November 2007 • TEC 25 • Summary

ENVIRONMENT DESIGN GUIDE

CIRCULATING FANS FOR SUMMER AND WINTER COMFORT AND INDOOR ENERGY EFFICIENCY

Richard Aynsley

Summary of

Actions Towards Sustainable Outcomes

Environmental Issues/Principal Impacts

- Substituting air flow for refrigerative cooling by air conditioning can save energy and reduce greenhouse gas emissions. Cooling building occupants by airflow uses less than 10 per cent of the energy needed for air conditioning.
- In heated spaces circulating air with fans makes better use of the hotter air that would otherwise accumulate at higher levels.
- In warm winterless climates, controlled airflow from circulating fans can often eliminate the need for air conditioning.
- Incorporating personally controlled fans for local air flow can enhance occupant satisfaction with their thermal comfort.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- The use of circulating fans to achieve substantial energy savings in air conditioned and heated spaces.
- The use of circulating fans to enhance summer thermal comfort reliability in naturally ventilated space.
- The use of circulating fans to overcome unwanted thermal stratification in tall spaces such as atria.

Cutting EDGe Strategies

- SET* (standard effective temperature) is a thermal comfort index that provides a new method for calculating the cooling effect of airflow on humans while accounting for all the principal heat exchange factors including evaporative cooling and skin wettedness.
- Using differences between SET* values as a measure for the cooling effect of airflow can now be used quantitatively to offset refrigerative cooling for thermal comfort in air conditioned space.
- Using differences between SET* values as a measure for the cooling effect of airflow from natural ventilation or circulating fans can now be used to achieve thermal comfort in a more quantitative manner.

Synergies and References

- Design for thermal comfort strategies that stress the need for more control by individuals of HVAC systems.
- Publications of the Center for the Built Environment, University of California, Berkeley, California, USA, available on the Internet at http://www.cbe.berkeley.edu/research/publications.htm
- *BEDP Environment Design Guide:* TEC 2: Natural Ventilation in Passive Design
  TEC 12: Ventilation – Emerging Technologies

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Richard Aynsley

Circulating fans are defined as a class of axial propeller fans, generally without an enclosing housing, and used for circulating air in a space. The energy-efficiency of circulating fans tends to increase with their size and reduction in their operating speed.

In summer, air movement from circulating fans can have a significant cooling effect on exposed skin, using less than ten percent of the energy used by an air conditioner to cool the air to achieve a similar effect. The cooling effect of airflow can be calculated from differences in standard effective temperature (SET) using readily available computer software.*

In winter, rising warmed air accumulates near the ceiling. Circulating fans can be used to mix this warmer air with the remainder of air in the room to provide a uniform temperature, providing warmer air in the occupied zone closer to floor level, and thus increase energy efficiency. Energy required to provide thermal comfort for people in a heated space is reduced, saving 3 per cent for each metre of ceiling height proportional to the heat released in the space.

Note: This paper includes a glossary at the end.

Keywords

Airflow, circulating fans, destratification, fans, standard effective temperature, SET, thermal comfort

1.0 INTRODUCTION

1.1 History Of Circulating Fans

It is not surprising that the fans waved by Egyptians thousands of years ago to provide local air movement would later be mechanised. Large fans held with both hands were also used in antiquity for winnowing chaff from grain. Smaller single-handed folding, highly decorated designs used for personal comfort were used in the Ming dynasty, 1368-1644. Fans of this type were introduced to Europe from China via the Middle East during this period.

The first remotely operated fans were *pankha* developed in the 1500's in India and the Middle East. These rectangular canvas covered frames, suspended overhead, were waved back and forth by servants. The servants, called *pankhawallah,* waved fans or pulled on a rope against a counter weight while seated outside the room. With the coming of the industrial revolution fans were belt-driven initially by waterwheels, and later by steam engines. In the USA in the 1880's Dr Schuyler Skaats Wheeler developed a two-bladed electric desk fan, which was commercially marketed by the Crocker and Curtis electric motor company. The electric ceiling fan was introduced in the USA in 1882 by Philip Diehl, a German immigrant, while developing electric sewing machines for the Singer Company in Elizabeth, New Jersey.

1.2 What Are Circulating Fans?

Circulating fans include table or desk fans (Figure 1), ceiling fans (Figure 2), and other unenclosed propeller-type air circulating devices up to the very large industrial ceiling fans (Figure 3). The common feature of all these fans is that they are axial fans or *propellers* without a cowl or duct enclosure. ANSI/AMCA Standard 230-07 covers these for rating purposes.

Circulating fans are used to circulate or mix air within a space, or provide local air movement to enhance thermal comfort of people in a space during warm conditions. The cooling effect provided by fans is a result of enhanced convective and evaporative heat loss from the skin.

Figure 1. Desktop air circulating fan

Figure 2. 1.5 m diameter industrial circulating ceiling fan on performance test rig

Figure 3. Measuring airflow from a 7.3M diameter hvls industrial ceiling fan

2.0 AIRFLOW CHARACTERISTICS

Circulating fans produce turbulent swirling jets of air. The effective length of the jet from the fan, referred to as its *throw*, depends on the rotational speed and the rake of the fan blades. The rake is the angle of the blades to the axis of rotation.

Fans with positive rake (Figure 4) have blades with tips of the blades downstream of their point of fixture to the hub by up to about 15°. These fans can throw a narrow swirling jet up to a distance of about 40 fan diameters or more.

Fans with zero rake blades (Figure 4) have blades that are perpendicular to the axis of rotation. These fans are the most common and produce a more diverging jet with a typical throw of about 25 fan diameters.

Fans with negative rake (Figure 4) have blades with tips of the blades upstream of their point of fixture at the hub by up to about 15°. These fans are less common and throw the broadest jet to a lesser distance of around 15 fan diameters or less.

Broader floor area coverage by airflow can be achieved by having the fan head oscillate as is done with many domestic pedestal fans.

2.1 Velocity Profiles

Manufacturers of circulating fans often provide velocity profiles for their products. These profiles-indicate the 5 minute mean values within the unobstructed jet from the fan. As obstructions to the jet have significant influence on the profile and are commonplace, air velocities in the field are likely to be somewhat different to the unobstructed velocity profile. Figure 5 is the velocity profile for a 0.6 m diameter pedestal fan with a relatively narrow jet. If broader floor area coverage is required another fan with a broader jet or an oscillating model could be selected. Velocity profiles can also be used to establish the volumetric airflow rate in litres per second associated with the principal jet from circulating fans.

3.0 CEILING FANS

3.1 Domestic Circulating Ceiling Fans

The dynamic pressure of the jet of air from domestic ceiling fans impacts the floor below it with significant velocity where it spreads out in a radial fashion across the floor. This pattern of airflow is an energy efficient way of circulating air in a room (Figure 6). The energy efficiency is achieved by having the airflow parallel and clinging to a smooth flat surface, thus enabling the air to flow further across a floor or ceiling. This is referred to as the **Coanda effect**. Where a jet of air penetrates a still body of air, the energy losses at the edges of a turbulent jet of air are large and proportional to the local velocity squared; whereas the energy losses due to skin friction across a smooth floor surface are less and proportional to the local velocity.

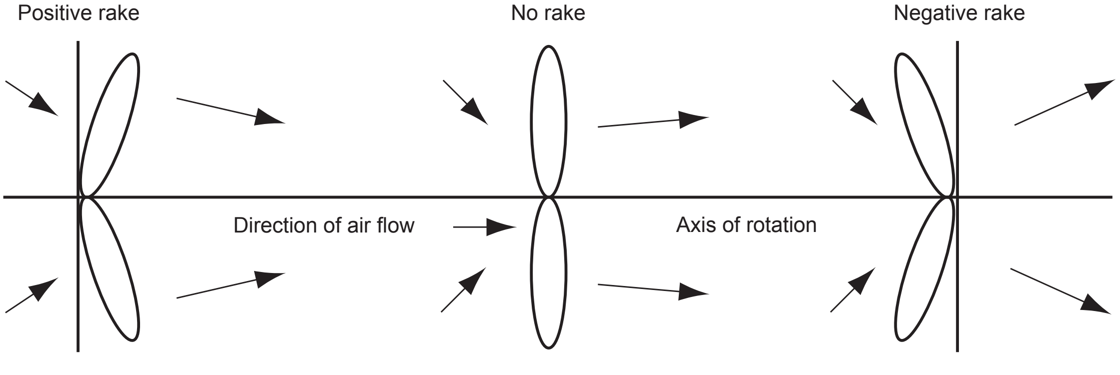

Figure 4. Influence of fan blade rake on downstream air jet

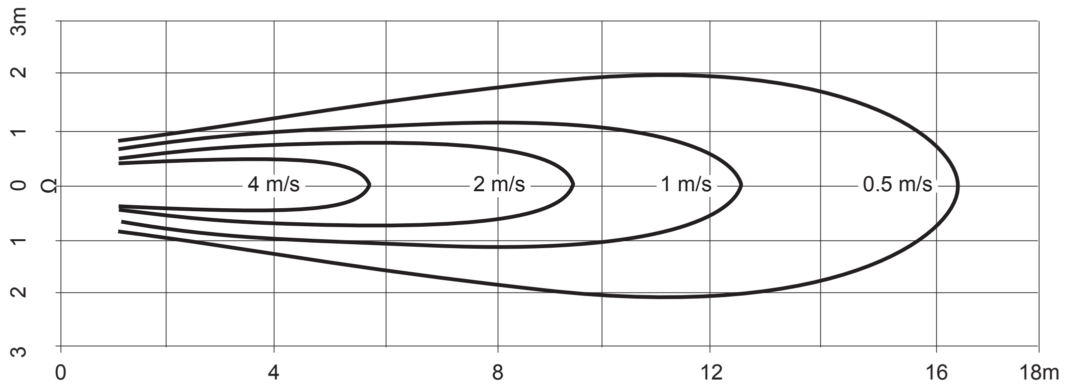

Figure 5. Velocity profile for a 0.6M diameter pedestal circulating fan

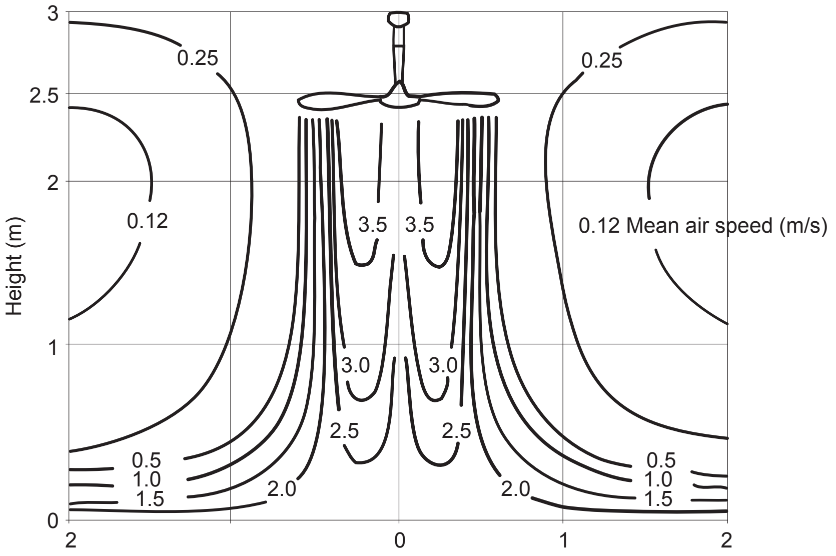

Figure 6. Velocity profile of a domestic ceiling fan

If ceiling fans are to be used to best effect then the ceiling height should be a minimum of 3m to allow 0.5m fan clearance from the ceiling. Fans that 'hug' ceilings due to the ceilings being too low (such as under 2.7m high) are 40 per cent less efficient.

Room area m²	Suggested fan diameter m
Up to 7	0.9
7 to 13	0.9 to 1
13 to 20	1 to 1.12
20 to 27	1.12 to 1.37
27 to 34	1.37 to 1.52

Table 1. Domestic ceiling fan size selection

Domestic ceiling fans should be located directly above positions where people sit or sleep. A guide to selecting the fan diameter can be based on the floor area of the room as given in Table 1. Fans larger than 1.12 m require a minimum ceiling height of 3.2 m. Rectangular spaces larger than 20 m² often benefit from the use of multiple smaller fans.

Most good quality circulator fans have speed control that can be used to moderate local velocities. In warm climates it is common to find ceiling fans fitted under roofs of outdoor deck areas for airflow during periods of inadequate breeze (Figure 7).

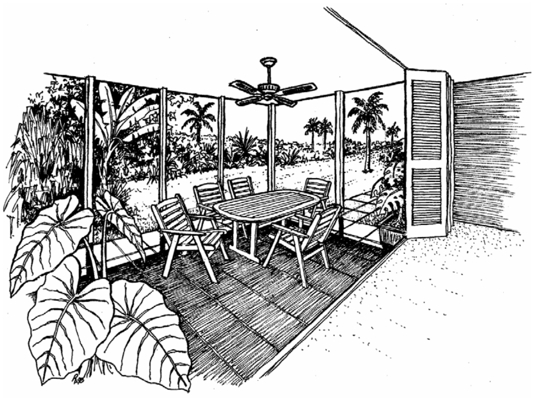

Figure 7. Ceiling fan installed over covered deck area

3.2 Workspace Airflow Criteria

While air movement in the workplace can enhance thermal comfort, local velocities around 1 m/s or higher can result in the disturbance of loose papers etc. Paper weights offer one solution but many people place desk fans beneath their desk so that the airflow is aimed at their midriff. Highly effective fans have been designed specifically for this purpose, Figure 8 (Gao, Niu and Zhang, 2006; Bauman and Arens, 1996).

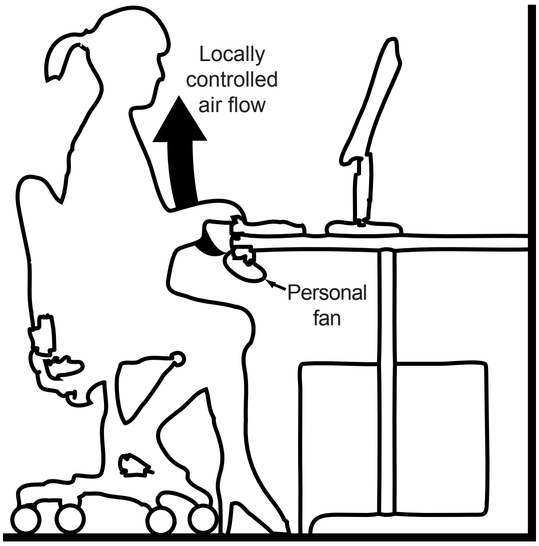

Figure 8. Under-desk fans for locally controlled airflow

3.3 Airflow Measuring Instruments

As obstructions in building spaces can have difficult to predict impacts on local air velocities, it is important to ensure that fan speeds can be adjusted so that air velocities in the finished building meet the desired level. Air velocity is measured using an anemometer of which there are several types. Most anemometers are highly directional in their response, so it is important to align the instrument with the direction of airflow. It is often useful to attach a lightweight ribbon or flexible thread to the anemometer to get a more accurate indication of airflow direction. Airflows in buildings are often quite turbulent so digital anemometers capable of averaging velocities over at least 5 minutes are required (Figure 9).

Figure 9. A hand-held digital averaging anemometer for on-site measurements

3.4 HVLS Circulating Fans

High-Volume, Low-Speed (HVLS) fans fall into the unducted circulating category covered by the international AMCA Standard 230-07. HVLS ceiling fans typically range in size from 2.4 m to 7.3 m diameter and are intended for spaces with ceiling heights over 8 m. They are driven through a gearbox by electric motors with variable frequency drive speed control. The smaller sizes are used to circulate air between large obstructions. In unobstructed spaces the suggested centre to centre fan spacing is 6 diameters for summer cooling. The larger fans require a minimum space of 1.5 m between the fan and the ceiling. These fans are extremely energy efficient, particularly for destratification at low speeds, achieving delivery of more than 400 litres/s per Watt. For effective destratification approximately half the volume of air in the space needs to be circulated each hour. The local air speed for destratification can be very low with less than 0.2 m/s required to avoid complaints of chilling drafts in winter when mixing air to thermally destratify a space. In summer the air speeds required for cooling is typically 1.3-2.3 m/s. In humid tropical regions air speeds for cooling building occupants may need to be 3 m/s or more.

An air delivery versus input power curve for air circulating fans may be obtained from manufacturers. When choosing a circulating fan using this curve, it is important to find a fan with its maximum efficiency around the fan speed relevant to the induced air speed most frequently required in the space.

Fan Blade Shape

The cross-section of most blades on circulating fans is flat or curved, with the blades commonly formed out of sheet metal or fibreboard. The flat blades are the least expensive and also the least efficient. A significant proportion of the input power is dissipated in turbulence. Curved sheet metal blades (Figure 10) can reduce pressure drag at higher fan speeds provided they are mounted at the appropriate angle of attack. To maximise aerodynamic efficiency, fan blades need to be a purpose-designed airfoil shape (Figure 10).

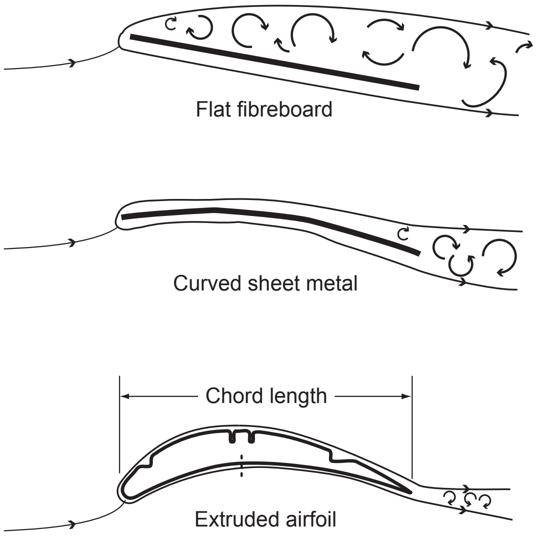

Figure 10. Airflow characteristics of flat, curved sheet and extruded airfoils

Pressure drag occurs when the airflow over the blade cannot cling to the blade surface and separates to form a turbulent wake. Pressure drag is proportional to the square of the upstream air speed. Increasing the number of airfoil blades, and decreasing the chord width increases the solidity of the fan without increasing the pressure drag penalty.

Solidity Ratio

The volume of airflow moved by the fan depends on the solidity ratio. This is simply the area of the blades relative to the area swept by the blades. Increasing the chord (width) of the blades will increase the blade area. The down side of increasing chord width of the blades is an increase in drag due to flow separation on the upstream surface of the blades. At low speed, increasing the chord of the blades is likely to result in separation of the airflow on the upstream surface of the blade and a substantial increase in pressure drag on the blades. Pressure drag is proportional to the square of the upstream air speed. Increasing the number of blades with a narrower chord increases the solidity without increasing the pressure drag penalty.

Blade-Tip Vortex Losses

When not contained by ductwork circulating fans develop strong vortexes at the tips of their blades. These vortexes reduce the aerodynamic performance of each blade for approximately the 15 per cent of its length near the blade tip. The vortexes are generated by air of a higher pressure on the underside of the fan blade flowing around the blade tip into the low pressure region on the upper surface of the fan blade rather than directly over the fan blade. This undesirable flow can be reduced by obstructing the airflow path by a winglet (Figures 11 and 12).

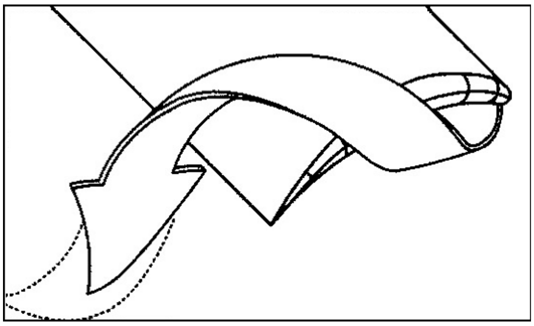

Figure 11. Tip vortex formation on fan blades

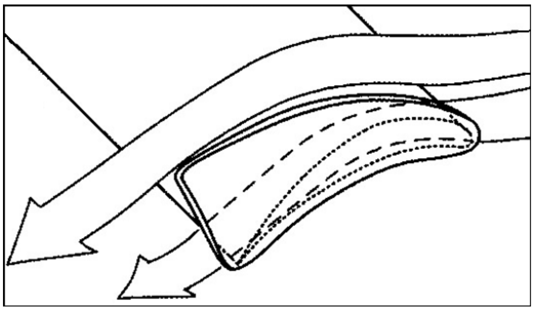

Figure 12. Tip vortex control using a winglet

4.0 COOLING EFFECT OF AIR SPEED ON HUMANS

Air movement can have a significant influence on human thermal comfort. Wind chill in cold conditions is detrimental but air movement in neutral to warm environments is considered beneficial. When air temperatures are above about 23ºC the body normally needs to lose heat in order to maintain a constant internal temperature.

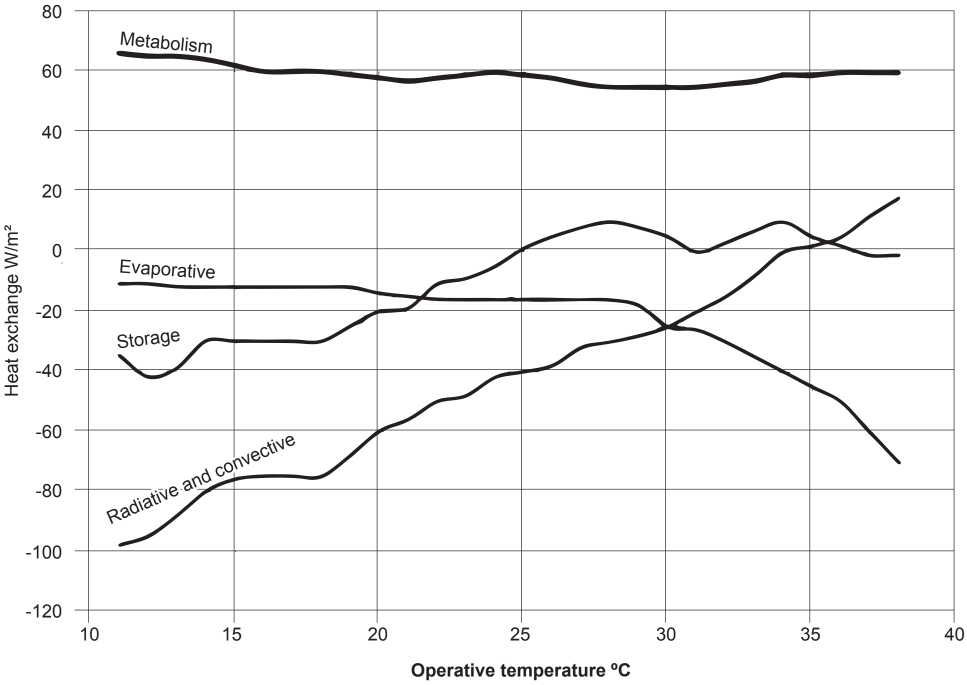

Figure 13. Human body heat exchange versus ambient operative temperature
(Source: City University, Hong Kong data)

Heat exchange between the human body and the surrounding environment is complex (Parsons, 2003).

Figure 13 indicates body heat exchanges over a range of operative temperatures from 11°C to 38°C from City University of Hong Kong data. Note that the effect of evaporative cooling, beyond that from breathing, begins from operative temperatures of approximately 30°C. The Radiative and Convective heat exchange line shows that as the body gets hotter it proportionally radiates more heat. The Heat Storage line indicates that at operative temperature above approximately 17°C, heat is increasingly stored in the body resulting in increasing body temperature.

A widely used mathematical model for predicting the thermal comfort responses of building occupants is the **Pierce Two Node Model** (Berglund 1978). This model is based on two concentric cylinders. The inner cylinder represents the inner body core including the major organs and the outer cylinder represents the skin. Heat transfer between body core and the skin is regulated by controlling blood flow by constricting or dilating blood vessels close to the surface of the skin. The dominant mode of heat loss from the skin at operative temperatures over 30°C is by evaporation of perspiration. Part of the computation of thermal comfort response in the Pierce Two Node model is computation of Standard Effective Temperature, signified as SET*. SET* is the climate chamber air temperature at 50 per cent relative humidity in which a person with standardised clothing and metabolic rate has the same skin temperature and skin wettedness (see glossary) as in an environment. Computation of SET* includes calculating skin wettedness. This makes SET* useful for calculating the cooling effect of elevated air speed. Calculating SET* is complex and computers are commonly used for this task. One readily available easy to use computer program for this purpose is the ASHRAE Thermal Comfort Tool associated with ASHRAE Standard 55-04.

When:
Air temperature = 35 °C
Mean radiant temperature = 35 °C
Air velocity = 3 m/s
Relative humidity = 70 per cent
Metabolic rate = 1.0 met
Clothing Insulation = 0.22 clo
SET* = 29.3 °C

The benefit of 3.0 m/s air velocity can be quantified by reducing air velocity to 0.15 m/s. A typical value used for assessing people engaged in light sedentary activity is 1.0 met.

When:
Air temperature = 35 °C
Mean radiant temperature = 35 °C
Air velocity = 0.15 m/s
Relative humidity = 70 per cent
Metabolic rate = 1.0 met
Clothing Insulation = 0.22 clo
SET* = 36.3 °C

The cooling effect of increasing a uniform air speed from 0.15 m/s to 3.0 m/s can be seen to be 7.0°C, the difference between SET* 36.3 and SET* 29.3. This cooling effect can be used to either evaluate the benefit of air speed through natural ventilated spaces, or to offset summer air conditioning cooling loads to save energy in air-conditioned space. For example, if an air velocity of 3 m/s is achieved by natural ventilation through a house when the air temperature is 35°C with a RH (Relative Humidity) of 70 per cent, then sedentary occupants in light clothing would experience a cooling effect equivalent to lowering the air temperature by 7°C. Alternately, if the thermostat in an air conditioned space with 70 per cent RH was raised to 35°C occupants seated at a desk in light clothing would feel like the air temperature was 29.3°C as long as they were exposed to airflow of 3 m/s from their under-desk fan.

The current ASHRAE standard 55-04 suggests limiting temperature offsets from elevated air speed to 4.4°C, from 1.6 m/s air speed, though this is likely to change given the energy efficiency of airflow for cooling people. Cooling occupants by increasing local airflow is ten times more energy efficient than refrigerating the air in a space.

Conventional centralised HVAC systems in buildings typically limit occupant interaction to adjusting the thermostat temperature setting in a space up or down. There is rarely any provision for occupant control of local air velocities. Personally controlled airflow for thermal comfort has been available in cars and aircraft for many years, and allows individuals to adjust airflow to offset personal comfort differences due to solar exposure, metabolic rate, type of clothing etc. Most cars have a four speed fan to provide airflow from 1 m/s up to 6 m/s from louvered outlets in the dashboard.

Activity	Met	W/m^2
Sleeping	0.7	40
Seated, quiet	1.0	45
Seated, typing	1.1	65
Standing, relaxed	1.2	70
Walking about	1.7	100
Lifting/packing	2.1	120

Table 2. Metabolic rates associated with various activities
(1 met = 58.2 W/m²)

It is interesting to note that the thermal receptors beneath human skin have a peak response to air gusts with a frequency around 0.5 Hz that is a gust about each 2 seconds (Yizai et al, 2000). At low air speeds gusts around 2 seconds apart have a cooling effect equivalent to a uniform air speed more than twice their mean air speed (Olesen, 1985).

4.1 Cooling Effect of Air Speed Provisions in Standards

ASHRAE Standard 55-04 section 5.2.3 indicates a temperature offset up to 4.4°C can be attributed to an elevated air speed up to 1.6 m/s associated with differences between mean radiant temperature and ambient air temperature. For light sedentary activity such as office deskwork the provision suggests limiting air speed to 0.8 m/s. This provision was developed in Europe for summer climates where humidity is modest. Where summer relative humidity exceeds 60 per cent the SET* cooling effect of air movement method described above is more appropriate.

The increased cooling effect of general turbulence in the air stream as measured by turbulence intensity (the ratio of standard deviation of air speed to the mean air speed), is indicated in a graph in section 5.2.3 of ASHRAE Standard 55-04, but does not accommodate the influence of gust frequency observed by Olesen in 1985.

4.2 An Added Benefit of Indoor Airflow – Insect and Bird Control

The turbulent airflow produced by circulating fans provides an additional benefit in regions plagued by flying insects or in aircraft hangars or similar open buildings where birds are a nuisance. Most insects and birds have difficulty flying in the turbulent jets of circulating fans. Many people living in naturally ventilated houses in humid tropical regions prefer to use circulating fans such as ceiling fans to discourage insects rather than insect screens over windows. Insect screens greatly reduce airflow, particularly at low wind speeds.

5.0 ENERGY SAVINGS

5.1 Estimating Air Conditioning Energy Savings from Increased Air Movement

Large amounts of energy are used to operate air conditioning equipment in buildings during hot summer months. The cooling effect of 3 m/s air movement of up to 7°C from circulating fans can be used in conjunction with raising the air conditioning SET* sensing thermostat to achieve significant savings while maintaining thermal comfort (Aynsley, 2005a). It should be noted that circulating fans do not cool air; they cool the skin of building occupants directly by enhancing convection and evaporation from the skin.

Research by the US utility company Reliant Energy indicated that for each degree Celsius rise in the thermostat setting above 25°C in summer, a cooling energy saving of between 9–12 per cent can be achieved (Reliant, 2006).

The energy consumption of circulating fans running at high speed for summer cooling will conservatively use approximately 2 per cent of the air conditioning savings leaving net savings from between 7 per cent to 10 per cent per for every degree Celsius of thermostat rise. That is, if the air conditioning thermostat is raised say 5°C and the cooling effect of circulating fans on occupants are used to offset this increase, then the net savings after accounting for energy used by the circulating fans would be from 35 per cent (5 x 7 per cent) up to 50 per cent (5 x 10 per cent) in active areas such as gymnasia. In office space air speed constraints limit local air speeds less than 1 m/s with a cooling effect of around 3°C with energy savings for cooling of approximately 20 per cent. Figure 14 illustrates a typical application of a large HVLS circulating fan in a warehouse where the comfort of relatively few employees requires the potential conditioning of large volumes of air.

Figure 14. Large HVLS circulating fans in a warehouse

5.2 Estimating Winter Energy Savings from Air Destratification or Mixing

Energy savings from using large circulating fans to destratify or mix heated air in spaces with tall ceilings or atria (Figure 15) can be significant (Aynsley, 2005b).

Conventional	Clo	Casual	Clo	Industrial	Clo
Briefs/panties (Bra add 0.01)	0.04	Briefs/panties (Bra add 0.01)	0.04	Briefs/panties (Bra add 0.01)	0.04
T-shirt or vest	0.08	T-shirt or blouse	0.08	T-shirt or blouse	0.08
Long sleeve shirt/ blouse	0.25	Walking shorts	0.08	Loose fit overalls	0.03
Trousers or slacks	0.24	Sandals	0.02	Socks	0.10
Shoes and socks	0.05			Boots	0.30
Total	**0.66**	**Total**	**0.22**	**Total**	**0.55**

Table 3. Clothing insulation values of summer clothing ensembles
(I clo = 0.155 m^2 .°C/W)

When air in a space is heated near floor level the hottest air rises to the ceiling, which typically results in an air temperature increase of around 1.4ºC per metre of height above floor level. The large temperature difference between indoor and outdoor air temperature can lead to the most significant heat loss from a heated space being through the roof. By mixing the indoor air to a uniform temperature, the air temperature under the roof becomes the average indoor air temperature and heat loss through the roof is reduced while at the same time maintaining comfortable warmth near floor level.

Figure 15. Atria with circulating fans for destratification

Before destratification the difference between the temperature of air near floor level and at the underside of a 10 m high roof deck can be up to 14ºC. Typical winter heating savings in warehouse buildings are around 10 per cent for each 3 m of ceiling height.

Cost of Operating Large Ceiling Fans for Destratification

Energy-efficient, large, low-speed ceiling fans are purchased principally for destratification in winter. A 5,388 m² shipping and receiving warehouse would typically have five 6 m diameter fans operating quietly at approximately 20 rpm continuously. While providing the destratification the air velocity at head-height above the floor is kept below 0.2 m/s to avoid draft complaints. Cost of purchase and installation of the five fans would be approximately AU$50,000. At 20 rpm, each fan would use 0.1 kW of power. Over the 89 day period of the heating season of this warehouse in White Plains near New York City, these fans running 24 hours per day would use 5 x 0.1 x 89 x 24 or 1068 kWh of electricity, costing approximately 6 ¢ per kWh, or AU$64.08 (Aynsley 2005b)

6.0 SUMMARY AND CONCLUSIONS

Circulating fans are often overlooked in building design as devices to enhance summer thermal comfort in naturally ventilated buildings in Australia's warm climates or to save both cooling and heating energy. In summer air speeds generated by fans should range from 0.2 m/s to over 3 m/s, although, as mentioned, speeds higher than about 1 m/s may disturb loose papers in office environments. Winter air speeds in occupied space should be less than 0.2 m/s to avoid complaints of drafts. Most airflow in buildings fluctuates significantly, so any air speed measurements should be averaged over at least 5 minutes to allow comparison air speeds at different locations. In many buildings large HVLS fans will offer the most energy efficient means for circulating air beyond that acquirable through natural ventilation.

The cooling effect of air speed in warm conditions is compromised by relative humidity in excess of 60 per cent. In these conditions the cooling effect of air speed can be calculated using Standard Effective Temperature (SET*). Standards such as ASHRAE 55-2004 have provisions for the cooling effect of elevated air speed. Rules of thumb exist for estimating the energy and cost saving from air movement in buildings. For each degree Celsius rise in the thermostat setting above 25 ºC in summer, a cooling energy saving of 7 per cent to 10 per cent can be achieved by compensating with increased airflow. In warehouses, winter heating energy is typically reduced by 3 percent for each metre of ceiling height by destratifying thermally stratified air using HVLS fans.

Use of circulating fans in buildings offers designers a relatively simple means for enhancing indoor thermal comfort and energy efficiency in their projects.

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GLOSSARY

Climate chamber is an enclosed laboratory space designed to accommodate people where they can be surveyed for their thermal responses to a wide range of precise environmental conditions, such as air temperature, mean radiant temperature, humidity and air movement.

Clo is a measure of the thermal insulation of clothing used in calculating heat exchanges between the human body and its surroundings. It is similar to a U-value and has the same units of measurement. 1 clo is equivalent to 6.45 W/m^2K.

Coanda Effect is the tendency for a jet of air, close and parallel to a smooth flat surface such as a ceiling or floor, to cling to that surface and travel further than the jet would normally travel as a free jet into a large body of air. It allows HVAC engineers to throw a jet of air from an air supply outlet much further into a room across a ceiling than they could with a free jet into the general space.

Dynamic pressure is the pressure exerted on an object in the direction of the airflow by a mass of moving air impacting on its surface. This pressure, in Pascals, is equal to $\frac{1}{2} \rho v^2$ where ρ is the mass density of air, typically 1.2 kg/m^2, and v is the velocity of the air in m/s.

Met is a measure of the heat release from a human body related to its metabolic rate. It is a function of the level of their physical activity. 1 met is equivalent to an average heat loss of 58.2 W/m^2 of surface area. The surface area of a person is calculated using the Du Bois area equation, $A_D = 0.202 \text{ x } M^{0.425} \text{ x } h^{0.725}$ where m is body weight in kilograms and h is body height in metres.

Pressure drag is the drag force acting on an object in the direction of the air stream resulting from surface pressure differences over the surface of the object. It is by far the largest drag force on non-streamlined objects where the airflow separates from the surface to form a broad turbulent downstream wake. There is also a much smaller skin friction drag force due to viscous shear forces in airflow attached to the surface of the object.

SET* or standard effective temperature, is the climate chamber air temperature at 50 per cent relative humidity in which a person with standardized clothing and met rate, has the same skin temperature and skin wettedness as in an environment. Skin wettedness is a key factor in evaporative cooling at air temperature above 30°C.

Static pressure is the pressure exerted equally in all directions at a point due to gravity acting on the air in the atmosphere above that point. When air is not moving the static pressure is equal to atmospheric pressure.

Wettedness *"The Skin Wettedness (w) is a rationally derived physiological index defined as the ratio of the actual sweating rate to the maximum rate of sweating that would occur if the skin were completely wet."* (Design Builder, 2007)

BIOGRAPHY

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