ASHRAE JOURNAL

Dehumidification and Cooling Loads From Ventilation Air

By Lewis G. Harriman III
Member ASHRAE

Dean Plager

and Douglas Kosar
Member ASHRAE

Ninety-five years since Willis Carrier began the modern era of air conditioning by dehumidifying a printing plant, our industry is becoming more concerned with the importance of controlling humidity in buildings. In part, this concern stems from indoor air quality problems associated with excess moisture in air-conditioning systems. But more universally, the need for ventilation air has forced HVAC equipment (originally optimized for high efficiency in removing sensible heat loads) to remove high moisture loads.[1]

To assist cooling equipment and meet the challenge of larger ventilation loads, several technologies have succeeded in commercial buildings. Newer technologies such as subcool/reheat and heat pipe reheat show promise. These increase latent capacity of cooling-based systems by reducing their sensible capacity. Also, desiccant wheels have traditionally provided deeper-drying capacity by using thermal energy in place of electrical power to remove the latent load.[2]

Regardless of what mix of technologies is best for a particular application, there is a need for a more effective way of thinking about the cooling loads created by ventilation air. It is clear from the literature that all-too-frequently, HVAC systems do not perform well unless the ventilation air loads have been effectively addressed at the original design stage.[3,4] This article proposes an engineering shorthand, an annual load index for ventilation air. This index will aid in the complex process of improving the ability of HVAC systems to deal efficiently with the amount of fresh air the industry has deemed useful for maintaining comfort in buildings.[5]

About the Authors

Lewis G. Harriman III is director of research at Mason-Grant, Portsmouth, N.H. He is the chair of the Handbook Subcommittee of ASHRAE Technical Committee 3.5 (Desiccant and Sorption Technologies) and is the author of *The Dehumidification Handbook*.

Dean Plager is senior analyst at Quantitative Decision Support, Portsmouth, N.H. He is also adjunct professor of quantitative analysis at the Whittemore School of Business Administration at the University of New Hampshire.

Douglas Kosar is principal product development manager at the Gas Research Institute, Chicago. His primary responsibility is development of gas-driven air treatment technologies for commercial buildings.

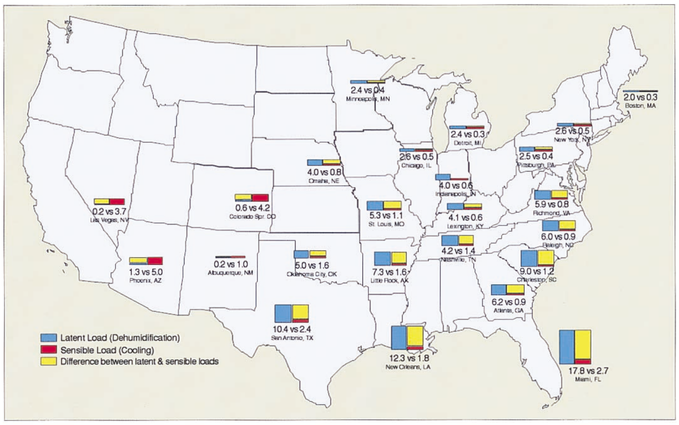

Fig. 1: Map of Ventilation Load Indexes (VLI) for selected locations.

The proposed "ventilation load index" (VLI) is the total load generated by one cubic foot per minute of fresh air brought from the weather to space-neutral conditions over the course of one year. It consists of two numbers, separating the load into its dehumidification and cooling components: latent ton-hours per cfm per year and sensible ton-hours per cfm per year. For example, a ventilation air load index of 6.7 + 1.1 means that the total annual latent load is 6.7 ton-hours per cfm, and the annual sensible load is 1.1 ton-hours per cfm.

The "VLI" is proposed in the same spirit that led to the use of the "degree-day" as shorthand for expressing heating and cooling loads on the envelope of a building, or the SEER as a means of expressing the relative efficiency of cooling equipment over time. Those engineering shorthand values reduce great complexity to simple terms. Although they cannot replace detailed examination of the phenomena they represent, they allow rapid comparisons between similar items. In the same way, the ventilation load index allows for quick comparisons between loads in different geographic locations.

Latent vs. Sensible Ton-hours per SCFM per Year

To calculate the index for a given location, one must compare the temperature and humidity levels in the weather to the temperature and humidity in the conditioned space. Then a calculation is made for every hour of the year. One must also decide what values to use for "space-neutral" temperature and humidity set points to compare with the weather conditions.

In calculating the indexes contained in this article, "space-neutral" conditions are defined as 75°F (24°C), 50% rh (65 gr/lb [39 g/.45 kg]). One could equally choose different set points for specialty applications, but 75°F (24°C), 50% rh seems to represent values consistent with human comfort research findings. This set point is at the middle of the combined summer and winter comfort zones with respect to dry bulb temperature and towards the upper limit of 60% rh for moisture in the combined zones.[6]

The latent ton-hours per scfm in a given hour are calculated as follows:

Latent ton-hours per scfm =

$$\frac{(\text{Outside air humidity ratio} - 65\ \text{gr/lb}) \times 4.5 \times 1050}{7000 \times 12{,}000} \quad (1)$$

4.5 = lbs of air per hour per cfm
7000 = grains of water vapor per lb
1050 = heat of vaporization of water at standard temperature and pressure in Btu per lb
12000 = represents the Btu's per hour of one ton of air conditioning capacity

The values for each of the 8760 hours of the year are calculated and summed to form the latent (dehumidification) load portion of the index.

Similarly, the sensible ton-hours per cfm in a given hour are calculated as follows:

Sensible ton-hours per scfm =

$$\frac{(\text{Outside dry bulb} - 75°\text{F}) \times 4.5 \times 1.08}{12000} \quad (2)$$

Where the outside dry bulb is the average dry bulb temperature in degrees Fahrenheit, 1.08 is the specific heat of air at standard temperature and pressure in Btu per degree Fahrenheit per lb and 12000 represents the number of Btu's per hour of one ton of air-conditioning capacity. To arrive at the value for the annual sensible heat load, separate calculations are made for each of the 8760 hours of typical weather observations for a given location.

Note that the index does not consider hours when no load exists. If, for example, the outdoor dry bulb temperature is 75°F (24°C), then there is no sensible load added to the cumulative total from that hour's observation. Likewise, the index does not consider either "free cooling" or "free dehumidification." For example, if the humidity ratio in the weather air is below the indoor set point of 65 gr/lb (39 g/0.45 kg), then no "credit" is subtracted from the cumulative total annual latent load for that hour.

City	State	Ventilation Load Index (Ton-hrs/scfm/yr) Latent + Sensible	Total	Cumulative Load Ratio Latent:Sensible
Albuquerque	NM	0.2 + 1.0	1.2	0.2:1
Boston	MA	2.0 + 0.3	2.3	6.4:1
Detroit	MI	2.4 + 0.3	2.7	7.4:1
Minneapolis	MN	2.4 + 0.4	2.8	6.2:1
Pittsburgh	PA	2.5 + 0.4	2.9	5.8:1
New York	NY	2.6 + 0.5	3.1	5.1:1
Chicago	IL	2.6 + 0.5	3.1	5.0:1
Las Vegas	NV	0.2 + 3.7	3.9	0.04:1
Indianapolis	IN	4.0 + 0.6	4.6	6.6:1
Lexington	KY	4.1 + 0.6	4.7	7.4:1
Colorado Spr.	CO	0.6 + 4.2	4.8	0.1:1
Omaha	NE	4.0 + 0.8	4.8	5.3:1
Phoenix	AZ	1.3 + 5.0	6.2	0.3:1
St. Louis	MO	5.3 + 1.1	6.4	4.7:1
Oklahoma City	OK	5.0 + 1.6	6.6	3.2:1
Richmond	VA	5.9 + 0.8	6.7	7.2:1
Raleigh	NC	6.0 + 0.9	6.9	6.8:1
Atlanta	GA	6.2 + 0.9	6.9	6.7:1
Nashville	TN	6.2 + 1.4	7.6	4.6:1
Little Rock	AK	7.3 + 1.6	8.8	4.7:1
Charleston	SC	9.0 + 1.2	10.3	7.3:1
San Antonio	TX	10.4 + 2.4	12.8	4.4:1
New Orleans	LA	12.3 + 1.8	14.1	6.8:1
Miami	FL	17.8 + 2.7	20.5	6.7:1

Table 1: Ventilation Load Indexes calculated by the BIN program.

Advantages of the VLI

There are several useful advantages of this index. Perhaps most importantly, it represents the cumulative annual load, as opposed to the load at only a single point of operation. In addition, the index has other advantages:

• Small numbers in both I-P and S-I units

As can be seen from the values in *Table 1*, the index yields values which are small numbers, making variations between different locations apparent at a glance. Also, when the index is recalculated using S-I units (kWh/l/sec per year) the values are similarly small.

• Encourages examination of system behavior in different operating modes

In weather systems, temperature and moisture levels are related, but they vary independently. Therefore an air-conditioning system may cool without dehumidifying or dehumidify without cooling. By separating and quantifying the annual loads for the latent and sensible components of the total load, the index encourages the engineer to consider whether the ventilation system is in fact capable of controlling temperature and humidity independently, as suggested by weather variations.

Calculation Methodology

The TMY-2 data set of hourly weather observations and a newly-developed computer program which accesses those data sets in order to perform annual summaries were used to calculate the indexes displayed in *Table 1*.

Annual data set: TMY-2

The TMY-2 data set was selected for several reasons. First, it contains complete records for 239 locations within the United States, by far the largest number of credible and complete annual records available at the present time. Secondly, the data shows observed values, rather than averaged values, and the methodology for constructing a TMY-2 data set is well-documented and repeatable. Finally, the records were produced for the U.S. Department of Energy using public funds, and as such, are nonproprietary, in the public domain and readily available to the public.[7]

The acronym TMY stands for "Typical Meteorological Year." That methodology selects "typical" months of weather observations from a long-term record of hourly observations. A "typical" month is selected based on how closely it con-

See Harriman, Page 40

Harriman, From Page 38

forms to the mean values of a given variable for that month over the 30-year period. So the TMY-2 file for a specific site may consist of its January record from 1962, February from 1975, March from 1981 and so forth.

The methodology allows for weighting different values more or less heavily for "typicality." In the current set, for example, solar observations are weighted slightly more heavily than the dry bulb temperature and the dew point. Consequently, the months selected contain solar data which are slightly "more average" than the dry bulb and dew-point data, and the temperature and humidity is slightly "more average" than the remaining values of wind-speed, precipitation and so forth. Given that 24 simultaneous variables can never have "typical" values in every one of the 8760 hours per year, the TMY-2 record containing "typical months" of actual observed data represents weather behavior better than older methodologies, which selected a single variable and then calculated averages for some of the other variables rather than recording the actual simultaneous observed data.

Calculation engine: BIN calculation program

The computer program which calculated the indices was developed initially to produce custom BIN data and joint-frequency tables of temperature, dew point and wind speed for use in estimating annual energy consumption of HVAC systems and unitary equipment. A public version of the program is under development, funded by the Gas Research Institute in cooperation with committees of ARI and ASHRAE.[8]

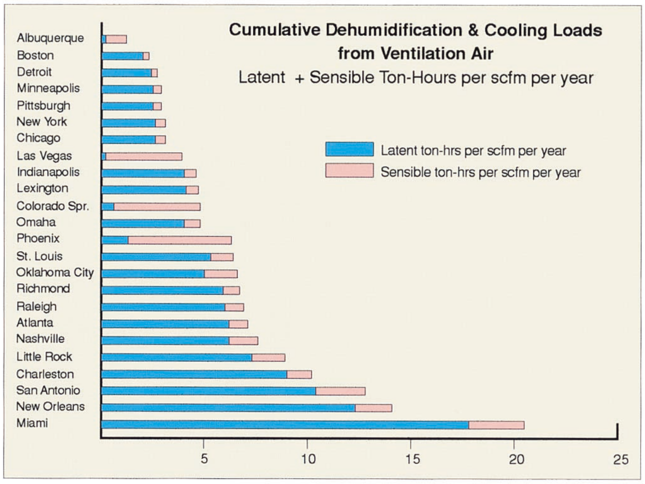

Fig. 2: Cumulative dehumidification and cooling loads from ventilation air for selected locations in the United States.

The program is written in a popular graphical version of the BASIC programming language. It runs on the most widely-used operating system for personal computers that are

See Harriman, Page 42

Harriman, From Page 40

equipped with at least eight megabytes of RAM and a CD-ROM drive. The program and all 239 TMY-2 files are contained on a single CD-ROM disk.

The "ventilation air pretreatment" routine looks at each hour's dry bulb temperature and humidity ratio and calculates the difference from the building's set points for temperature and humidity. The program allows the user to select the set point values for air delivered to the building. For these indexes, 75°F (24°C), 50% rh, 65 gr/lb (39 g/0.45 kg) were chosen. Then the program totals loads for each of the 8760 hours in the TMY-2 file selected by the user. The routine accumulates the loads for sensible and latent heat separately, because there are many hours when one load is present without the other. For example, if the outdoor temperature is 74°F (23°C) in a given hour, there is no sensible load. But if the moisture outdoors during that same hour is 85 gr/lb (5.5 g/0.45 kg), then there is a moisture load to be removed when ventilation air is brought to the target value of 65 gr/lb (39 g/0.45 kg).

By using an hour-by-hour calculation, the procedure avoids the distortion of traditional BIN summaries. For example, when weather observations are "BINned" by temperature with mean coincident (average) values for moisture, annual latent loads are underestimated by 25 to 35% of their true dimension. Likewise, BINning the observations by dew point and averaging the coincident values for dry bulb temperature would underestimate the sensible load by 10 to 20%. The program's ventilation air subroutine produces more meaningful indexes because they are non-averaged, separate values for latent and sensible loads.

Validation of Pretreatment Subroutine Results

A separate program, operated by a second programmer, was used to generate values for all stations and to compare them to results produced by the BIN program. The check program used was a general-purpose statistical analysis program designed to run on workstations.[9]

The check program was customized by the addition of commercially-available psychrometric subroutines.[10] The agreement between the BIN program and the statistical analysis program was good. Specifically, the R^2 value for the sensible load values was 0.98 and the R^2 value for latent loads was 0.97. *Table 1* contains a few of the index values calculated by the BIN program. Several interesting points become clear from the information presented in that table.

Differences Between Latent and Sensible Loads

One might expect that sensible heat loads and moisture loads generated by ventilation air would be similar, but that is not the case. None of the locations shown here have equal latent and sensible loads. In fact, all locations have loads that differ by at least 3:1, and loads at most locations differ by 4:1 or greater.

Latent Loads Compared to Sensible Loads

Except for desert climates, the latent loads are always higher than the sensible loads. Even in San Antonio, Texas, and Oklahoma City, which most would assume have arid climates, the annual latent load exceeds the sensible load by four and five times, respectively.

As one would expect, the total annual cooling loads are larger in southern climates and smaller in northern locations.

See Harriman, Page 44

Harriman, From Page 44

For example, the sum of the latent and sensible loads in Miami are 20.5 ton-hours per scfm per year, and loads in Boston only total 2.3 ton-hours per scfm per year—Miami's load is nearly nine times that of Boston. However, the ratio of latent to sensible loads does not always vary by similar amounts between locations. In "humid" Miami, the latent load exceeds the sensible by 6.7:1. But in "dry" Boston, the latent load still exceeds the sensible load by 6.4:1.

Possible Implications for System Design

The implications of the indices for system design will vary according to the importance of controlling humidity and the volume of outside air needed for a given application. Where ventilation air is a high proportion of the total airflow, latent loads probably require more attention in the future than they have received in the past. Examples would include high-occupancy areas such as a classroom, theater, restaurant, retail store or health-care facility.

Where there is an economic benefit to controlling humidity combined with large ventilation loads, the ventilation air should be examined carefully and perhaps singled-out for attention separate from the balance of the system. This suggestion is supported by the fact that the latent and sensible loads are so different in dimension and are seldom concurrent. Independent control of temperature and humidity would allow closer control of each variable.

Where there is an economic benefit to such control, a moisture removal system for ventilation air, combined with a sensible heat removal system for the combined supply air, would reduce variation in temperature and moisture levels. Examples might include laboratory systems, where temperature or moisture excursions might cost money, or printing and electronic assembly, where humidity variations can slow or stop high-speed, automated processes.

Annual Loads vs. Peak Design

Using TMY-2 records to examine loads on an annual basis is useful for evaluating configurations, components and controls; but average data does not yield the peak design loads needed for sizing equipment. By definition, the TMY loads are typical rather than extreme. ASHRAE Technical Committees 4.2 (Engineering Weather Data) and 3.5 (Desiccant and Sorption Technologies) collaborated on a joint research project which addresses this problem.[11] The results of that project are printed in Chapter 24 of the *1997 ASHRAE Handbook—Fundamentals*. For the first time, the correct and separate peak values for temperature and moisture are provided for the designer.

Summary

Examination of typical behavior of weather shows that latent loads usually exceed sensible loads in ventilation air by at least 3:1 and often as much as 8:1. A designer can use the engineering shorthand indexes presented in *Table 1* to quickly assess the importance of this fact for a given system design. To size those components after they are selected, the designer can refer to Chapter 24 of the *1997 ASHRAE Handbook—Fundamentals,* which, includes separate values for peak moisture and peak temperature.

Acknowledgments

The authors would like to thank the Gas Research Institute for the financial support necessary for the BIN program devel-

	Tons-Hours per SCFM Per Year	
Alabama		
Birmingham	7.1	1.2
Huntsville	6.4	1.1
Mobile	11.2	1.7
Montgomery	9.4	1.6
Arkansas		
Fort Smith	6.9	1.6
Little Rock	7.3	1.6
Arizona		
Flagstaff	1.0	1.8
Phoenix	1.3	5.0
Prescott	0.2	0.9
Tucson	1.5	3.0
California		
Arcata	0.1	0.0
Bakersfield	0.3	2.4
Daggett	0.3	3.3
Fresno	0.3	2.1
Long Beach	2.2	0.4
Los Angeles	2.1	0.1
Sacramento	0.2	1.1
San Diego	2.4	0.2
San Francisco	0.1	0.1
Santa Maria	0.1	0.1
Colorado		
Alamosa	0.0	0.1
Boulder	0.2	0.6
Colorado Springs	0.6	4.2
Eagle	0.0	0.3
Grand Junction	0.1	1.0
Pueblo	0.5	1.1
Connecticut		
Bridgeport	3.2	0.3
Hartford	3.0	0.6
Delaware		
Wilmington	4.3	0.7
Florida		
Daytona Beach	12.3	1.7
Jacksonville	12.2	1.8
Key West	21.6	3.5
Miami	17.8	2.7
Tallahassee	11.6	1.7
Tampa	14.2	2.3
West Palm Beach	17.0	2.3
Georgia		
Athens	7.1	1.0
Atlanta	6.2	0.9
Augusta	7.7	1.3
Columbus	9.1	1.5
Macon	8.6	1.5
Savannah	10.1	1.5
Iowa		
Des Moines	2.9	0.7
Mason City	2.5	0.3
Sioux City	3.0	0.7
Waterloo	2.8	0.4
Idaho		
Boise	0.0	0.8
Pocatello	0.0	0.6
Illinois		
Chicago	2.6	0.5
Moline	3.1	0.7
Peoria	3.4	0.6
Rockford	3.0	0.4
Springfield	4.5	0.8
Indiana		
Evansville	5.6	1.0
Fort Wayne	3.1	0.4
Indianapolis	4.0	0.6
South Bend	3.4	0.5
Kansas		
Dodge City	2.4	1.3
Goodland	0.9	0.9
Topeka	5.2	1.0
Wichita	4.2	1.5
Kentucky		
Covington	4.0	0.6
Lexington	4.1	0.6
Louisville	5.0	0.9
Louisiana		
Baton Rouge	11.3	1.7
Lake Charles	13.5	1.7
New Orleans	12.3	1.8
Shreveport	9.7	1.7
Massachusets		
Boston	2.0	0.3
Worchester	1.9	0.2
Maryland		
Baltimore	4.7	0.8
Maine		
Caribou	1.0	0.1
Portland	1.9	0.2
Michigan		
Alpena	1.2	0.1
Detroit	2.4	0.3
Flint	1.8	0.3
Grand Rapids	2.0	0.3
Houghton	1.6	0.1
Lansing	2.4	0.4
Muskegon	1.8	0.2
Sault Ste. Marie	0.9	0.1
Traverse City	1.7	0.3
Minnesota		
Duluth	0.8	0.1
International Falls	7.7	0.1
Minneapolis	2.4	0.4
Rochester	2.3	0.3
Saint Cloud	1.8	0.3
Missouri		
Columbia	4.3	0.9
Kansas City	5.3	1.1
Springfield	5.6	1.0
St. Louis	5.3	1.1
Mississippi		
Jackson	9.9	1.7
Meridian	8.9	1.5
Montana		
Billings	0.1	0.6
Cut Bank	0.0	0.1
Glasgow	0.2	0.4
Great Falls	0.0	0.4
Helena	0.0	0.4
Kalispell	0.0	0.2
Lewistown	0.1	0.3
Miles City	0.1	0.6
Missoula	0.0	0.4
North Carolina		
Asheville	4.6	0.4
Cape Hatteras	9.0	0.7
Charlotte	5.8	1.0
Greensboro	5.8	0.7
Raleigh	6.0	0.9

Table 2: Ventilation cooling load indexes for 48 states.

	Tons-Hours per SCFM Per Year	
Wilmington	9.8	1.2
North Dakota		
Bismarck	1.0	0.4
Fargo	1.7	0.4
Minot	0.6	0.3
Nebraska		
Grand Island	2.6	0.8
Norfolk	2.4	0.8
North Platte	1.3	0.8
Omaha	4.0	0.8
Scottsbluff	0.5	0.8
New Hampshire		
Concord	2.0	0.4
New Jersey		
Atlantic City	4.1	0.6
Newark	3.1	0.6
New Mexico		
Albuquerque	0.2	1.0
Tucumcari	1.0	1.3
Nevada		
Elko	0.0	0.6
Ely	0.0	0.4
Las Vegas	0.2	3.7
Reno	0.0	0.8
Tonopah	0.0	0.9
Winnemucca	0.1	1.0
New York		
Albany	2.3	0.4
Binghamton	2.2	0.1
Buffalo	1.9	0.2
Massena	2.1	0.2
New York City	2.6	0.5
Rochester	2.4	0.4
Syracuse	2.1	0.3
Ohio		
Akron	2.5	0.3
Cleveland	2.4	0.4
Columbus	2.8	0.5
Dayton	2.9	0.4
Mansfield	2.5	0.4
Toledo	2.5	0.4
Youngstown	2.6	0.3
Oklahoma		
Oklahoma City	5.0	1.6
Tulsa	6.5	2.0
Oregon		
Astoria	0.2	0.0
Burns	0.0	0.3
Eugene	0.2	0.3
Medford	0.0	0.9
North Bend	0.1	0.0
Pendleton	0.1	0.7
Portland	1.8	2.3
Redmond	0.0	0.4
Salem	0.1	0.3
Pennsylvania		
Allentown	3.2	0.4
Bradford	1.5	0.1
Erie	2.4	0.2
Harrisburg	3.2	0.7
Philadelphia	4.1	0.6
Pittsburgh	2.5	0.4
Wilkes-Barre	2.5	0.3
Williamsport	3.4	0.4
Rhode Island		
Providence	2.4	0.3
South Carolina		
Charleston	9.0	1.2
Columbia	7.8	1.4
Greenville	5.8	0.9
South Dakota		
Huron	2.1	0.5
Pierre	1.3	0.8
Rapid City	0.3	0.5
Sioux Falls	1.9	0.8
Tennessee		
Bristol	4.2	0.5
Chattanooga	6.3	1.2
Knoxville	6.4	0.8
Memphis	7.8	1.6
Nashville	6.2	1.4
Texas		
Abilene	4.2	2.1
Amarillo	1.4	1.2
Austin	10.4	2.4
Brownsville	16.4	2.6
Corpus Christi	16.7	2.5
El Paso	1.2	2.2
Fort Worth	7.6	2.1
Houston	13.3	2.1
Lubbock	2.3	1.3
Lufkin	10.8	1.9
Midland	2.4	2.0
Port Arthur	14.0	1.9
San Angelo	4.4	2.0
San Antonio	10.4	2.4
Victoria	13.8	2.2
Waco	8.2	2.3
Wichita Falls	6.4	2.4
Utah		
Cedar City	0.0	0.7
Salt Lake City	0.1	1.1
Virginia		
Lynchburg	4.0	0.7
Norfolk	6.5	0.8
Richmond	5.9	0.8
Roanoke	4.1	0.6
Sterling	4.6	0.7
Vermont		
Burlington	1.8	0.3
Washington		
Olympia	0.2	0.2
Quillayute	0.1	0.0
Seattle	0.1	0.1
Spokane	0.0	0.4
Yakima	0.0	0.5
Wisconsin		
Eau Claire	2.1	0.3
Green Bay	2.0	0.3
La Crosse	2.8	0.4
Madison	2.2	0.4
Milwaukee	2.2	0.3
West Virginia		
Charleston	4.0	0.5
Elkins	2.8	0.2
Huntington	4.5	0.6
Wyoming		
Casper	0.0	0.4
Cheyenne	0.0	0.3
Lander	0.0	0.4
Rock Springs	0.0	0.3
Sheridan	0.0	0.5

opment, and the U.S. Department of Energy and the National Renewable Energy Laboratory in Golden, Colo., for generating and making available the TMY-2 data set, without which these indexes could not have been calculated. Also, we thank James Judge, P.E., Member ASHRAE, for use of the psychrometric routines contained in the BIN program, and for his assistance in assuring their accurate and appropriate use. Additionally, the members of ASHRAE Technical Committees 4.2 and 3.5 have provided generous and extensive assistance over the last eight years in assessing the effect of weather moisture on systems and supporting and guiding the effort to calculate and include correct values for peak moisture loads into non-proprietary industry reference books.

References

1. Shakun, Wallace, Ph.D, P.E. The Causes and Control of Mold and Mildew in Hot and Humid Climates (Air conditioner characteristics) *Transactions of ASHRAE*, 1992, V. Pt. 1, AN-92-18-2 American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

2. ASHRAE Technical Committee 3.5, Harriman et.al. Desiccant Cooling & Dehumidification. ASHRAE Special Publication, 1992.

3. The American Hotel & Motel Association Executive Engineer's Committee, Salmen et.al. Mold & Mildew in Hotels and Motels, 1991. A survey report of the AH&MA, Washington, DC.

4. Thomann, Wayne R. Dr. P.H and Tulis, Jerry J. Ph.D. *Fungal Contamination of HVAC Surfaces: The Role of Dewpoint in Microbial Amplification*. Proceedings of IAQ/96, pp. 25-29. Baltimore, MD. 1996 ASHRAE, Atlanta, GA.

5. *ANSI/ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality*, Table 2, Outdoor air requirements for ventilation. 1989. ASHRAE, Atlanta, GA.

6. *1993 ASHRAE Handbook—Fundamentals*, Figure 5, Chapter 8, Standard effective temperature and ASHRAE comfort zones. ASHRAE, Atlanta, GA.

7. National Renewable Energy Laboratory, Marion, Upton et.al. 1995. Typical meteorological years derived from the 1961-1990 National Solar Radiation Database. NREL, Golden, CO.

8. Kosar, Douglas, Plager, Dean and Harriman, Lewis G. III. Bin-Maker© Weather summary generator, 1997. Gas Research Institute, Chicago, IL.

9. SPSS Professional Statistics, Release 7.0, 1996. SPSS Inc. Chicago, IL.

10. Judge, James, P.E. PSYCHLIB dynamic link library, 1996, Psychrometric library subroutines based on *1993 ASHRAE Handbook—Fundamentals*. LINRIC Company, Bradford, MA.

11. Colliver, Donald, Ph.D, P.E. et al. Determination of the 0.4%, 1% and 2% annual occurrences of temperature and moisture and the 99% and 98% occurrences of temperature for 1400 national and international locations. 1997. ASHRAE Research Project RP-890, ASHRAE, Atlanta, GA. ■

Please circle the appropriate number on the Reader Service Card at the back of the publication.

Extremely Helpful 454
Helpful 455
Somewhat Helpful 456
Not Helpful 457