represented. Samsung nominated four models in the SR Series including the SR-V52, SR-V57, SR-L628EV and SR-L626EV and all four won energy efficiency awards.

New air filter company

A new company, Air Safe Australia Pty Limited, has been formed that will manufacture and market air filters for the Australian market in air conditioning and ventilation systems installed in commercial and industrial buildings. The company is jointly owned by Robert Garnett, John Hill and James N. Kirby Pty Limited.

Kirby Refrigeration will be the sole Australian distributor for the range of filters manufactured by Air Safe Australia at Bankstown in Sydney.

Air Safe Australia has the exclusive rights for Scandfilter AB of Sweden, who manufactures filter media that meet the most stringent requirements for commercial and industrial applications. The product range includes cardboard disposable, pocket bag, vee mesh, pad, carbon activated and Hepa filters.

Scandfilter is one of only three filter media manufacturers in the world manufacturing electrostatically charged media.

This enables Air Safe Australia to manufacture filters for the Australian market with high initial performance and higher average performance than filters manufactured from non-electrostatically charged media with the same EU rating.

Robert Garnett has worked in the air conditioning industry for 30 years with companies such as McNeall Air Conditioning and Atlas Air Australia, and he has been a member of AIRAH for 25 years. Mr Garnett, who is a director of the company, says: "The company is well positioned to gain a significant market share of the filter business through having the right product and a company structure to suit the competitive market of the 1990s."

The company will offer building owners and managers technical support on ways of improving their building indoor air quality. This support will be provided through the expertise of John Hill, one of the company directors. John is an industrial chemist and has worked for companies such as CIG, Gelman Sciences and Clyde Apac. He has many years' experience in identifying indoor air quality problems.

Kirby Refrigeration's Grant Shallcross, national product manager - air filters, explains that with the formation of this new company Kirby is again offering a world class product to the industry. "We are very enthusiastic about this venture as it presents an excellent opportunity to get involved in a growing market due mainly to the heightened awareness of the need for superior air quality in so many applications.

With the technical backing of A.S.A. and the comprehensive range of world class filtration equipment we can now offer the industry, we at Kirby will have the answers to solve air quality problems for our customers."

For further information contact Air Safe Australia Pty Ltd, PO Box 4305, Milperra, NSW 1891, phone (02) 9708, fax (02) 9708 0688.

Copeland's Asian boost

Copeland Corporation, manufacturer of air conditioning and refrigeration compressors, is demonstrating its strong commitment to meeting the needs of customers in the fast-growing Asian markets by opening one new manufacturing facility in the region and breaking ground for another.

The company recently officially opened a US$70 million, 13,500m^2 facility on a 23-acre site in Rayong, Thailand. It is Copeland's first manufacturing plant in Asia and it will manufacture 250,000 units in 1998. It has installed capacity to produce 500,000 of the company's hitech compliance scroll compressors a year; and it will later be expanded to produce 1,000,000 compressors a year.

It has also held a ground-breaking ceremony to start the construction of a second facility in Suzhou, China. Representing a US$180 million investment, the 40,000m^2 Suzhou plant will also be capable of manufacturing a million compressors annually.

Award for back-saving device

A review of gas cylinder handling operations at a Newcastle Gas & Gear centre has led to BOC Gases developing a pneumatic cylinder lifting device which won the 1997 WorkCover NSW Back Injury Prevention Equipment Award as part of the WorkCover NSW BackWatch program.

The cylinder lifting device cost $150,000 and took 12 months to develop.

According to BOC Gases quality and safety specialist Marian McLean, the cylinder lifter greatly reduces the potential for workplace back injuries.

She said the cylinder lifter was developed by a special BOC Gases project team formed to identify how to improve workplace practices involving the manual handling of gas cylinders.

After reviewing existing operations, project team members sketched out their individual concepts of a model cylinder loading and unloading facility and pooled their ideas. A wooden prototype was built which led to the development of a working model and a final product.

Numerous safety features have been built into the design including a safety link at the end of the hoist chain, guarding on the cam mechanism and a warning bell in the event of a fall in air pressure.

The cylinder lifter can be used at any location where gas cylinders are singly handled and an overhead lifting system is available with a five metre clearance from floor to roof.

BOC Gases is seeking opportunities to market the device elsewhere in Australia and overseas.

For further information contact BOC Gases, phone (02) 9936 3666, fax (02) 9928 3900.

Ventilation design options for IAQ in HVAC systems

By Andrew J Crabtree, MA, MIEAust, CPEng, M.AIRAH*

This paper uses the "Amenity Index" concept introduced in the draft revision to *AS1668 — The Use of Ventilation and Air Conditioning in Buildings, Part 2 Ventilation of Buildings* to examine various techniques by which the ventilation aspects of indoor air quality (IAQ) in air conditioned buildings may be improved.

A common building model and ventilation system model are described, which incorporate perimeter and interior zones, high-occupancy and low-occupancy zones and a smoking zone to illustrate the demands imposed by these differing characteristics. The results of computerised calculations to determine the Amenity Indices for the basic model and for various supplementary techniques, both individually and in combination, are tabulated and discussed.

The particular problems associated with IAQ design in variable air volume (VAV) systems are briefly discussed. A suggested approach to the IAQ calculations in VAV systems is suggested, and two potential equipment/system options are described for resolving localised ventilation deficiencies.

Andrew Crabtree is principal of Crabtree Engineering Software, Perth, WA and is author of the computer program VENTPAC. This paper was presented at the 1997 AIRAH Conference, Hobart, Tasmania.

Introduction

The introduction of AS1668.2-1991 [1], and in particular the ventilation requirements detailed in Section 2 of that Standard, entitled "Supply Air Dilution Procedure", radically changed the way in which HVAC designers are required to assess the ventilation performance of the air conditioning and ventilation systems they design.

At the time of writing this paper, the Standard is in the process of revision, and the draft Standard for Comment (DR96425) [2] was issued on October 1, 1996 with the closing date for comment being 30 November 1996. In this paper, the expression "the draft Standard" is used to denote the above document.

The author wishes to emphasise that:

a) The DR96425 document is a draft only and is liable to change.

b) The opinions expressed in this paper and the interpretations of the draft Standard are those of the author and not those of Standards Australia.

The provisions of AS1668.2-1991 are complex, and have not been fully understood or implemented by many designers, including some of the most eminent design offices in Australia.

Whilst the calculation procedures required for an "engineered" solution are no less demanding under the draft revision to the Standard, the Amenity Index concept adopted in the revision facilitates the explanation of the objectives of the Standard and provides a basis for predicting the relative effectiveness of different alternatives.

This paper uses the Amenity Index concept to examine the relative merits of various techniques for IAQ enhancement, and proposes a general design procedure which will assist the HVAC designer in meeting the often conflicting objectives of maximising indoor air quality for environmental health reasons whilst minimising outdoor air quantity for energy conservation and capital cost reasons.

It was initially the author's intention to cover IAQ design for variable air volume (VAV) systems in this paper. Having embarked upon this segment, however, it soon became apparent that it is too large and complex a topic to be covered as a subsection of this paper, and merits a paper in its own right at a future date. Brief guidelines have been included in this paper which are intended to assist designers in addressing the IAQ issues relevant to this system design option.

The building and ventilation system model

This paper uses a common building and ventilation system model to demonstrate the effect of various individual techniques. A floor plan of the building model is shown in Figure 1, and the principal properties of the elements shown are detailed in Table 1.

Assumptions and factors of particular relevance to the performance of the ventilation systems are as follows:

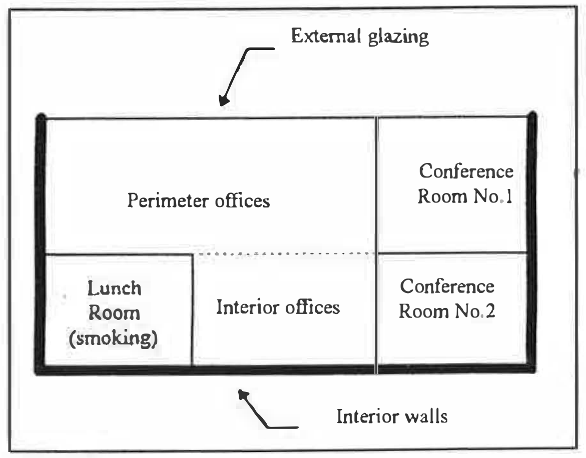
a) All areas of the model are air conditioned from a common central constant air volume (CAV) system with a design indoor maximum temperature of less than 27°CDB.

b) Both conference rooms have been modelled with an occupancy of 2m^2 per person. While this is half of the default occupancy recommended in AS1668.2 and/or the draft revision, it is a fairly common density of occupation in many existing applications.

c) Smoking is prohibited and activity level is "light" in all areas except the lunch room, where smoking classification is "intense" and activity level is "medium".

d) Supply air quantity ranges from 20 L/s per square metre in conference room 1, which has high occupancy and high solar and external fabric loads, down to 5 L/s per square metre in the interior offices, which have low occupancy and

Figure 1. Floor plan of the building model



Zone No.	Description	Floor area (m²)	Enclosure type	Occupants Air (L/s)	Supply	Notes
1	Perimeter offices	200	Offices - office areas	20	3500	Perimeter zone
2	Interior offices	150	Offices - office areas	15	750	Interior zone
3	Conference room 1	50	Offices - conference rooms	25	1000	Perimeter zone
4	Conference room 2	50	Offices - conference rooms	25	500	Interior zone
5	Lunch room	50	Food and drink services - dining rooms	30	750	Smoking
	Totals0	**500**		**115**	**6500**	

Table 1. General data for the building model

no external fabric loads. This distribution is consistent with the assumption of air conditioned spaces on the other sides of all three interior walls and on floors above and below.

e) The common air handling unit is modelled with central air filters rated F4 to AS1324.1, as required by the draft Standard (ie. minimum efficiency of 20 per cent using test dust No. 1).

IAQ performance assessment methodology

Ventilation system performance and the resulting indoor air quality in the ventilated spaces has been analysed using a development version of a computer program named VENTPAC [3] Version 3.

VENTPAC Version 3 uses the principles and equations contained in the draft Standard. Where necessary, the equations have been adapted to suit computerised calculation techniques and/or to accommodate system options which are consistent with the principles of the draft Standard but are not accommodated within the equations contained in it. In particular, this applies to the supplementary outdoor air option (see clause "Supplementary tempered outdoor air to high-load areas" below).

In the draft Standard, the measure which is used to assess the indoor air quality of each space is termed the "Amenity Index". In interpreting the Amenity Index, the following notes may be usefull:

a) For any enclosure, Amenity Index is calculated for each of three contaminants, namely body odour (BO), tobacco dmoke odour (TSO) and tobacco smoke particulates (TSP).

b) The Amenity Index is the inverse of the "Used Air Fraction" in the enclosure; ie. an Amenity Index of 1.0 indicates a Used Air Fraction of 100 per cent, or complete contamination.

c) An Amenity Index of 3.5 corresponds to a Used Air Fraction of approximately 30 per cent, and is the minimum allowable under the draft Standard for any of the enclosures.

d) An Amenity Index of 5.0 corresponds to a Used Air Fraction of 20 per cent, and is the recommended minimum under the draft Standard for conference rooms or dining rooms.

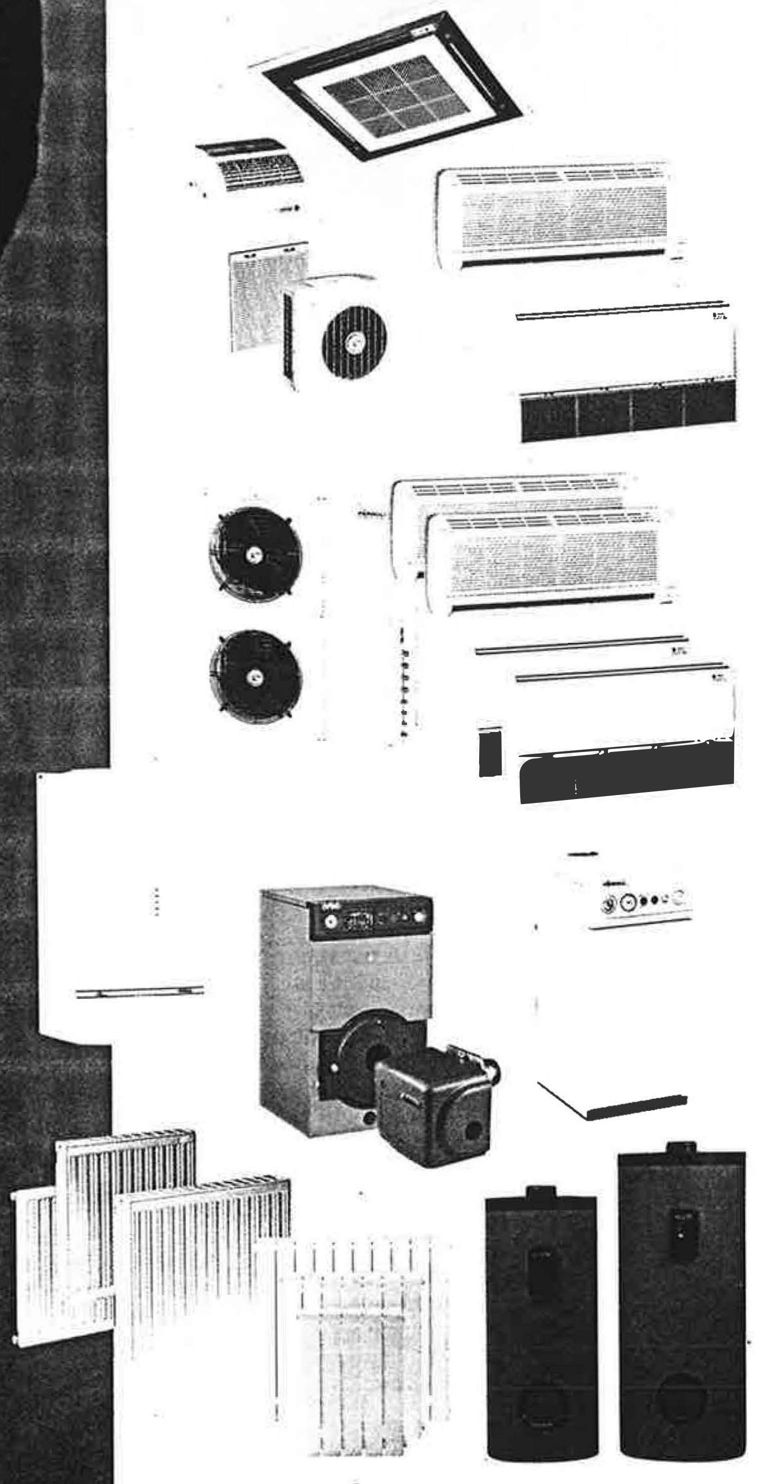
e) An Amenity Index of 7.5 corresponds to a Used Air Fraction of approximately 13 per cent, and is the recommended minimum under the draft Standard for office areas.

An iterative calculation procedure is

Table 2. IAQ performance comparison for system options

	Description	OAQ L/s	Amenity Indices														
			Perim. Offices			Interior Offices			Conf. Room 1			Conf. Room 2			Lunch Room		
			BO	TSO	TSP	BO	TSO	TSP	BO	TSO	TSP	BO	TSO	TSP	BO	TSO	TSP
	AS1668.2 Minimum		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	AS1668.2 Recommended		7.5	7.5	7.5	7.5	7.5	7.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1a	Basic system design	750	**4.7**	10.0	31.9	**4.4**	10.0	31.9	**4.3**	10.0	31.9	**3.9**	10.0	31.9	**3.0**	**4.7**	7.0
1b	No smoking, light activity	750	**7.0**	N/A	N/A	**6.4**	N/A	N/A	6.2	N/A	N/A	5.4	N/A	N/A	5.7	N/A	N/A
2a	O/A to DR96425-Clause 4.3.5	875	**5.6**	12.0	34.3	**5.2**	12.0	34.3	5.0	12.0	34.3	**4.5**	12.0	34.3	**3.4**	5.1	7.1
2b	O/A to DR96425-Clause 4.3.6	1650	11.8	26.3	52.2	10.1	26.3	52.2	9.6	26.3	52.2	7.7	26.3	52.2	5.0	6.7	7.6
3a	Exhaust Lunch Room	750	8.3	N/A	N/A	**7.4**	N/A	N/A	7.2	N/A	N/A	6.1	N/A	N/A	**4.3**	8.9	8.9
3b	Exhaust Perimeter Offices	750	**4.3**	8.9	28.2	**4.0**	8.9	28.2	**3.9**	8.9	28.2	**3.6**	8.9	28.2	**2.9**	**4.4**	6.8
4	Supp. O/A to Lunch Room	750	**6.3**	13.7	36.7	**5.8**	13.7	36.7	5.6	13.7	36.7	**4.9**	13.7	36.7	5.0	7.4	9.8
5a	Relief Perim.>Lunch Room	750	**4.7**	10.0	31.9	**4.4**	10.0	31.9	**4.3**	10.0	31.9	**3.9**	10.0	31.9	**3.5**	6.0	10.1
5b	Relief Conf. Rm 2>Interior	750	**4.7**	10.0	31.9	**4.2**	10.0	31.9	**4.3**	8.5	30.0	**3.9**	8.5	30.0	**3.0**	**4.7**	7.0
6	Increase Lunch Room S/A	750	**4.6**	9.9	33.3	**4.3**	9.9	33.3	**4.3**	9.9	33.3	**3.8**	9.9	33.3	**3.5**	6.0	10.3
7	Central air cleaning	400	11.5	11.2	25.7	9.9	11.2	25.7	9.4	11.2	25.7	7.6	11.2	25.7	5.0	5.0	6.6
8	Lunch Room S/A cleaning	650	**6.5**	10.6	31.9	**5.9**	10.6	31.9	5.8	10.6	31.9	5.0	10.6	31.9	5.0	5.0	7.0
9	Lunch Rm recirc. cleaner	650	**6.5**	10.6	31.9	**5.9**	10.6	31.9	5.8	10.6	31.9	5.0	10.6	31.9	5.0	5.0	7.0
10	Supp. O/A to Lunch Room Exhaust Lunch Room Relief Perim.>Interior Off.	150 + 750	8.3	N/A	N/A	7.9	N/A	N/A	7.2	N/A	N/A	6.1	N/A	N/A	5.1	10.6	10.7

Table 2



used to determine Amenity Index based on the following equations:

$U_{rc} = \Sigma(q_r/AI_c)/\Sigma q_r$ for all enclosures

$U_{sc} = U_{rc} \times [1 - (Q_f/Q_s)] \times (1 - \varepsilon_{cc})$

$AI_c = [q_s + q_t + (q_l \times \varepsilon_{lc}) + q_{sup}] / [((n \times a_{uc}) + (U_{sc} \times q_s \times (1 - \varepsilon_{lc})) + \Sigma(q_t/AI_{tc})]$

where:

AI_c = Amenity Index in the enclosure with respect to contaminant c

AI_{tc} = Amenity Index in an enclosure from which relief air is drawn with respect to contaminant c

a_{uc} = Contamination rate (air used) per person in L/s

n = Number of occupants in the enclosure

q_l = Recirculating air quantity through the local recirculating air cleaner/filter in L/s

q_r = Return air quantity from the enclosure to the common return air duct in L/s

q_s = Supply air quantity to the enclosure in L/s

q_{sup} = Supplementary outdoor air to the enclosure in L/s

q_t = Relief air transferred into the enclosure from an adjacent enclosure in L/s

Q_f = Total outdoor air drawn into the common air handling unit in L/s

Q_s = Total supply air delivered by the common air handling unit in L/s

U_{rc} = Used air fraction in the return airstream to the air handling unit with respect to contaminant c

U_{sc} = Used air fraction in the common supply air duct to all enclosures with respect to contaminant c

ε_{cc} = Air cleaning efficiency of the central air cleaner/filter with respect to contaminant c

ε_{lc} = Air cleaning efficiency of the local recirculating air cleaner/filter with respect to contaminant c

ε_{sc} = Air cleaning efficiency of the local supply air cleaner/filter with respect to contaminant c

Ventilation system performance and IAQ enhancement options

General

Table 2 shows the required performance of the ventilation system to comply with the draft Standard, the calculated performance of the basic system, and the calculated system performance with a variety of additions or modifications.

The left hand column shows a reference number which will be used in the following text to denote the system configuration.

It can be seen from configuration 1a (Basic system design) that the basic system using 12 per cent (750 L/s) outdoor air provides Amenity Indices in the body odour category which are less than recommended minimum in all five enclosures. Indeed, in the lunch room, which is evidently the most demanding enclosure, the Amenity Index for body odour is less than the minimum allowable value of 3.5, and the Amenity Index for tobacco smoke odours is less than the recommended minimum value of 5.0.

Because the lunch room is the most demanding enclosure, most of the IAQ enhancement techniques outlined in the following clauses are focused on improving the Amenity Indices in this enclosure.

The following properties of the basic system performance are of particular interest:

a) The Amenity Indices for tobacco smoke odours (TSO) are equal in all enclosures except the lunch room because all these enclosures are non-smoking. Therefore the Used Air Fraction of the air in each enclosure equals the Used Air Fraction U_s in the common supply air duct.

b) The same also applies to the tobacco smoke particulates (TSP) Amenity Indices. In addition, the 20 per cent efficient particulate air filters in the central air handling unit result in higher Amenity Indices with respect to tobacco smoke particulates (TSP) in all enclosures than for the other contaminants.

As a comparison, configuration 1b illustrates the effect if the lunch room were declared non-smoking and with light activity only. Since all enclosures are now non-smoking, there is no contamination in any enclosure with respect to tobacco smoke odours (TSO) and tobacco smoke particulates (TSP). Since the lunch room activity level is now light, BO contamination has been reduced and the lunch room Amenity Index now complies with DR96425. However, the Amenity Index in the perimeter and interior offices still falls short of the recommended minima, as these enclosures have the highest design values.

Using the Basic System Design of configuration la as the "benchmark", the following examples in the next eight clauses show the effect of implementing individual techniques to assess their impact on the Amenity Indices within the enclosures, and the example in the clause headed "Combination of techniques" shows the potential effect of combining a number of these techniques into one system.

Increasing outdoor air

Using the basic model of Table 1, if the prescriptive procedure of DR96425 Clause 4.3.5 is adopted, the required outdoor air quantity would be 875 L/s (ie. 85 people @ 5 L/s per person + 30 people @ 15 L/s per person).

The effect of increasing outdoor air flow rate to this value is shown as configuration 2a. This illustrates that although the BO Amenity Index in conference room 1 narrowly achieves its recommended minimum, the values in all other areas still fall short of the recommended level, and indeed in the lunch room is still below the minimum allowable value of 3.5.

It is important to note that this configuration is, in any case, not allowable under the requirements of DR96425 Clause 4.3.4(a), as the 750 L/s supply air quantity to the lunch room is less than the required minimum to comply with equation 4(1) of 969 L/s.

Alternatively, the minimum outdoor air quantity required by DR96425 Clause 4.3.6 to achieve the recommended Amenity Indices in all areas is 1650 L/s, with the lunch room being the critical area. The effect of this is illustrated in configuration 2b.

Increasing outdoor air quantity is the most common and simplest technique for improving IAQ, but has a significant capital and energy cost. The outdoor air quantity has increased from 12 per cent of supply air in the basic model to approximately 25 per cent, incurring additional cooling and heating loads of up to 40 per cent, depending upon location and ambient conditions.

Exhaust from high-load areas

Exhaust air drawn from the most demanding, or "dirtiest" enclosure reduces the amount of contamination which is returned into the common return airstream. This reduced Used Air Fraction in the return airstream results in a reduction in the Used Air Fraction in the supply airstream, which therefore improves the Amenity Indices in all enclosures.

Configuration 3a is based on an exhaust rate equal to the supply air to the enclosure, resulting in no return air to the common return air duct. This in turn results in Amenity Indices for tobacco smoke odours and particulates (TSO and TSP) in all enclosures other than the lunch room of infinity (ie. zero contamination) as there is no contamination either from the supply air duct or from within the enclosure. Paradoxically, though, configuration 3b models an exhaust rate of 750 L/s drawn from the perimeter offices, which have the highest Amenity Indices of all enclosures. By exhausting air from the "cleanest" enclosure, the concentration of contaminants in the common return airstream, and hence in the supply airstream, is increased and the Amenity Indices in all enclosures decrease.

Thus it is evident that careful consideration should be given to the relief air paths through which relief air to exhaust systems may best be drawn, and that where possible relief air should be drawn from densely occupied or "dirty" areas.

Supplementary tempered outdoor air to high-load areas

Configuration 4 illustrates the effect of supplying 270 L/s of supplementary outdoor air directly to the lunch room. This supplementary air would need to be tempered to design room temperature and may be delivered through common air diffusion fittings or separate air diffusion fittings to supply air from the main system.

Whilst its primary effect is to enhance the Amenity Indices in the lunch room so as to achieve recommended values, it also provides significant enhancement of the Amenity Indices in the other enclosures. This is the combined result of the dilution of the contaminants in the return air from the lunch room and the increase in contaminated "spill" air prior to the air handling unit.

In large buildings where changes of usage or partitioning are likely to occur from time to time, such as office towers, a supplementary tempered outdoor air supply system with a capacity of, say, 5 per cent of the main air handling system supply air could prove an effective tool in providing flexibility for the IAQ requirements of future tenancy changes.

Relief air from one enclosure to another

The location of the return air grilles within an air conditioning system is an often neglected facet of system design, and is commonly based simply upon the economics of duct and building layout without reference to any performance considerations.

Configurations 5a and 5b provide examples of how relief air paths can either enhance IAQ or diminish IAQ in the enclosures into which air is relieved.

In configuration 5a, 500 L/s is transferred from the perimeter offices to the lunch room, with a corresponding increase in the return air quantity collected from the lunch room and decrease in the return air quantity collected from the perimeter offices. Because the Amenity Indices in the perimeter offices are higher than those in the lunch room, this provides an enhancement of the Amenity Indices in the lunch room.

Conversely, however, in configuration 5b, the total supply air quantity is relieved from conference room 2 into the interior offices, a common design practice in many systems. This has the effect of diminishing the air quality in the interior offices due to the relatively low Amenity Indices in conference room 2. If relief air from the lunch room were used, this would have an even more damaging effect on interior offices IAQ.

It is interesting to note that this technique only affects the air quality in the enclosures into which relief air is transferred, as it only alters the path through which contaminants are returned to the air handling unit, but not the quantity of contaminants.

Increasing supply air to high-load areas

Configuration 6 illustrates the effect of increasing the supply air quantity to the lunch room from 750 L/s to 1250 L/s. This has the effect of diluting the contamination in the room air and the return air from the lunch room.

However, as the total return air quantity increases but the "spill" air quantity remains unchanged, a higher proportion of the total contamination generated within the building is returned to the air handling unit, and the Used Air Fraction in the supply air duct increases, causing a reduction in the Amenity Indices in the other enclosures.

In simple CAV systems, this is an option which is often inappropriate, as the increase in supply air quantity would require zone reheat to avoid unacceptable temperature deviations. In some system types, however, in particular face-and-bypass multizone systems or some dual-duct systems, this would be an option which offers no such barriers, as the full load supply air quantity would merely include a higher proportion of bypass air.

Central air cleaning/filtration

Configuration 7 demonstrates the effect of providing central air filters/air cleaners with adequate efficiencies for each contaminant to enhance the lunch room Amenity Indices to the recommended minimum.

This example uses efficiencies of 20 per cent efficiency with respect to body odour and 7 per cent with respect to tobacco smoke odour. Efficiency with respect to tobacco smoke particulates remains at 20 per cent as required by the draft Standard, and produces an Amenity Index which comfortably exceeds the recommended minimum.

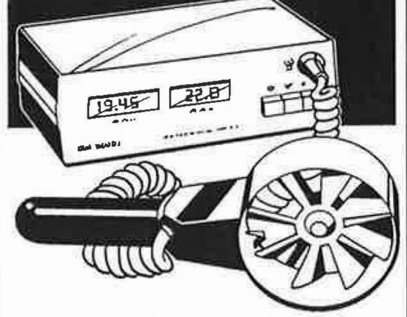
In addition, the outdoor air intake to the system has been reduced to 402.5 L/s which equates to the absolute minimum allowed under the draft Standard, Clause 4.3.6(a) — ie. 3.5 L/s per person.

It may be noted that, as the result in the lunch room is achieved by reduction of the Used Air Fraction in the common supply air duct, this solution also provides Amenity Indices which meet the requirements of the draft Standard in all other enclosures with a generous margin.

IMPORTANT NOTE:

Whilst activated carbon filters are extensively used for odour control, and may well be able to achieve the required levels of odour removal to meet the objectives of the draft Standard, neither AS1668.2-1991 nor the draft revision DR96425 acknowledge the existence of acceptable test methods for determination of the efficiency of odour-removing devices within the body odour or tobacco smoke odour ranges.

This effectively means that the performance benefits resulting from odour-removing air cleaners cannot be used to achieve compliance with the Standards.



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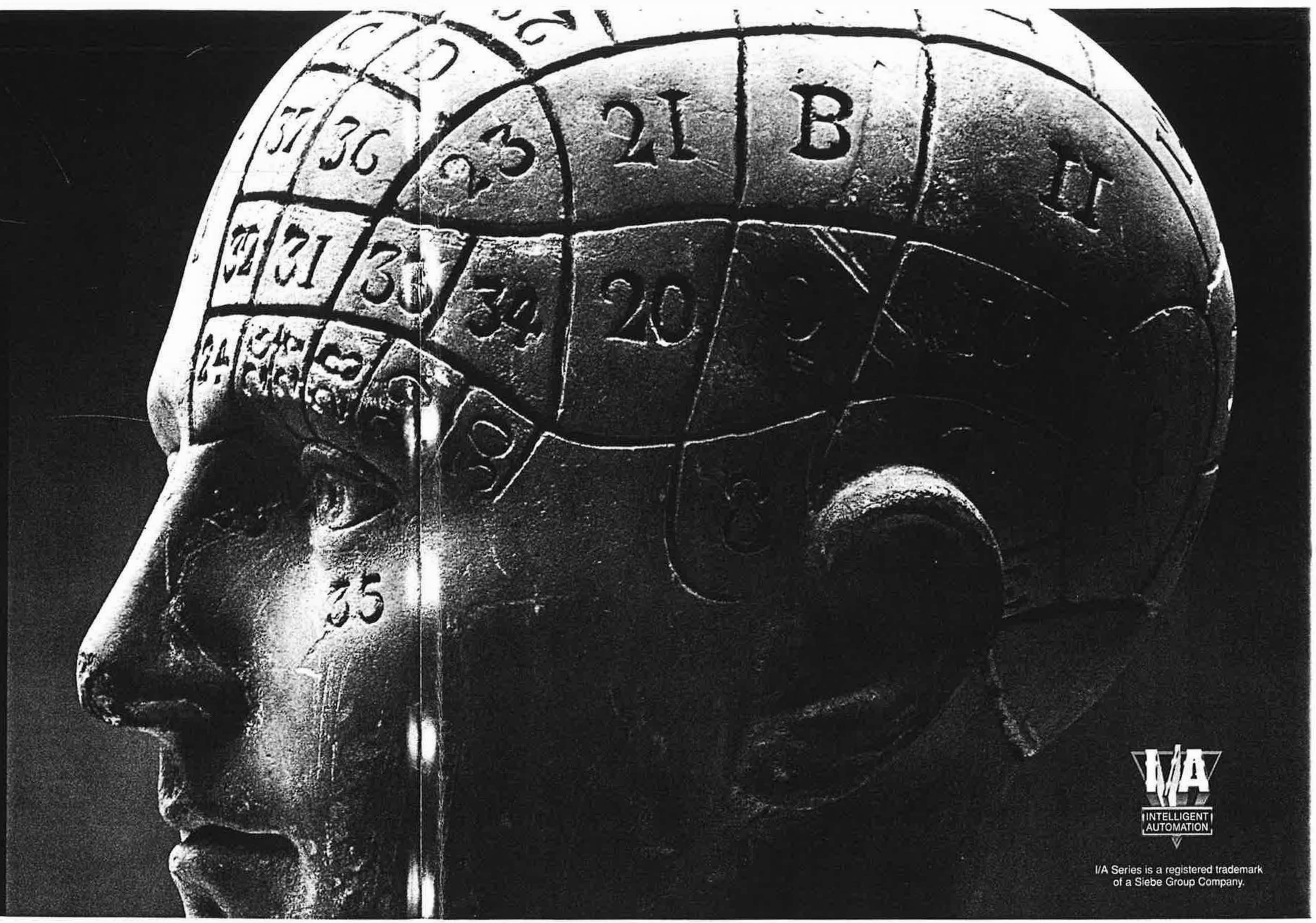

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Local supply air cleaning/filtration in high-load areas

Configuration 8 demonstrates the effect of providing terminal supply air filtration/cleaning of the supply air delivered to the lunch room. In this example, efficiencies of 45 per cent (body odour) and 7 per cent (tobacco smoke odour) are required to meet the recommended minimum Amenity Indices for the lunch room.

No additional air cleaning is required with respect to tobacco smoke particulates as the central particulate air filters already meet this requirement.

It may be noted that body odour Amenity Indices in the perimeter offices and interior in this example are still less than the recommended minima, although they have improved with respect to the basic design model in configuration 1. This improvement is due to the reduction in the contamination from the lunch room to the common return air duct.

A similar caution must be applied to the practical application of this technique with respect to removal of body odours and tobacco smoke odours as stipulated in clause "Central air cleaning/filtration" above.

Local recirculating air cleaners in high-load areas

Configuration 9 demonstrates the effect of a local recirculating air cleaner in the lunch room.

In this example the recirculating air cleaner has a recirculating air quantity of 500 L/s, with air cleaning efficiencies of 50 per cent with respect to body odours and 5 per cent with respect to tobacco smoke odours.

It should be noted that the performance of these units is a function of the product of airflow multiplied by efficiency, so a unit with a recirculating air quantity of 1000 L/s and efficiencies of 25 per cent and 2.5 per cent respectively would achieve the same performance with respect to air quality, although it may well require consideration of other factors such as air movement.

The performance and qualifications for this configuration are generally the same as those outlined in the clause above for configuration 8, including the caution regarding practical availability of odour control techniques.

Combinations of techniques

The techniques described above may be used individually or in conjunction. Configuration 10 shows, as an example, that the Amenity Indices in all areas will meet the recommendations of the draft Standard in a system which includes the following:

a) 750 L/s of outdoor air via the air handling unit
b) 150 L/s of supplementary outdoor air to the lunch room
c) 100 per cent exhaust of all air delivered to the lunch room (ie.900 L/s total exhaust)
d) 750 L/s relief air transferred from the perimeter offices to the interior offices.

This combination has been selected as a practical combination which does not include odour-removing air cleaning devices, due to the lack of availability of such equipment as noted in "Central air cleaning/filtration" above.

This combination provides a system requiring 900 L/s total outdoor air (or approximately 7.8 L/s per person) of outdoor air in comparison with 1650 L/s (or approximately 14.4 L/s per person) if increased outdoor air alone were used. It is worth noting that the total outdoor air quantity in this configuration is only marginally greater than that in configuration 2a (see "Increasing outdoor air" above), but with significantly improved Amenity Indices in all enclosures.

Other combinations of techniques to suit the characteristics of a particular installation may be used to achieve similar results.

Variable air volume (VAV) systems

General

There has been frequent and lengthy debate in several corners of the HVAC industry over the relationship between supply air quantity and occupancy in variable air volume systems, and how this should be applied to the calculations required by AS 1668.2-1991. The draft revision DR96425 mentions some of the related issues but does not resolve this question.

The following brief notes are offered to promote consideration of the important issues of relevance to VAV systems and to suggest some ways of tackling problem areas.

Modelling of supply air distribution

In general, the "critical" enclosure in any system will be the enclosure with the minimum value of supply air quantity per person. This may be untrue where enclosures have different classes of occupancy, activity or smoking levels, or where design Amenity Indices vary between enclosures.

Whilst a detailed analysis should be carried out to examine the full range of operating conditions for the system and for all enclosures, the following guidelines may be useful in achieving an approximate assessment of the likely system configuration:

For VAV svstems with fixed supply air temperature:

- In interior zones with no fabric or solar load, assume that maximum occupancy coincides with maximum supply air volume.
- In perimeter zones, calculate the supply air volume applicable to maximum occupancy and interior loads but with zero fabric and solar loads.

For VAV svstems with supply air temperature reset:

- Identify two system configurations, Configuration 1 using minimum supply air temperature (at maximum design ambient conditions) and Configuration 2 using maximum supply air temperature.
- In interior zones with no fabric or solar load, calculate the supply air volume which applies under each system configuration with maximum occupancy and internal loads — this should equal maximum air volume in Configuration 2 and a lesser value in Configuration 1.
- In perimeter zones, calculate the supply air volume applicable to maximum occupancy and interior loads, using maximum design ambient conditions for Configuration 1 and zero fabric and solar loads for Configuration 2 — this should equal maximum air volume in Configuration 1 and a lesser or equal value in Configuration 2.
- Separate calculations should be carried out for each of these configurations to determine the outdoor air requirements.

Improving IAQ in VAV systems

Any of the techniques outlined in the section headed "Ventilation system performance and IAQ enhancement options" of this paper may be used with VAV systems to improve local indoor air quality. Some of these techniques can present new problems which need attention, particularly the balancing of airflows and transfer air in the case of supplementary outdoor air systems and local exhaust systems.

Two particular equipment/system options have particular potential in addressing localised IAQ problems in VAV systems under part-load conditions, as follows:

a) "Dual-duct" type VAV units with tempered supplementary outdoor air to the secondary air inlet, to enhance the proportion of outdoor air in the supply airstream as the primary airflow decreases under part-load conditions. Total airflow through such units need not necessarily be constant, but could be "ramped" to ensure adequate outdoor air under a variety of load configurations.
b) "Fan-terminal" type VAV units incorporating air filters/air cleaners in the recycle air path. Since these units are commonly designed to provide a constant total airflow to the enclosure, the recycle airflow increases as the primary airflow decreases, and consequently the contaminant removal rate will similarly increase. However, for this system option to be useful within the context of the draft Standard, it is essential that approved test methods for odour-removing air cleaning devices be established.

Conclusions

The following conclusions may be drawn from this paper:

- The outdoor air quantity required for a ventilation system to comply with the requirements and/or recommendations of the draft Australian Standard DR96425 can be significantly reduced by intelligent use of a variety of system design options. Similarly, the indoor air quality in a system with a predetermined outdoor air quantity can be significantly improved by use of the same techniques.
- A structured design process should include the following general procedure for optimisation of indoor air quality and outdoor air quantity:

  a) Determine the physical data, including dimensions, occupancy, usage and supply air quantity for each enclosure.
  b) Calculate the outdoor air quantity required to achieve the recommended Amenity Indices for all contaminants in each enclosure, without the use of any optimisation techniques.
  c) If the required outdoor air quantity is deemed excessive, then:
  i) Identify the critical enclosure(s).
  ii) Identify the available design options from "Ventilation system performance and IAQ enhancement options" of this paper, with due consideration of the system type and economic factors; in the case of VAV systems, review the additional options described in subsection "Improving IAQ in VAV systems".
  iii) Apply these techniques individually

and/or in combination, giving priority to the critical enclosure(s), and recalculate the required outdoor air quantity.

d) In variable air volume systems, determine multiple "worst-case" system configurations as described in "Variable air volume (VAV) systems" of this paper, and repeat (a) to (c) above for each configuration.

- Where possible, relief air to exhaust systems should always be drawn from relatively "dirty" enclosures with low Amenity Indices.
- Where possible, relief air transferred from one enclosure to another should always be from the "cleaner" enclosure (with higher Amenity Indices) to the "dirtier" enclosure (with lower Amenity Indices).
- Serious consideration should be given by HVAC designers to provision of supplementary tempered outdoor air systems in large buildings to provide flexibility for future changes of usage in parts of the building. Matching flexibility should also be considered in common exhaust systems.
- The development of approved test methods for determination of efficiencies of odour-removing air cleaners should be a high priority for manufacturers and testing authorities, and would significantly extend the options available for optimising ventilation system design and operation.

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References

1. Australian Standard AS1668.2-1991, "The use of mechanical ventilation and air conditioning in buildings, Part 2: Mechanical ventilation for acceptable indoor air quality", published 4 March 1991.

2. Draft Australian/New Zealand Standard for Comment DR96425: "The use of Ventilation and Air Conditioning in Buildings, Part 2: Ventilation of Buildings", issued for comment 1 October 1996, closing date for comment 30 November 1996.

3. VENTPAC is a computer program developed by Crabtree Engineering Software and distributed by Standards Australia. Version 2 includes calculations to AS1668.2-1991 and Version 3, which is currently in development, will include calculations to the revised edition of AS 1668.2 when published.

Ventilation by displacement — its characteristics, design and other related developments

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Recent literature, mainly from Scandinavian countries, on displacement ventilation is reviewed in this paper. The paper first discusses the thermal-fluid flow and contaminant removal characteristics in displacement ventilated rooms and the flow behaviour of low-velocity air supply registers. This discussion outlines the main differences between displacement ventilation and mixing ventilation systems, which have implications for various design components in displacement ventilation.

Engineering models for calculating near-field length, airspeed in the farfield, air temperature near the floor and the ceiling, cooling load, vertical air temperature gradient, concentration in the upper pollutant zone, and the clean zone height are summarised. Preliminary work on integrating the four-node model into an Australian building thermal modelling code, CHEETAH, is presented. This work will eventually enable improved calculations of cooling loads due to heat conduction through walls and solar radiation through windows to be done for displacement ventilation systems in realistic buildings.

General guidelines for design displacement ventilation systems using these simple prediction tools are provided. Additionally, other related developments on near-body flows, effects of moving bodies, raised floor systems and chilled ceiling systems are briefly mentioned.

Introduction

Air distribution

The concept of ventilation has evolved to include not only the fresh air requirements, but also how the supplied air is distributed. A good air distribution system delivers sufficient fresh air to occupied regions and removes contaminants (including heat) from occupied regions as quickly as possible. There are four basic types of air distribution patterns, namely fully mixed flow, piston-like flow, short-circuiting and stagnant flow patterns.

A piston-like flow pattern is the most efficient way to deliver fresh air and remove contaminants. But it is always hard or expensive to maintain such an ideal flow pattern. In displacement ventilation, such a flow pattern is partly achieved by using the simplest natural convection principle, ie. warmer air rises. Thermal plumes over a person or a computer, and upward natural convection along a warmer wall surface, all tend to rise.

These upward flows transport the contaminants generated in the occupied regions or in the same source where the heat is generated. Such a flow behaviour is utilised in displacement ventilation to maintain a vertical upward displacement flow pattern. In a conventional mixing ventilation system, the room convection flows are not directly used, but rather are "destroyed" to some extent to achieve a flow pattern dominated by supply jets.

In many situations, displacement ventilation has been proved to be more efficient than mixing ventilation for simultaneously removing excess heat and achieving good air quality. It should be mentioned that displacement ventilation is primarily designed for cooling purposes. Its use alone is not efficient for heating.

Natural convection flows

Very early studies on ventilation, eg. Shaw [20], have suggested that natural convective flows over the human body are the most important factor in room ventilation. Shaw asked: if natural convection around a body did not exist, what would happen to the air surrounding the head? He suggested an interesting comparison between a fish in water and a man in air. Water density cannot be substantially affected by fish body temperature as occurs to air by the human body. If a fish were to breathe water in and out, as humans breathe air in and out, a cloud of used water would be formed in front of the fish which would be breathed over and over again. Shaw interestingly speculated that this might be the reason that fish use gills to direct used water out behind the head. Fish cannot take advantage of the natural convective plume to expel the used water.

The author repeatedly suggested that "for the purpose of ventilation, convection is the primary condition of success though it is the cause of many failures". It has been realised now that the near-body natural convection currents (not only the plume over the human body) are very important to the effectiveness of displacement ventilation.

In a simple displacement ventilation system, cool air is supplied with a low velocity at floor level, which is then transported upward by natural convection and plumes. The used air is exhausted at the ceiling level (see Figure 1). Using smoke flow visualisation, one can find that there are generally two distinct zones — one lower clean zone containing fresh air and one upper polluted zone.

Figure 1. Basic flow principles in a room ventilated by displacement