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Information paper – 20

Ventilation rates in offices – mechanical and natural

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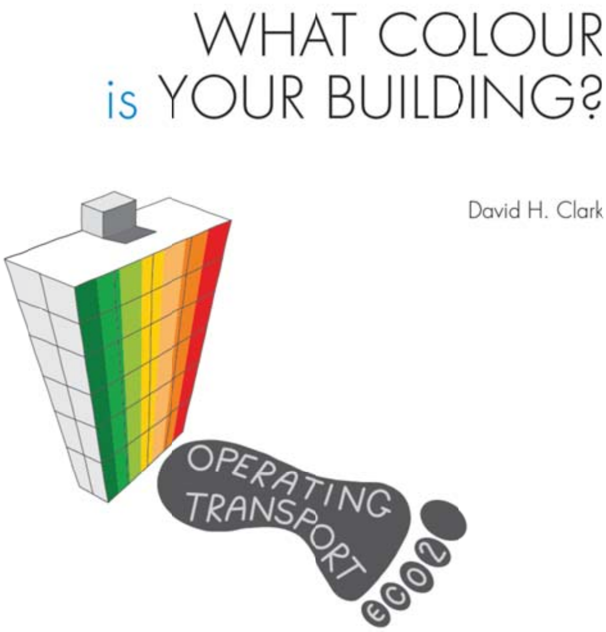

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This information paper is one of a series of papers written during the preparation of the book **What Colour is Your Building?** (www.whatcolourisyourbuilding.com). The papers do not form part of the book and have not been peer reviewed. They provide further technical detail, analysis and information to support statements made in the book. All of the papers can be downloaded from www.wholecarbonfootprint.com.

Ventilation rates in offices – mechanical and natural

This information paper provides an overview of the rates used in various standards for mechanical and natural ventilation.

1. AIR QUALITY AND FRESH (OUTDOOR) AIR RATES

Table 1 summarises the drivers behind the minimum fresh (outside) air requirements in office buildings.

Issue	Fresh Air Requirement
Odours	Research shows that an occupant's perception of indoor air quality is strongly influenced by odour.[1] This can be controlled by introducing fresh air and/or treating recirculated air. Toilet exhausts are an example of removing odours at source without recirculation.
CO_2	CO_2 concentrations are often used as a surrogate indicator for odours inside buildings, with a limit of between 1,000 to 1,500 ppm typically adopted,[2] (compared to 450 ppm currently found in outside air). This typically requires between 7.5 to 10 l/s/person of outside air to achieve. Prolonged CO_2 levels above 1,500 ppm may cause occupants to feel drowsy, get headaches, or function at lower activity levels.
Indoor pollutants	These include volatile organic compounds (VOC) and formaldehyde (off-gassing from carpets, paint and furniture), ozone (from photocopiers), carbon monoxide, radon, sulphur dioxide, and a host of other substances. The best approach is to avoid introducing pollutants in the first place by selecting low off-gassing materials and to exhaust sources of pollution locally (e.g. direct exhaust of photocopy rooms).
Cigarette smoke	Smoking indoors was a major source of indoor pollutant and has been banned in many countries. A ventilation rate of at least 30 l/s/person is typically required if smoking is permitted.[3]
Oxygen to breathe	To meet the human body's demand for oxygen when seated typically requires less than 0.2 l/s/person of fresh air.[4] This is clearly not a driver for minimum ventilation rates in buildings.

Table 1 Summary of fresh air requirements in office buildings

The minimum fresh air requirement of 8 to 10 l/s per person typically adopted in mechanically ventilated spaces is supported by a variety of sources (refer to section 2). Fresh air requirements for naturally ventilated spaces are treated differently (refer to section 3).

British Standard BS EN 13779 provides four classifications of indoor air quality as shown in Table 2.

Classification	Indoor air quality standard	Fresh air ventilation range (L/s/p)	Fresh air default value (L/s/p)	Approximate indoor CO_2 concentration (ppm) *
IDA1	High	>15	20	700 to 750
IDA2	Medium	10–15	12.5	850 to 900
IDA3	Moderate	6–10	8	1,150 to 1,200
IDA4	Low	<6	5	1,550 to 1,600

* taken from Table 4.2, CIBSE Guide A, including CO_2 concentration rise plus external CO_2

Table 2 Indoor air quality classifications in BS EN 13779

2. MINIMUM FRESH (OUTDOOR) AIR VENTILATION RATES

Table 3 provides a summary of various regulations, standards and guidelines related to minimum fresh (outdoor) air rates.

Source	l/s per person	Comments
Part F, UK Building Regulations 2010	10	Total outdoor air supply rate with no smoking and no significant pollution sources. Extract rates are also given: • Printers / Photocopier rooms – 20 l/s per machine • WC/Urinal – 6 l/s each • Shower – 15 l/s each
CIBSE Guide A, Table 1.5	10	Applies to executive, general and open plan offices. Assumes no smoking.
CIBSE Guide A, section 8.4.1.2	8	As a general rule, the fresh air supply rate should not fall below between 5 and 8 l/s per occupant but this will depend on various other factors including floor area per occupant, processes carried out, equipment used and whether the work is strenuous. For office workers, 8 l/s fresh air is roughly equivalent to an elevation of 600 ppm of carbon dioxide (CO_2) which, when added to the normal outdoor CO_2 of 400 ppm, gives an internal CO_2 concentration of 1,000 ppm; 5 l/s would be equivalent to 1,350 ppm internally. The higher ventilation rate of 8 l/s per person is recommended. *Note: Schools have prescribed ventilation rates of 3 l/s per person for background ventilation and 8 L/s per person when required.*
BCO Guide to Specification 2009	12 to 16	Suggests an allowance of 1.2 to1.6 l/s per m^2, which based on a standard occupancy of 1 person per $10m^2$ equates to 12 to16 l/s/person. For an occupancy of 1 per 6 m^2 this equates to 7 to 10 l/s/person.
ASHRAE Handbook: Fundamentals 2009, chapter 16.10	10	Engineering experience and field studies indicate that an outdoor air supply of about 10 l/s per person is very likely to provide acceptable perceived indoor air quality in office spaces, whereas lower rates may lead to increased sick building syndrome symptoms.
ASHRAE Technical FAQ ID 34 www.ashrae.org – accessed 16 June 2012.	7.5	'At the activity levels found in typical office buildings, steady-state CO_2 concentrations of about 700 ppm above outdoor air levels indicate an outdoor air ventilation rate of about 7.5 l/s/person. Laboratory and field studies have shown that this rate of ventilation will dilute odours from human bio-effluents to levels that will satisfy a substantial majority (about 80%) of un-adapted persons (visitors) in a space.'

Source	l/s per person	Comments
ASHRAE Standard 62.1-2007	8.5	The fresh air required is based on both the number of occupants, the area of the space and the effectiveness of the ventilation system to deliver the fresh air to the breathing zone (refer Section H4.12 in Appendix H). For a typical office the calculation is: $$\text{Fresh air (l/s)} = \frac{(2.5\text{ l/s} \times \text{no. of people}) + (0.3 \times \text{floor area})}{\text{Ventilation effectiveness factor}}$$ The default occupancy of 1 per 20 m^2 gives 8.5 l/s/person (0.36 l/s/m^2) and is used when the actual occupancy is not known. An occupancy of 1 per 10 m^2 gives 5.5 l/s/person (0.55 l/s/m^2). As occupancy density increases the amount of fresh air per person reduces.
BB101 – Ventilation in Schools	3 to 10	When measured at seated head height, during the continuous period between the start and finish of teaching on any day, the average concentration of CO_2 should not exceed 1,500ppm. In addition, the maximum concentration should not exceed 5,000 ppm during the teaching day and at any occupied time, including teaching, the occupants should be able to lower the concentration to 1,000 ppm. Purpose-provided ventilation should provide external air supply to all teaching and learning spaces of a minimum of 3 l/s per person and a minimum daily average of 5 l/s per person. The capability of achieving a minimum of 8 l/s per person, under the control of the occupant, at any time must also be provided, which should lower CO_2 levels below 1,000ppm. 10 l/s/person is defined for office accommodation in schools.
AS1668.2-1991 (Australia)	7.5	The minimum outdoor airflow rate for dilution of gaseous contaminants (e.g. body odours) is 7.5 l/s/person if the temperature in the enclosed space is below 27°C in normal use, and 15 l/s/person if it rises above 27°C in normal use.

Table 3 **Minimum fresh (outside) air rates from various sources**

3. MINIMUM NATURAL VENTILATION REQUIREMENTS

A typical rule of thumb for natural ventilation is to provide an effective ventilation area equivalent to 5% of the floor area served – refer to Section H4.2 in Appendix H. The 5% minimum ventilation area requirement in Part F (Ventilation) of the UK Building Regulations was replaced in 2006 with reference to *Natural ventilation in non-domestic buildings*, CIBSE Applications Manual AM10. This manual provides detailed guidance on natural ventilation design and analysis, taking into account both stack and wind effects. No simple percentages are given for opening areas. BREEAM 2011 allows the 5% rule of thumb to be used as an alternative to using AM10.

FREE AND EFFECTIVE VENTILATION AREAS

Free area and effective ventilation area are not the same. Free area is the physical size of the opening. Effective area is determined in a test facility based on the resistance to airflow through the opening.

Example calculation to test the rule of thumb for 5% natural ventilation area

The design formulae in CIBSE Guide A and CIBSE Guide AM10 have been used to test a 15 m wide floor plate with 5% ventilation openings distributed evenly on opposite facades and at high and low levels – refer to Figure 1.

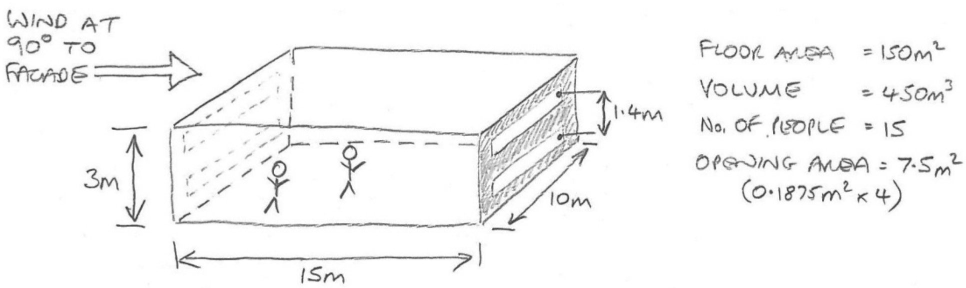

Fig 1 **Example building zone with cross ventilation and 5% ventilation openings**

To keep CO_2 levels to less than an average 1,000 ppm during the day a ventilation rate of 10 l/s/person is typically adopted. This is equivalent to an air change per hour (ach) of 1.2 in this example (= 10 l/s x 15 people x 3.6 / 450 m^3). The AM10 Design Tool v5[5] was used to calculate the CO_2 concentrations based on this, and also the concentrations if only 3 l/s/person (0.36 ach) were provided using trickle ventilators in the window frames.

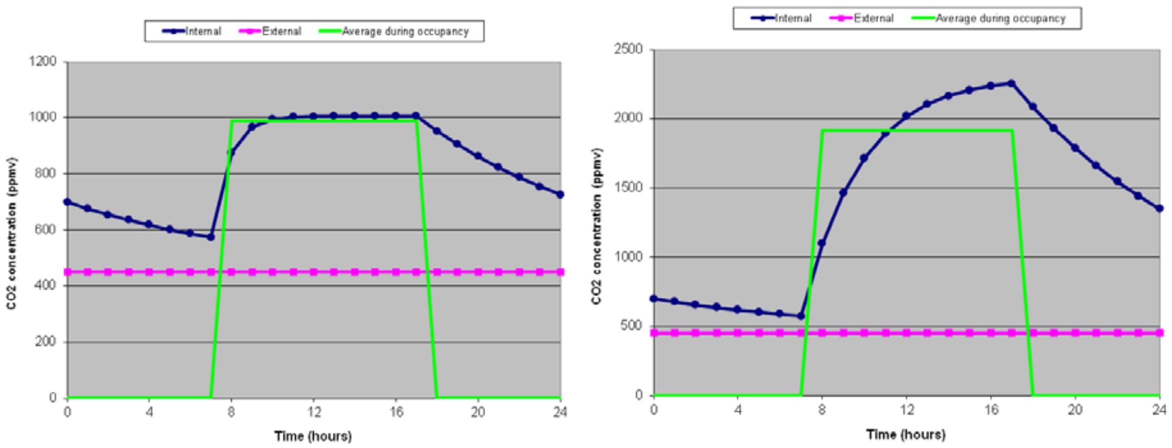

Fig 2 **CO_2 concentration (ppm) for 10 l/s/person (left) and 3 l/s/person (right) from CIBSE AM10 Design Tool v5**

Relying only on trickle ventilation could lead to unacceptable CO_2 concentrations when the space is fully occupied. Opening the windows in winter could cause draughts and will increase heating energy consumption. However, in a mechanical system 10 l/s/person of fresh air would be provided and this also needs to be heated (and there is also additional energy consumption due to the fans). Consequently, if the mechanical system doesn't have heat recovery then natural ventilation should potentially have the lowest energy consumption if controlled properly.

However, if the mechanical system has heat recovery (to preheat the fresh air supply) then this is likely to be the most energy efficient solution, provided the fan energy consumption does not outweigh the heating energy savings. This is the PassivHaus approach to ventilation in winter.

Air speed and natural ventilation areas for minimum fresh air

If fresh air enters through two windows on opposite facades then the air speed through an opening can be crudely estimated as:

Air speed (m/s) = air flow (m^3/s) / ventilation area (m^2)

An air supply of 10 l/s/person is equivalent to 0.15 m^3/s. An air speed of 0.15 m/s inside buildings is generally considered to be imperceptible and not draughty. If the air speed is limited to 0.15 m/s then the minimum ventilation area required is 1 m^3 (or 0.7% of floor area). This illustrates that the 5% rule of thumb is based on providing sufficient ventilation to remove heat gains in summer and not to provide minimum fresh air during winter (which can often be achieved using trickle ventilators).

Natural ventilation driving force – wind versus temperature

The formulae in Table 4.22 of CIBSE Guide A can be used to estimate the airflow rates for simple building layouts, with openings on opposite sides, based on wind driven and stack driven (temperature difference) effects. The assumptions made to calculate these for the building in Figure 1 are shown in Table 4

Wind			Temperature	
Wind speed (imperceptible)	1.5 m/s		External temperature	25°C
Pressure coeff – 90° front	0.2		Internal temperature	28°C
Pressure coeff – 90° rear	-0.25		Difference	3°C
Pressure coeff – 45° front	0.05			
Pressure coeff – 45° front	-0.35			

Table 4 **Assumptions made to calculate wind and temperature driven natural ventilation**

A coefficient of discharge (Cd) of 0.61 is adopted based on cl 4.6.1 of CIBSE Guide A to take into account the pressure drop through a sharp edged opening, such as a window. The resulting air flow rates are shown in Table 5.

	Wind @ 90°	Wind @ 45°	Stack effect
Airflow rate (m^3/s)	1.61	1.42	0.84
Air changes per hour (ach)	12.8	11.3	6.7
l/s/person	107	94	56

Table 5 **Natural ventilation air flow rates using formula in CIBSE Guide A**

The wind speed at which wind driven ventilation dominates compared to the stack effect (with a temperature difference of 3°C) is around 0.8 m/s. On all but the stillest days, wind is likely to be the driving ventilation force. Figure 3 shows plots of air changes per hour for different wind speeds and temperature differences in the example building in Figure 1.

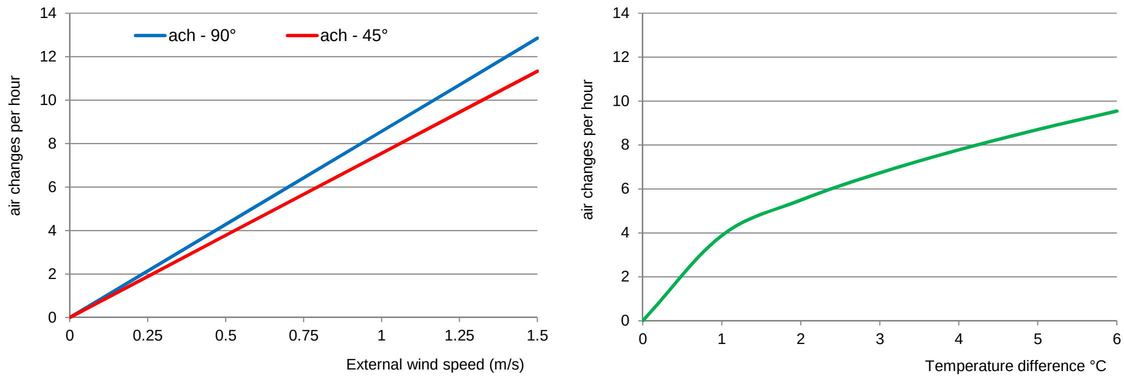

Fig 3 **Air changes per hour in example building for different wind speeds and ΔT**

Cooling benefit of natural ventilation

The ability of natural ventilation to remove heat depends on the ventilation rate and the temperature difference between outside and inside. The equations are:

Heat extracted = 1.2 x q x dT OR (N x V / 3) x dT

where:

dT = difference in internal & external temperature
q = ventilation rate (l/s)
N = no. of air changes per hour
V = volume of space

Table 6 shows the cooling effects of the three options in Table 5 assuming a 3°C temperature differential.

	Wind @ 90°	Wind @ 45°	Stack effect
Air changes per hour	12.8	11.3	6.7
Cooling (W/m²)	39	34	20

Table 6 **Cooling effect due to wind and stack effect with △T = 3°C**

Figure 4 shows the cooling capacity (W/m²) for different air change rates and temperature differences for a space with a ceiling height of 3 m calculated using the formula above.

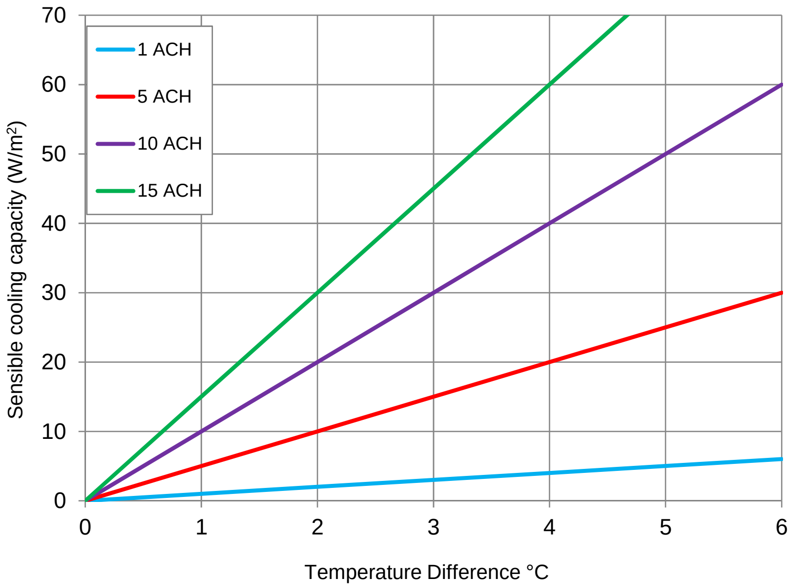

Fig 4 **Effect of temperature difference and air change rate on sensible cooling capacity of ventilation air (height of space = 3m)**

Notes

All websites were accessed on 29 July 2013 unless noted otherwise.

1. *History of the Changing Concepts In Ventilation Requirements* by Klauss et al, ASHRAE Journal, June 1970

2. Adapted from guidelines from CIBSE and ASHRAE.

3. CIBSE Guide A recommends a minimum fresh air rate of 45 l/s/person. The 1999 version of the guide, before smoking was banned in buildings in the UK, gave different ventilation rates based on the proportion of occupants smoking: 0% = 8 l/s, 25% = 16 l/s, 50% = 24 l/s, 75% = 36 l/s.

4. The amount of air breathed by an adult when seated is less than 10 litres per minute (0.17 l/s). This increases to 58 litres (1 l/s) for an adult male running at 5 mph. Source: *How Much Air Do We Breathe?* California Environmental Protection Agency,Research Note 94-11, August 1994. www.arb.ca.gov/research/resnotes/notes/94-11.htm

5. CIBSE AM10 Design Tool v5 can be downloaded from www.cibse.org/docs/AM10CalcToolv5.xls.