Average Versus Simultaneous Climatic Data for Estimates of Natural Ventilation Cooling Potentia

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ABSTRACT

Airflow through houses from onshore coastal breezes in warm humid tropical climates is the principal passive means of achieving indoor thermal comfort when air temperatures exceed 30°C and relative humidity exceeds 60%. Estimates of indoor natural ventilation cooling potential have been based on indoor wind speed coefficients determined from boundary layer wind tunnel tests combined with wind frequency, air temperature and relative humidity data. The paper refers to studies of a naturally ventilated house design proposed for Townsville, a provincial city of 120,000 people in the warm humid tropics on the east coast of northern Australia.

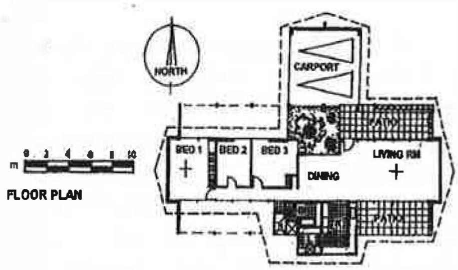
One estimate of natural ventilation cooling potential for indoor thermal comfort used 20 year mean dry bulb and wet bulb air temperature at 3 PM together with 20 year wind frequency data. This estimate was compared with natural ventilation cooling based on actual simultaneous temperature and wind data for January 1980. This comparison showed that the estimate of natural ventilation cooling potential based on the long term mean 3 PM dry bulb and wet bulb air temperatures plus one standard deviation compared very well with natural ventilation cooling potential calculated from actual temperature and wind data for January 1980, suggested by Bureau of Meteorology staff as a "typical year". A similar result was achieved when a comparison was made for 9 PM data when the frequency of calms was significantly higher.

KEYWORDS

Cross ventilation, Natural ventilation, Residential buildings, Thermal comfort

INTRODUCTION

This paper explores how the use of readily available monthly average DBT and WBT data in estimating natural ventilation cooling potential compares with similar estimates using a month of measured data. The study focuses on the Living Room of a proposed house (Figure 1) in the city of Townsville (Aynsley, 1996). Townsville is a provincial city of 120,000 people located in the warm humid tropics on the east coast of northern Australia, 19 degrees South latitude.



Estimates of natural ventilation cooling potential in buildings from wind, need to take into account the normal variability of wind, air temperature and humidity. Most of the thermal comfort design criteria has been developed for use in climate controlled air conditioned environments in temperate climates (Fanger, 1970, 1982). Simple criteria have been suggested (Macfarlane, 1958) for evaluating thermal comfort in humid tropical climates. More recently extensive field studies (Auliciems, 1981, de Dear, 1997, Auliciems and Szokolay, 1997) have focussed on identifying thermal neutrality in naturally varying thermal environments. Thermal neutrality, T_n, is the dry bulb air temperatures at which minimal thermal stress reported on verbal response scales (Auliciems, 1981).

$$T_n = 17.6 + 0.31T_m \quad (1)$$

where T_m is the mean monthly dry bulb or globe air temperature.

The interval of responses between categories of *slightly cool* to *slightly warm*, accommodating 85% of responses was considered a comfort zone, and was found to be thermal neutrality temperature +/- 2°C. Where indoor surface temperatures exceed 38°C radiant heat gains will be noticed by occupants and globe temperature should be used. From a design viewpoint it is advisable to avoid indoor radiant heat gains. This is done by ensuring that external building surfaces, particularly the roof, reflect solar radiation and are sufficiently insulated to ensure that internal surface temperatures do not exceed 38°C.

In humid tropical environments during the hotter months, conditions often exceed the thermal comfort zone and cause symptoms of heat stress. A common index for quantifying heat stress is the Wet Bulb Globe Temperature Index (WBGT) in which the combined effects of dry bulb air temperature (DBT) and humidity are accommodated by incorporated wet bulb air temperature (WBT).

$$\text{WBGT} = 0.3\ \text{DBT(or globe)} + 0.7\ \text{WBT} \quad {}^\circ\text{C} \quad (2)$$

Globe air temperature, measured with a globe thermometer, is used when there are significant radiant heat gains. Impacts of heat stress begin when the WBGT Index exceeds 30°C. In Townsville during January, a typical combination dry bulb air temperature and wet bulb air temperature resulting in a WBGT of 30°C is 32.2°C DBT and 25.1°C WBT. An upper comfort limit of 60% relative humidity (Nevins, 1975) equates to a WBT as 22.2°C when taken together with 28.1°C DBT, the upper limit of the comfort zone for Townsville during January. Above these thermal comfort limits the writer suggests that, T_{ex}, the combined effects of elevated DBT and WBT on discomfort, be estimated using the relative contributions established in the WBGT Index.

$$T_{ex} = 0.3(\text{DBT}-28.1) + 0.7(\text{WBT}-22.2)\,{}^\circ\text{C} \quad (3)$$

The cooling effect of air flow on building occupants wearing light clothing (0.5 Clo) has been studied in a variety of environments (Gagge et al, 1970, McIntyre, 1976, Arens et al, 1980) producing a variety of equations. ASHRAE Standard 55 (1992) permits an extension of upper comfort limits by 1°C for each 0.275m/s air velocity (between 0.25m/s and 0.8m/s). Givoni (1994) suggests that in warm climates the beneficial cooling effects of air movement should be extended up to 2m/s. Based on these recommendations Szokolay (Auliciems and Szokolay, 1997) suggests the following equation for dT, the equivalent cooling effect of an air flow of V m/s in degrees Celsius for air flow up to 2m/s:

$$dT = 6(V-0.25) - (V-0.25)^2 \quad {}^\circ\text{C} \quad (4)$$

When houses in humid tropical climates are designed for cross ventilation airflows of around 1m/s the result is hundreds of air changes per hour of cross ventilation. With these rates of air change, indoor humidity and dry bulb air temperatures are similar to ambient external conditions, exceptions being when large amounts of heat or water vapour are released indoors from extensive hot water washing or cooking. When indoor DBT and WBT follow outdoor ambient DBT, WBT and wind data can be used to evaluate natural ventilation cooling potential. In humid tropical environments in Australia, long term average maximum monthly DBT and WBT are readily available for 900hrs and 1500hrs. Other more detailed daily data at 3 hourly interval is available from recording sites but at a substantial cost.

METHODS

Indoor airflow rates were quantified using mean wind speed coefficients measured in carefully conducted boundary layer wind tunnel studies (Aynsley, 1996). Indoor wind speeds, WS_i, at the centre of the Living Room marked + in Figure 1, were measured using a miniature cylindrical hot film anemometer probe. Wind speed coefficients were calculated by dividing the indoor wind speed measurement by the simultaneous outdoor reference wind speed measurement. Wind speed coefficients for each wind direction are included in Table 1. The outdoor reference wind speed was measured 10m above ground approximately six building heights upstream outside the local flow influences associated with the building. The wind speed at the nearby airport, WS_a, was calculated using Equation 5.

$$WS_a = 1.12 \times WS_i / C_{ws} \quad \text{m/s} \qquad (5)$$

The factor 1.12 relates the local outdoor wind reference speeds 10m above ground level at the site to wind speeds recorded 10 m above ground at the airport. The minimum indoor wind speed, WS_i, needed to restore indoor thermal comfort against a given thermal excess, T_{ex}, was calculated using Equation 4.

Estimates Based on Average DBT and WBT.

The 50 year mean monthly dry bulb air temperature, T_m, for Townsville during January is 27.6°C (Bureau of Meteorology, 1975). From this mean monthly dry bulb air temperature, thermal neutrality T_n, from Equation 1 is 26.1°C. Adding and subtracting 2°C to 26.1°C gives a comfort zone for January of 24.1°C to 28.1°C. In Townsville during January the 20 year mean daily DBT at 1500hrs is 30.3°C with a standard deviation, calculated by the writers of 2.3°C and WBT is 24.9°C with a standard deviation of 1.3°C. As temperature distributions are very close to a normal distribution, 68% of DBTs would be between the mean ± one standard deviation, that is 28.0°C to 32.6°C and WBTs 23.6°C to 26.2°C. Using the upper mean DBT and WBT plus one standard deviation the thermal excess beyond the comfort zone at 1500hrs from Equation 3 was 4.15°C. These design values of DBT and WBT were chosen on the basis that they represent typical conditions in the population of temperatures above the mean where cooling is more critical. From Equation 4, a thermal excess of 4.15°C would require an air flow of 1.04 m/s to restore thermal comfort.

Estimates of the percentage of time when natural ventilation will provide sufficient cooling to restore thermal comfort at 1500hrs in Table 1 began setting WS_i to the design wind speed to restore thermal comfort in the living room, 1.04 m/s. The wind speed needed at the airport to achieve this indoor wind speed was calculated using Equation 5. The influence of wind direction being taken account of by the wind speed coefficient, C_{ws}. The probability of the airport wind speed equalling or exceeding that for comfort was found by summing the probabilities associated with wind speed intervals exceeding that airport wind speed needed to restore thermal comfort. The result was 94.5%. Where WS_a fell within a wind speed interval, the percentage of time associated with wind speeds exceeding WS_a were calculated using linear interpolation.

Wind Direct 1500hr	Wind Speed Coefficient Cws	WSa = WSi/Cws x 1.12	0.1 to 0.99 m/s	1.0 to 1.99 m/s	2.0 to 2.99 m/s	3.0 to 3.99 m/s	>3.99 m/s	% Time Comfort Restored
N	0.92	1.33 m/s	0.3%	1.6%	1.6%	2.4%	5.5%	10.6
NNE	1.10	1.11 m/s		0.6%	0.9%	2.4%	4.4%	8.2
NE	0.96	1.27 m/s	0.3%	0.2%	2.6%	2.2%	19.7%	24.7
ENE	0.77	1.58 m/s		0.6%	0.5%	2.6%	28.6%	32.0
E	0.73	1.67 m/s	0.2%	0.2%	0.5%	0.6%	6.8%	8.0
ESE	0.69	1.77 m/s	0.2%	0.3%			2.0%	2.3
SE	1.15	1.06 m/s		0.2%	0.2%	0.6%	1.7%	2.6
SSE	0.95	1.28 m/s		0.2%	0.2%	0.2%	0.4%	0.9
S	0.65	1.88 m/s			0.2%	0.3%	0.4%	0.9
SSW	0.40	3.05 m/s					0.2%	0.2
SW	0.35	3.49 m/s					0.2%	0.2
WSW	0.35	3.49 m/s		0.2%			0.2%	0.2
W	0.38	3.21 m/s						0.0
WNW	0.40	3.05 m/s		0.2%			0.2%	0.2
NW	0.44	2.77 m/s	0.2%	0.2%	0.6%	0.2%	0.2%	0.5
NNW	0.54	2.26 m/s		0.2%	0.5%	0.8%	1.8%	3.0
Calms		0						0
Totals			1.2%	4.7%	7.8%		86.3%	94.5%

Tables 1. Estimated percentage of time thermal comfort is likely to be restored by wind driven natural ventilation in the Living Room during January in Townsville at 1500hrs from 20 year DBT, WBT and wind frequency data.

Later in the evening in Townsville during January the 20 year mean daily DBT at 2100hrs is 27.2°C with a standard deviation of 1.67°C and WBT is 24.8°C with a standard deviation of 1.81°C. Based on these values the thermal excess was 3.31°C. From Equation 4, a thermal excess of 3.31°C would require an air flow of 0.86 m/s to restore thermal comfort. The result of using the procedure in Table 1 on this data indicated that the percentage of time when natural ventilation cooling would restore thermal comfort was 74.1%.

Estimates Based on Simultaneous Recorded Daily Climatic Data.

Human thermal comfort is a response to simultaneous climatic conditions at particular points in time. The evaluation in Table 2 used January 1980 1500hrs daily simultaneous records of DBT, WBT (Bureau of Meteorology, 1975) and wind data. Choice of the year 1980 was on the advice of Bureau of Meteorology officers who chose the year as *typical year*, not a record dry or a record wet year as have occurred during recent times. The thermal excess for each day was calculated using Equation 3. The airflow needed to be equalled or exceeded to restore thermal comfort was calculated using Equation 4. Estimates of daily indoor wind speed, WS_i, were calculated using Equation 5.

Jan	Natural Ventilation Evaluation for Living Room - Townsville Jan 1980							1500hrs
Day	Dry Bulb Temp	Wet Bulb Temp	Degs over Comfort	Air Flow for Comft	IndoorWS m/s	AirportWS m/s	Wind Dir.	WSCoeff Living Rm
1	28.2	23.0	0.89	0.40	4.85	5.7	NE	0.96
2	29.3	23.5	1.27	0.47	5.05	5.1	NNE	1.10
3	29.7	25.3	2.65	0.73	6.62	7.7	NE	0.96
4	26.9	24.3	1.11	0.44	4.41	5.1	NE	0.96
5	24.8	23.9	0.20	0.28	4.85	5.7	NE	0.96
6	27.3	26.2	1.16	0.45	3.38	4.1	N	0.92
7	29.7	24.2	1.88	0.58	1.29	4.1	SW	0.35
8	31.1	25.3	3.07	0.81	1.77	2.1	NE	0.96
9	29.0	25.6	2.65	0.73	1.01	2.6	NW	0.44
10	31.0	26.5	3.88	0.98	0.99	2.1	NNW	0.54
11	32.3	25.1	3.29	0.86	2.11	2.6	N	0.92
12	31.7	26.2	3.88	0.98	1.42	3.6	NW	0.44
13	33.4	28.0	5.65	1.42	2.63	6.7	NW	0.44
14	32.5	28.1	5.45	1.36	1.77	2.1	NE	0.96
15	33.0	28.0	5.53	1.38	2.48	5.1	NNW	0.54
16	34.9	25.3	4.21	1.06	0.81	2.1	NW	0.44
17	31.6	26.1	3.78	0.96	2.53	2.6	NNE	1.10
18	31.1	25.5	3.21	0.84	5.56	5.7	NNE	1.10
19	32.5	24.5	2.93	0.78	1.49	3.1	NNW	0.54
20	32.0	24.6	2.85	0.77	1.24	2.6	NNW	0.54
21	32.5	25.8	3.84	0.97	1.52	1.5	NNE	1.10
22	31.1	26.3	3.77	0.96	7.08	7.2	NNE	1.10
23	31.0	26.6	3.95	1.00	4.04	4.1	NNE	1.10
24	32.6	26.0	4.01	1.01	1.32	1.5	NE	0.96
25	32.9	26.7	4.59	1.15	3.03	3.1	NNE	1.10
26	32.1	26.4	4.84	1.21	2.54	3.1	N	0.92
27	30.4	24.9	2.58	0.71	4.41	5.1	NE	0.96
28	29.1	24.6	1.98	0.60	3.09	3.6	NE	0.96
29	31.0	25.0	2.83	0.76	4.55	4.6	NNE	1.10
30	31.7	25.8	3.60	0.92	5.30	6.2	NE	0.96
31	31.4	25.0	2.95	0.79	3.09	3.6	NE	0.96

Tables 2. Estimated percentage of time thermal comfort is likely to be restored by wind driven natural ventilation in the Living Room during January in Townsville at 1500hrs from January 1980 daily climatic data.

Evaluation of airflow needed to restore thermal comfort in the Living Room together with the estimated wind generated airflow at 1500hrs during January 1980 (Table 2) revealed that:

- the mean temperatures for this time of the day were DBT 30.9°C and WBT 25.6°C (within 1 °C of 50 year means at 1500hrs are DBT 30.3 and WBT 24.9).
- air flow was required every day. (100% of the time).
- the minimum airflow required to restore comfort was 0.28 m/s, mean 0.85 m/s and maximum 1.42 m/s.
- conditions were within the thermal comfort zone on 29 of the 31 days (93.5% of time)

- there was insufficient wind to restore comfort on days 16 & 22 (6.5% of time).
- mean wind speed at the airport at 1500hrs was 4.0 m/s.
- there were no occurrences of calms.

In summary, the amount of thermal discomfort is significant at this time of day driven by higher air temperatures, particularly WBT. Conditions were within the thermal comfort zone for 93.5% of the time due to a high mean wind speed of 4.0 m/s and an absence of calms.

Similar evaluation of data for 2100hrs during January 1980 revealed:

- the mean temperatures for this time of the day were DBT 27.8°C and WBT 24.4°C.
- air flow was not required on days 1,3,5 and 7 (12.9% of the time).
- the minimum airflow required to restore comfort was 0.27 m/s, mean 0.57 m/s and maximum 0.87 m/s.
- conditions were within the thermal comfort zone on 22 of the 31 days (71% of time)
- there was insufficient wind to restore comfort on days 8,9,10,11,12,14,16,24, and 28 (29% of time).
- mean wind speed at the airport at 2100hrs was 2.1 m/s
- there were 7 occurrences of calms (22.6% of time).

In summary, the amount of thermal discomfort is driven by higher humidity but is significantly less at 2100hrs than during daylight hours. Lower mean wind speeds and a significant number of calms limited the ability of natural ventilation to restore thermal comfort to only 71% of the time. Ceiling fans could have restored thermal comfort for the remaining 29% of time.

RESULTS & DISCUSSION

The natural variability of DBT, WBT and wind create difficulties in estimating natural ventilation cooling potential. Few have attempted (Arens, 1984, 1986, Byrne, 1986).

In humid tropical environments the need for cooling to restore indoor thermal comfort varies throughout each day as well as throughout each year. While temperatures are generally higher during daylight hours, strong onshore sea breezes in Townsville usually provide adequate cooling. The temperature around 2100hrs usually falls a few degrees from that at sunset but this is often accompanied by a greater occurrence of calms reducing natural ventilation cooling (Aynsley, 1997).

The influence of climatic variability on accuracy of estimates can be reduced by focussing estimates of natural ventilation cooling on specific times of day when reliable long term (at least 20 years) DBT and WBT data are available. Errors arising from wind frequency data can be minimised to a fraction of a percent of time by using at least 20 years of full sixteen wind direction data and adopting narrow ranges of wind speeds for wind speed intervals particularly in the wind speed range 0 to 2 m/s.

Estimated percentage of time thermal comfort is likely to be restored by wind driven natural ventilation in the Living Room during January in Townsville at 1500hrs and 2100hrs from 20 year mean DBT, WBT and wind frequency data of 94.5% and 74.1% agreed well with estimates using actual January 1980 1500hr and 2100hr daily climatic data of 93.5% and 71% respectively. The maximum difference between these estimates is equal to 3.1% (1 occurrence in 31 days), and therefore satisfactory for design purposes. The design criteria of mean monthly DBT and WBT plus one standard deviation accommodates a cumulative 84% of the population conforming to a normal distribution.

Further comparisons with non-typical years, using mean DBT and WBT plus two standard deviations to determine thermal excess beyond the comfort zone, are needed to determine if such an approach can yield satisfactory comparisons with years with extreme conditions.

CONCLUSIONS

Estimates of indoor natural ventilation often focus on the hotter periods of the day when solar gain is high. What is clear from the estimates provided in this paper is that houses which experience satisfactory natural ventilation during hot afternoons when wind events are concentrated around 6.7 to 7.7 m/s, may not perform as well during the evening when wind events are concentrated around 3.6 to 4.6 m/s. It is important to have some estimate of the percentage of time when natural ventilation is unable to restore thermal comfort so that a rational choice and sizing of backup ceiling fans or air conditioners can be made.

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