PRECONDITIONING OUTSIDE AIR: COOLING LOADS FROM BUILDING VENTILATION

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ABSTRACT

HVAC equipment manufacturers, specifiers and end users interacting in the marketplace today are only beginning to address the series of issues promulgated by the increased outside air requirements in ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality", that has cascaded into building codes over the early to mid 1990's. There has been a twofold to fourfold increase in outside air requirements for many commercial building applications, compared to the 1981 version of the standard. To mitigate or nullify these additional weather loads, outdoor air preconditioning technologies are being promoted in combination with conventional HVAC operations downstream as a means to deliver the required fresh air and control humidity indoors. Preconditioning is the term applied for taking outside air to the indoor air setpoint (dry bulb temperature and relative humidity).

The large humidity loads from outside air can now be readily recognized and quantified at cooling design point conditions using the extreme humidity ratios/dew points presented in the ASHRAE Handbook of Fundamentals Chapter 26 "Climatic Design Information". This paper presents an annual index called the Ventilation Load Index (VLI), recently developed by the Gas Research Institute (GRI) that measures the magnitude of latent (and sensible) loads for preconditioning outside air to indoor space conditions over the course of an entire year. The VLI has units of ton-hrs/scfm of outside air. The loads are generated using new weather data binning software called BinMaker™, also from GRI, that organizes the 239 city, 8760 hour by hour, TMY2 weather data into user selected bin/tables. The VLI provides a simple methodlogy for accessing the cooling load impact of increased ventilation air volumes and a potential basis for defining a "humid" climate location.

INTRODUCTION

In the commercial sector marketplace today, indoor air quality (IAQ) equates directly to outside air quantity, as prescribed by the 1989 version of ASHRAE Standard 62 "Ventilation for Acceptable Indoor Air Quality" [1]. During the early 1990's, these ventilation rates were adopted by all three major model building codes [2,3,4]. In turn, those revised model codes were accepted into many state and local codes by the mid 1990's. In response to the appearance of sick building syndrome in the 1980's, Standard 62-1989 prescribed a twofold to fourfold increase in outside air requirements for many applications over the 1981 standard [5]. For example, non-smoking area outside air requirements changed from 5 to 10 cfm/person for retail spaces, from 7 to 15 cfm/person for auditoriums, from 7 to 20 cfm/person for meeting rooms, and from 5 to 20 cfm/person for offices.

Moisture loads present in outside air are finally being given long overdue recognition with the publication of the 1997 edition of the ASHRAE *Handbook of Fundamentals* [6]. The 1993 Handbook (Chapter 24) contains only cooling design data for dry bulb temperatures (1%, 2.5% and 5% summer conditions now replaced by 0.4%, 1% and 2% annual conditions in 1997 edition) [7]. The 1997 edition (Chapter 26) now also contains the design dew point temperature and design humidity ratio. This design dew point/humidity ratio has been the long overlooked "other peak cooling condition." In fact, in non-arid climates, the cooling load resulting from outside air is larger at the design dew-point/humidity ratio than at the design dry bulb[8].

To assist cooling equipment in meeting the challenge of larger ventilation loads, several technologies are succeeding in commercial buildings. Technologies such as subcool/reheat and heat pipe reheat show promise. These approaches increase latent capacity of cooling systems by reducing their sensible capacity. Also, desiccant wheels as either enthalpy exchangers or thermally regenerated dehumidifiers are pretreating outside air for cooling systems.

Regardless of which mix of technologies is best for which applications, there is a need for a more effective way of thinking about the cooling loads created by ventilation air over the course of a year not just at design conditions. The Ventilation Load Index introduced in late 1997[9], is an engineering shorthand, an annual load index for ventilation air to aid in the complex process of improving the ability of HVAC systems to deal efficiently with the amount of fresh air that the standard/code authorities have decided is necessary for maintaining IAQ in buildings.

VENTILATION LOAD INDEX (VLI)

The 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 latent (dehumidification or moisture removal) and sensible cooling (temperature reduction) load components: latent ton-hours per scfm per year plus sensible ton-hours per scfm 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 scfm, and the annual sensible load is 1.1 ton-hours per scfm.

The VLI was 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. These 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 this way, the ventilation load index allows for quick comparisons between loads in different geographic locations. As a result, the index can help an engineer consider how the HVAC system design and equipment selection should vary according to climate and amount of outside air. It can potenitally serve as basis for defining a "humid" climate location, as well [10].

To calculate the VLI 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 setpoints to compare with the weather conditions. In calculating the indexes presented in Table 1, the "space-neutral" conditions are defined as 75°F, 50%rh (65 gr/lb at sea level). One could have chosen different set points for specialty applications, as will be illustrated later, but 75°F, 50%rh seems to represent an upper level of tolerance of many commercial building users based on informal input from engineers and owners of commercial buildings. Those baseline values seem consistent with human comfort research findings, as well. This setpoint 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[7].

The baseline latent ton-hours per standard cubic feet per minute (scfm) in a given hour are calculated as follows:

Latent ton-hours per scfm =
((Outside air humidity ratio - gr/lb @ 75°F, 50%rh) x 4.5 x 1050)
÷ (7000 x 12,000)

Where 4.5 is the lbs of air per hour per scfm; 1050 is the heat of vaporization of water at standard temperature and pressure in Btu per lb; 7000 is the grains of water vapor per lb; and 12,000 represents the Btus 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 VLI.

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

Sensible ton-hours per scfm =
((Outside dry bulb - 75°F) x 1.08) ÷ 12,000

Where the outside dry bulb is the dry bulb temperature in degrees Fahrenheit; 1.08 is a factor that converts temperature differences into energy differences (using the specific heat of air and its density at standard conditions) on a per scfm basis as follows:

$$(60 \text{ min/hr}) \times (.24 \text{ Btu/lb °F}) \times (.075 \text{ lb/ft}^3) = 1.08 \text{ (Btu/hr)/(scfm °F)}$$

; and 12000 represents the number of Btus 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, 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 humidity set point of 50%rh at 75°F, then no "credit" is subtracted from the cumulative total annual latent load for that hour.

VLI CALCULATION SOFTWARE

To calculate the VLIs, the TMY-2 data set of hourly weather observations was used along with a newly-developed computer program which accesses those data sets in order to perform annual summaries.

The TMY-2 data set was selected for several reasons. First, it contains complete records for 239 locations within the U.S, 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 [11] using public funds, and as such, are nonproprietary, in the public domain and readily available to the public through the National Technical Information Service.

The acronym TMY stands for "Typical Meteorological Year". The "2" designator represents the fact that this 239-file data set was produced using the second, most current file format for the TMY methodology. That methodology is based on the concept of selecting "typical" months of weather observations from a long-term record of hourly observations. A "typical" month is selected from the 30-year record based on how closely it conforms 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. Then, to join different monthly records together smoothly, interpolation is applied at the end of one month and the beginning of another.

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 dewpoint. Consequently, the months selected contain solar data which is slightly "more average" than the dry bulb and dewpoint 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.

The computer program which calculated the indices is named BinMaker^{TM} and was developed initially to produce custom bin weather data and joint-frequency tables of temperature, humidity and wind speed to be used for estimating annual building loads and HVAC system energy consumption. The program, funded by the Gas Research Institute in cooperation with committees of ARI and ASHRAE, was released to the public for sale in early 1998[12].

The program is written in a popular graphical version of the BASIC programming language. It runs on the presently most widely-used operating system for personal computers, when they are equipped with at least 8 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 program's "ventilation preconditioning bins" routine looks at each hour's ambient dry bulb temperature and humidity ratio, and calculates the difference between them and the building set points for temperature and humidity. The program allows the user to select the set point values for the building. For these indexes, we chose 75°F, 50%rh, 65 gr.lb. 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 in a given hour, there is no sensible load. But if the moisture outdoors during that same hour is 85 gr/lb, then there is a moisture load to be removed when ventilation air is brought to the target value of 65 gr/lb.

BASELINE VLI VALUES

The baseline latent and sensible VLIs (based on the 75°F/50% rh building indoor setpoints) for 56 cities in 10 states in the hot, humid southeastern region of the U.S. are contained in Table 1.

Except for the arid climate of west Texas (see El Paso in Table 1), the latent loads are always higher than the sensible loads. Even in San Antonio, or other central and western cities in Texas, which most would assume have arid climates, the annual latent load exceeds the sensible load by up to 4 times.

As one would expect, the total annual cooling loads are larger in the more southern locations. For example, the sum of the latent and sensible loads in Miami, FL are 20.5 ton-hours per scfm per year, and loads in Nashville, TN only total 7.6 ton-hours per scfm per year—Miami's VLI is nearly 3 times that of Nashville. However, the ratio of latent to sensible loads does not always vary by similar amounts between locations. In Miami, the latent load exceeds the sensible by 6.7 to 1. But in Nashville, the latent load still exceeds the sensible load by 4.4 to 1

State/City	Latent VLI	Sensible VLI
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
Florida		
Daytona Beach	12.3	1.7
Jacksonville	12.2	1.8
Key West	21.6	3.5
Miami	17.6	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
Louisiana		
Baton Rouge	11.3	1.7
Lake Charles	13.5	1.7
New Orleans	12.3	1.8
Shreveport	9.7	1.7
Mississippi		
Jackson	9.9	1.7
Meridian	8.9	1.5
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
Wilimington	9.8	1.2
South Carolina		
Charelston	9.0	1.2
Columbia	7.8	1.4
Greenville	5.8	0.9

State/City	Latent VLI	Sensible VLI
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

Table 1. Baseline VLI Values for 56 Cities (based on the 75°F/50% rh building indoor setpoints).

OTHER VLI VALUES

Specialty applications may have setpoints well below the 75°F, 50%rh (65 gr/lb at sea level) typical of most commercial buildings. In such buildings, factors other than human comfort dictate the building control levels. Some examples are: ice arenas and refrigerated warehouse loading dock areas at 55°F, 40%rh (25 gr/lb at sea level); supermarkets at 75°F, 35%rh (45 gr/lb at sea level); and hospital ORs at 65°F, 50%rh (45 gr/lb at sea level). Hospital surgical suites now generally require these lower temperatures with humidity control and the other applications obtain improvements in refrigeration operations, especially from the drier air. The increases in the latent or dehumidification VLI for specialty application building types for a few selected cities from Table 1 is illustrated in Figure 1.

Depending on the setpoints in these specialty buildings, the latent VLI can more than double the baseline VLI.

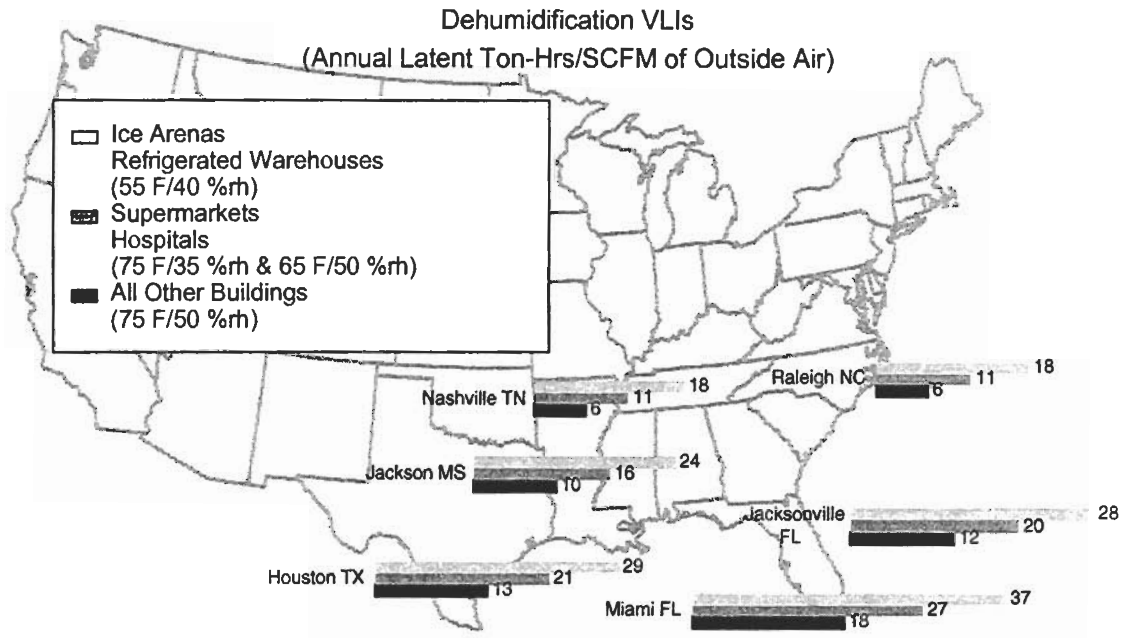

Figure 1. Specialty Application VLIs.

PRORATEDVLI VALUES

Most commercial buildings do not operate HVAC systems 24 hours a day, 7 days a week year round – a full 8760 hours. Two building operating schedules were inputted to the ventilation preconditioning bins routine in BinMaker™. One schedule more typical of an office building required ventilation air Monday through Friday from 8:00 AM to 5:00 PM year round. The other schedule represented a movie theater operating schedule with ventilation air required every day from 2:00 PM through midnight.

As Table 2 indicates the sensible VLI does not proportion accurately based on a simple ratio of actual operating hours over 8760 hours. Prorating the sensible VLI appears more erroneous for operating schedules dominated by daylight hours. However, the limited data presented in the table does suggest that the latent LVI can be proportioned by the simple operating hour ratio regardless of the nature of operating schedule. This result may be rather intuitive given the strong diurnal swings in dry bulb temperature, whereas humidity ratio changes are related more to weather pattern variations over the course of days rather than daily solar energy inputs.

City	VLI	Baseline Operation 8760 Hours	Actual Mo - Fr 8AM - 5PM 2340 Hours	Prorated = Baseline x 2340/8760	Actual Mo -Su 2PM - Midnite 4015 Hours	Prorated = Baseline x 4015/8760
Houston, TX	Latent	13.3	3.5	3.6	6.1	6.1
	Sensible	2.1	1.0	0.6	1.2	1.0
Jackson, MS	Latent	9.9	2.6	2.6	4.4	4.5
	Sensible	1.7	0.9	0.5	0.9	0.8
Raleigh, NC	Latent	6.0	1.8	1.6	2.7	2.7
	Sensible	0.9	0.5	0.2	0.6	0.4

CONCLUSIONS

Examination of typical behavior of weather in more humid climates 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 – Ventilation Load Indexes or VLIs -- presented in Table 1 to quickly assess the importance of this fact for the operation of a cooling system in a given location. It appears the latent component of the annual VLI can be prorated based on a simple ratio of scheduled operating hours to 8760 hours.

The implications of the indices for cooling system operation will vary according to the importance of controlling humidity and the volume of outside air needed for a given application. In cooling system applications where the ventilation air requirement may be more than 15% to 20% of the total system airflow, assistance from a separate subsystem for ventilation air, or modification to trade part of its sensible capacity for increased latent removal capacity, should be considered [13]. To size those components after they are selected, the designer can refer to Chapter 26 of the 1997 ASHRAE Handbook of Fundamentals, which, for the first time, includes separate values for peak moisture and peak temperature.

The VLI has units of ton-hrs/scfm of outside air. The loads are generated using new weather data binning software called BinMaker™, that organizes the 239 city, 8760 hour by hour, TMY2 weather data into user selected bin/tables. The VLI provides a simple methodlogy for accessing the cooling load impact of increased ventilation air volumes, as well as a potential basis for defining a "humid" climate location.

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