity levels prevailing all-year round. This paper outlines some of the key factors that could lead to inadequate or inefficient ventilation and, thereby, poor IAQ. An overview of some integrated IAQ-energy audit case studies conducted in Singapore in the mid nineties is presented. Finally, a couple of emerging technologies related to air-conditioning and air distribution that are particularly ideal for hot and humid climate are presented.

KEYWORDS

Indoor air quality, energy efficiency, ventilation, hot and humid climate, air-conditioned buildings

INTRODUCTION

In hot and humid climates, one of the biggest challenges to overcome from an air-conditioning system design perspective is dehumidification or moisture removal. In this regard, the "H" can be conveniently removed from HVAC as Heating is seldom considered and designers are confronted only with the Ventilation and Air-Conditioning aspects. The process of cooling and dehumidification in practical air-conditioning system designs is one in which the dynamically varying sensible and latent cooling requirements are to be met in the correct proportion in which they occur in the occupied zones, and consequently at the cooling and dehumidifying coil. In other words, the dynamically varying Room Sensible Heat Ratio (RSHR) needs to be appropriately handled by the cooling coil performance. Invariably, this is the challenge as an improperly selected coil may lead to either inadequate dehumidifying performance, resulting in elevated humidity levels in the occupied zones or overcooling, resulting in an energy penalty. It is, thus, evident that the call for higher ventilation rates is always going to be perceived with trepidation in view of the energy issues. However, the lack of good ventilation would almost certainly lead to poor indoor air quality (IAQ) and eventually lead to rectification measures that could be more expensive than if it were to have been addressed in the original design. This paper deals with some of the ventilation, IAQ and energy related code of practice requirements in Singapore, following which an overview of ventilation and IAQ measurements conducted in air-conditioned buildings in Singapore in the mid nineties will be presented. Finally, a couple of emerging energy efficient technologies for effective and practical zone-level ventilation control that shows promise for the hot humid climates is discussed.

INTEGRATED IAQ AND ENERGY AUDIT STUDIES

A comprehensive study of five air-conditioned buildings in Singapore was undertaken in the mid nineties, which included measurements of exposures and technical characteristics as well as occupants' perception and symptoms (Sekhar et al., 2003). A summary of the research framework and the findings of this study are now discussed.

The measured concentration levels of the physical, chemical and biological pollutants were compared with relevant local and international standards/guidelines to establish the IAQ status of the building. In particular, continuous chemical monitoring data of carbon dioxide, carbon monoxide, formaldehyde and TVOC allows the profiling of the prevailing concentration levels over a weekly period, resulting in an "IAQ signature". In order to express the quality of indoor air in different premises, an indoor pollutant standard index (IPSI) was proposed, which recognises that the characteristics of indoor air pollutants are significantly different from each other and their effect on human health and comfort are also different from one another.

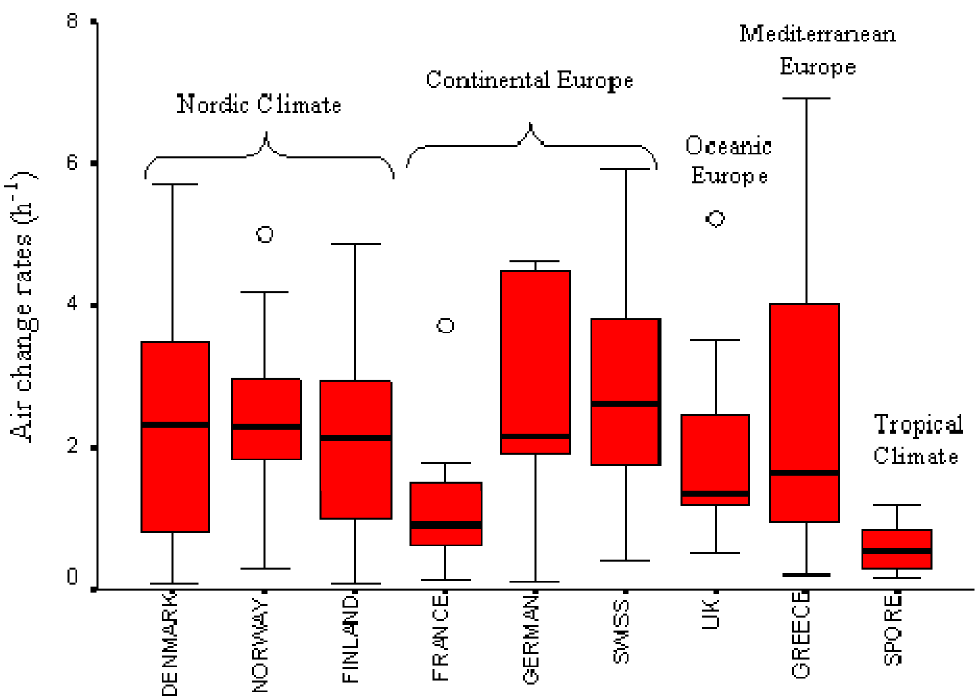

Figure 1 : Air change rates (ACH) measured in the European and Singapore buildings studied

Tracer gas techniques were employed to determine the ventilation characteristics such as the air change per hour (ACH), Air Exchange Effectiveness (AEE) parameters and the global air exchange efficiency. The ventilation index (lps/sq.m), normalized on the basis of air-conditioned floor area, is based on the actual amount of fresh air provided, calculated from measured air change rates (ACH). A comparison of the outdoor ACH between Singapore studies and those in other countries is shown in Figure 1, which indicates a high recirculation rate in air-conditioned buildings in hot humid climates (Zuraimi et al., 2005).

The IAQ-energy audit methodology, adopted in this study was based on a system-zone concept, which implies that all the indoor sampling points for a measurement set-up belong to a zone(s) that are served by the same air-conditioning and ventilation system. In the event of a zone(s) that constitute a control volume of space being served by more than one Air Handling Unit (AHU), then all the relevant AHUs serving the set of zones are included in the study as part of the same set-up. Such a “system-zone” concept was employed to ensure that the prevailing IAQ levels in the occupied zones could be attributed to the characteristics of the air-conditioning and the air distribution system. This was also envisaged to facilitate a study of the energy consumption at the micro level associated with a certain level of IAQ.

Building Symptom Index (BSI) was another parameter computed, which is an indicator of the well-being and health condition of the occupants as deduced from a questionnaire survey. It is the average number of sickness symptoms declared per person, out of a selected list. In deriving the BSI, only the symptoms that disappear after leaving the building are considered, in conformance to the notion of sick building syndrome terminology. BSI values were also computed separately for male and female occupants to explore the differences in perceptions between genders, as this has been observed to be a significant consideration in earlier studies.

A total of 5 buildings were studied and although large differences in the mean values of all the measured and computed parameters between individual buildings were observed, it is to be noted that they generally met the requirements of the local guidelines in Singapore. In the case of thermal comfort parameters, despite the mean values of operative temperatures for each building being reasonable, certain measured locations indicated air temperatures in the low range of the recommended values. A slight increase in these temperatures would imply an energy saving potential. The monthly energy consumption per air-conditioned floor area varied by a factor of 4.6 for the least energy consuming building to the most energy consuming building, which showed a reasonable theoretical economy potential as well as a significant diversity of conditions. The air temperatures measured in the occupied spaces of the audited buildings were generally in the lower range of the recommended values, and raising the air temperature set-points could provide an energy saving potential. Among the five buildings studied in this project, four of the buildings did not exhibit any clear relationship of poor IAQ and low energy consumption or vice versa.

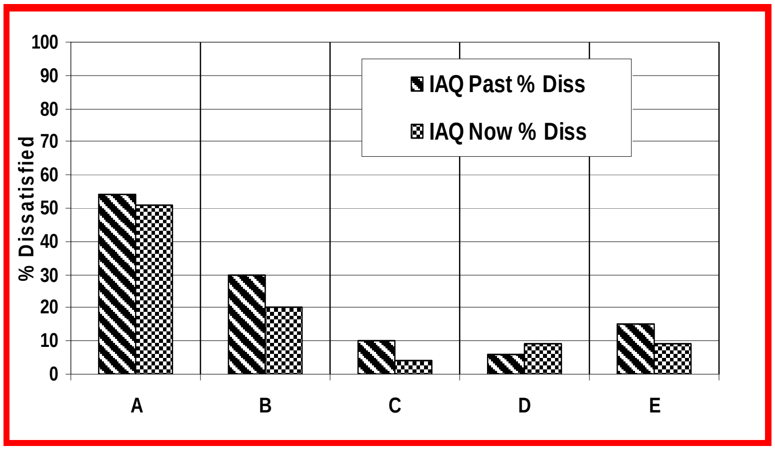

Figure 2 : IAQ acceptability rated by occupants expressed in percentage dissatisfied

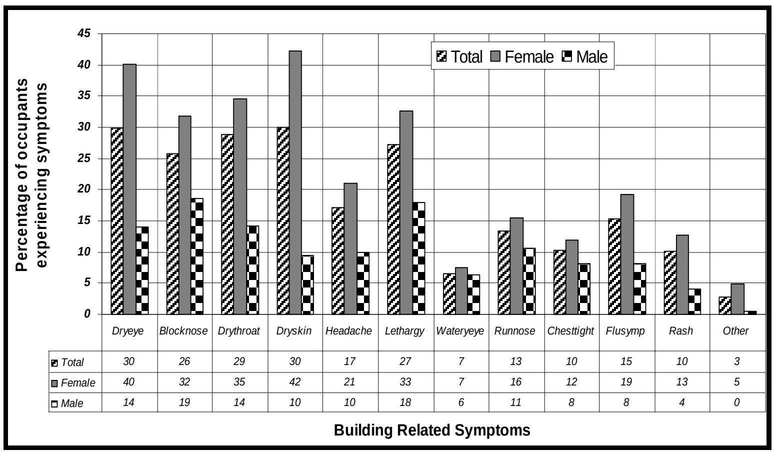

Figure 3 : A comparison of MALE and FEMALE Building Related Symptoms
(Mean of all 5 buildings) – Here and Now (%)

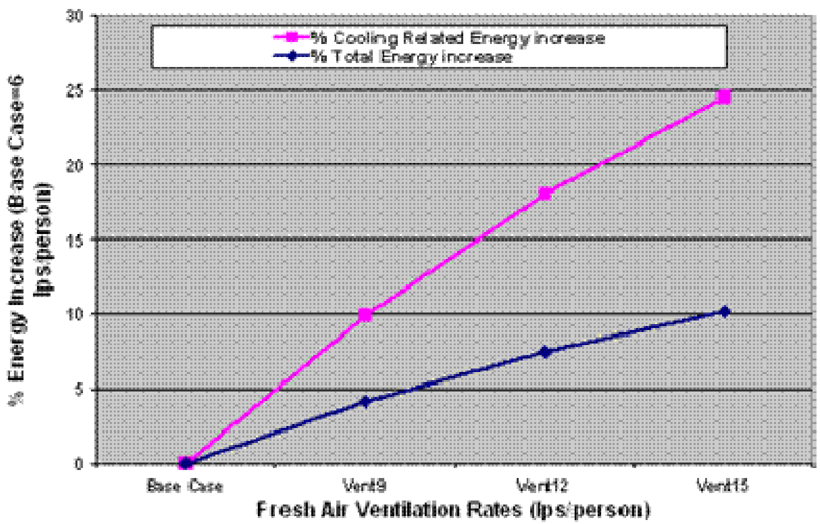

Figure 4 : Ventilation rates – Energy implications in hot and humid climate

Occupants' satisfaction with their indoor air quality is presented in Figure 2. The level of overall acceptability for thermal comfort was better than indoor air quality in general. Female occupants register significantly higher building related symptoms in comparison to their male counterparts in both the "past month" and the "here and now" periods, as shown in Figure 3. These observations were consistent with those seen in European studies (Bluyssen et al., 1996). The study suggested that the occupants' perception of symptoms experienced as well as environmental acceptability is quite distinct from IAQ acceptability determined from empirical measurements of indoor pollutants, which reinforces the complex nature of IAQ issues.

ENERGY EFFICIENCY AND ENHANCED IAQ

It is apparent that there would be a significant energy penalty with increased ventilation rates in conventionally designed air-conditioning and air distribution systems. A comparison of energy implications with varying ventilation rates is shown in Figure 4. The cooling energy increase between a ventilation rate of 6 lps/person to 15 lps/person could be as high as 25%. The challenge, then, is to explore the possibility of providing the ventilation to the occupied zones in such a way that adequate ventilation is provided at all times during human occupancy. A couple of technologies that are found promising are now discussed, with a particular emphasis for hot humid climate.

Single Coil Twin Fan (SCTF) System

The SCTF concept involves two variable air volume (VAV) systems employing one compartmented cooling and dehumidifying coil. A prototype unit was developed and installed to serve conditioned air to two rooms of an IAQ chamber in the Department of Building at the National University of Singapore (Sekhar et al., 2004). A schematic diagram of the SCTF air-conditioning and air distribution system is shown in Figure 5. The fresh air is conditioned in the "fresh air" compartment of the air handling unit (AHU) and distributed to the various VAV boxes that form part of the air distribution network. Each of these F/A VAV boxes is controlled by its own localized carbon dioxide (CO_2) sensors, which will ensure an adequate ventilation (F/A) provision at all times. As the main purpose of the F/A VAV box is to ensure adequate fresh air quantity based on occupant density, it helps in achieving energy conservation in the event of reduced occupant loads.

The return air from the various zones of the same distribution network is conditioned in the "recirculated air" compartment of the same AHU and distributed to a separate set of the various VAV boxes. Each of these R/A VAV boxes is controlled by its own localized zone thermostats, which addresses diversity in cooling loads, and consequently helps in achieving significant energy savings at part load operating conditions resulting from non-occupancy related factors. Based on our preliminary findings, energy savings up to 12% in conjunction with significantly improved IAQ have been observed in comparison with conventional air-conditioning systems (Sekhar et al., 2004). The conditioned Fresh Air and the conditioned Return Air travel in parallel ducts and do not mix until just before the supply air diffusers in the mixing chamber of the modified VAV box.

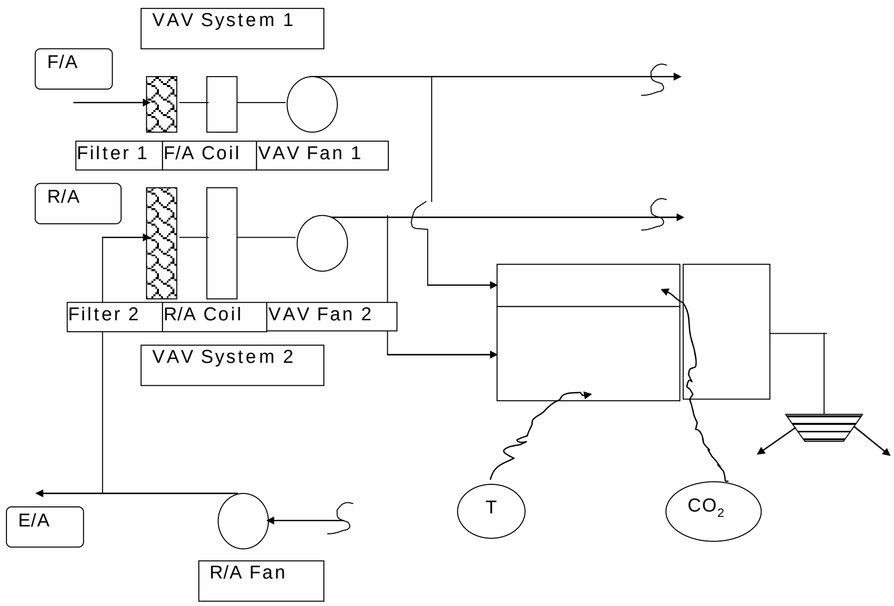

Figure 5 : The Single Coil Twin Fan (SCTF) system

Personalised Ventilation (PV) System

Whilst the concept of personalised ventilation (PV) is still primarily at the research stage in the area of air-conditioning, it shows tremendous promise for the future designs of buildings and is fundamentally based on improving ventilation to every individual in the built environment (Kaczmarczyk et al. 2004; Kaczmarczyk et al., 2002; Melikov et al., 2002). The PV concept has tremendous potential in enhancing the acceptability of Ventilation, Indoor Air Quality and Thermal Comfort in air-conditioned buildings by supplying clean fresh air directly to the occupant breathing zone without mixing with recirculated air, which is usually contaminated with indoor pollutants. The inability of conventional air-conditioning systems to do so often leads to occupant dissatisfaction.

Preliminary findings from a pilot study conducted at the National University of Singapore suggest that the use of PV system in conjunction with a secondary air-conditioning system significantly enhances thermal comfort and IAQ acceptability as well as the perception of freshness in the air (Sekhar et al., 2005). It was observed that the ventilation effectiveness of the PV system is significantly higher than conventional mixing ventilation system. Based on the responses of thermal comfort and IAQ acceptability, it is evident that the subjects do find the PV system to be significantly better than total mixing system. The pilot study has also indicated that the PV system has a potential to save energy in tropical designs.

The combination of the SCTF system and the PV system has attractive benefits to several building types, particularly those where considerable occupant and functional diversity are expected. For example in a health care facility, the fresh air supplied by the SCTF system can be easily configured as a PV air terminal device to provide in such a way that it flows through the doctor's immediate breathing zone before going towards the patient. This is envisaged to offer better infection control between the doctor and a sick patient.

CONCLUSIONS

This paper has highlighted the ventilation, IAQ and energy issues in air-conditioned buildings in a hot and humid climate. The Sick Building Syndrome symptoms experienced in the Singapore studies were quite similar to those observed in European studies. A couple of emerging air-conditioning and air distribution technologies are presented that could offer significant benefits both in terms of enhanced IAQ as well as energy efficiency.

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