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IMPACTS OF VARIATIONS IN WIND DATA ON BUILDING ENERGY CALCULATIONS

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ABSTRACT

Wind is one of the key climatic factors affecting energy use in buildings. This is particularly true of residential buildings, especially single-family homes. In order to properly evaluate the climatic variation within urban areas, it is necessary to understand how variations in wind-speed data affect the energy calculations that rely on that data. The wind that affects energy use in a particular building often differs in significant ways from the wind data used in energy calculations, and the wind effect predicted by those energy calculations may be inaccurate as a result. This paper reports on three aspects of the situation.

The first section investigates the difference in energy calculations caused by conversions of standard (usually airport) wind data to more realistic local conditions. The second looks at the influence of infiltration algorithms on the sensitivity to wind-speed data differences. The third compares the energy calculation effects of variations in wind data between the standard hourly climatic data sets.

The key conclusions of this investigation are that (1) differences between standard urban area wind-speed data and site-specific wind speeds can have a significant effect on the wind-induced energy loads and on the total energy loads of a typical residence; (2) these differences can lead to inappropriate decisions on how to deal with energy issues; and (3) although there are some cases in which differences between wind data in existing standard climatic data sets might lead to different conclusions, in general, the energy impacts of such differences are insignificant.

INTRODUCTION

Wind is one of the key climatic factors affecting energy use in buildings. This is particularly true of residential buildings, especially single-family homes. In order to properly evaluate the effect of climatic variation within urban areas, it is necessary to understand how variations in wind speed data affect the energy calculations that rely on that data. The wind that affects energy use in a particular building often differs in significant ways from the wind data used in energy calculations, and the wind effect predicted by those energy calculations may be inaccurate as a result. This paper reports on three aspects of the situation.

The wind data used in energy calculations are typically derived for a specific site, generally within the same urban area. However, wind speed, direction, and patterns can vary systematically and dramatically within an urban area. The impact of such variation on energy load calculations is determined with reference to alternate algorithms for determining wind at a specific site.

Energy load calculations themselves treat wind data in different ways. The dominant wind effect in residential energy use is its impact on infiltration. Alternative infiltration algorithms can change the influence that differences in wind speed have on load calculations.

Climatic data, including wind data, used in energy calculations come from a variety of sources. For dynamic, hourly simulations, there are three weather data sets in general use. Measures of wind and wind-induced energy loads are used to compare the sensitivity of energy calculations to the variation of wind data in the weather data sets considered.

This paper examines the effects on energy use of different sets of wind data, as identified above. These effects are quantified through the use of detailed hourly simulations of building energy use and by direct exploration of the wind data sets themselves.

WIND VARIATION DUE TO LOCATION

Airport vs. Site Data

One aspect of weather data collected on a large scale is that it is usually collected at airports or similar stations. There are good reasons for this, both practical and scientific, but it causes some problems for wind data use for buildings work. Airports are largely unobstructed sites, where there is minimal interference with the instrumentation, and the climate itself is not altered by local variations in terrain or nearby obstructions. Wind data are typically measured atop a mast, usually standardized now to 25 feet or 10 meters but historically highly variable. Wind speeds around buildings, however, are rarely unobstructed, and the height of the winds of interest is usually much lower than that at which most measurements are made.

Despite this distinction between measured wind data and that which would better represent wind speeds *near*

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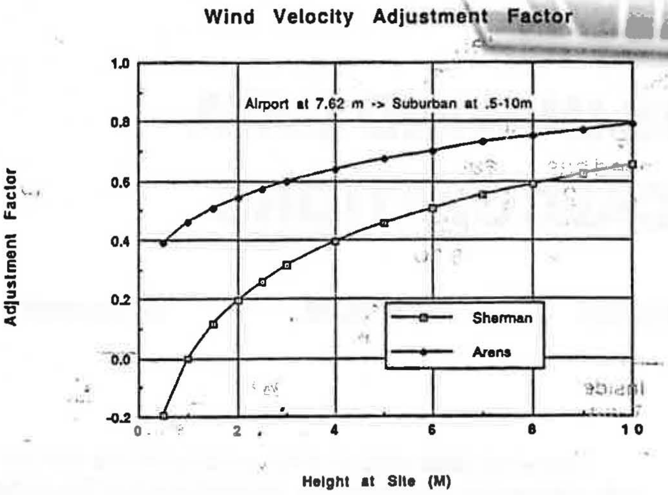

Figure 1 *Factors for adjusting airport wind data to building site data based on two different algorithms (described in the text)*

the building, the building analysis is typically not corrected for the difference between measured airport data and wind activity around a building. The result is that algorithms designed for use with local wind speed are being provided with airport wind speeds and making calculations on that basis.

Wind-Speed Algorithms: Sherman and Arens

Alternative algorithms exist, and two well-documented ones were chosen to test the sensitivity of building energy analyses to variations in the wind data used. The algorithms relate winds speed at different heights and with different obstructions within the same atmospheric wind regime. Using them, the unobstructed, elevated wind data can be converted to a wind speed at the building, accounting for changes in height and obstruction. The first algorithm is part of a method used by Sherman and Grimsrud (1982) to identify the actual wind behavior and effects around single-family residences. The second is used by Arens et al. (1985) for a program that takes weather station data and adjusts it for use at a specific building site.

Figure 1 shows the effect of applying the Sherman and Arens algorithms to wind-speeds, varying the height of the object building. Although they are applied to small buildings, the curves diverge, particularly for lower heights (< 4 m) because data near the ground are subject to a variety of factors making it difficult to fit a curve to them. As a result, both algorithms were included to identify a range of possible alteration, although Arens suggests that at the height used (2 m), the reduction in wind speed may be greater than either algorithm predicts.*

Simulation comparisons were made for a standard situation: a one-story residence in a suburban setting in Nashville, with a three-story office building down the street. The building is reasonably energy efficient. The monthly average wind speed at the building, calculated by these algorithms, indicates that the differences between weather data sets, while important in isolated instances, pales in comparison to the differences between wind speed at the airport and the associated wind speed at the building. Of greater importance, however, is the effect that this change would have on the heating and cooling loads in a total building energy analysis.

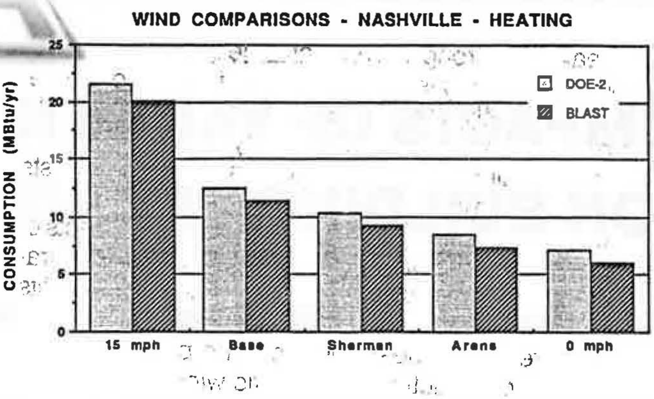

Figure 2 *Effect of different airport-site wind velocity corrections on annual heating requirements for a typical residence in Nashville*

In all, five different wind data sets were used in building energy simulations for comparison purposes:

- A constant, high wind (15 mph) superimposed on standard TMY climatic data,to set an upper limit
- TMY climatic data, unaltered, the base case
- TMY data with wind speed altered according to the Sherman algorithm
- TMY data with wind speed altered according to the Arens algorithm
- No wind (0 mph) superimposed on the TMY data, to set a lower limit

Each set was run with both DOE-2 and BLAST, in order to identify any program-specific anomalies that might occur.

Results

The results can be seen in Figures 2 and 3, which show heating and cooling loads. In comparison with the base case, overall heating loads are down 19% (Sherman) to 34% (Arens). Cooling loads are up 7% (Sherman) to 17% (Arens). BLAST and DOE-2 show essentially identical effects.

To a designer, the more important point might be to identify the total wind impact on energy use. Starting at the level of no wind, wind adds 20%, 46%, or 81%, respectively, to the heating load, depending on whether Arens, Sherman, or the base case is used. Likewise, wind lowers the cooling load 8%, 16%, or 21% for the same three cases.

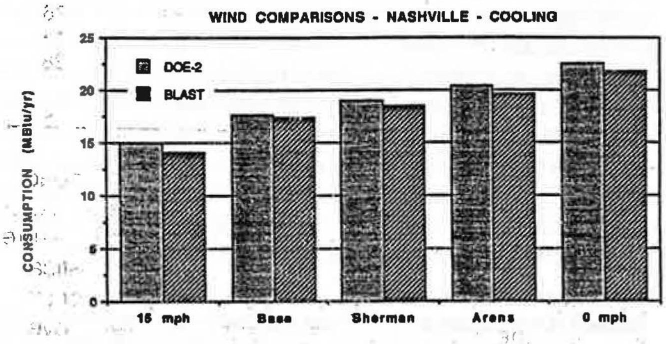

Figure 3 *Effect of different airport-site wind velocity corrections on annual cooling requirements for a typical residence in Nashville*

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*Personal communications, E. Arens.

Clearly, the wrong data can provide a false perception of how much energy is being used and for what purpose. More significantly, those false perceptions can lead to design decisions that are not justified by the actual environment of the building. In new buildings, substantial costs might be incurred in order to solve wind-induced problems that do not warrant them, while more important aspects of the energy environment might be ignored. Likewise, infiltration may be an overemphasized retrofit option, the benefits of which may be considerably less than expected.

These results argue strongly for an improved method of determining the actual site-specific wind speed in the vicinity of a specific building, and incorporating that actual wind-speed into building energy analysis techniques, possibly into the data itself.

INTERACTION OF WIND DATA AND INFILTRATION ALGORITHMS

Comparison of Load Impacts with Different Infiltration Algorithms

The results above are conservative in two respects. First, as mentioned, the reduction in wind speed at low heights may be greater than predicted by either of the wind speed algorithms used. Second, the infiltration options used in both BLAST and DOE-2 put a relatively low value on the impact of wind on infiltration. The sensitivity of energy calculations to the choice of infiltration algorithm used is discussed here.

Infiltration Algorithms: Achenbach-Coblentz vs. the LBL Model The Achenbach-Coblentz relationship (Coblentz and Achenbach 1963) is the traditional algorithm used to relate environmental characteristics to infiltration rates. This was the algorithm used in the simulations discussed in the previous section. It is based on empirical data from test buildings and consists of three basic components: a constant parameter, a parameter dependent on inside-outside temperature differences, and a wind-dependent parameter. The wind-dependent portion generally accounts for 15% to 40% of the infiltration. Table 1 gives examples of the relationships.

TABLE 1
Achenbach-Coblentz Infiltration Model

Inside Temp. (°F)	Outside Temp. (°F)	Wind Speed (mph)	% Infiltration Effect		
			Constant	Temperature	Wind
68	30	5	37	47	16
68	30	15	28	36	36
68	55	3	59	26	15
68	55	10	44	19	38
74	70	6	60	8	31
78	90	8	48	19	33

There has been some objection to the Achenbach-Coblentz relationship on the basis that, theoretically, a zero-ΔT/zero-wind-speed environment will produce no pressure differences and, therefore, no infiltration. While, realistically, that condition never occurs around a building, the constant factor in Achenbach-Coblentz nevertheless seems overly large. The calculated infiltration under ideal "no pressure difference" conditions will be nearly half of what it is under typical wind and temperature regimes. Further, the relationship was developed from heating data only.

Various alternative algorithms relating wind and temperature to infiltration have been developed. We chose to use one developed at LBL specifically for residences (Sherman et al. 1982). With this algorithm, variation in wind speed has a greater effect on the infiltration rate, as shown in Table 2 using the same conditions as in Table 1. The algorithm attributes larger, interrelated roles to wind and temperature and uses no constant terms.

TABLE 2
LBL Infiltration Model

Inside Temp. (°F)	Outside Temp. (°F)	Wind Speed (mph)	% Infiltration Effect*		
			Constant	Temperature	Wind
68	30	5	0	70	30
68	30	15	0	44	56
68	55	3	0	70	30
68	55	10	0	41	59
74	70	6	0	40	60
78	90	8	0	46	54

*Temperature and wind effects are interrelated, so percentage effects are approximate.

The wind-dependent portion of the infiltration with this algorithm ranges between 30% and 60%, a much more pronounced wind-speed effect than with the Achenbach-Coblentz algorithm.

Comparison of Simulated Energy Performance Based on Two Infiltration Algorithms Three of the five simulations made earlier to test the sensitivity of heating and cooling loads to changes in wind data were repeated using the LBL infiltration model. This time only BLAST was used, as the earlier results for BLAST and DOE-2 were so similar. To achieve a more instructive comparison of the effects of infiltration changes on wind data sensitivity, the coefficients used in the LBL algorithm were adjusted proportionately such that the base case infiltration would be close to the base case infiltration from the first set of simulations using Achenbach-Coblentz.

The results in Figure 4 show a comparison of the Achenbach-Coblentz and LBL infiltration models for both heating and cooling load. In this case, the effects are even more pronounced when the wind-speed data are adjusted by the same two algorithms (Sherman and Arens) used in the previous section. In comparison with the base case,

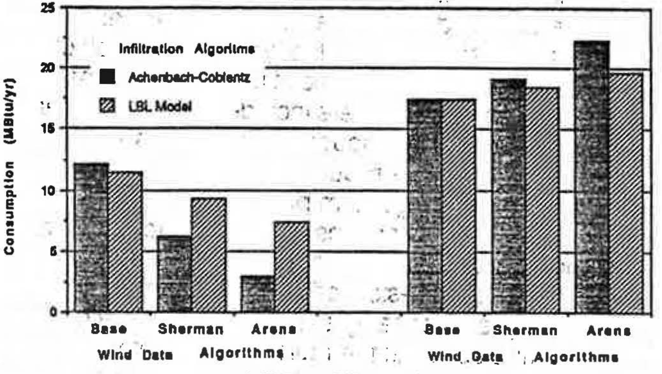

Figure 4 *Simultaneous comparison of the effects of both the infiltration model and the airport-site correction algorithms for wind speed on the annual heating and cooling requirements for a typical residence in Nashville*

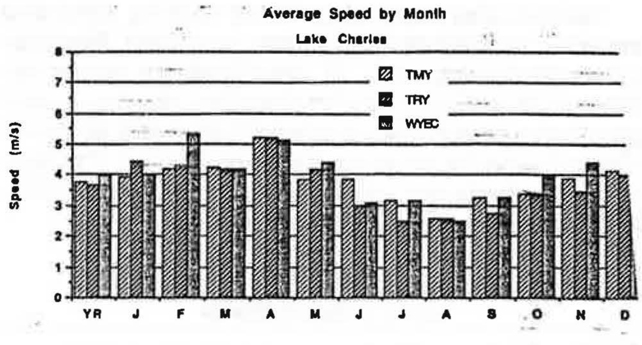

Figure 5 *Comparison of average monthly wind speeds in Lake Charles from three different NOAA-based weather data sets*

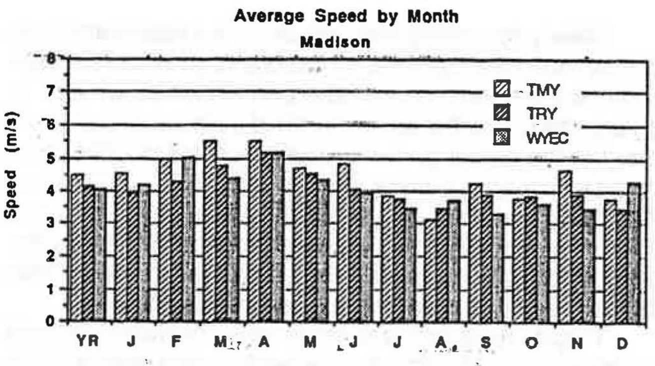

Figure 6 *Comparison of average monthly wind speeds in Madison from three different NOAA-based weather data sets*

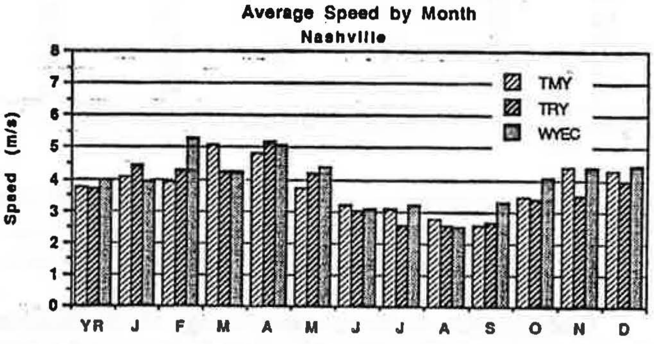

Figure 7 *Comparison of average monthly wind speeds in Nashville from three different NOAA-based weather data sets*

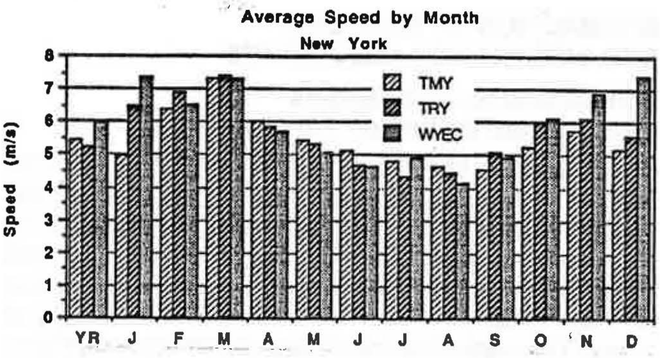

Figure 8 *Comparison of average montly wind speeds in New York City from three different NOAA-based weather data sets*

overall heating loads are down 48% (Sherman) to 74% (Arens). Cooling loads are up 10% (Sherman) to 25% (Arens). At least with respect to the residential case for which this alternative algorithm was developed, it would appear that the significant inferences identified in the earlier results are, if anything, conservative. Thus, a wind speed inappropriate to the building site can cause dramatic differences in energy characteristics derived from a detailed building energy analysis. The wrong wind speed can lead to wholly inappropriate decisions on how to deal with energy issues.

VARIATIONS IN WIND DATA SOURCES

Many weather data sets have been derived from various sources for a range of building analysis tasks. Clearly, there will be some differences in hourly wind speeds between some of these data sets. We chose three that have been widely used and have gained some acceptance as standard yearly data sets for building energy analysis: Typical Meteorological Year (TMY) [NCC 1981], Test Reference Year (TRY) [ERDA 1977], and Weather Year for Energy Calculations (WYEC) [Crow 1984]. All have been used for building energy simulations, although TRY is now used primarily for historical consistency with previous simulations. In addition, all of these data sets were developed from the same base, a 25- to 30-year record of meteorological measurements made available by NOAA for most of their data, including winds speed and direction.

A wide range of statistics was generated from various weather data sets, some focusing solely on wind and some on the more general relations between wind, temperature, and building energy use. Some of the most useful comparisons are shown in Figures 5-14.

The first set (Figures 5-8) shows the average wind speed per month for four sites, Nashville, Madison, Lake Charles, and New York, based on airport data. Madison and Lake Charles were chosen as heating- and cooling-dominated climates, respectively, Nashville because a residence there has relatively equal heating and cooling loads and New York because of the large population living in similar climates. In all four places, the three weather tapes show roughly the same patterns, but in each there are some nontrivial differences. In Lake Charles, WYEC wind speeds exceed the other two in October, November, December, and February, by .4-1.1 m/s (1 m/s = 2.2 mph). In Madison, TMY is noticeably higher in January, March, April, June, September, and November by .4-1.1 m/s. In Nashville, WYEC is higher in February by 1.3 m/s and in September and October by .8 m/s, while TMY is higher in March by .9 m/s. New York shows the most important variation, where the WYEC wind speed exceeds TMY in October (1 m/s), November (1.3 m/s), December (2.4 m/s), and January (2.7 m/s).

In the second set of graphs (Figures 9-12), data related to building energy use are shown. The greatest impact of wind on residences is its influence on infiltration and the heating loads that result. An algorithm was applied to the data to estimate the heating load on a residence induced by the wind.* In this case, the results are shown by direc-

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*This algorithm simply determines the energy required to heat the infiltrated air due to a particular infiltration algorithm and wind data, based on the corresponding hourly inside-outside temperature differences.

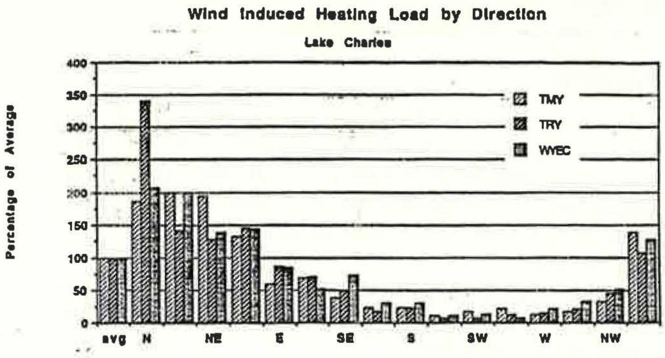

Figure 9 *Comparison of wind-induced infiltration heating requirements for different wind directions and NOAA-based weather sets for a typical residence in Lake Charles*

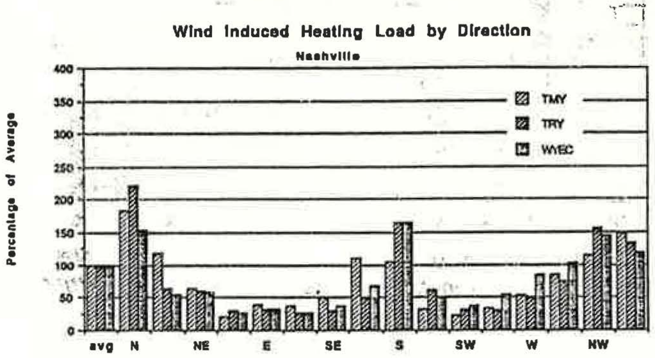

Figure 11 *Comparison of wind-induced infiltration heating requirements for different wind directions and NOAA-based weather sets for a typical residence in Nashville*

tion, since it is by orientation and directional techniques that building designers are most likely to attempt to resolve such problems. At all four sites, there are localized differences, but in most cases inconsistencies in one direction are compensated for by complementary differences in a similar direction, e.g., N and NNE in Lake Charles. In New York, values of wind-induced heating for WYEC are significantly higher than for TMY and TRY for four contiguous directions (SW-WNW). In Nashville, the values for WYEC exceed the other two for the same directions but are lower for NNW, N, and NNE. Such differences could alter a designer's perceptions of the need for, and placement of, wind mitigation elements.

Finally, both wind-induced and total monthly heating loads are shown for Nashville (Figures 13-14). The results are similar, although the differences are naturally less pronounced when all heating loads are accounted for. The major discrepancy is that WYEC data show notably lower loads in October and November and higher loads in December and January.

In summary, there are local discrepancies among all three sets of weather data There are also some cases in which the wind data on one weather tape may imply an action to a building designer or owner while the wind data on another may have different implications. In general, while the patterns are similar and would prompt similar responses from those using the different weather data sets

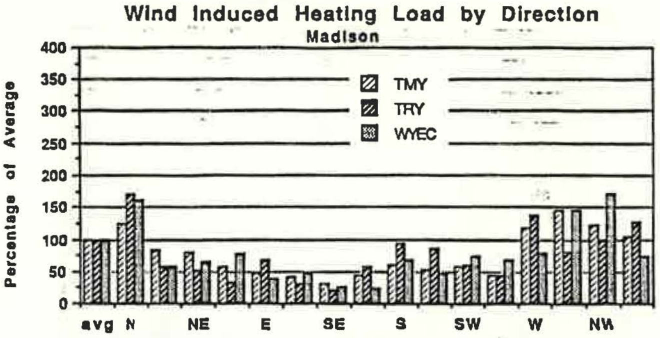

Figure 10 *Comparison of wind-induced infiltration heating requirements for different wind directions and NOAA-based weather sets for a typical residence in Madison*

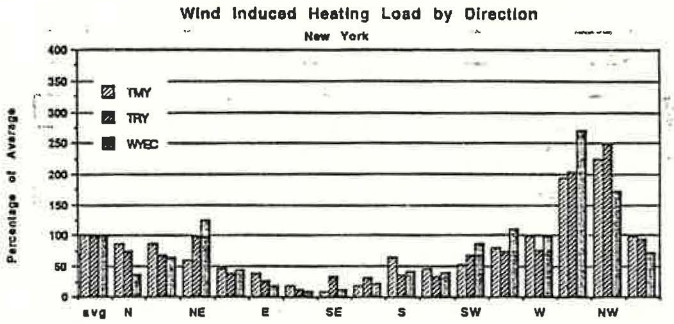

Figure 12 *Comparison of wind-induced infiltration heating requirements for different wind directions and NOAA-based weather sets for a typical residence in New York City.*

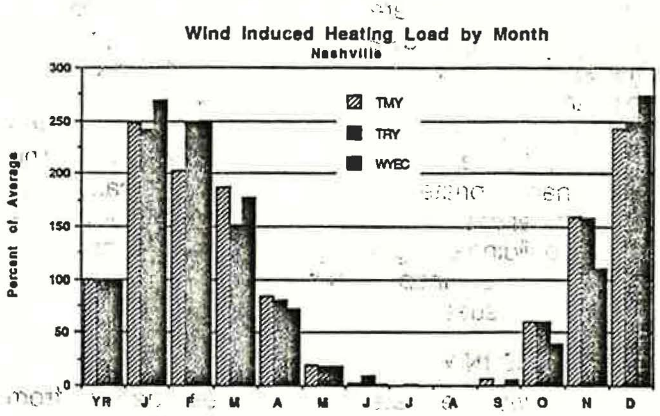

Figure 13 *Monthly variation of wind-induced heating load only compared to an annual average for a typical residence in Nashville*

for building energy analysis, the discrepancies are sufficient to prompt concern about specific situations and about weather data sets that might not be so closely tied to each other in terms of source data as these three are.

SUMMARY

Each of the relationships between wind data, energy calculations, and design reported in this paper leads to a separate conclusion:

- Differences between standard urban area wind-speed data and site-specific wind speeds can have a significant effect on the wind-induced energy loads *and* on the total energy loads of a typical residence; methods of adjusting

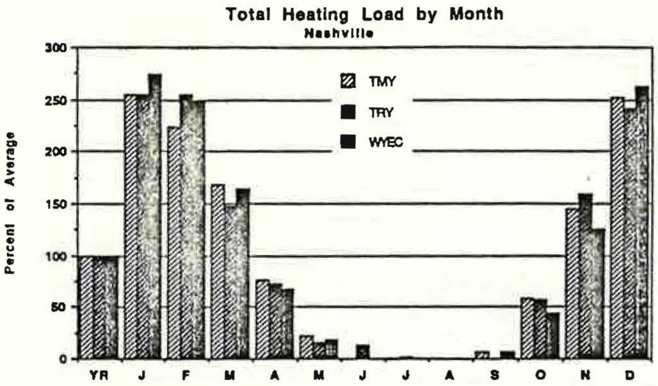

Figure 14 *Monthly variation of total heating requirements compared to an annual average for a typical residence in Nashville*

wind data to account for these differences should be explored.

- The more recent LBL infiltration algorithm generally attributes greater influence to wind than the older Achenbach-Coblentz infiltration algorithm; as a result, the potential calculation and decision errors associated with wind-speed data variation are even greater than suggested by the first conclusion above.
- Although there are some cases in which differences in wind data between standard climatic data sets might lead to different conclusions, in general, the energy impacts of such differences are insignificant.

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