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The Efficiency of Single-sided and Cross Ventilation in Office Spaces

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SYNOPSIS

This paper reports on work carried out at BRE to address the need for guidance on designing for natural ventilation via single-sided and cross-ventilation in office spaces and the limits of application in terms of plan depth. Present guidance suggests that natural ventilation will be adequate up to 6 m from the ventilating facade. This leads to the conventional design of offices up to 6 m deep on either side of a central corridor, giving as a rule of thumb a width of 15 m for a building with natural cross-ventilation.

The present work looks at the opportunities for going beyond these rules of thumb. The implications for thermal comfort and draught risk are also assessed. In the conclusions issues such as, local ventilation rates, ventilating air penetration from a facade, the use of artificial mixing (eg ceiling fans) on hot days, the position of windows, and means of enhancing internal air speeds and air change rates are discussed.

1. INTRODUCTION

In designing for natural ventilation, existing guidance[1] advises that air distribution will be 'reasonable' in naturally ventilated buildings with 6 m wide rooms either side of a central corridor. This results in the rule of thumb that 15 m is an effective limit for the width of the building. The same guidance may be interpreted as setting a limit of 6 m to the depth of a naturally ventilated space with single-sided ventilation. The work described below suggests that, depending on circumstances, this limit may be qualified or revised.

Effective natural ventilation must satisfy the following requirements:

- Overall air change rate must be adequate in winter for occupant health and safety, contaminant removal etc. and, in summer, to maintain thermal comfort.
- Distribution of fresh air must be even so that all occupied parts of the space receive an adequate supply.
- Air movement should be sufficient for thermal comfort in summer, but draughts causing discomfort or nuisance must be avoided.

If these can be satisfied, natural ventilation would be possible in deep open plan style rooms and buildings wider than 15 m.

The following key issues affecting the distribution of natural ventilation in deep office spaces are addressed:

- Single-sided ventilation compared with cross-ventilation
- Effect of window location
- Effect of partitions
- Possible impact of wind shelter

Measurements were carried out over a wide range of realistic conditions in several deep office rooms. Heated cylinders (approximately 100 Watts) were used to represent the influence of occupants and equipment on local ventilation rates. Window opening was usually set to maintain broadly typical indoor temperatures.

2. MEASUREMENTS AND RESULTS

Adequacy of air distribution with single-sided ventilation

Tests were carried out to assess air distribution in a deep office, 10.4 m deep normal to the windows, with single-sided ventilation[2]. It was found that local ventilation rates with single-sided ventilation were similar throughout the space. The variation was generally within about 15% of the mean, Figure 1 shows typical graphs of logarithmic tracer gas concentration against time for even and uneven air distribution. Wind direction appeared to be a key factor affecting the distribution of local ventilation rates. Distribution of air was more uniform with openings in the lee of the building, and less so when winds were generally light and towards the openings.

Comparison of air distribution between cross and single-sided ventilation

Tests were carried out to compare air distribution for single-sided ventilation with that for cross-ventilation[3]. The office was on the upper floor of a two-storey building and measured 9.7 m deep, normal to the windows. Alternate tests with single-sided ventilation and cross-ventilation were carried out in pairs on each day.

Cross ventilation and single-sided ventilation achieved similarly even distributions of local ventilation rate throughout the space. Room-average ventilation rates were generally less for single-sided ventilation when compared to cross-ventilation with the same open area, but similar when purely buoyancy-driven. In two cases the observed room-average ventilation rate was less than that expected due to buoyancy alone, illustrating that wind and buoyancy forces can combine in a way which is, as yet, not fully explained.

Comparison of single-sided ventilation in 'sheltered' and 'exposed' offices

Parallel tests were carried out in a ground floor office in a sheltered location[3] and the second-storey office. The sheltered office was 9.65 m deep normal to the windows, with the same window open area and orientation as the second storey office.

Ventilation flow rates in the sheltered office were either slightly greater or similar (within 19%) to those measured in the more exposed office in 83% of tests. This may be a consequence of low wind speeds during the tests and ventilation rates being dominated by temperature difference between inside and outside (ie buoyancy forces). In the remaining tests (17%), ventilation rates in the sheltered office were less (by approximately 10%) than in the exposed office . In these cases the wind speeds were much higher (4.0 m/s), and would be expected to dominate over stack induced ventilation, thereby increasing ventilation rates in the exposed office compared to those observed in the sheltered office.

Effect of window location (height)

There is evidence[4] to suggest that draughts may be avoided, and air distribution improved if windows are located higher above working level. Tests were carried out, in pairs in the second storey office, to assess the possible effect of the height of the opening above the office floor[3]. One test was with 'standard' window openings (ie as found) where the lower edge was 1.6 m above the floor, and about 0.85 m above desk level. The second test had 'high-level' windows, the lower half being blocked off to a height of 2.1 m above the floor, about 1.35 m above desk height. The same total open window area was used in a given pair. Air speeds were measured, at a height of 1.1 m, along the centre line normal to the windows. Figure 2 shows typical air speed profiles down the room for single-sided and cross ventilation with 'standard' and 'high level' windows.

Local ventilation rates throughout the space were similar for tests with either window type. With single-sided ventilation, air speeds varied only slightly along the depth of the room, with either high-level or standard windows. During these tests, wind speeds were quite significant, in the range 2.1 m/s to 6.1 m/s (typically around 4.0 m/s). In two of the test pairs, higher air speeds were recorded near the window (1 m into the room) with the standard window opening. The reason for this was not clear, although it was noted that in these cases the wind speeds were quite low, less than 2.0 m/s, and within one pair of tests there was a change of wind direction of some 120 degrees.

With cross-ventilation, air speeds near to windows located at high-level were lower than for the standard windows. This indicates that, for cross-ventilation, high level windows may reduce the risk of draughts nearby at working level. This may be particularly beneficial in deep, multi-occupancy rooms, by providing a more even 'cooling' effect for all occupants, and reducing the likelihood of the window being closed by the nearby occupant.

Effect of partitions

In many large open plan offices, work areas are marked out by partitions, usually lightweight panels approximately 1.5 m high. A pair of identical adjacent offices, 9.3 m deep normal to the windows, were used to study the possible effect of such partitions on air distribution and internal climate[3]. One office was partitioned into four equal areas, the other was left unobstructed. Partition sizes were based on commercially available partitions. Tests were carried out in pairs, one with standard windows the other with high level windows and repeated for both single-sided and cross-ventilation. It was found that local ventilation rates were similar in both rooms. Air speeds were generally low whether with or without partitions, over a wide range of external air speeds.

3. ANALYSIS OF DRAUGHT RISK AND THERMAL COMFORT IN DEEP OFFICE ROOMS

An assessment of draught, air movement and thermal comfort in deep offices with single-sided or cross-ventilation was made based on the above work.

Draught

A maximum air speed of 0.8 m/s[5] may be assumed above which nuisance may be expected (papers blowing) and thermal comfort may be difficult to maintain. Mean air speeds were generally below this; those measured at 1 m from the windows were below 0.8 m/s in 96% of tests. In a typical test, speeds exceeded 0.8 m/s for only about 5% of the time. Results show that at depths beyond about 1 m draught annoyance would not be expected to be significant for occupants. However, the 5% occurrence rate of intermittent higher speeds may indicate the likelihood of short duration gusts, which could cause annoyance or thermal discomfort if the incoming air is several degrees Celsius below room temperature.

Thermal discomfort may arise following the sudden opening of a window when ventilation is driven by temperature difference between inside and outside[6]. A possible approach to reduce these potential problems may be to provide a greater number of opening windows, at higher level, preferably opening in unison, for more even distribution of incoming air.

The applicability of the draught risk equation developed by Fanger et al[7] was assessed. Generally the calculated draught risk was low, due to the low air speeds. In some instances draught risk was high (eg 75 %) 1 m away from the window even though air speeds were moderate, ie in the range 0.1 - 0.34 m/s. This was primarily due to low air speeds in combination with relatively high turbulence levels. This indicates that the current draught risk expression may be inappropriate for natural ventilation in summer, especially when cooler incoming air may be regarded as pleasant. The underlying problem may be due to the original formulation of the draught risk expression from tests in an environmentally controlled chamber, in which subjects were exposed to forced air supply conditions.

Thermal comfort

The tests were not designed to directly assess the ability of a typical office room to maintain thermal comfort in summertime. However, the following results do give a reference perspective.

For tests in summer (ie. all except those in the partitioned rooms), external air temperatures ranged from 11 °C to 27 °C, while most internal air temperatures were in the range 17 °C to 27 °C, ranging from slightly cool to slightly warm on the ASHRAE standard scale[8] of thermal comfort (after Fanger[9]). The exceptions to the above were a case where internal air temperature reached 34 °C when the external temperature was also 34 °C; and two cases where the internal temperatures rose above external (eventhough this could have been avoided by opening more windows).

A desk study was carried out using existing design guidance procedures. Mean and peak internal temperatures were calculated using the Environmental Design Manual[10], which is based on the Admittance Method[5]. The manual is limited to maximum total internal heat gains of 15 W/m^2, which is low by today's standards. Currently internal gains in naturally ventilated buildings are typically [11] in the range 10 - 40 W/m^2, allowing for increased use of IT equipment. This highlights the importance of solar shading, for offices without external shading, solar gains are potentially the most dominant heat input to the room.

The desk study considered three categories of thermal mass, ie; 'light', 'medium' and 'heavyweight' (admittance values 8, 16 and 24 W/m^2/°C resp.) with windows shaded by internal Venetian blinds. Calculations showed, in medium to heavyweight buildings with such blinds, an 'intermediate' level of thermal comfort could be maintained for most of the summer, ie mean temperatures not greater than 24 °C and 'swings' not greater than 4 °C for 50 days in 10 years. External blinds significantly improved this to 30 days or less depending on thermal mass.

4. CONCLUSIONS

The key findings of the above measurements can be summarised as follows:

Ventilation and its distribution: Local ventilation rates are broadly even throughout deep spaces up to 10 m deep, for single-sided and cross-ventilation. Implying that, if adequate overall ventilation rates can be achieved, then ventilation will be adequate throughout the room. However, it is noted that other factors need to be considered when assessing the potential thermal comfort of occupants, eg proximity to windows, and local air currents.

Air movement and draught: Mean air speeds were low (unnoticeable) in about 75% of tests. Significant air speeds were measured in about 25% of tests, rarely exceeding the level which would cause draught nuisance (papers blowing, difficulty maintaining thermal comfort). Higher air speeds did occur occasionally during a typical test.

Air speeds at depth - 'rule of thumb': The measured results were dependent on many possible influences, not all of which could be isolated. Even so, results tend to indicate that air speeds fall from a maximum near the opening (measured at 1 m from the opening) to a minimum for cross-ventilation, or a uniform background level for single-sided ventilation, at or near the room centre 5 m into the space. This supports the existing rule of thumb of 6 m for the depth of penetration of fresh air, in that it appears to describe small scale locally unmixed air currents, not the distribution of local ventilation rates. The rule is more applicable to achieving adequate air movement through natural ventilation in summertime when we wish to provide rapid ventilation.

Proximity to windows and enhancing air movement: In offices deeper than 6 m, occupants not adjacent to windows may not share the benefit of cooler incoming currents and, on warm days, may find air movement inadequate for thermal comfort. One strategy to overcome this potential problem may be to mix incoming air more uniformly and enhance air movement, using (say) ceiling fans. An additional benefit of increasing air speeds artificially is that the range of thermal comfort may be extended by up to 3 °C, without the need to increase ventilation rates. Another strategy, mentioned below, is to optimise the window opening design.

Draught: Where air speeds were significant, they could cause thermal discomfort if combined with low outside air temperatures, or possibly gusts. Improved window design (described below), and possibly artificial mixing should help reduce these problems. Draught risk was calculated using the expression developed by Fanger. Calculations were dominated by low air speeds combined with relatively high turbulence levels, and would appear to undervalue the beneficial cooling effect of air movement in summer conditions. This suggests that there is an underlying problem in applying the Fanger draught expression to natural ventilation in summer, for which it was not formulated.

Window design: With cross-ventilation, higher level windows may reduce draughts nearby at working level. Results suggest that neither the overall ventilation rate nor its local distribution is significantly affected by such small changes in the height of the window opening above the floor. A greater number of smaller openings, placed at high level, may be expected to produce smaller 'jets' which will dissipate more quickly and allow incoming air to warm-up by increased "contact" with internal air. This may help to reduce possible thermal discomfort caused by large 'unmixed jets' of cool air entering through a few large openings.

Effect of partitions: For simple partition layouts, and two different window heights, local ventilation rate distribution was relatively even over a 10 m deep narrow office space, for both single-sided and cross-ventilation. Air speeds were generally low with or without partitions for a wide range of external air speeds.

Thermal comfort: With few exceptions the measured internal climate stayed within conventional comfort limits. Calculations showed that, in medium to heavyweight buildings with internal venetian blinds, an 'intermediate' level of thermal comfort could be maintained for the greater part of the summer, and was significantly improved with external shading.

In conclusion the following design guidance is proposed based on this research:

- Rule of thumb that ventilating air penetrates to about 6 m from an open window applies only to air speeds and unmixed incoming air currents.
- Local ventilation rates are generally evenly spread in deep office rooms (up to 10 m deep) either with cross- or single-sided ventilation
- Higher level windows may reduce draughts at working level and adjacent to windows particularly when cross ventilating.
- Distributed openings may avoid thermal discomfort problems due to draughts.
- Artificial mixing (eg ceiling fans) may avoid unmixed air currents local to an opening, producing more evenly distributed conditions for comfort; in warm conditions, increased air movement also extends the range of thermal comfort.

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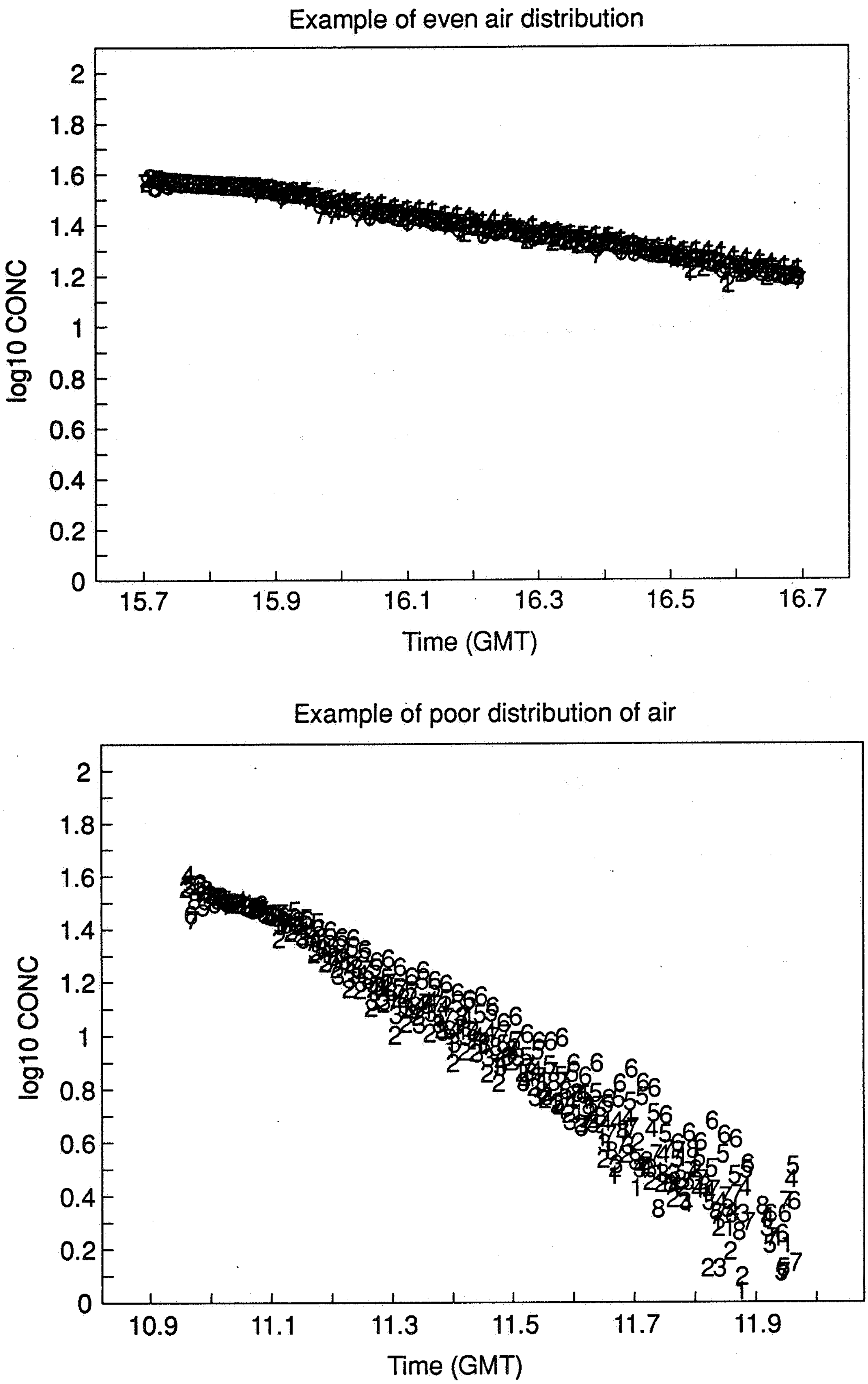

Figure 1. Examples of typical tracer gas decay curves

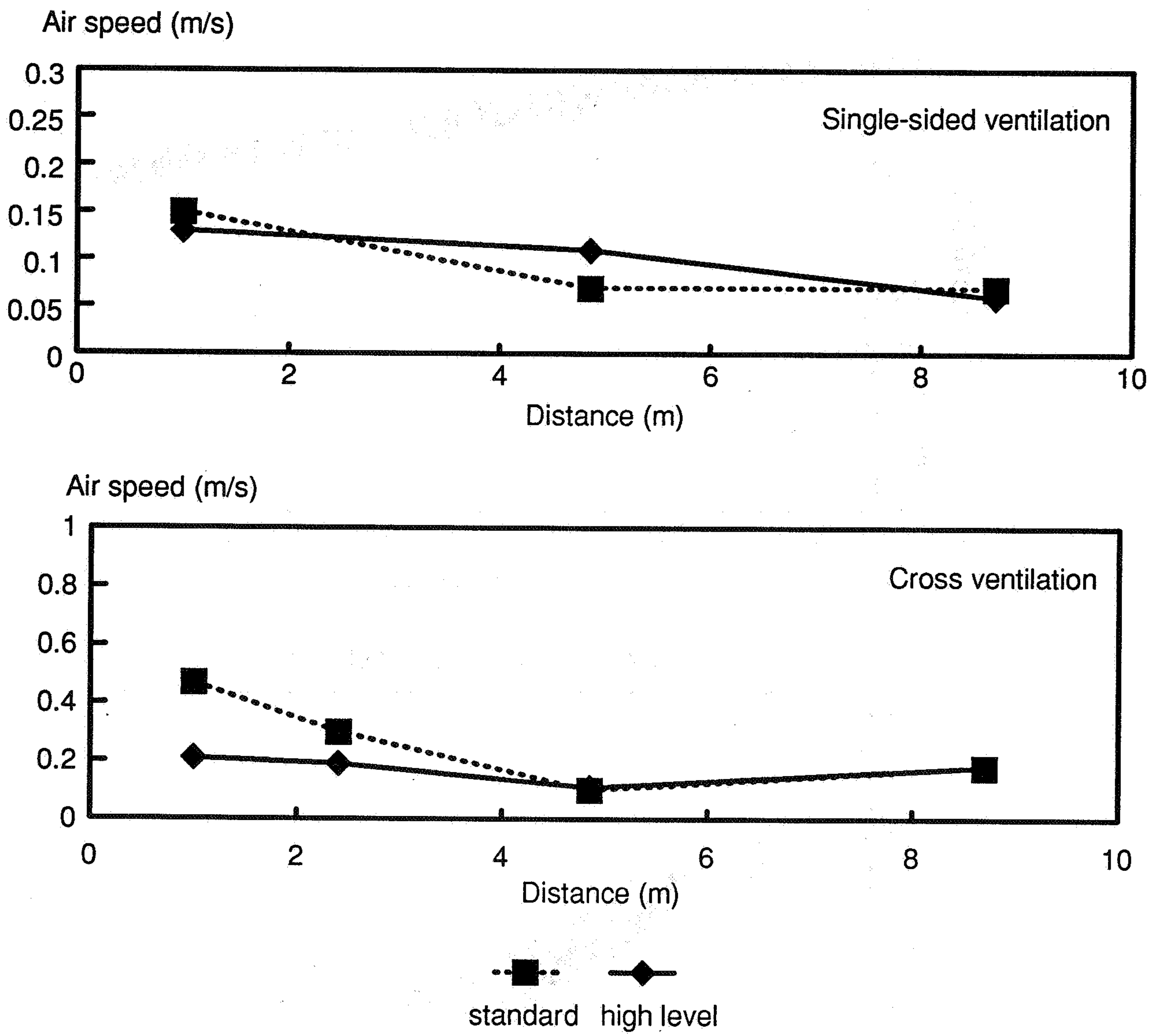

Figure 2. Air speeds at increasing room depth for standard and high level windows