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D.M. Foley

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The Impact of Wind Induced Ventilation on Residential Cooling Load and Human Comfort

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ABSTRACT

This paper describes an analysis of long-term, hourly weather data in several climates to determine the conditions for which available wind speed and coincident temperature and humidity can be used to meet human 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 results are summarized in graphic formats, which allow a designer to determine (1) the effect of ventilation on human comfort, (2) the orientation of building openings that will maximize ventilative cooling of the building occupants, and (3) the potential cooling load reduction due to increasing the ventilation air speed in typical residential buildings. The analysis makes use of the Pierce Two Node Comfort Model (Gagge et al. 1971) and a data base of residential cooling loads (Huang et al. 1986) developed with the DOE-2 building energy simulation program (BESG 1985).

INTRODUCTION

In hot climates, wind induced ventilation of buildings can be a significant means of increasing occupant comfort and reducing cooling energy consumption. Ongoing research by these authors is intended to quantify the magnitude of the potential energy savings and how buildings might be better designed to realize that potential. This paper describes the first phase of that project -- the development of simple graphic tools that enable a building designer to evaluate the potential for wind induced ventilation cooling in several climate zones.

We first analyzed long-term, hourly weather data in several climates to determine the conditions for which available wind speed can be used to meet human comfort conditions. Then, 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 results are summarized in graphic formats, which allow a designer to determine:

1) the human comfort level when the interior air speed is held to various fractions of the available exterior wind speed at the building site,
2) the direction from which the wind is blowing when mechanical cooling is required to maintain comfort and
3) the building cooling load for those ambient conditions that are uncomfortable as well as the potential reduction in the cooling load due to increasing the ventilation air speed.

Thus, the results indicate the potential savings from inducing various building airflow 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 taken into account. Because local weather patterns are common and instantaneous conditions are seldom constant at monthly (or annual) average conditions, this hourly analysis is necessary to accurately determine the level of human comfort and the resulting building cooling load.

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WEATHER DATA

In order to properly size and orient building openings to take advantage of ventilative cooling, a designer must be aware of the direction and speed of local wind, as well as coincident ambient dry-bulb temperature and relative humidity, so that the human comfort level can be determined. 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 (NOAA 1980) of conditions at local weather stations. Although this information has traditionally been used as an indication of average local wind conditions, its usefulness in building design is limited. Wind rose plots (see examples in Figure 1) 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 (NOAA 1981), the designer is at best given a rough estimate that indicates little about the effect on human comfort and building cooling load.

Hourly weather data are available in a variety of formats and can be obtained for multiple, contiguous years (NOAA 1978) or for a single, average year (NATO 1977; Hall 1979; Crow 1981). For this analysis, we chose to analyze long-term (approximately 11 contiguous years) data for each location, because the methods for determining "average" years emphasize average temperature and solar radiation but not wind speed and direction. In 1965, weather station reporting frequency was changed from hourly to once every three hours at most locations. In addition, the method of recording wind direction was changed in 1964, so we used data prior to 1964 in order to make use of both hourly frequency and consistent recording methodology. Available weather tapes begin during mid 1952 and early 1953, thus yielding approximately 11 years of hourly data for each location. Our summarized results, therefore, represent average potential for wind-induced ventilative cooling and may not be exactly the same for any specific year.

Because this analysis is intended to show the benefit of ventilative 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, accounting for (1) the difference in height between the weather station anemometer and a typical building height and (2) the difference in terrain between the weather station and a typical residential building site (Sherman and Grimsrud 1980). In this work, we converted the weather station wind speed to a height of 9.8 ft (3 m) in a suburban area. The wind direction was unchanged from the measured value. This represents the available wind speed and direction for ventilative cooling of most single family houses. Local obstructions (e.g., large, nearby buildings, trees, or hills) might further reduce the wind speed or alter the direction and should be accounted for in the actual building design.

MATHEMATICAL MODELING OF HUMAN COMFORT

To be acceptable to its occupants, a building must provide thermal comfort. Achieving an acceptable level of comfort depends on both environmental and personal factors, some subject to the occupant's control, and others not. The important environmental determinants of thermal comfort are temperature, humidity, thermal 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 that can be measured or calculated (e.g., skin temperature, body core temperature, rates of sweating and breathing, etc). Reported thermal sensations from human test subjects 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.

Three of the most widely used comfort algorithms are the Fanger Comfort Model (Fanger 1970), the Pierce Two Node Model (Gagge et al. 1971), and the KSU Two Node Model (Azer and Hsu 1977). A comparison of the three algorithms is given by Berglund (1978). For the work that 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 close tolerance, the temperature of their body core. The Pierce model describes this heat exchange process by modeling the human body as two discrete compartments: an inner core and an outer skin. The core, which is assumed to be of uniform temperature, is modeled 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 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 and evaporation of sweat.

From the values of physiological variables calculated in the model, the index of discomfort (DISC) can be determined. A discomfort index of zero indicates occupant comfort. The greater the value of DISC, the warmer the occupants are likely to be; conversely, the more negative the value of DISC, the cooler the occupants are likely to feel. In the version of the Pierce model that we used, DISC is calculated by:

$$\mathrm{DISC} = 5.0 \cdot \frac{\dfrac{(0.68 \cdot E_{rsw}) + E_{dif}}{E_{max}} - P_{wet}}{1.0 - P_{wet}} \tag{1}$$

where:

E_{rsw} = rate of heat loss from evaporation of sweat, Btu/h·ft^2 (W/m^2)
E_{dif} = rate of heat loss from water vapor diffusion, Btu/h·ft^2 (W/m^2)
E_{max} = maximum rate of evaporation of sweat, Btu/h·ft^2 (W/m^2)
= $A_{cl}\, h_e\, (P_{cl} - P_a)$
A_{cl} = surface area of the clothed body, ft^2 (m^2)
h_e = evaporative heat transfer coefficient, Btu/h·ft^2·F (W/m^2·C)
P_{cl} = saturation vapor pressure at clothing temperature, lb/in^2 (kPa)
P_a = partial vapor pressure at air temperature, lb/in^2 (kPa)
P_{wet} = fraction of skin wettedness (dimensionless)

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 is equal to the dry-bulb temperature, which is often the case for lightweight residential construction. We also assumed the occupants are not directly exposed to solar radiation. Therefore, the influence of thermal radiation in the model was negligible. We tested the sensitivity of the model to other environmental and personal factors by analyzing a parametric series of simulations. Figures 2 and 3 show sample results.

Figure 2 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 air movement to provide occupant comfort is more significant in hot-humid climates than in hot-arid climates.

Figure 3 displays DISC 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.

In the remainder of our work, we assumed a clo value of 0.5, corresponding to light clothing suitable for office or home use in a warm climate. We set the activity level at 1.1 met, representing a person working at a desk, reading, or watching television (ASHRAE 1985). Further, in our analysis using actual weather data, we set the maximum acceptable interior air speed to 3.3 ft/s (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, which is the upper limit of the neutral comfort zone (Fanger 1970).

DETERMINING COMFORT FROM WEATHER DATA

After testing the Pierce Two-Node Model under hypothetical conditions, we modeled the human response to actual weather conditions in several locations. We modeled six possible interior ventilation rates, by using 0% to 100%, in increments of 20%, of the adjusted outside wind speed (see above). We used the Pierce algorithm to determine if each ventilation rate (and coincident temperature, humidity and barometric pressure) would provide comfort. We recorded the number of hours that were both comfortable (DISC $<$ 0.5) and uncomfortable (DISC $\geq$ 0.5) at each interior air speed, discarding all hours for which data were unrecorded.

Shown in Figures 4-7 is the fraction of time that cooling is required at each interior air speed as a function of month of the year for Charleston, Fort Worth, Miami and Phoenix. The figures also indicate the duration of the season for which mechanical cooling is required. In each figure, the 0% curve shows the extent to which comfort is obtained without any natural ventilation; therefore, the area between the 0% and 100% curves represents the full potential for natural ventilation to provide thermal comfort and reduce the need for mechanical air conditioning.

Introducing natural ventilation significantly increases the fraction of time that a person is comfortable. However, each successive increase in the interior air speed contributes less to occupant comfort than the previous increase. This conclusion agrees with the previous analysis (Figure 2) in which hypothetical conditions were assumed. In Figures 4-7,

there is a marked difference between the 0% and 20% curves, and another large increase between the 20% and 40% curves. The increase in comfort between the 40% and 60% curves varies among cities and, in each of the cities shown, increasing ventilation beyond 60% of the outside wind speed yields little additional benefit.

Ventilation not only increases the fraction of time that a person is comfortable, but also lengthens the season of the year during which virtually no air conditioning is required. For example, with no ventilation in Miami, air conditioning is required during a portion of every month of the year. At an interior air speed of 60% of the outside wind speed, air conditioning is required only between May and November. In each of the four cities, ventilation is unable to eliminate totally the need for air conditioning. However, in hot-humid climates, such as Charleston and Miami, the fraction of time for which ventilation provides comfort during the critical summer months is greater than in hot-dry climates, such as Phoenix. This also agrees with the trends shown in Figure 2.

ESTIMATING BUILDING COOLING LOAD

An accurate indicator of building cooling load should predict latent as well as sensible cooling load. Annual cooling loads from a data base of DOE-2 simulations for a typical one-story residential prototype in 45 U.S. locations (Huang et al. 1986) show that the latent cooling load fraction varies from 5% for an uninsulated house in arid Phoenix to 35% for a moderately insulated house in Miami. Therefore, climatic parameters based only on temperature difference, such as cooling degree-days or degree-hours, can be substantially in error when used for estimating building cooling load. This is confirmed in comparisons made between cooling load and degree-hour data for the same locations. Although cooling degree-hours correlate reasonably well with sensible cooling load, there is significant error when used to predict to total cooling load (see Figures 8 and 9).

To incorporate the effects of latent cooling, we used the concept of cooling enthalpy hours. Cooling enthalpy hours, consisting of both sensible and latent components, define the amount of energy that must be removed from the air each hour to lower the interior air to a reference condition defined by dry-bulb temperature *as well as* humidity ratio. The sensible component is proportional to cooling degree-days and is useful for estimating sensible cooling load using a standard UAΔT calculation. The latent component can be correlated to latent cooling load for a given infiltration rate and interior latent load generation.

On a psychrometric chart, cooling enthalpy appears as the difference in enthalpy between the ambient air condition and the reference point. The latent component is the enthalpy reduction necessary to lower the humidity ratio to the reference level, keeping the dry-bulb temperature fixed. The sensible component is the additional enthalpy reduction necessary to 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 a psychometric chart. The total difference in enthalpy times the number of hours that difference exists equals the number of cooling enthalpy hours.

The reference dry-bulb temperature for calculating cooling 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 interior temperature specified by the thermostat set point. To account for the effects of solar gain, we used a reference temperature of 65 F (18 C) for the daytime, and 75 F (24 C) for the nighttime hours. We calculated the balance point temperatures assuming a typical 1540 ft^2 (143 m^2) prototypical house with 0.05 Btu/h·ft^2·F (0.30 W/m^2·C) ceilings, 0.10 Btu/h·ft^2 (0.52 W/m^2·C) walls, and 0.5 ac/h infiltration. More details on the prototypical house and operating conditions as well as the data base that was used for the statistical analysis, are given by Huang et al. (1986). The balance point is determined by:

$$T_{bp} = T_{set} - \frac{Q_{sun} + Q_{int}}{K} \tag{2}$$

where:

T_{bp} = balance point temperature
T_{set} = thermostat setting 78 F (25.6 C)
K = total house K-value (UA plus infiltration),
= 711 Btu/h·F (375 W/C)
Q_{sun} = average hourly summertime solar heat gain,
= 7115 Btu/h (2084 W) daytime,†
= 0 Btu/h (0 W) nighttime
Q_{int} = average hourly internal sensible heat gain,
= 2348 Btu/h (688 W)

†Average hourly insolation during July in Miami on 1540 ft^2 (14.3 m^2) of equally distributed vertical windows.

therefore:

Daytime: $T_{bp} = 78 - [(7115 + 2348) / 711] \approx 65$ F
$= 25.6 - [(2084 + 688) / 375] \approx 18$ C

Nighttime: $T_{bp} = 78 - (2348 / 711) \approx 75$ F
$= 25.6 - (688 / 375) \approx 24$ C

The reference humidity ratio is more difficult to define, since cooling controls in residential systems generally respond only to interior temperature and not to humidity. For this study, we chose a humidity ratio of 0.0116 lb of moisture / lb of dry air (kg of moisture / kg of dry air), corresponding to the upper limit of the human comfort zone (ASHRAE 1985). This humidity ratio is chosen on the assumption that a properly sized air conditioner will maintain occupant comfort by keeping the humidity ratio below this level.

When calculating the number of cooling enthalpy hours from weather tapes for each location, we imposed two limiting conditions: (1) latent enthalpy hours were not counted when sensible enthalpy hours were nonpositive; and (2) negative latent enthalpy hours were 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 enthalpy content than the reference point. The second condition assumes that typical residential air conditioning systems do not humidify, even though the ambient air may be hot and dry.

The relationship of sensible and latent enthalpy hours to cooling load for a particular house depends on its total conductance and infiltration rate. For this study, we assumed an average summer infiltration rate of 0.5 ac/h for a prototypical one-story house with a volume of 12,320 ft^3 (349 m^3). The latent cooling load is estimated from latent enthalpy hours by:

$$Q_{lat} = HH_{lat} \cdot V \cdot \rho \tag{3}$$

where:

HH_{lat} = latent enthalpy hours, Btu·h/lb dry air (kJ·h/kg dry air)
V = volumetric air change rate, 0.5 ac/h · 12,320 ft^3 (349 m^3)
ρ = density of air, 0.075 lb/ft^3 (1.2 kg/m^3)

or:

$Q_{lat} = HH_{lat} \cdot 462$ lb/h (Btu)
$= HH_{lat} \cdot 209$ kg/h (kJ)

The sensible cooling load is estimated from sensible enthalpy hours by:

$$Q_{sen} = (HH_{sen} \cdot V \cdot \rho) + (HH_{sen} \cdot UA / \Delta h_a) \tag{4}$$

where:

HH_{sen} = sensible enthalpy hours, Btu·hr/lb dry air (kJ·h/kg dry air)
V, ρ = same as for Q_{lat} above
UA = building conductance, 556 Btu/h·F (1055 kJ/h·C)
Δh_a = change in specific enthalpy for dry air per degree, 0.239 Btu/lb·F (1.0 kJ/kg·C)

or:

$Q_{sen} = (HH_{sen} \cdot 462) + (HH_{sen} \cdot 2325) = HH_{sen} \cdot 2787$ lb/h (Btu)
$= (HH_{sen} \cdot 209) + (HH_{sen} \cdot 1055) = HH_{sen} \cdot 1264$kg/h (kJ)

The estimated total cooling load is then:

$$Q_{total} = (HH_{lat} \cdot 460) + (HH_{sen} \cdot 2787) \quad \text{(Btu)} \tag{5}$$
$$Q_{total} = (HH_{lat} \cdot 209) + (HH_{sen} \cdot 1264) \quad \text{(kJ)}$$

To check the reliability of the above procedure for estimating total building cooling load, we compared it to the same LBL residential data base for 45 cities shown in Figure 9. As Figure 10 shows, there is a high correlation between the predicted cooling load and the results of DOE-2 simulations. This simplified calculation technique enabled us to quickly estimate the total cooling load of a typical house for the extensive number of cases examined in the development of the cooling load wind roses.

DEVELOPMENT OF COOLING LOAD WIND ROSES

By using the Pierce Two Node Model, we were able to analyze long term weather data for several locations and determine the hours for which an acceptable comfort level could not be achieved with various interior air speeds. The assumed clothing and activity levels, interior air speeds, and maximum acceptable discomfort index were consistent with the analysis described above. For each hour that was uncomfortable, we calculated the sensible and latent cooling enthalpy hours and estimated the resulting cooling load. Figure 11 shows total cooling load, as a function of interior air speed, for several cities. It indicates the relative importance of ventilation (measured in reduction of annual cooling load) in different climates. A large cooling load savings can be achieved in Miami at ventilation rates up to 60% of the outside wind speed, while in Albuquerque a substantial reduction occurs at 20% of the outside wind speed, but further increases in the ventilation rate are relatively less effective. Increased air movement is shown to improve comfort more in hot-humid climates than in hot-arid climates.

We then binned the cooling load data corresponding to each wind speed according to the direction from which the wind was blowing when mechanical cooling was required. Figures 12 through 17 show plots of building cooling load as a function of wind speed and direction for six cities representing a variety of climatic zones. The center of each plot represents zero cooling load and the outermost circle is the maximum cooling load (shown as Q_{max}) while the wind is blowing from 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 contour line is for the case with no ventilation; the next contour line inward is the cooling load with 20% of the outside wind speed available for ventilation. The innermost contour line represents the cooling load with 100% of the outside wind speed used for ventilation. Therefore, the shaded area between the 0% and 100% contour lines indicates the total potential for increasing human comfort and consequently reducing cooling load by inducing natural ventilation. 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.

The primary usefulness of these plots is in the ability of a designer to assess quickly the potential benefit of ventilative cooling and the impact 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. As shown in Figure 17, a building designed for Miami should have ventilation openings oriented to receive wind from the southeast, while a building in Albuquerque (Figure 12) should be oriented to receive wind from the southwest. Certain plots (Fort Worth, Figure 14, and Fresno, Figure 15) show a highly directional ventilation requirement, indicating that the building or subdivision should be oriented within close tolerances. However, other cities (Albuquerque, Figure 12, and Charleston, Figure 13) 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. In climates with high sensible heat gain (Fort Worth, Figure 14), it can be seen that there is a significant cooling load that cannot be eliminated regardless of the ventilation rate; while in other locations (Lake Charles, Figure 16) there is a substantial cooling load (Q_{nwd}) at times when there is no available wind to reduce the level of discomfort.

By comparing the previously available wind roses with these plots of cooling load, it is possible to compare building designs based only on directional frequency and prevailing wind versus designs based on actual cooling load reduction. For Miami (Figures 1c and 17), the resulting building may be very similar. However, in Albuquerque (Figures 1a and 12), the orientation may be 90 degrees different, which will have a substantial impact on the actual building design and consequently on the ventilation rate and annual cooling load.

It is important to note that this analysis accounts only for the impact of ventilation on cooling load, and a building designed to conserve energy should also account for the effects of solar gain. In cooling dominated climates, it may be necessary to design ventilation openings that are well shaded from direct solar radiation in order to prevent the increased solar gain from offsetting the benefits of ventilation. Further, this analysis is based on the effect of ventilation on cooling the occupants of a building, rather than on structural cooling of the building itself. Nighttime cooling of massive buildings has been shown to be a useful strategy in hot-arid regions where the diurnal temperature range is large (Kammerud 1984). Finally, we do not propose here the means by which any particular ventilation rate can be induced in a building. Several researchers have dealt with this problem, and an extensive literature exists on the subject of natural ventilation (Bowen et al. 1981). Ongoing research by the authors is aimed at developing simplified design tools that will be able to determine the potential ventilation rate of various strategies and provide guidance to the designer of energy-efficient buildings.

ACKNOWLEDGMENTS

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Figures 1a-1c. Annual Wind Roses for Three Locations.

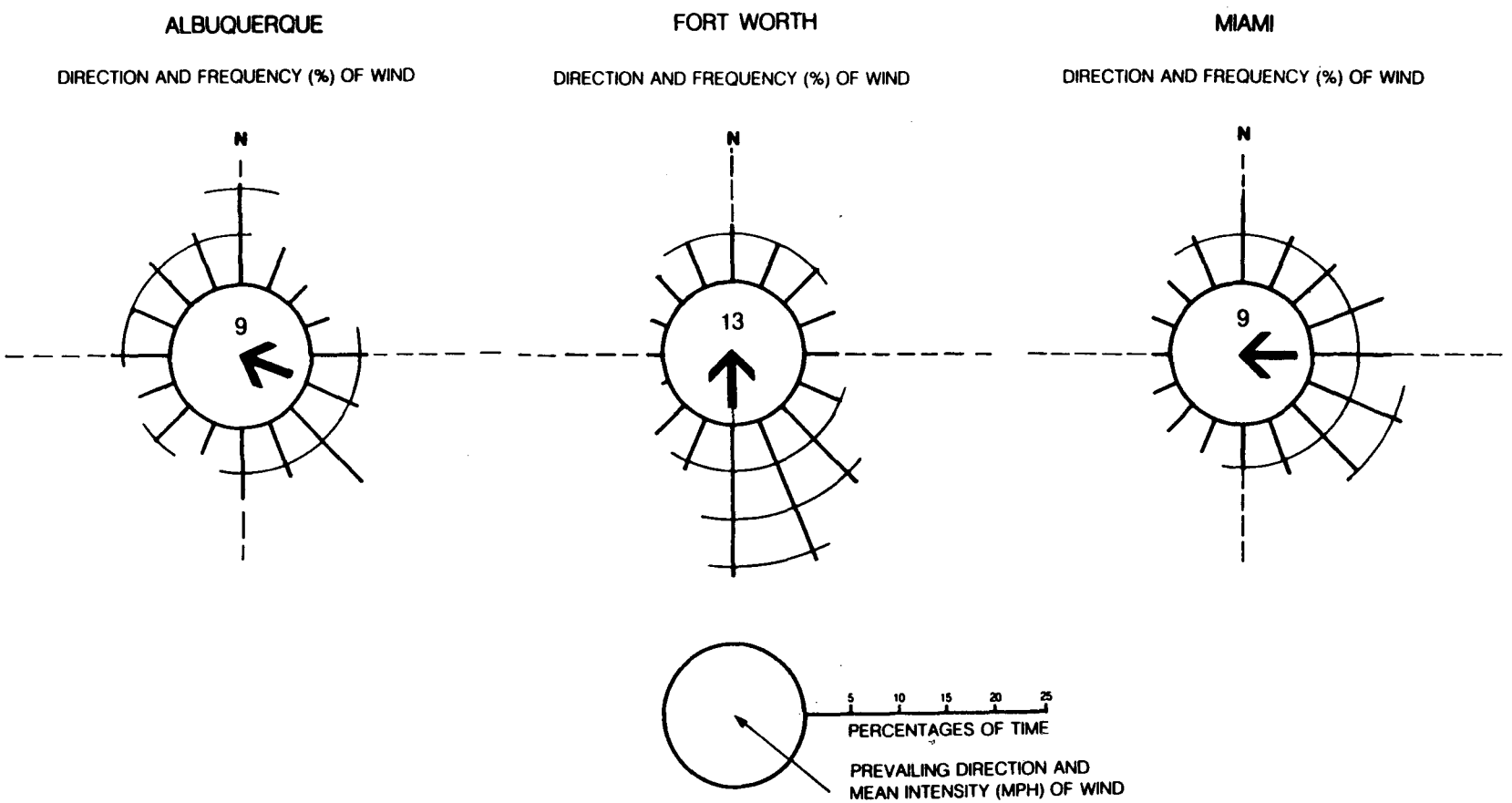


Figure 2. Discomfort Index as a Function of Dry Bulb Temperature and Relative Humidity for Three Wind Speeds (clo = 0.5, met = 1.1).

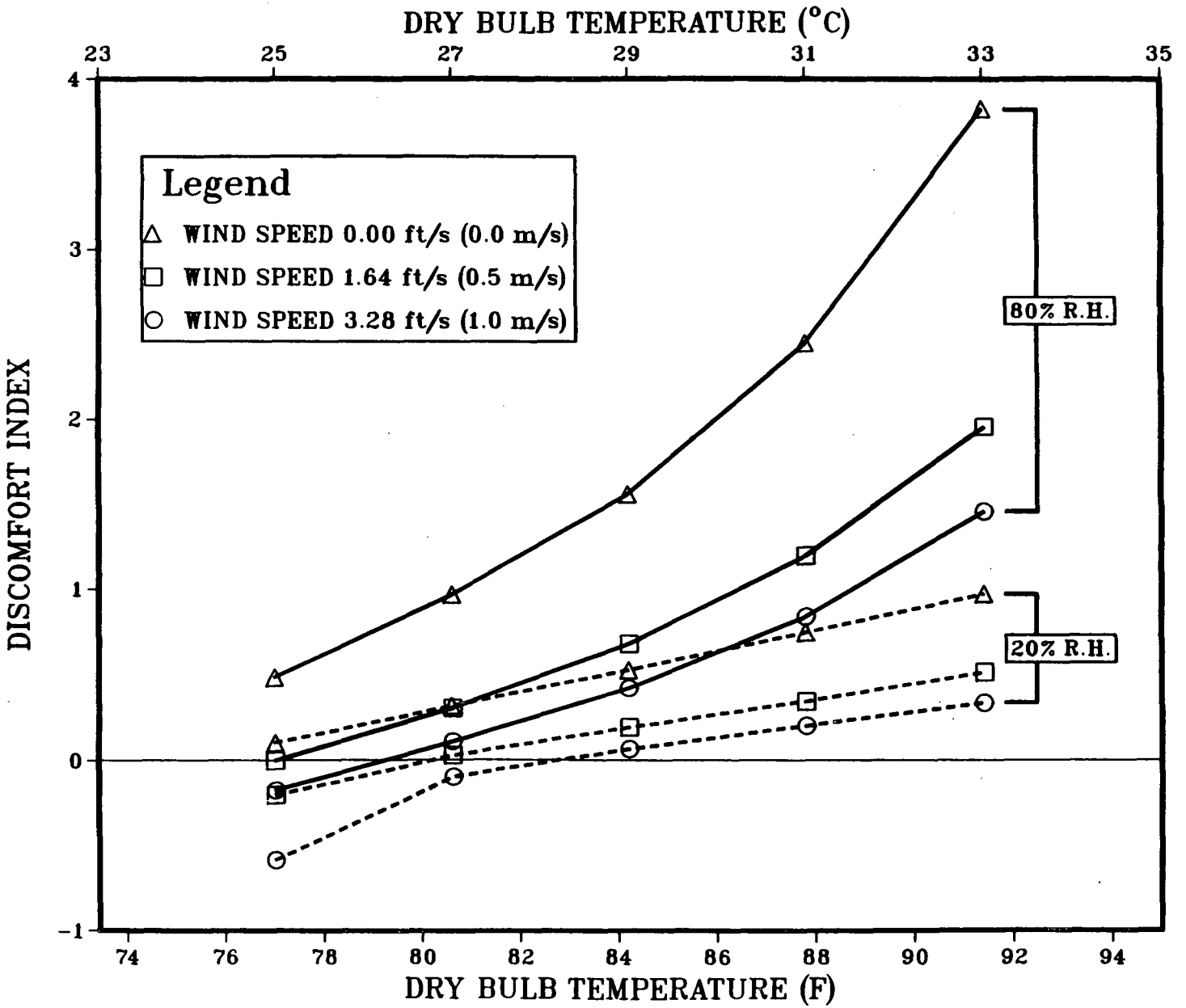


Figure 3. Discomfort Index as a Function of Dry Bulb Temperature and Clothing Level for Three Metabolic Rates (air speed = 0.2 m/s, R.H. = 50%).

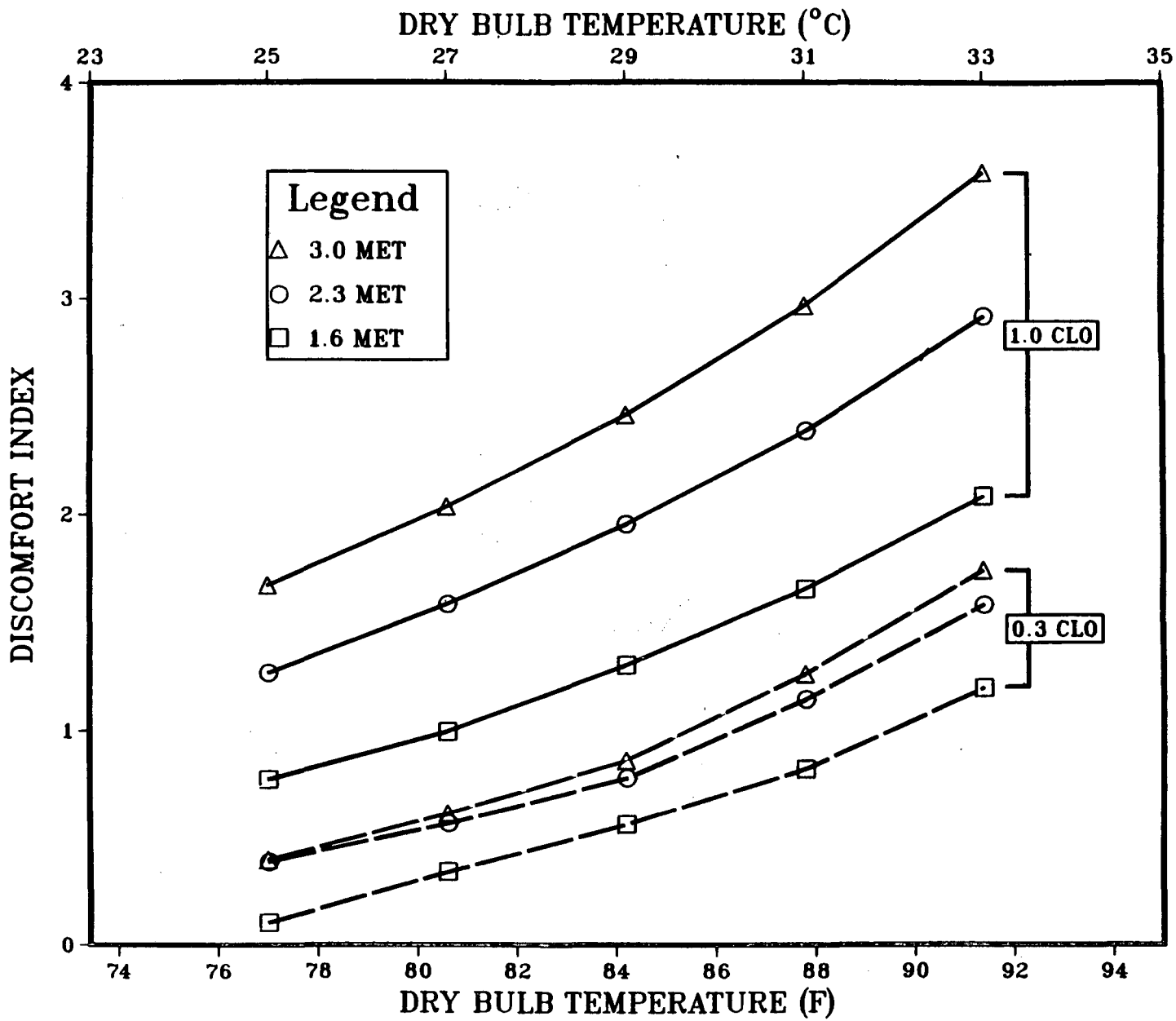


Figure 4. Fraction of Time Mechanical Cooling is Required to Provide Occupant Comfort at Various Ventilation Air Speeds: Charleston, SC.

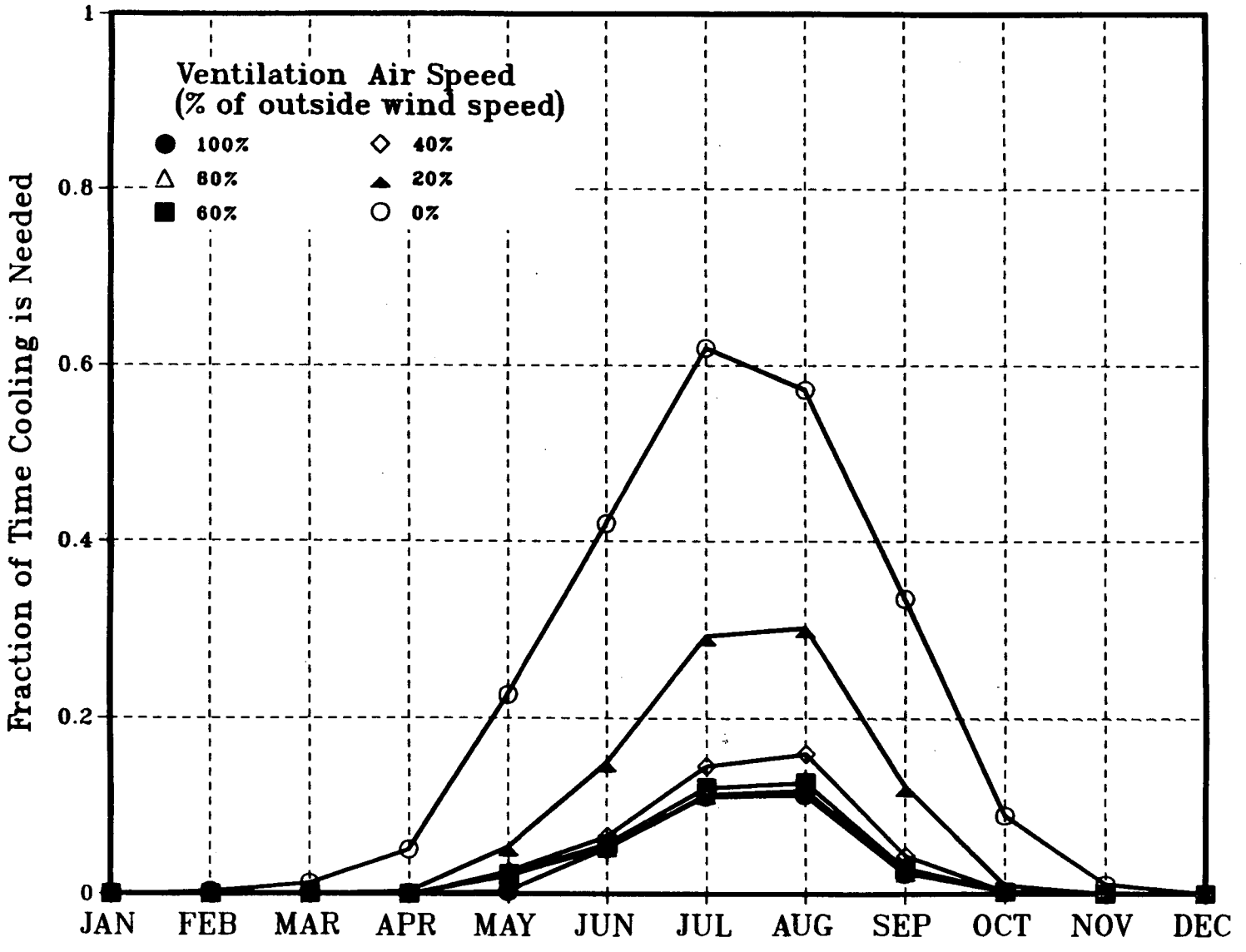


Figure 5. Fraction of Time Mechanical Cooling is Required to Provide Occupant Comfort at Various Ventilation Air Speeds: Fort Worth, TX.

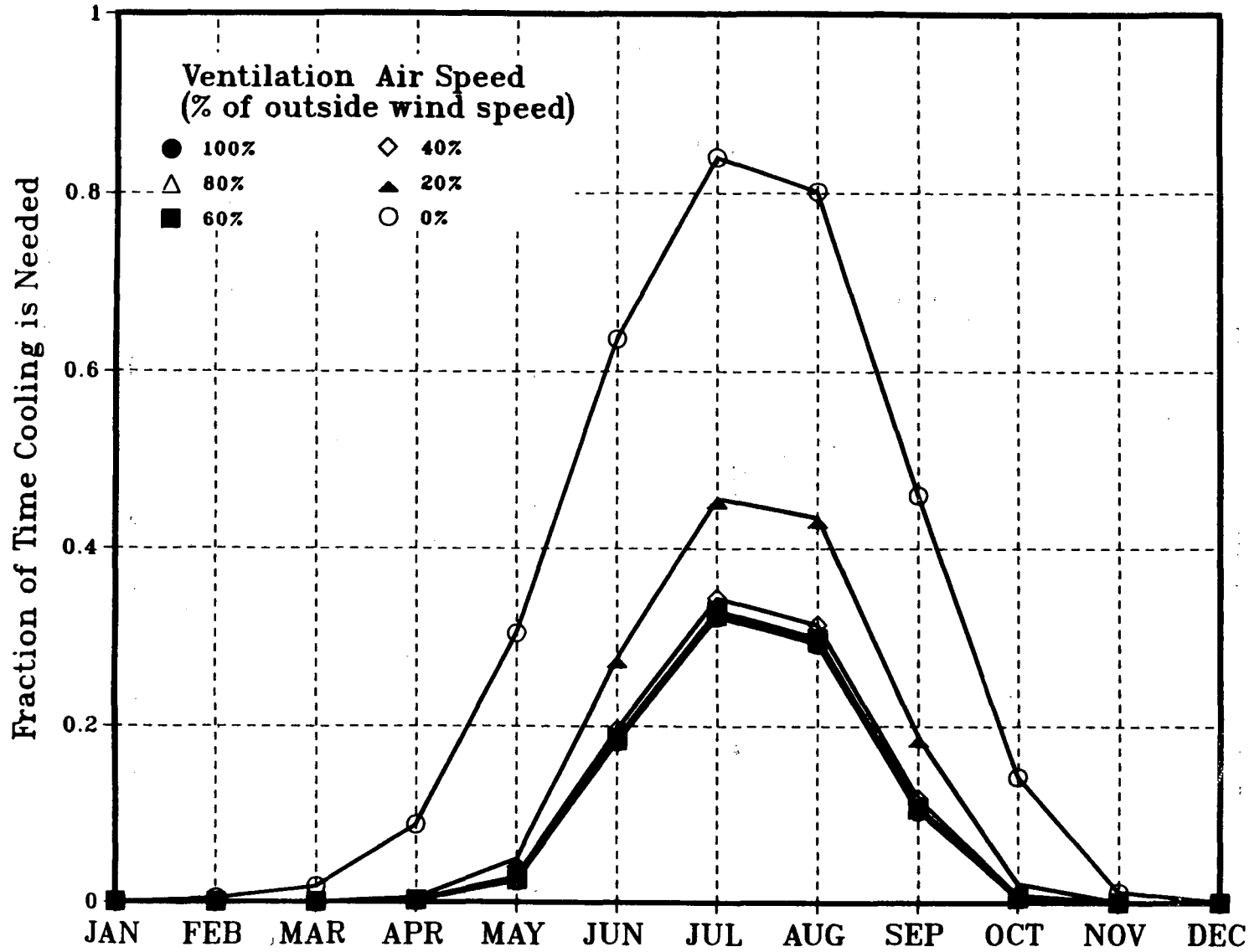


Figure 6. Fraction of Time Mechanical Cooling is Required to Provide Occupant Comfort at Various Ventilation Air Speeds: Miami, FL.

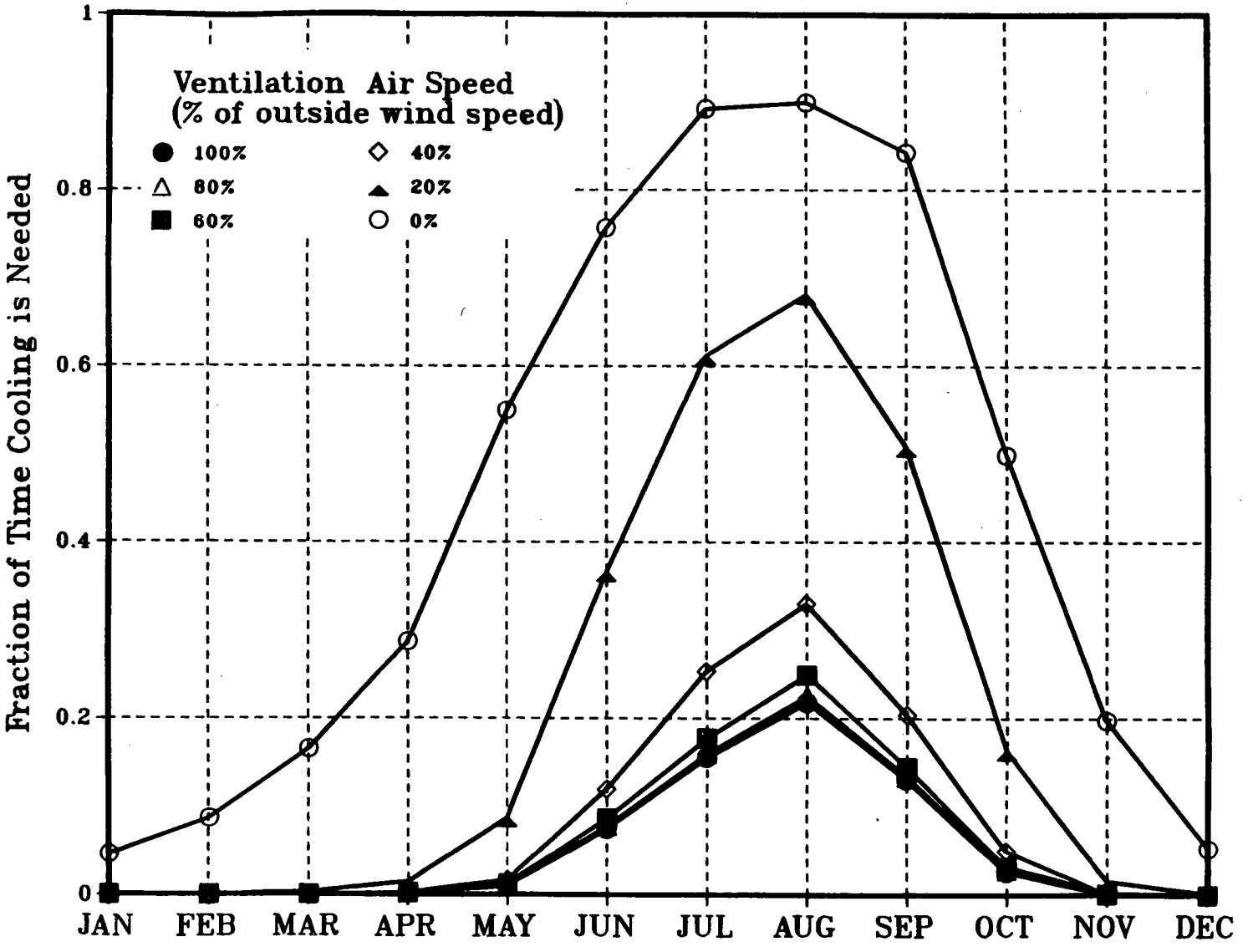


Figure 7. Fraction of Time Mechanical Cooling is Required to Provide Occupant Comfort at Various Ventilation Air Speeds: Phoenix, AZ.

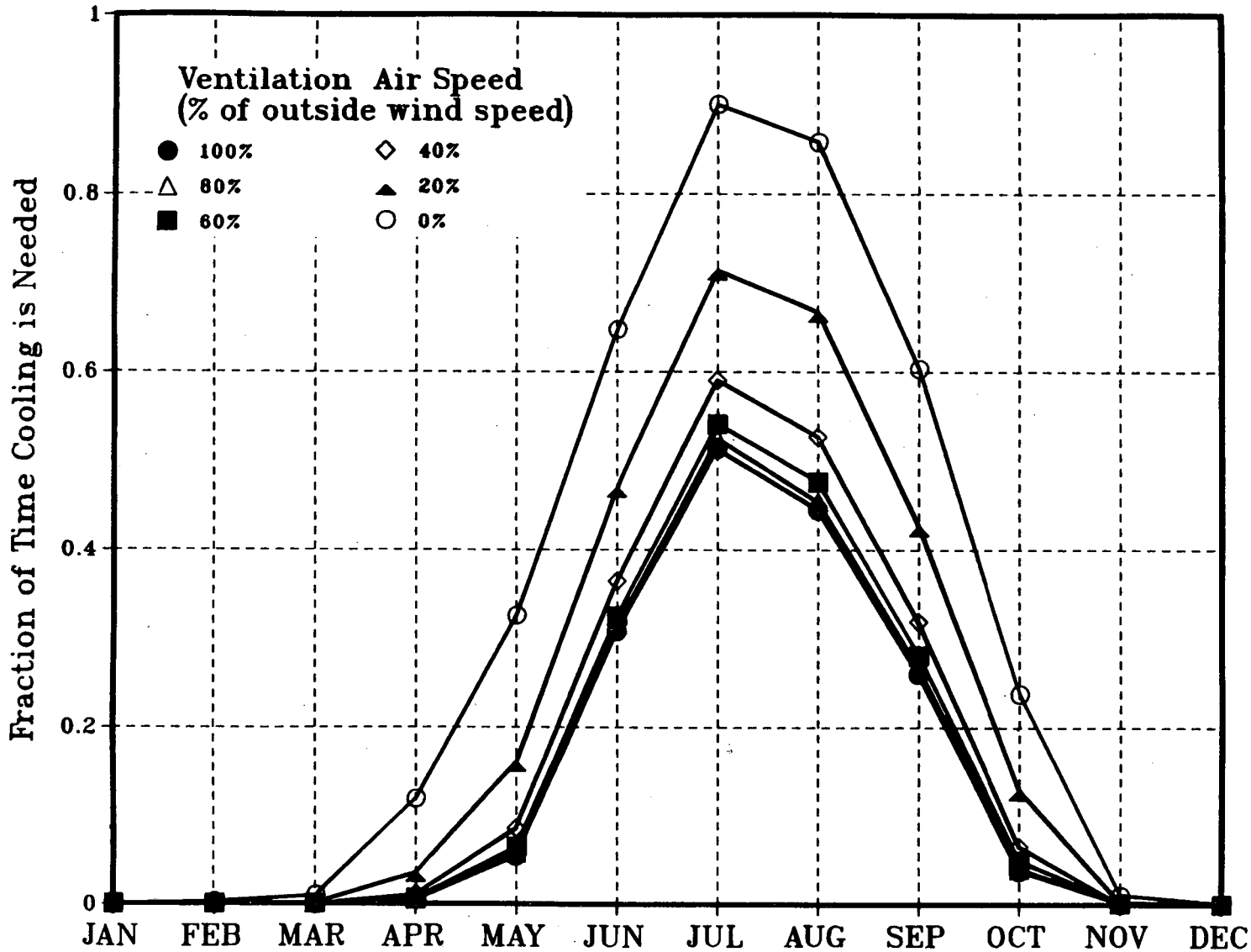


Figure 8. Sensible Cooling Loads as Calculated by DOE-2 and Cooling Degree Days in Several Climates.

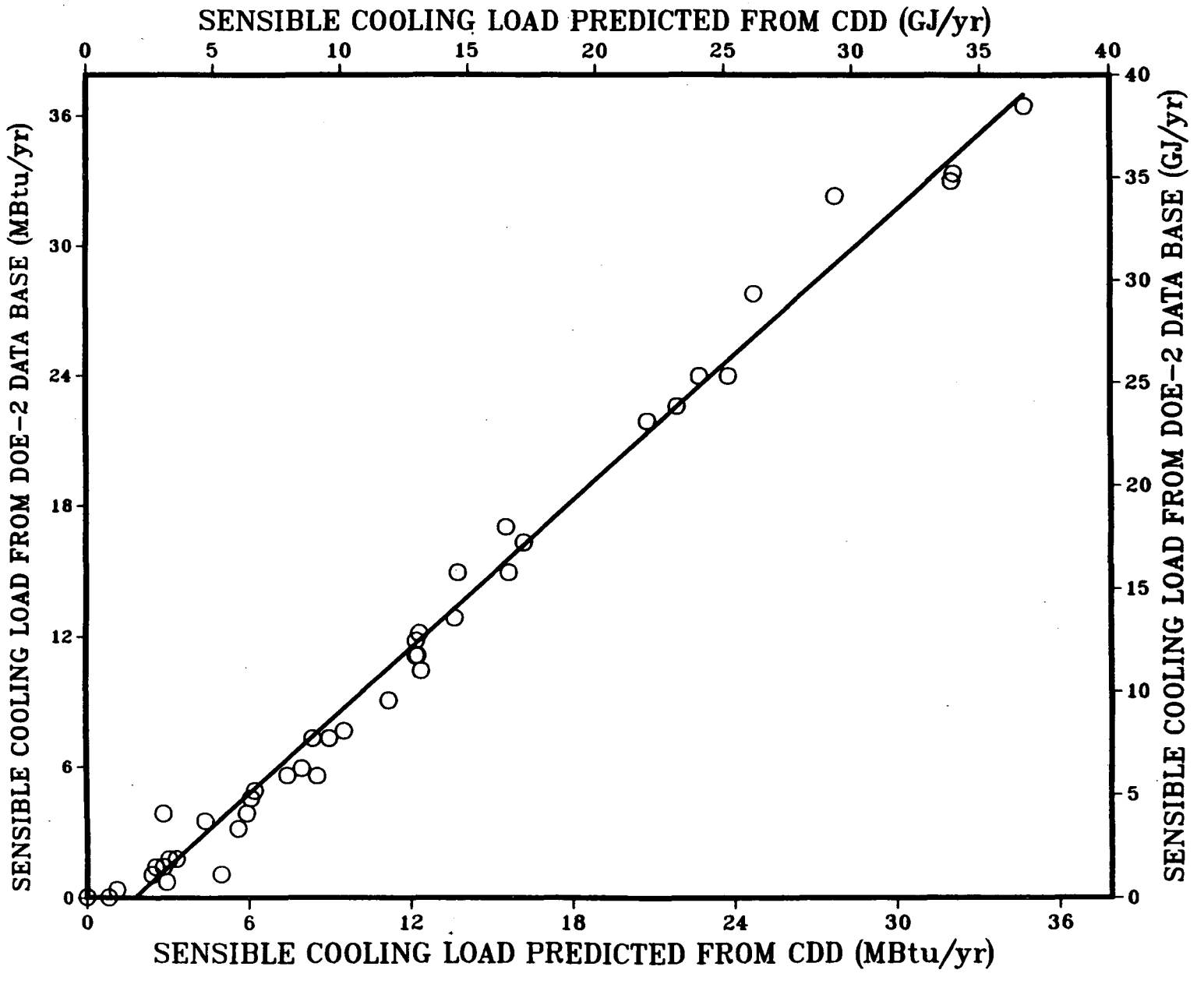


Figure 9. Total (Sensible + Latent) Cooling Loads as Calculated by DOE-2 and Cooling Degree Days in Several Climates.

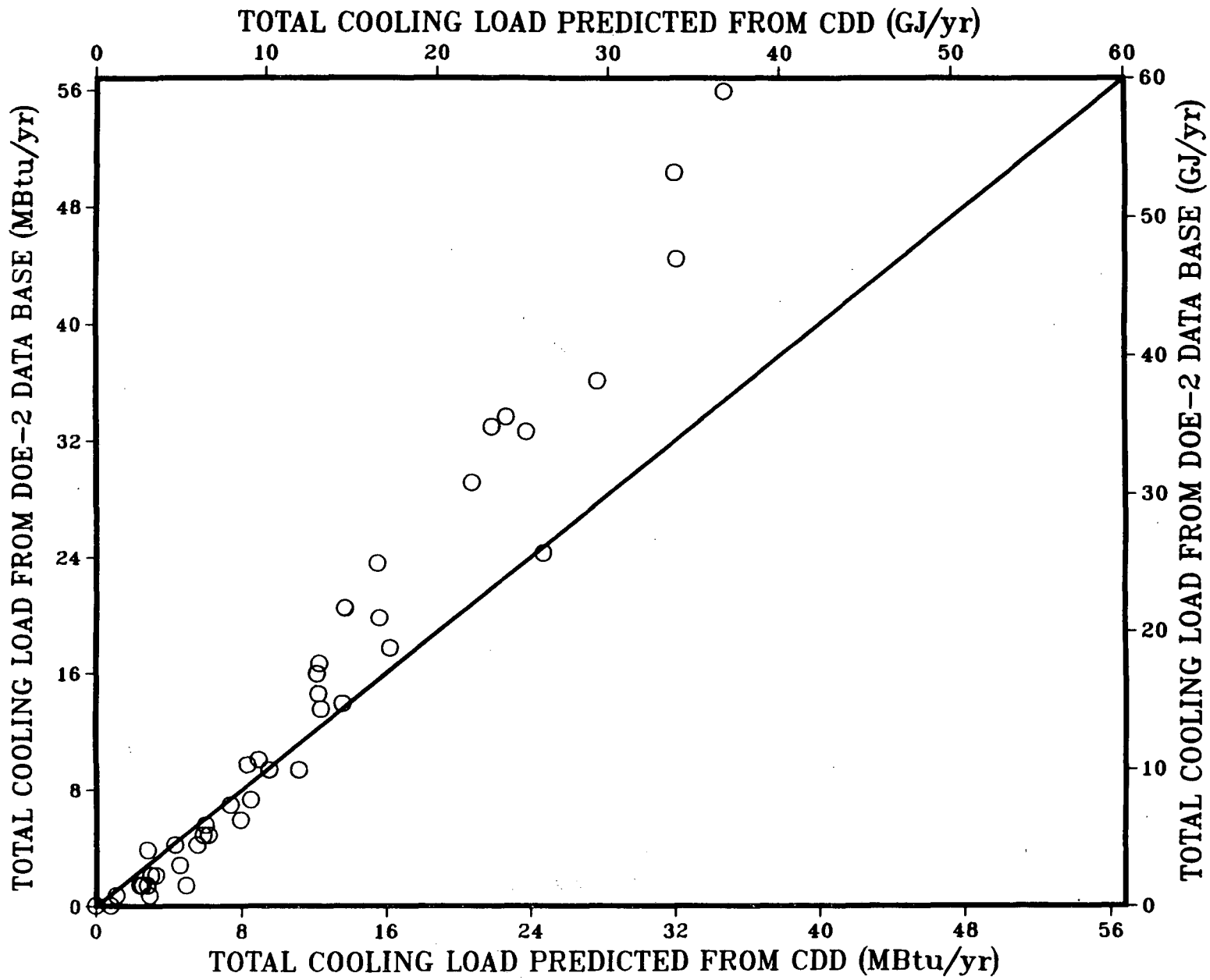


Figure 10. Total (Sensible + Latent) Cooling Loads as Calculated by DOE-2 and Cooling Enthalpy Hours in Several Climates.

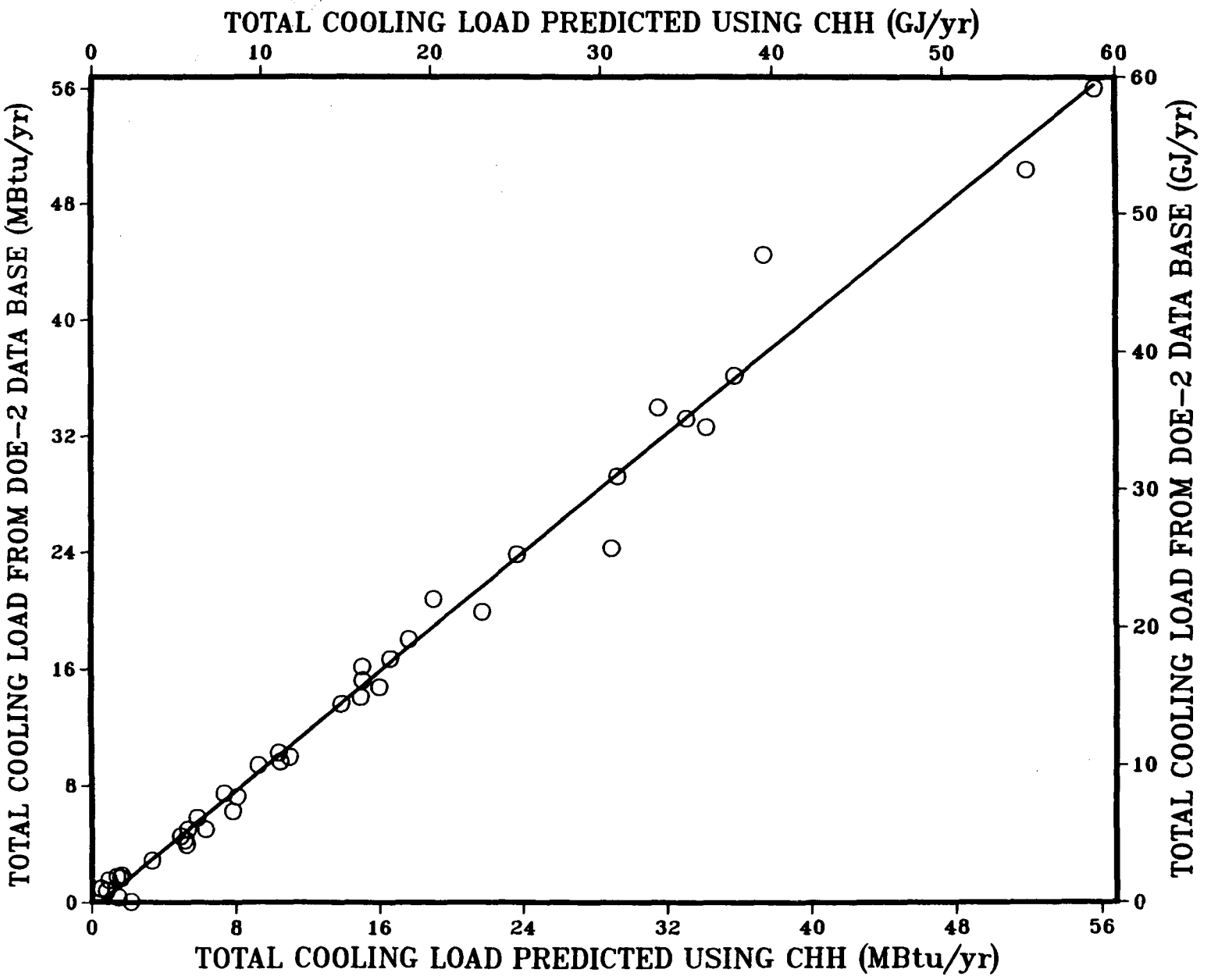
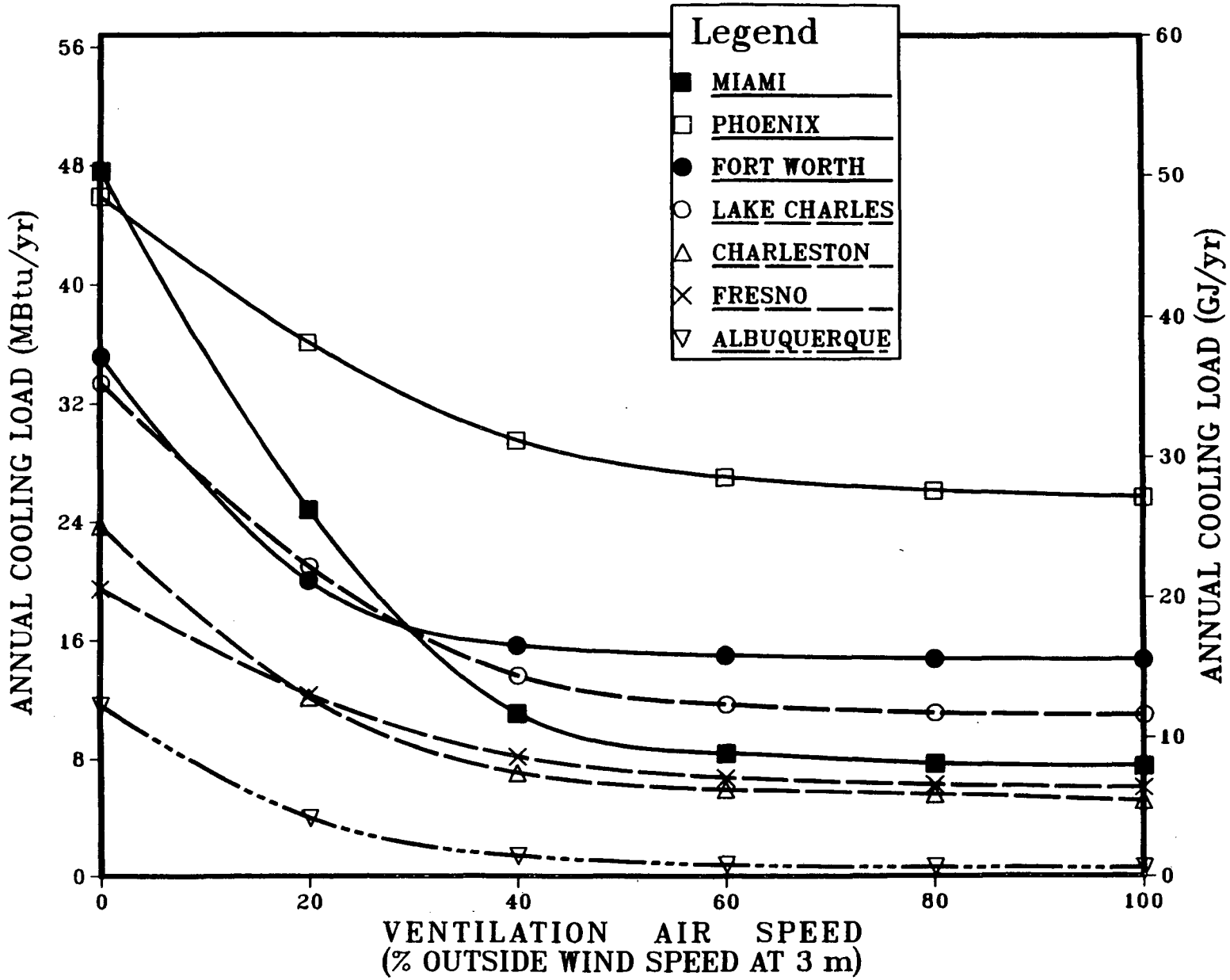
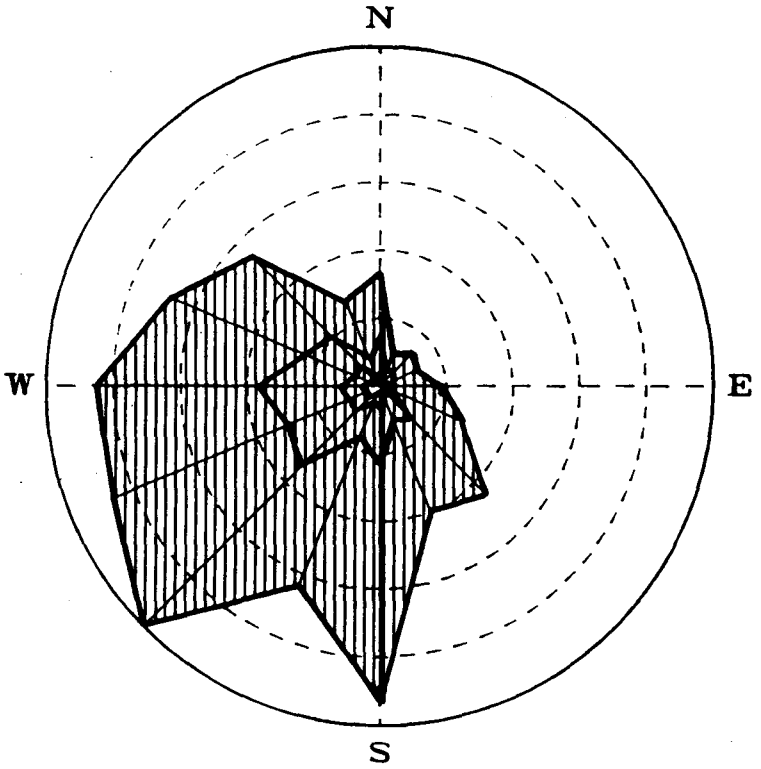


Figure 11. Annual Cooling Load as a Function of Ventilation Air Speed in Several Climates.



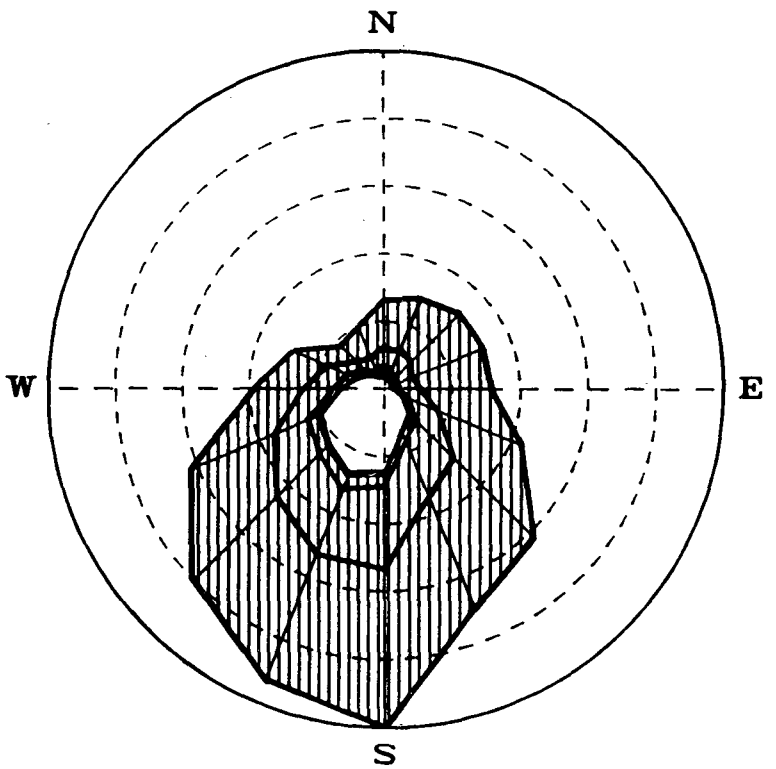
Figures 12-13. Cooling Load Wind Roses.



ALBUQUERQUE

Q_{max} = 1.56 MJ/yr (1.48 kBtu/yr)

Q_{nwd} = 0.23 MJ/yr (0.22 kBtu/yr)

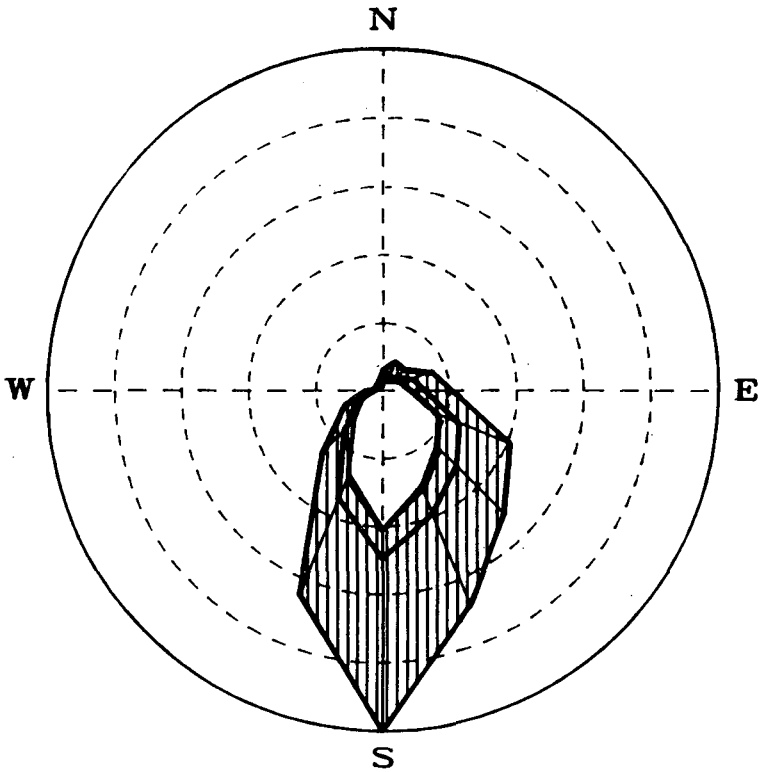


CHARLESTON

Q_{max} = 3.20 MJ/yr (3.03 kBtu/yr)

Q_{nwd} = 0.50 MJ/yr (0.47 kBtu/yr)

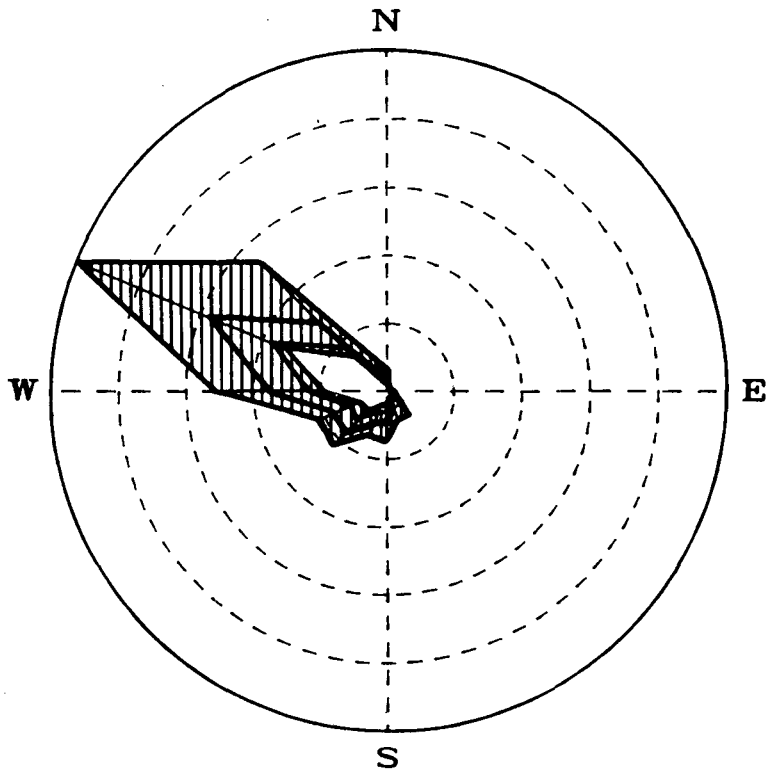
Figures 14-15. Cooling Load Wind Roses.



FORT WORTH

Q_{max} = 8.41 MJ/yr (7.96 kBtu/yr)

Q_{nwd} = 0.26 MJ/yr (0.25 kBtu/yr)

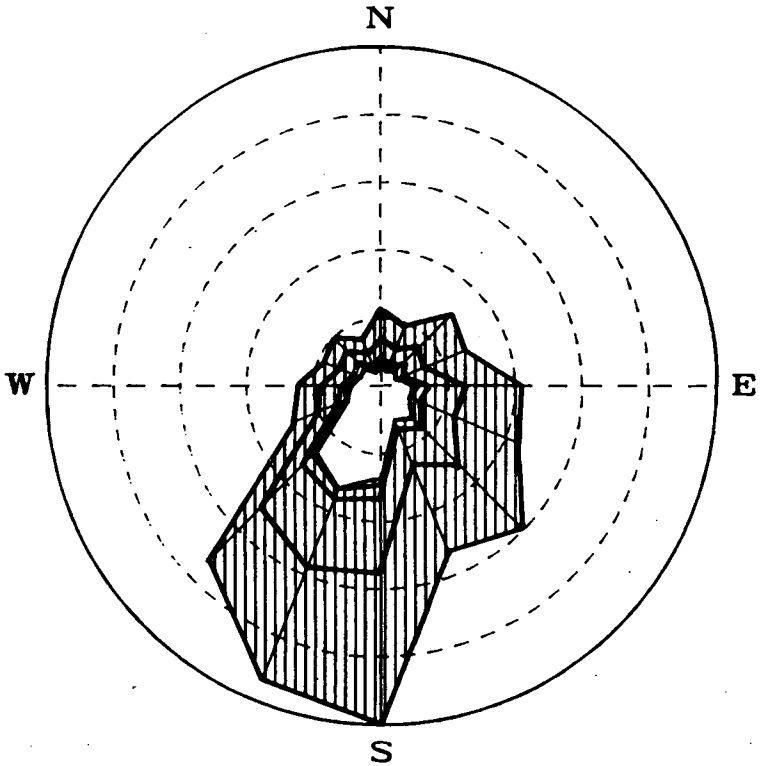


FRESNO

Q_{max} = 6.31 MJ/yr (5.98 kBtu/yr)

Q_{nwd} = 0.23 MJ/yr (0.22 kBtu/yr)

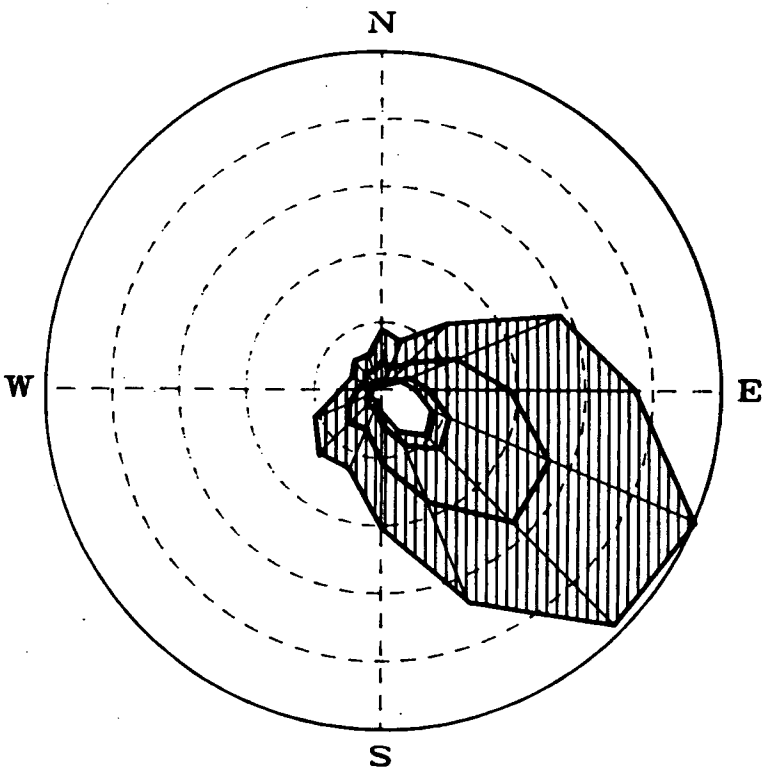
Figures 16-17. Cooling Load Wind Roses.



LAKE CHARLES

Q_{max} = 4.89 MJ/yr (4.63 kBtu/yr)

Q_{nwd} = 2.65 MJ/yr (2.51 kBtu/yr)



MIAMI

Q_{max} = 8.00 MJ/yr (7.58 kBtu/yr)

Q_{nwd} = 0.90 MJ/yr (0.85 kBtu/yr)

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