Title

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THE POTENTIAL FOR WIND INDUCED VENTILATION TO MEET OCCUPANT COMFORT CONDITIONS

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DISCLAIMER

The Potential for Wind Induced Ventilation to Meet Occupant Comfort Conditions†

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Abstract

This paper describes a simple graphic tool that enables a building designer to evaluate the potential for wind induced ventilation cooling in several climate zones. Long term weather data were analyzed to determine the conditions for which available wind speed can be used to meet occupant comfort conditions. By calculating the change in enthalpy produced by a typical residential air conditioner during those hours when an occupant is uncomfortable, we were able to estimate the impact of natural ventilation on building cooling load. The graphic presentation of the results allows a designer to determine the potential energy savings of increasing the ventilation air flow rate as well as the orientation of building openings that will maximize ventilation cooling of the building occupants.

KEYWORDS: climate, comfort, cooling, energy, ventilation, wind

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Introduction

Wind induced ventilation of buildings can be a significant means of increasing occupant comfort and reducing cooling energy consumption in hot climates. In order to properly size and orient building openings to take advantage of ventilation cooling, a designer must be aware of the direction and speed of local wind as well as ambient dry bulb temperature and relative humidity. This information is available on hourly weather tapes but needs to be reduced to a simple format to be useful during the early phases of the design process.

Summary information on wind direction, frequency and prevailing wind speed is available as "wind rose" plots[1] of conditions at local weather stations. Although this information has traditionally been used as the only source of average local wind conditions, its usefulness in building design is very limited. Wind rose plots (see examples in Figures 1-3) indicate frequency of wind blowing in each of 16 directions and wind speed is given for the prevailing wind direction. This provides a designer with no information on *coincident* temperature and humidity which must be used to determine whether ventilation is beneficial. Although it is possible to use monthly wind roses together with monthly average weather data,[2] the designer is at best left with a rough estimate

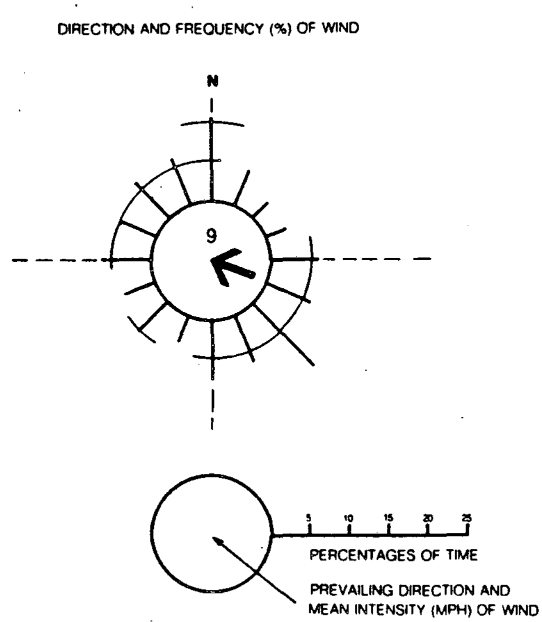

Figure 1: Annual Wind Rose for Albuquerque.

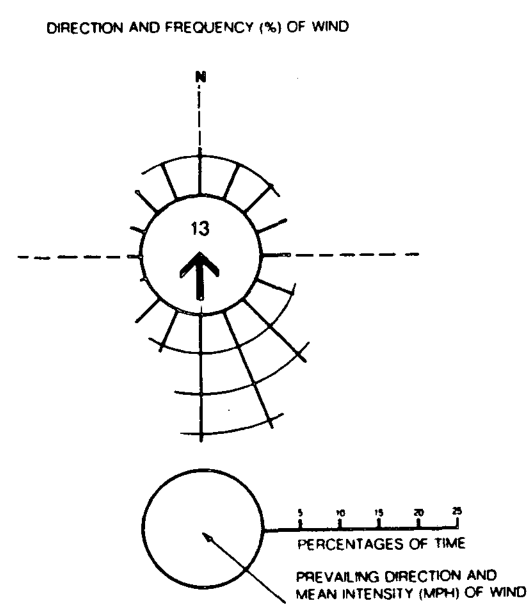

Figure 2: Annual Wind Rose for Fort Worth.

that indicates little about the effect on human comfort and building cooling loads.

We have attempted to correct this deficiency by a detailed analysis of long term, hourly weather tapes in which *coincident* data on wind direction and speed, ambient dry bulb temperature, relative humidity and barometric pressure can be used as input to mathematical models of human comfort and building cooling loads. By this analysis, it is possible to determine:

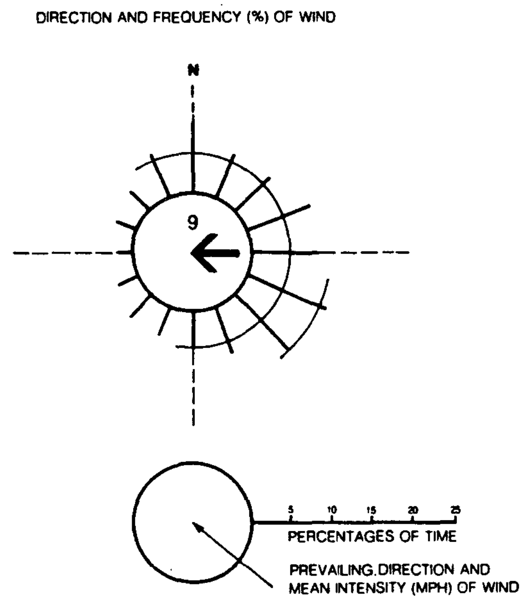

Figure 3: Annual Wind Rose for Miami.

1) the human comfort level when the interior wind speed is held to various fractions of the available exterior wind speed,

2) the building cooling load for those ambient conditions that are uncomfortable and

3) the direction the wind is blowing from when mechanical cooling is required to maintain comfort.

Thus, the results indicate the potential savings from inducing various building air flow rates as well as the orientation of building openings that will minimize the annual cooling load. Local weather patterns, such as strong northerly winds, combined with lower air temperature during brief storms (in which case mechanical cooling could be unnecessary) are automatically accounted for and are weighted by the frequency of occurrence when annual summaries are compiled. Because local weather patterns are common and instantaneous conditions are seldom constant at monthly (or annual) average conditions, this hourly analysis of all factors affecting comfort and cooling load is essential.

Weather Data

Hourly weather data are available in a variety of formats and can be obtained for multiple, contiguous years[3] or for a single, average year.[4,5,6] For this analysis, we chose to analyze long term (approximately 12 contiguous years) data for each location, because the methods for determining "average" years emphasize average temperature and solar radiation but not wind speed or direction. We used data from years prior to 1965, when reporting frequency was changed from hourly to once every three hours at most locations. Available weather tapes begin during mid 1952 through early 1953, thus yielding approximately 12 years of hourly data for each location. Our summarized results, therefore, represent average potential for wind induced ventilation cooling and may not be exactly the same for any specific year.

Because this analysis is intended to show the benefit of ventilation cooling in buildings, the wind speed measured at the local weather station (usually a nearby airport) was translated to what could be expected at the building site. The difference in height between the weather station wind tower and the actual building height, as well as differences in terrain were accounted for with the following algorithm:[7]

$$WS_{site} = WS_{stat} * \frac{\alpha_w \left(\frac{H_w}{10} \right)^{\gamma_w}}{\alpha_t \left(\frac{H_t}{10} \right)^{\gamma_t}} \tag{1}$$

where:

WS_{site} = wind speed at building site (m/s)
WS_{stat} = wind speed at weather station (m/s)
H_w = height of wind at building site (m)
H_t = height of tower at weather station (m)
α_w = terrain coefficient for building site (see Table 1)
α_t = terrain coefficient for weather station (see Table 1)
γ_w = terrain exponent of building site (see Table 1)
γ_t = terrain exponent of weather station (see Table 1)

In this work, we converted the weather station wind speed to a height of 3 meters in a suburban area. The wind direction was unchanged from the measured value. This represents

Table 1.
Terrain Parameters for Standard Terrain Classes[7]

Class	γ	α	Description of Terrain
I	0.10	1.30	Ocean or other body of water with at least 5 km of unrestricted expanse.
II	0.15	1.00	Flat terrain with some isolated obstacles.
III	0.20	0.85	Suburban areas with low buildings, trees, or other scattered obstacles.
IV	0.25	0.67	Urban, industrial, forest or other built-up area.
V	0.35	0.47	Center of large city or other heavily built-up area.

the available wind speed and direction for ventilation cooling of most single family houses. Local obstructions (e.g. large, nearby buildings, trees or hills) might reduce the wind speed or alter the direction and should be accounted for in the actual building design.

Mathematical Modelling of Human Comfort

To be acceptable to its occupants, a built environment must provide thermal comfort. Achieving thermal comfort depends on both environmental and personal factors, some subject to the occupants' control, and others not. The important environmental determinants of thermal comfort are temperature, humidity, radiation and air movement, while important personal factors are clothing and activity level.

Because thermal comfort and discomfort are subjective sensations, it is difficult to predict the effects of any combination of environmental and personal factors. However, sensations of comfort or discomfort correlate with physiological quantities which can be measured or calculated (e.g. skin temperature, body core temperature, rates of sweating and breathing, etc). Thousands of test subjects have reported their thermal sensations in controlled environments, using the thermal sensation scale found in Table 2. These reports have been compared with physiological measurements, and from these data, researchers have been able to develop mathematical models and computer algorithms to predict the response of a person to a given thermal environment, taking into account that person's clothing and activity level.

Table 2. Thermal Sensation Scale[8]	
Numerical Code	Sensation
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Three of the most widely used comfort algorithms are the Fanger Comfort Model, developed by P.O. Fanger of the Technical University of Denmark,[8] the Pierce Two Node Model, developed by A.P. Gagge and colleagues at the J.B. Pierce Foundation,[9] and the KSU Two Node Model, developed by N.Z. Azer and colleagues at Kansas State University.[10] A comparison of the three algorithms is given by Berglund.[11] For the work which led to this paper, we used a modified version of the Pierce Two Node Model.

Humans regulate their heat exchange with the environment in order to maintain, within a very close tolerance, the temperature of their body core. The Pierce model describes this heat exchange process by modelling the human body as two discrete compartments: an inner core and an outer skin (see Figure 4). The core, which is assumed to be of uniform temperature, is modelled as the source of all metabolic heat production. To maintain a constant core temperature, all of the metabolic heat and work must be transferred to the surroundings. In the model, the core transfers energy directly to the environment through respiration and work. The remaining metabolic heat is transferred

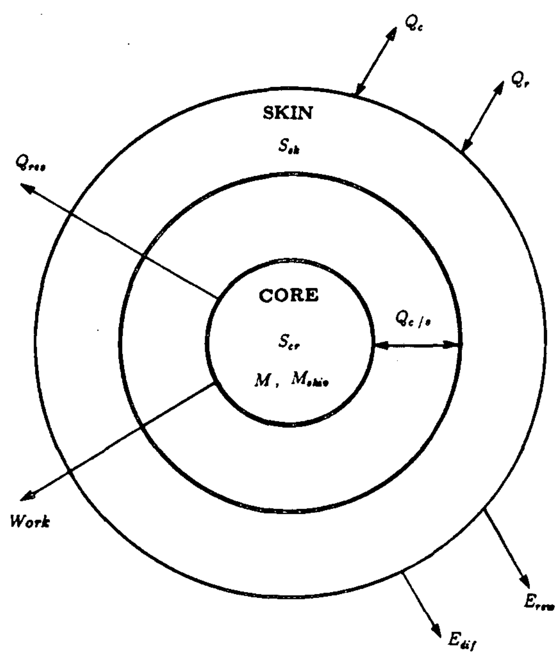

Figure 4: Pierce Two Compartment Physiological Heat Exchange Model.

to the skin compartment, both passively by conduction and actively by the controlled flow of blood from the core to the skin. The skin gives off heat to the environment through convection, radiation, evaporation of sweat and diffusion of water vapor through the skin. The Pierce model describes this process with two coupled heat balance equations:

$$S_{cr} = M + M_{shiv} - W - Q_{res} - Q_{c/s} \tag{2}$$

$$S_{sk} = Q_{c/s} - Q_c - Q_r - E_{rsw} - E_{dif} \tag{3}$$

where:

S_{cr} = heat storage in the core (W/m^2);
S_{sk} = heat storage in the skin (W/m^2);
M = metabolic heat from oxidation processes (W/m^2);
M_{shiv} = metabolic heat from shivering (W/m^2);
W = work done by the body on its surroundings (W/m^2);
Q_{res} = heat loss from respiration (W/m^2);
$Q_{c/s}$ = heat transfer between the core and the skin (W/m^2);
Q_c = convective heat transfer (W/m^2);
Q_r = radiative heat transfer (W/m^2);
E_{rsw} = heat loss from evaporation of sweat (W/m^2);
E_{dif} = heat loss from water vapor diffusion (W/m^2).

At a given increment of time, the model calculates the above physiological factors as well as the rate of change of the skin and core temperatures. The model then numerically integrates the temperature differentials to find the skin and core temperatures for the next time step. Thus, the model seeks dynamically to adjust skin and core temperatures for the prevailing conditions.

From the values of physiological variables calculated in the model, the discomfort index can be determined. In the version of the Pierce model that we used, the discomfort index, DISC, is calculated by:

$$DISC = 5.0 * \frac{\frac{(0.68 * E_{rsw}) + E_{dif}}{E_{max}} - P_{wet}}{1.0 - P_{wet}} \tag{4}$$

where:

E_{max} = maximum rate of evaporation of sweat (W/m^2),
= $(P_{sk} - P_a)/(1/h_{cl} + 1/(16.5h_c))$;
P_{sk} = saturation vapor pressure at skin temperature (kPa);
P_a = partial vapor pressure at air temperature (kPa);
h_{cl} = moisture conductance of clothing (W/m^2kPa),
= $115 / I_{clo}$;
I_{clo} = thermal resistance of clothing (clo);
h_c = convective heat transfer coefficient (W/m^2K),
= $8.6 * V^{0.56}$;
V = air velocity (m/s);
P_{wet} = fraction of skin wettedness (dimensionless),
= 0.08 * ACT / 58.2 - 0.02;
ACT = metabolic heat from activity (W/m^2).

Each of the environmental determinants of thermal comfort has some influence on the discomfort index. In our work, we assumed that the mean radiant temperature of the building was equal to the dry bulb temperature, which is often the case for light weight residential construction. We also assumed the occupants are not directly exposed to solar radiation. Therefore, the influence of radiation in the model was negligible. We tested the sensitivity of the model to temperature, humidity, air movement, activity level and clothing.

Figure 5 shows the discomfort index (DISC) as a function of dry bulb temperature, relative humidity and wind speed. The rate of increase in DISC with temperature is significantly higher at 80% RH than at 20% RH. Likewise, the impact of wind speed on comfort is greater at higher humidity and temperature levels. Thus, a combination of increasing temperature and humidity affects comfort more than either parameter alone and the use of wind to provide occupant comfort is more significant in hot-humid cli-

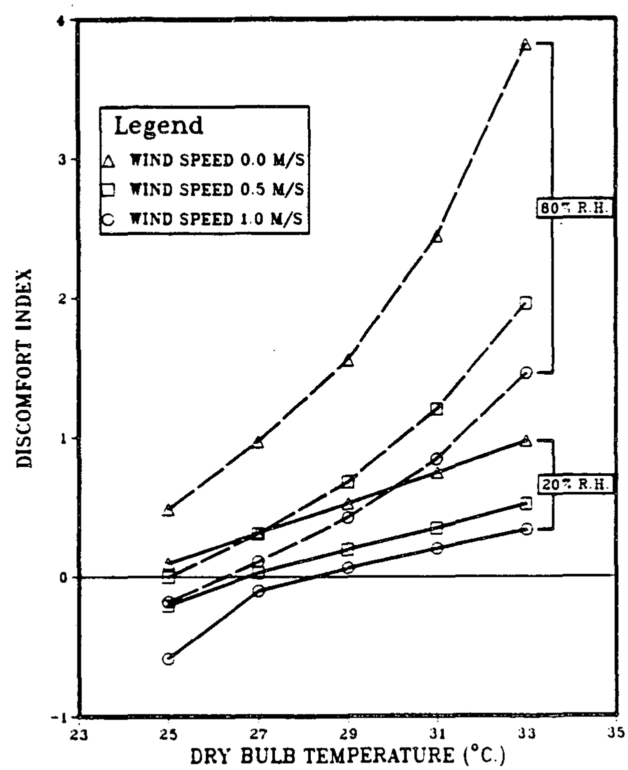

Figure 5: Discomfort as a Function of Temperature, Windspeed and Relative Humidity.

mates than in hot-arid climates.

In Figure 6, DISC is shown as a function of dry bulb temperature, activity level and clothing (0.3 clo = very light clothing, 1.0 clo = a wool business suit). Increasing the activity level increases metabolic heat production, and thus, at high ambient temperatures, increases thermal discomfort. The rate of increase of discomfort with activity level is greater when the clo value is greater, because clothing acts as an impedance to heat dissipation.

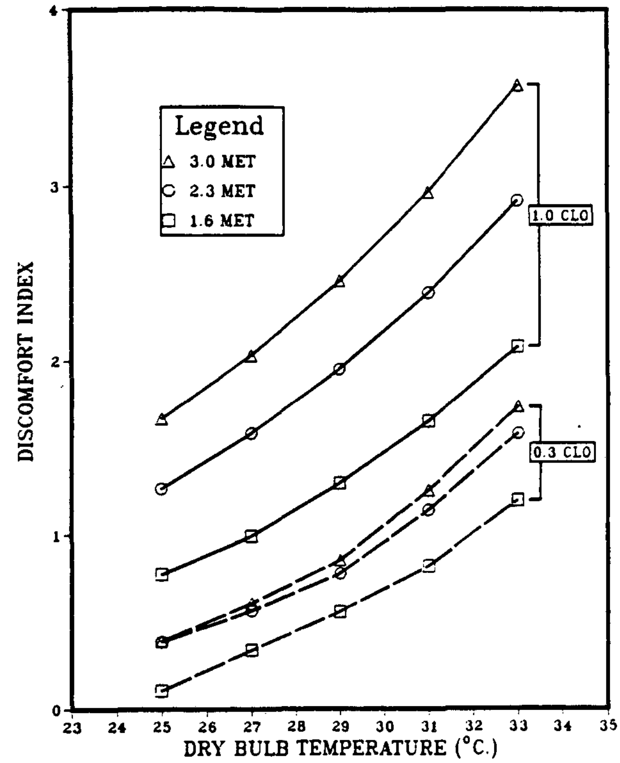

Figure 6: Discomfort as a Function of Temperature, Activity Level and Clothing.

In our work, we assumed a clo value of 0.5, corresponding to light clothing suitable for office or home in a warm climate. We set the activity level at 1.1 met, representing a person working at a desk, reading or watching television.[12] Further, we set the maximum acceptable interior wind speed to 1.0 m/s, since any wind above that speed is likely to cause papers to rustle and may be irritating to occupants. We set the discomfort index at which a person is likely to turn on an air conditioner to 0.5.

Estimating Building Cooling Load

A reliable indicator for building cooling loads should recognize latent as well as sensible cooling loads. Data from a LBL data base of DOE-2.1A loads for a typical 1-story residential prototype in 45 U.S. locations showed latent percentages varying from 5% for an uninsulated house in arid Phoenix to 35% for a moderately well-insulated house in Miami. Therefore, climate parameters based only on temperature differences, such as cooling degree days or degree hours, can be substantially in error for estimating cooling loads. This is confirmed in comparisons made between the cooling loads and degree hour data for the same locations. Although cooling degree hours correlated reasonably well to sensible cooling loads, there is more scatter from the regression line when applied to total cooling loads (see Figures 7 and 8).

To incorporate the effects of latent cooling, we used the concept of cooling enthalpy hours. Enthalpy hours are given in (kJ-h/kg of dry air) and define the amount of energy that must be removed from the air each hour to lower ambient air conditions to a reference condition defined by dry bulb temperature *as well as* humidity ratio. Cooling enthalpy hours can be further divided into sensible and latent components. The sensible component is proportional to cooling degree days and is useful for estimating sensible loads using standard UAΔT calculations. The latent component can be related to latent cooling loads for a given infiltration rate.

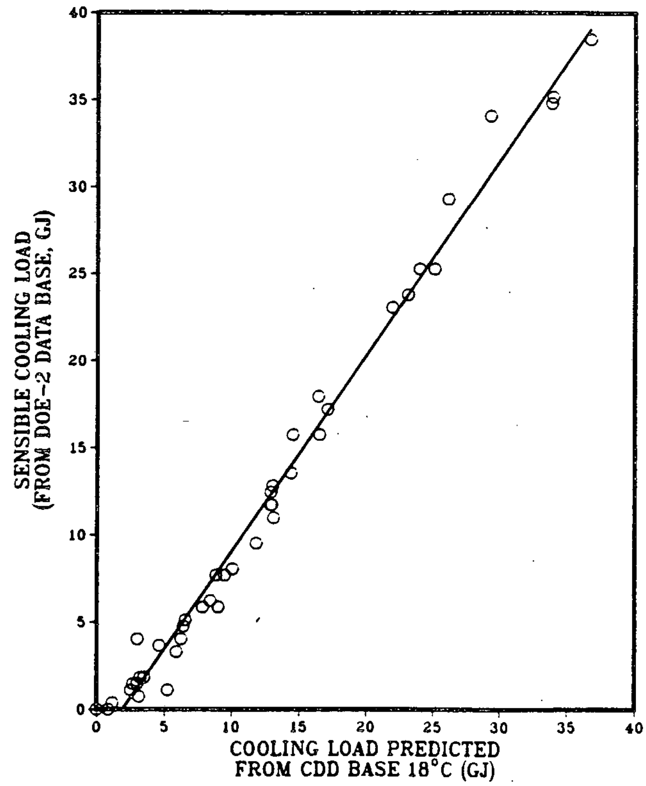

Figure 7: Degree Days Vs. Sensible Cooling Load for 45 Locations.

On a psychometric chart, cooling enthalpy appears as the difference in enthalpy between the ambient air condition and the reference point (see Figure 9). Latent enthalpy is the enthalpy reduction necessary to lower humidity ratios to the reference level, keeping the dry bulb temperature fixed. Sensible enthalpy is the additional enthalpy reduction necessary to

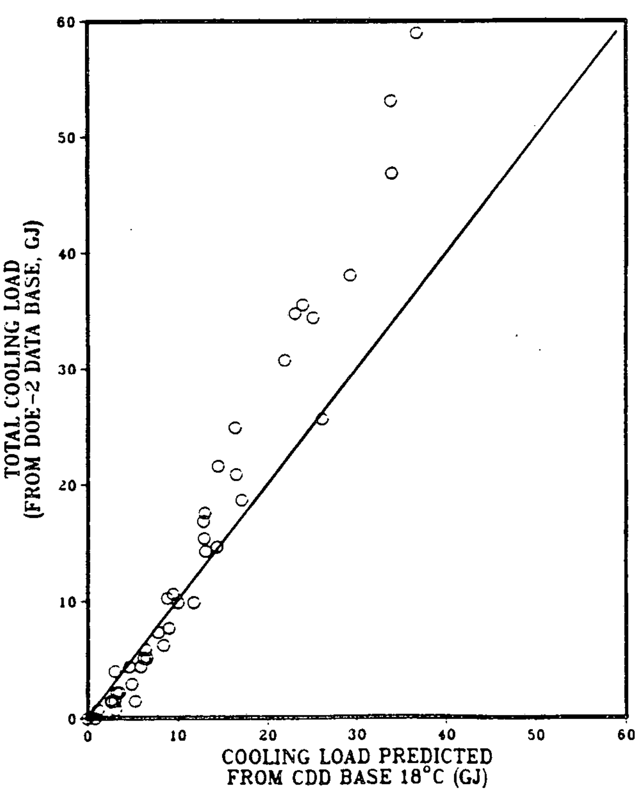

Figure 8: Degree Days Vs. Total Cooling Load for 45 Locations.

lower the dry bulb temperature to the base temperature, keeping the humidity ratio constant. Therefore, latent enthalpy corresponds to a vertical movement, and sensible enthalpy to a horizontal movement on the psychometric chart. The total change in enthalpy times the number of hours that condition exists equals the number of enthalpy hours.

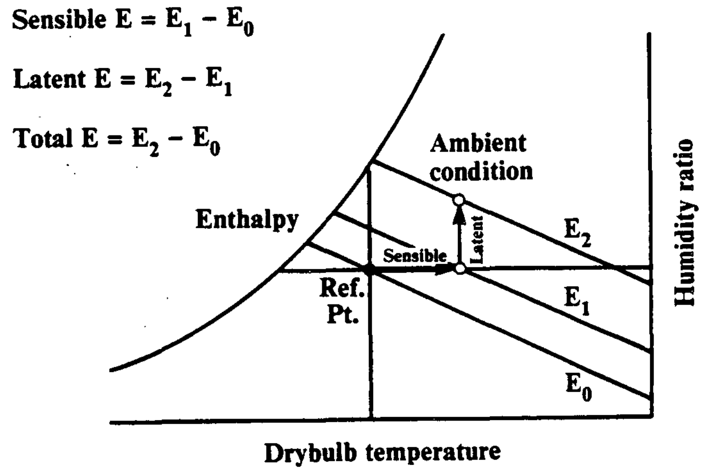

Figure 9: Psychrometric Chart.

The reference dry bulb temperature for calculating enthalpy hours is interpreted, similar to cooling degree days, as the balance point or threshold ambient temperature above which mechanical cooling will be required to maintain the indoor temperature specified by the thermostat set point. Because of solar gain, we used reference temperatures of 18 °C for the daytime, and 24 °C for the nighttime hours. We calculated the balance point temperatures assuming a typical 143 m^2 prototype house with 0.30 $W/m^2 \,^\circ C$ ceilings, 0.52 $W/m^2 \,^\circ C$ walls, and 0.5 ach infiltration. More details on the prototype house and operating conditions as well as the LBL data base are given by Huang.[13]

Thus:

$$T_{bp} = T_{set} - \frac{Q_{sun} + Q_{int}}{K} \tag{5}$$

where:
T_{bp} = balance point temperature
T_{set} = thermostat setting of 25.6 °C
K = total house K-value (UA plus infiltration)
= 1350 kJ/h-°C
Q_{sun} = average hourly summertime solar heat gain
= 7507 kJ/h (daytime), 0 kJ/h (nighttime) †
Q_{int} = average hourly internal sensible heat gain
= 2477 kJ/h

†Average hourly insolation during July in Miami on 14.3 m^2 of equally distributed vertical windows.

Therefore:

Daytime -- $T_{bp} = 25.6 - (7507 + 2477) / 1350$
$\simeq 18\,^{\circ}C$

Nighttime -- $T_{bp} = 25.6 - 2477 / 1350$
$\simeq 24\,^{\circ}C$

The reference humidity ratio is more difficult to define, since cooling controls in residential systems generally respond only to indoor temperatures and not to humidity. For this study, we chose a humidity ratio of 0.0116 (kg of moisture / kg of dry air), corresponding to the upper limit of the human comfort zone.[12] This humidity ratio is chosen on the assumption that a properly sized air conditioner will maintain indoor comfort by keeping the humidity ratio below this level. As shown in Figure 10, latent loads from the LBL residential data base correlate well with latent enthalpy hours at 0.0116 base humidity ratio.

We imposed two conditions on the calculations: (1) latent enthalpy hours are not counted when sensible enthalpy hours are nonpositive; and (2) negative latent enthalpy hours are set to zero. The first condition assumes that the air conditioner will be off because the ambient air is cool, even though it has more enthalphy content than the reference point. The second condition assumes that typical residential cooling systems do not humidify even though ambient air conditions may be hot and dry.

The relationship of sensible and latent enthalpy hours to cooling loads for a particular house depends on its total conductance and infiltration rate. For this study, we assume an average summer infiltration rate of 0.5 ach (air changes/hour) for a prototype 1-story house with a volume of 348.9 m^3. The latent load (kJ) is estimated from latent enthalpy hours by:

$$Q_{lat} = HH_{lat} * V * \rho \qquad (6)$$

where:

HH_{lat} = latent enthalpy hours (kJ-h/kg dry air);
V = volumetric air change rate (348.9 m^3/h * 0.5);
ρ = density of air (1.2 kg/m^3);

or:

Q_{lat} $= HH_{lat} * 209$ kg/h.

The sensible load (kJ) is estimated from sensible enthalpy hours by:

$$Q_{sen} = (HH_{sen} * V * \rho) + (HH_{sen} * UA) \quad (7)$$

where:

HH_{sen} = sensible enthalpy hours (kJ-h/kg dry air);
V, ρ = same as for Q_{lat} above;
UA = building conductance,
= 1055 kJ/h-°C;

or:

Q_{sen} $= (HH_{sen} * 209) + (HH_{sen} * 1055)$
$= HH_{sen} * 1264$ kg/h.

The estimated total cooling load (kJ) is then:

$$Q_{total} = (HH_{lat} * 209) + (HH_{sen} * 1264) \quad (8)$$

To check the reliability of the above procedure for estimating total cooling loads, it was applied to the same LBL residential data base for 45 cities shown in Figure 7. As Figure 10 shows, we found a generally linear relationship.

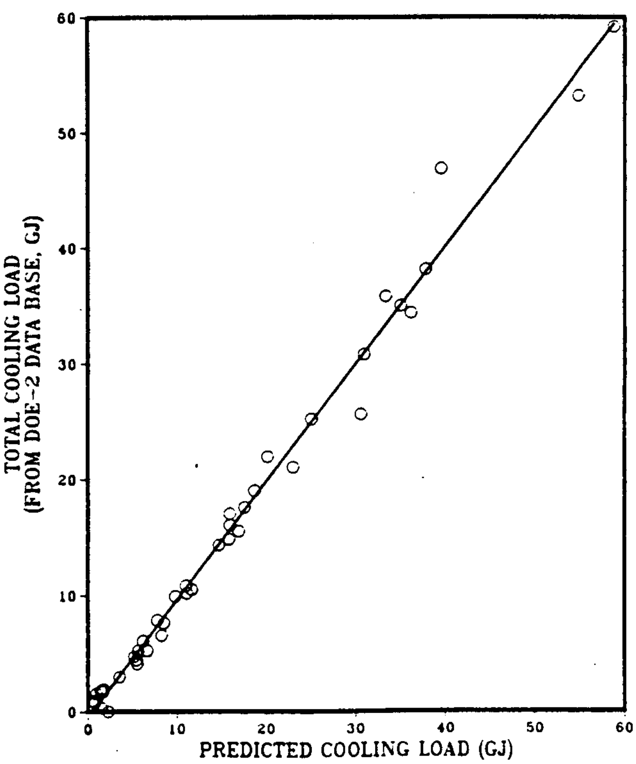

Figure 10: Latent Load Vs. Latent Enthalpy Hours for 45 Locations.

Program Logic

In order to display better the usefulness and limitations of this building design tool, we describe here the logic of the FORTRAN program used to generate the results. For each hour of the weather tape (8760 h/y * approx. 12 years), climate data (dry bulb temperature, dewpoint, barometric pressure, wind speed & wind direction) are read. The program then loops through the comfort model with the interior (perceived) wind speed varied from zero up to 100% of the outside (actual) wind speed -- with the maximum interior speed held at 1.0 m/s. For each wind speed, the comfort level is calculated. If it exceeds 0.5, the sensible and latent enthalpy hours are calculated (base 24°C if nighttime, base 18°C if daytime) and then binned by wind direction and percent of the outside wind speed. The program then advances to the next hour on the tape and repeats the above process. Upon reaching the end of the weather data, the sensible and latent enthalpy hours are used to calculate building cooling load, which is plotted versus wind direction and fraction of outside wind speed (Figures 11-16). Various checks are built into the program to handle missing or inaccurate weather data.

Application

The primary usefulness of the resulting plot of building cooling load vs. wind speed and direction is in the ability of a designer to assess quickly the potential benefit of ventilation cooling and the impact that it will have on orientation of a single building or an entire subdivision. This can be accomplished early in the design process to ensure that subsequent design decisions do not conflict with the ventilation scheme.

Figures 11 through 16 show plots for six cities representing a variety of climate zones. The center of each plot represents zero cooling load and the outer most circle is the maximum cooling load (shown as Q_{max}) while the wind is blowing in any single direction. Thus, the scale on each plot varies so that the resolution can be kept as large as possible. The contour lines represent the building cooling load at various percentages of the outside wind speed. The outermost (solid) contour line is for the case of no ventilation; the next (dashed) contour line inward is the cooling load with 20% of the outside wind speed available for ventilation. Contour lines alternate between solid and dashed lines and are plotted for 0%, 20%, 40%, 60%, and 100% of the outside wind speed. In addition to the cooling load while the wind is blowing, there is a load during periods of no wind (shown as Q_{nwd}) that should be accounted for in any annual energy calculations.

As shown in Figure 16, a building designed for Miami should have ventilation openings oriented to receive wind from the southeast, while a building in Albuquerque (Figure 11) should be oriented to receive wind from the southwest. Further, the plots show that large reductions in cooling load can be achieved in Miami at ventilation rates up to 60% of the outside wind speed, while in Albuquerque substantial reductions occur at 20% of the outside wind speed but further increases in the ventilation rate are relatively less effective.

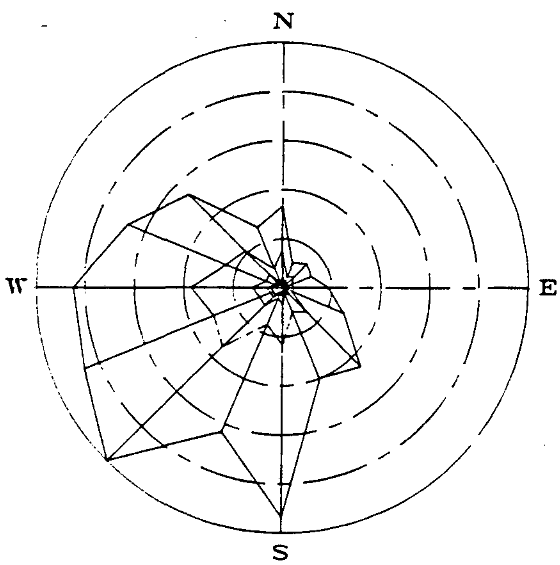

Figure 11: ALBUQUERQUE
$Q_{max} = 1.6$ **MJ/yr** $Q_{nwd} = 0.23$ **MJ/yr**

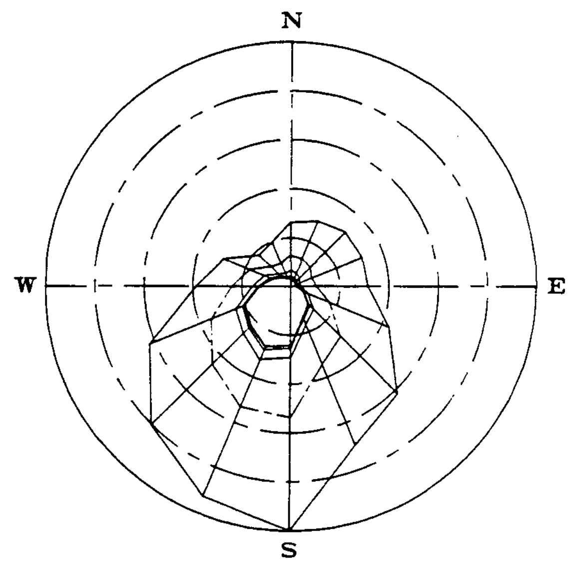

Figure 12: CHARLESTON
$Q_{max} = 3.2$ **MJ/yr** $Q_{nwd} = 0.50$ **MJ/yr**

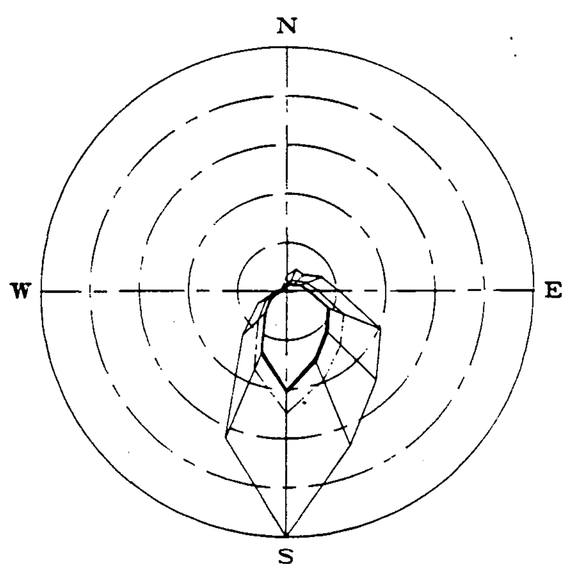

Figure 13: FORT WORTH
$Q_{max} = 8.4$ **MJ/yr** $Q_{nwd} = 0.26$ **MJ/yr**

In climates with high sensible heat gain (Fort Worth, Figure 13), it can be seen that there is a significant cooling load that can not be eliminated regardless of the ventilation rate; while in other locations (Lake Charles, Figure 15) there is a substantial cooling load at times when there is no available wind to decrease the discomfort level.

Certain plots (Fort Worth, Figure 13 and Fresno, Figure 14) show a highly directional ventilation requirement, indicating that the building or subdivision should be oriented within close tolerences. However, other cities (Albuquerque, Figure 11 and Charleston, Figure 12) show a need for ventilation from a much larger directional angle so ventilation devices should be designed to work effectively with wind blowing from several directions.

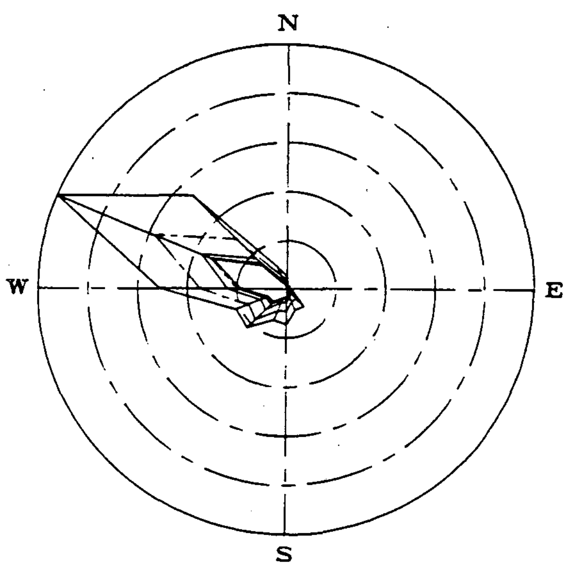

Figure 14: FRESNO
$Q_{max} = 6.3$ **MJ/yr** $Q_{nwd} = 0.23$ **MJ/yr**

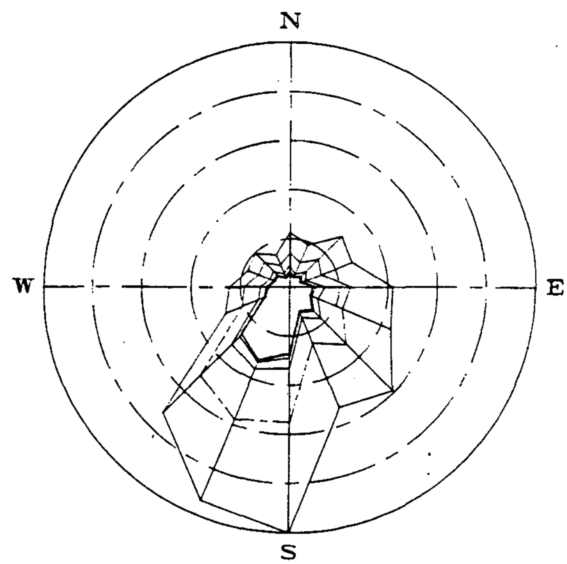

Figure 15: LAKE CHARLES
$Q_{max} = 4.9$ **MJ/yr** $Q_{nwd} = 2.65$ **MJ/yr**

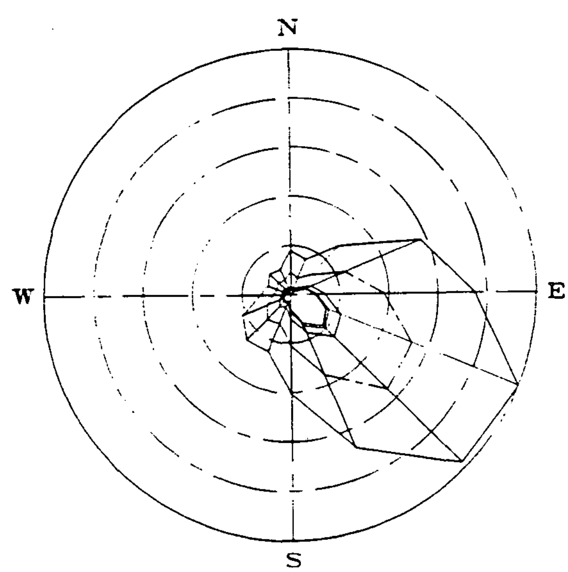

Figure 16: MIAMI
$Q_{max} = 8.0$ **MJ/yr** $Q_{nwd} = 0.90$ **MJ/yr**

By comparing the previously available wind roses with these plots of cooling load, it is possible to compare building designs based on prevailing wind only versus designs based on actual cooling load reduction. For Miami (Figures 3 and 16), the resulting building may be very similar. However, in Albuquerque (Figures 1 and 11), the orientation may be 90° different, which will have a substantial impact on the actual ventilation rate and resulting cooling load.

It is important to note that these plots account only for the impact of ventilation on cooling load and a building designed for minimal energy consumption should also account for the effects of solar gain. It may be necessary to design ventilation openings that are well shaded from direct solar radiation in order to prevent the additional solar gain from offsetting the benefits of ventilation.

In this paper, we do not propose the means by which any particular ventilation rate can be induced in a building. Numerous researchers have dealt with this problem, and an extensive literature exists on the subject of natural ventilation.[14] Architects and contractors can consult this literature to find methods to ventilate buildings, and from their experience, estimate the construction costs of various ventilation strategies.

Our work can help a designer or contractor to decide what additional construction costs will be economically justified. Figure 17 shows total cooling load, as a function of interior wind speed, for several cities. Cooling loads can be converted to cooling costs, using local energy prices and seasonal equipment efficiencies. An architect or builder then knows how much savings to expect from various ventilation rates, and can compare these savings to the estimated

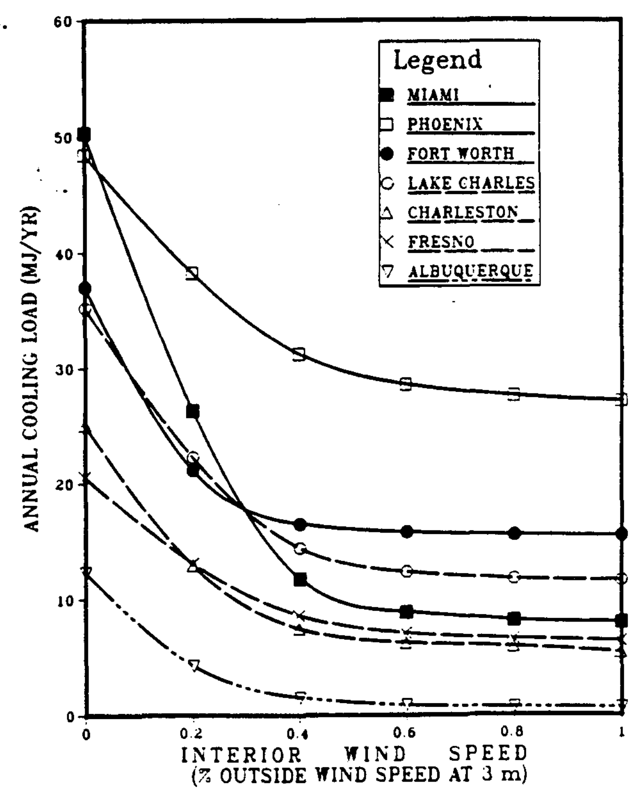

Figure 17: Annual Cooling Load as a Function of Interior Wind Speed.

costs of achieving those ventilation rates. Life cycle cost analysis then can be used to determine how much added expense is justified by cooling energy savings.

References

1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Climates of the United States,* Ashville, North Carolina, 1980.

2. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Local Climatological Data: Annual Summaries for 1981,* Ashville, North Carolina, 1981.

3. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *SOLMET Volume 1: User's Manual,* Ashville, North Carolina, 1978.

4. Hall, I.J., "Generation of Typical Meterological Years for 26 SOLMET Stations," *ASHRAE Transactions,* 1979, v.85, part 2.

5. "Test Reference Year (TRY) Final Report," Rational Use of Energy Pilot Study, North Atlantic Treaty Organization, Report #NATO/CCMS-60, 1977.

6. Crow, L.W., "Development of Hourly Data for Weather Year for Energy Calculations (WYEC)," *ASHRAE Journal,* October, 1981.

7. Sherman, M.H. and D.T. Grimsrud, *Measurement of Infiltration Using Fan Pressurization and Weather Data,* Lawrence Berkeley Laboratory Report #LBL-10852, Berkeley, California, 1980.

8. Fanger, P.O., *Thermal Comfort: Analysis and Applications in Environmental Engineering,* Danish Technical Press, Copenhagen, Denmark 1970.

9. Gagge, A.P., J. Stolwijk and Y. Nishi, "An Effective Temperature Scale Based on a Simple Model of Human Physiological Regulatory Response," *ASHRAE Transactions,* 1971, v.77, part 2.

10. Azer, N.Z. and S. Hsu, "The Prediction of Thermal Sensation from a Simple Model of the Physiological Regulatory Response," *ASHRAE Transactions,* 1977, v.83, part 1.

11. Berglund, Larry, "Mathematical Models for Predicting the Thermal Response of Building Occupants," *ASHRAE Transactions,* 1978, v.84, part 1.

12. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, *ASHRAE Handbook: Fundamentals,* Atlanta, Georgia, 1985.

13. Huang, Y. J., et. al., *Affordable Housing through Energy Conservation, Technical Support* Document, Lawrence Berkeley Laboratory Report LBL-16342, Berkeley, California, 1985.

14. Bowen, A., et. al., *Passive Cooling by Natural Ventilation, World Literature Review and Annotated Bibliography,* Florida Solar Energy Center, Cape Canaveral, Florida, 1981.

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