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Energy Requirements for Conditioning of Ventilating Air

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SYNOPSIS

The energy impact involved between bringing in outdoor air for indoor air pollution reduction and the energy required to condition this air are investigated in this report. Long-term hourly weather data from several European and American locations were analyzed to determine the average conditions of air over the period of record of the data. These data were then analyzed to determine the psychrometric process theoretical heating, cooling and moisture removal energy requirements for a constant mass of airflow per hour (MJ·h/kg). This paper summarizes the information contained in a longer report [3].

It was found that a significant amount of energy is required to condition air which is used for ventilation. The annual energy required per kg-dry-air/hr of airflow varied from 22.1 MJ·h/kg for Los Angeles to 102.5 MJ·h/kg for Omaha. In Europe the range was from 45.6 MJ·h/kg for Nice to 101.1 MJ·h/kg for Saint-Hubert. In Europe most of the energy was used to heat the air to the desired setpoint. In America there were significant amounts of both heating and cooling required. Much of the variation was due to the amount of moisture in the air which had to be removed in air conditioning. In situations where air conditioning is used, a significant amount of this energy is used in dehumidifying the air. For example, in Miami 86% of the energy is used for moisture removal. It was also found that the energy used was highly sensitive to the heating, cooling and relative humidity setpoints.

1. INTRODUCTION

Outdoor air is brought into buildings for many different reasons such as free cooling, "fresh air" and pollution reduction. Over the last several years structures have been built tighter to reduce air infiltration and conserve energy used to heat the air coming into the building. Several standards and organizations have been specifying minimum amounts of "fresh" outdoor air for indoor air quality purposes. There have been several questions however about the energy impact and/or tradeoffs involved between bringing in outdoor air (for pollution reduction) and the energy required to condition this air. This work is intended to provide an initial estimate of the theoretical energy required.

2. OBJECTIVES

The objectives of this work are: first to determine the theoretical energy requirements per constant mass unit of outdoor air used for ventilation for a number of different climates and locations in North America and Europe; and secondly to determine the variation of this annual ventilation heating and cooling energy requirements due to the setpoints for temperature and humidity.

3. PSYCHROMETRIC PROCESSES ASSOCIATED WITH VENTILATION

A psychrometric chart is a visual presentation of the possible characteristics of an air-water vapor mixture and is often used to describe the possible conditions or statepoints which may be obtained by the air. The psychrometric chart is commonly used to determine the heat and moisture changes in the air as it goes from one condition (such as 32 °C, 65% relative humidity outdoor air) to another condition (26 °C, 40% relative humidity) such as inside a building.

The psychrometric chart can also be used to determine the heat and moisture which must be added or subtracted from the air. Therefore if the average conditions of the outdoor air are known, the theoretical energy which must be added or subtracted from the air to heat, cool and/or dehumidify it when the air enters the building may be determined.

The amount of sensible energy need to heat or cool air is calculated from:

$$\text{Sensible} = (C_{pa} + W * C_{pw})(t_{db\text{-}setpt} - t_{db\text{-}outside}) \quad (1)$$

where:
C_{pa} = Specific heat of dry air (1.0056 kJ/kg-dry air·°C)
W = Amount of moisture in the air (kg)
C_{pw} = Specific heat of water vapor (1.86 kJ/kg water·°C)
$t_{db\text{-}setpt}$ = Setpoint dry-bulb temperature (°C)
$t_{db\text{-}outside}$ = Outside dry-bulb temperature (°C)

Latent heat is that energy which must be added or withdrawn when water is vaporized (in the case of humidification) or condensed (in the case of dehumidification) from the air. The latent heat transfer, or the energy which must be used for moisture control with humidification/dehumidification, can be determined from the amount of moisture which must be added or removed as:

$$\text{Latent} = L * \Delta W \quad (2)$$

where:
L = Latent heat of vaporization (2501.3 kJ/kg water)

The amount of water which must be subtracted from the air is:

$$\Delta W = H_{setpt} - H_{outside} \quad (3)$$

where:
H_{setpt} = Humidity ratio of the air at the setpoint (kg water vapor/kg dry air)
$H_{outside}$ = Humidity ratio of the outside air (kg water vapor/kg dry air)

If two independent measurements (such as dry-bulb and relative humidity) and the air pressure are known, the others characteristics (such as humidity ratio, wet-bulb temperature, dew-point temperature, etc) may be determined from the psychrometric chart or from equations which mathematically describing it. The computerized psychrometric routines used in this work [5, 9] are available via anonymous ftp in the directory /pub/bae/psych at the site: ftp.ca.uky.edu.

The psychrometric chart may be divided into several regions where the air being described by that region undergoes the same psychrometric process to reach the desired condition of temperature and moisture content. If the average condition (over all the hours the air is within that region) for the air within that region is known, then the energy and moisture which must be added or subtracted may then be determined. The conditions of the outdoor air fall into six different regions on the chart with respect to the desired condition of the air in the building (see Figure 1).

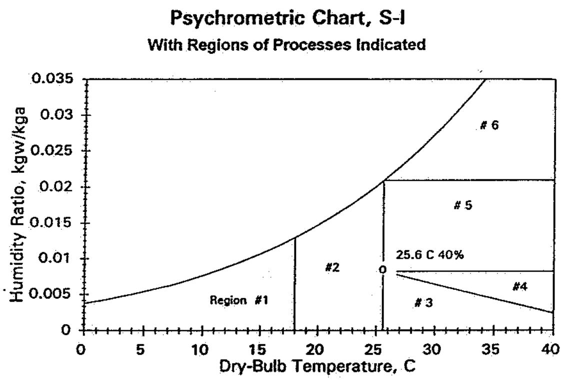

Figure 1. Psychrometric Chart with Regions of Processes Used to Reach Desired Statepoint

Region 1: Outdoor Dry-Bulb Temperature Less Than Heating Setpoint ($T_{db\text{-}outdoor} < T_{dbh\text{-}setpt}$) (Heating Region)

This is the typical wintertime condition when heat is being added to the ventilation air. In this case only sensible heat is added to the air to reach the desired statepoint since typically moisture is not controlled in heating situations. There is no intentional latent heat exchange in this region.

Region 2: Outdoor Dry-Bulb Temperature Greater Than Heating Setpoint but Less Than Cooling Setpoint ($T_{dbh\text{-}setpt} < T_{db\text{-}outdoor} < T_{dbc\text{-}setpt}$) (No Heating or Cooling Region)

This is the condition when the outdoor air does not need to be either heated or cooled. It represents the moderate weather conditions typically encountered during the spring and fall or at other times when neither heating or cooling are needed. This also represents the situation when the outdoor air is being introducing into the building for natural ventilation. In this case there is no sensible or latent energy exchange required to condition the air.

Region 3: Dry-Bulb Temperature Greater Than Cooling Setpoint Temperature and Wet-Bulb Less Than Desired Wet-Bulb ($T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} < T_{wbc\text{-}setpt}$) (Evaporative Cooling Region)

The air in this region has a higher dry-bulb temperature than desired, however the outdoor wet-bulb temperature is less than the wet-bulb of the design setpoint. This condition is typically associated with hot, dry weather. Evaporative cooling (a process which approximately follows the wet-bulb line) can be used in this psychrometric region to provide the desired reduction in dry-bulb temperature. The sensible energy used to cool the air comes from the latent heat of evaporization of the water added to the air. Since there is an exchange of sensible and latent heat in this region and in practice the energy required is for pumping/spraying which has comparatively small energy expenditure, the sensible and latent energy requirements for this region will not be included in the total energy requirements.

Region 4: Outdoor Dry-Bulb and Wet-Bulb Temperatures Greater Than Cooling Setpoint Temperatures, Dew-Point Less Than Setpoint ($T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} > T_{wbc\text{-}setpt}$, $T_{dp\text{-}outdoor} < T_{dpc\text{-}setpt}$) (Refrigerative and Evaporative Cooling Region)

Air in this region may be partially cooled with evaporate cooling (up to the dew-point of the setpoint) and then external energy must be used to remove the remaining sensible heat if moisture conditioning is achieved. In many cases, cooling is only controlled based upon dry-bulb temperature and moisture is controlled with the system design. For the purposes of this study, the total energy required is the net of the sensible and latent heats.

Region 5: Outdoor Dry-Bulb Temperature Greater Than Cooling Setpoint Temperature, Outdoor Dew-Point Greater than Setpoint and Less Than Saturation ($T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} > T_{wbc\text{-}setpt}$, $T_{dpc\text{-}setpt} < T_{dp\text{-}outdoor} < T_{dpc\text{-}sat}$)
(Refrigerative Cooling Region, Dew-point less than Setpoint Saturation Temperature)

Air in this region must have both sensible heat and moisture (latent heat) removed to maintain the desired setpoint. The amount of moisture removed may be used to determine the amount of latent heat which is removed for humidity control. The sensible and latent energy requirements in this region are defined by eqns 1 and 2.

Region 6: Outdoor Dry-Bulb and Dew-Point Temperatures Greater Than Cooling Dry-Bulb Setpoint Temperature and Dewpoint at Saturation ($T_{db\text{-}outdoor} > T_{dbc\text{-}setpt}$, $T_{wb\text{-}outdoor} > T_{wbc\text{-}setpt}$, $T_{dp\text{-}outdoor} > T_{dpc\text{-}sat}$) (Refrigerative Cooling Region, Dew-point greater than Setpoint Saturation Temp)

Air in this region is hot and humid. The latent (moisture) heat removal is the significant energy requirement to maintain the desired conditions. The sensible and latent energy requirements in this region are defined by eqns 1 and 2.

It should be recognized that the energy values presented are for the minimum theoretical enthalpy changes of the air and the total amount of equipment energy used in Regions 4,5 and 6 may be larger than the theoretical energies given due to the system design and equipment efficiencies.

4. PROCEDURE

Estimates were made of the theoretical amount of energy needed to condition a constant airflow rate of one kg of dry air per hour (kg/hr) of outdoor air used for ventilation. These estimates were made using measured hourly weather data from a number of locations and the theoretical energy and moisture change needed to condition the air to the desired statepoint. The weather data for each location were analyzed to determine the number of hours the outdoor air conditions fell within each psychrometric process region and the weighted average air property for each region. The sensible and latent energies required in each of the psychrometric process regions were then determined by calculating the energy difference between the air statepoint representing the average condition for all the hours within that region and the air at the desired setpoint. Energy values from each of the processes were then combined to determine the total energy per unit mass of ventilation. The effects of equipment and different heating and/or cooling techniques are not included due to the wide variety and efficiencies of possible equipment. Summary weather data are provided in [3] to determine these effects if desired.

4.1 ENERGY TRANSFER SUMMARY

The sensible energy which must be used over all the psychrometric regions to heat to the desired heating setpoint and cool to the desired cooling setpoint is the sum of the heating and cooling energy requirements, or:

$$Sen_{total} = S_1 + | S_4 + S_5 + S_6 | \qquad (5)$$

where S represents equation 1 and the subscript represents the region.

The total latent energy which must be removed to obtain the desired cooling humidity conditions is:

$$Lat_{total} = | L_4 + L_5 + L_6 | \qquad (6)$$

where L represents equation 2 and the subscript represents the region.

The theoretical total energy which must be supplied to maintain the desired conditions is the sum of the sensible and latent heat transfers or:

$$Energy_{Total} = Sen_{total} + Lat_{total} \qquad (7)$$

4.2 WEATHER DATA SOURCES

Measured hourly weather data from a number of locations in North America and Europe were used to determine the average outdoor weather conditions. Long-term (30 years) hourly weather data for 238 US locations are available in the SAMSON data set [8]. A subset of these weather data sets was selected based upon their climate classification region [4, 7] to be representative of the range of climates and weather conditions experienced in America [2]. European locations were selected based upon the availability of hourly weather data. Hourly weather data for most of the British locations were obtained from the CIBSE Example Weather Years, EWY [6]. Weather data for other European locations and four additional UK locations were obtained from the CEC Test Reference Years [1]. The selected American and European locations are presented in Table 1.

4.3 DETERMINATION OF THE AVERAGE CONDITION FOR EACH PSYCHROMETRIC REGION

The "average air" in each psychrometric region for each location was determined by analyzing the measured weather data. Coincident matrices or arrays were made which contained the number of hours each dew-point temperature occurred coincidentally with each dry-bulb temperature. These X-Y arrays (X dry-bulb temperature vs Y dew-point temperature) contained the number of occurrences of Y dew-point temperature which had occurred at X dry-bulb temperature. Thirteen (12 monthly and one yearly total) matrices were determined from the long-term weather data for each location. One °C bins were used for both dry-bulb and dew-point temperatures.

The "average air" statepoint for each region was then determined from the matrices by assuming that it was a mixing process of all the occurrences of conditions within a psychrometric region. In this situation each dry-bulb/dew-point combination was weighted by the number of hours of occurrence of that condition in the historical data set. Dry-bulb and absolute humidity for the given dew-point were the psychrometric parameters used in the mixing routines. The psychrometric properties were calculated using C^{++} routines [5,9]. Standard air pressure based upon station elevation was used for all the mixing calculations.

The average percentage of the annual hours in each psychrometric region and the corresponding average dry-bulb temperature and humidity ratio are given in [3] for each of the locations investigated. The percentage of the total number of hours in each region is given for four locations in the pie charts in Figure 2.

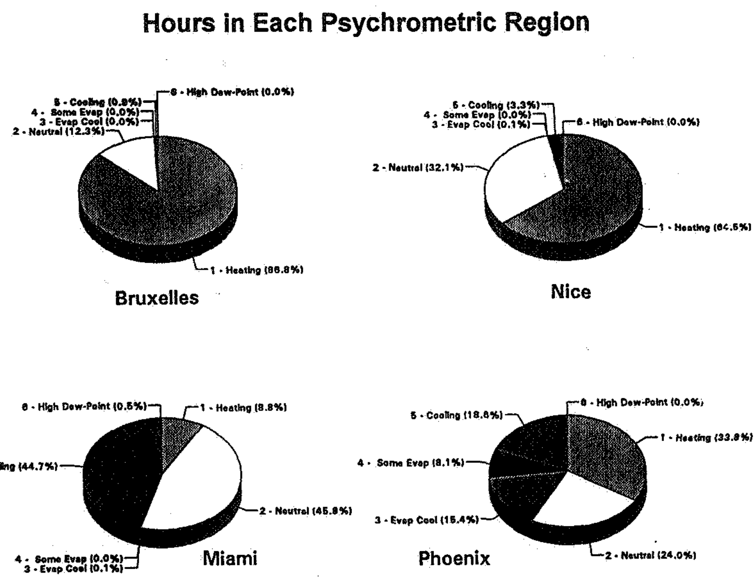

Figure 2. Pie Chart with Percentage of Hours in Each Psychrometric Region

5. RESULTS AND DISCUSSION

5.1 ANNUAL HEATING ENERGY REQUIREMENTS

The amount of sensible heating required for conditioning a constant airflow of one kgdryair/hr of ventilating air to 18 °C was determined for each of the locations and is presented in Table 1. This setpoint was used to closely correspond to a setpoint commonly used in some American standards which relate to air infiltration and ventilation (ASHRAE Standards 119 and 136).

There is a significant amount of energy used to heat the incoming air. For the 18°C setpoint it varies from approximately 101 MJ·h/kg for Saint-Hubert, Belgium (cold climate) to 3.3 MJ·h/kg for Miami, USA (warm climate). These account for 99.6% and 2.3% of the total energy for each location respectively.

Sometimes it is assumed that the entering air needs to be heated to a temperature less than the setpoint due to solar and internal heat gains. A sensitivity analysis of the energy required to heat the air to 1,2, and 3 degrees less than the setpoint (i.e. 17, 16, & 15 °C respectively) was conducted. It was found that for the locations selected in this work which had a significant amount of heating required that there was approximately a 10% (7.2 MJ·h/kg) reduction in this energy for every °C of reduction in the setpoint. The expanded version of this work [3] also contains an equation with location dependent coefficients which describe the variation of the heating requirements over a range of setpoints from 5 to 40 °C.

5.2 ANNUAL SENSIBLE AND LATENT COOLING ENERGY REQUIREMENTS

The total theoretical sensible and latent energy exchange required for humidity control and cooling to the desired statepoint of 25.6 °C and 40% RH for psychrometric regions 4 through 6 are presented in Table 1. The sensible and latent energy exchange for each of the regions 3 through 6 are contained in [3].

These results indicate that conditioning of air to provide cooling and dehumidification can require significant amounts of energy. The greatest amount of sensible cooling was required in Phoenix, AZ (20.2 MJ·h/kg dry air) and the greatest amount of latent cooling was required in Miami, FL (82.2 MJ·h/kg). The total cooling load (combined sensible and latent) is highest in Miami (92.1 MJ·h/kg) which has a hot humid climate.

On the average (each station weighted evenly), latent cooling required 65.3% of the total cooling load for all the locations investigated. When only those locations requiring more than 5 MJ·h/kg are considered (i.e. consider only those locations typically requiring air conditioning), the latent cooling required 79.7% of the total cooling load. This implies that more energy is used in air conditioning for moisture control than dry-bulb temperature control.

Variation of Energy Required due to Setpoint:

The effect of the cooling dry-bulb temperature setpoint on the energy required was determined by changing the setpoint plus and minus two °C for those locations which had greater than 5 MJ·h/kg cooling load. A great sensitivity of the cooling energy requirements to the control setpoint selected was found [3]. The greatest change in energy requirements was for Miami where the cooling energy required at 2 higher and lower setpoints was 151.4% and 49.5% of the energy required at 25.6 °C.

Variation of Energy Required due to Humidity Design Setpoint:

The latent energy requirements previously identified indicate that a significant amount of the energy used is for dehumidifying the air to the desired condition. Thus the design relative humidity greatly impacts the energy requirements. (The energy requirements were determined initially for a 40% relative humidity design.) In order to determine the sensitivity of the relative humidity setting, the energy required for relative humidity designs of 60% and 80% were also determined for the 25.6 °C setpoint.

Increasing the relative humidity setpoint from 40% to 60% had a significant impact on the energy requirements for those locations with significant cooling requirements. The energy requirements at 60% RH relative to that required at 40% RH ranged from 15.2% for Carpentras to 59.0% for Brownsville. When the setpoint was raised to 80% there was an even greater reduction in the energy requirements. The fraction of energy required at 80% RH ranged from 0.0% to 21.2% of that when the setpoint was 40% RH.

5.3 COMBINED ANNUAL SENSIBLE, LATENT AND TOTAL ENERGY REQUIREMENTS PER UNITARY AIRFLOW RATE

The combined heating and cooling sensible, latent and total energy requirements (based on the 18°C heating, and 25.6°C, 40% cooling setpoints) are presented for each of the locations in Table 1 and Figure 3. This is the total theoretical energy required over the entire year which must be supplied to condition the ventilation air to the desired conditions. The total energy required ranged from 22.1 to 102.5 MJ·h/kg in America (Los Angeles and Omaha) and from 45.6 to 101.1 in Europe (Nice and Saint-Hubert). Heating accounted for almost all the energy used for conditioning ventilating air in Europe with the maximum air conditioning load being 5.5 MJ·h/kg (12.1% of total) in Nice. In America the fraction of the total energy used for cooling varied from 96.5 to 0.1% (92.1 to 0.1 MJ·h/kg for Miami and Cheyenne respectively). The latent load was larger than the sensible load for air conditioning in all the locations with a significant cooling load except Phoenix which has a hot dry climate.

6. SUMMARY

Estimates were made of the theoretical amount of energy needed to condition a constant airflow rate of one kg of dry air per hour (kg/hr) of outdoor air used for ventilation. These estimates were made using measured hourly weather data from a number of locations and the theoretical energy and moisture change needed to condition the air to the desired statepoint. It was found that a significant amount of energy is required to condition air used for ventilation. The annual energy required per kg/hr of airflow varied in America from 22.1 MJ·h/kg for Los Angeles to 102.5 MJ·h/kg for Omaha. In Europe the range was from 45.6 MJ·h/kg for Nice to 101.1 MJ·h/kg for Saint-Hubert. In Europe most of the energy was used to heat the air to the desired setpoint. In America there were significant amounts of both heating and cooling required. Much of the variation was due to the amount of moisture in the air which had to be removed in air conditioning. In situations where air conditioning is used, a significant amount of this energy is used in dehumidifying the air. For example in Miami 86.1% of the energy is used for moisture removal.

Table 1. Annual Sensible, Latent and Total Energy Requirements (MJ·h/kg dry-air)

			Total Heating (MJ·h/kg)	Cooling Sensible (MJ·h/kg)	Cooling Latent (MJ·h/kg)	Total Cooling (MJ·h/kg)	TOTAL HEATING & COOLING (MJ·h/kg)
1	BEL	Bruxelles	73.4	-0.1	-1.0	-1.1	74.5
2	BEL	Oostende	76.0	0.0	0.0	0.0	76.0
3	BEL	Saint-Hubert	101.1	0.0	0.0	0.0	101.1
4	DK	Copenhagen	89.6	0.0	-0.1	-0.1	89.7
5	FR	Carpentras	55.0	-1.8	-3.5	-5.3	60.3
6	FR	Limoges	70.3	-0.3	-0.7	-1.0	71.3
7	FR	Macon	72.4	-0.6	-1.7	-2.3	74.7
8	FR	Nancy	78.7	-0.2	-0.9	-1.1	79.7
9	FR	Nice	40.1	-0.4	-5.1	-5.5	45.6
10	FR	Trappes	74.5	0.0	-0.3	-0.3	74.8
11	GB	Aberdeen	88.2	0.0	0.0	0.0	88.2
12	GB	Aberporth	72.7	0.0	-0.1	-0.1	72.8
13	GB	Aberporth,CEC	73.9	0.0	0.0	0.0	73.9
14	GB	Aldergrove	82.2	0.0	0.0	0.0	82.2
15	GB	Birmingham	77.0	0.0	-0.1	-0.1	77.1
16	GB	Bristol	82.1	0.0	0.0	-0.1	82.2
17	GB	Camborne	67.0	0.0	0.0	0.0	67.0
18	GB	Dundee	84.6	0.0	0.0	0.0	84.6
19	GB	Eskdalemuir	95.1	0.0	0.0	0.0	95.1
20	GB	Eskdalemuir,CEC	96.1	0.0	0.0	0.0	96.1
21	GB	Glasgow	81.2	0.0	-0.1	-0.1	81.2
22	GB	Heathrow	67.6	0.0	-0.2	-0.2	67.8
23	GB	Kew	71.7	0.0	0.0	0.0	71.7
24	GB	Kew, CEC	70.4	0.0	0.0	-0.1	70.5
25	GB	Lerwick, CEC	97.5	0.0	0.0	0.0	97.5
26	GB	Manchester	78.6	0.0	-0.1	-0.1	78.7
27	GB	Newcastle	88.0	0.0	0.0	0.0	88.0
28	GB	Norwich	79.5	0.0	-0.3	-0.4	79.8
29	GB	Sheffield	80.4	0.0	-0.1	-0.1	80.5
30	NL	DeBilt	77.5	-0.1	-0.2	-0.3	77.9
31	NL	Eelde	83.2	0.0	-0.1	-0.1	83.2
32	NL	Vlissingen	69.8	0.0	0.0	0.0	69.9
33	USA	Boston, MA	77.3	-1.4	-5.8	-7.2	84.5
34	USA	Brownsville, TX	10.7	-11.7	-76.4	-88.1	98.7
35	USA	Cheyenne, WY	100.0	-0.1	0.0	-0.1	100.1
36	USA	Ft. Worth, TX	34.9	-10.4	-34.5	-44.9	79.8
37	USA	Lexington, KY	64.9	-2.5	-12.0	-14.5	79.4
38	USA	Los Angeles, CA	20.9	-0.3	-1.0	-1.2	22.1
39	USA	Miami, FL	3.3	-9.9	-82.2	-92.1	95.4
40	USA	Omaha, NE	84.7	-3.6	-14.1	-17.8	102.5
41	USA	Phoenix, AZ	19.5	-20.2	-8.7	-28.8	48.3
42	USA	Salt Lake City, UT	79.2	-2.4	0.7	-1.6	80.8
43	USA	Seattle, WA	67.2	-0.4	-0.4	-0.7	67.9

Note: Negative energy represents energy extracted in cooling.
The total is the sum of the absolute values of heating and cooling.

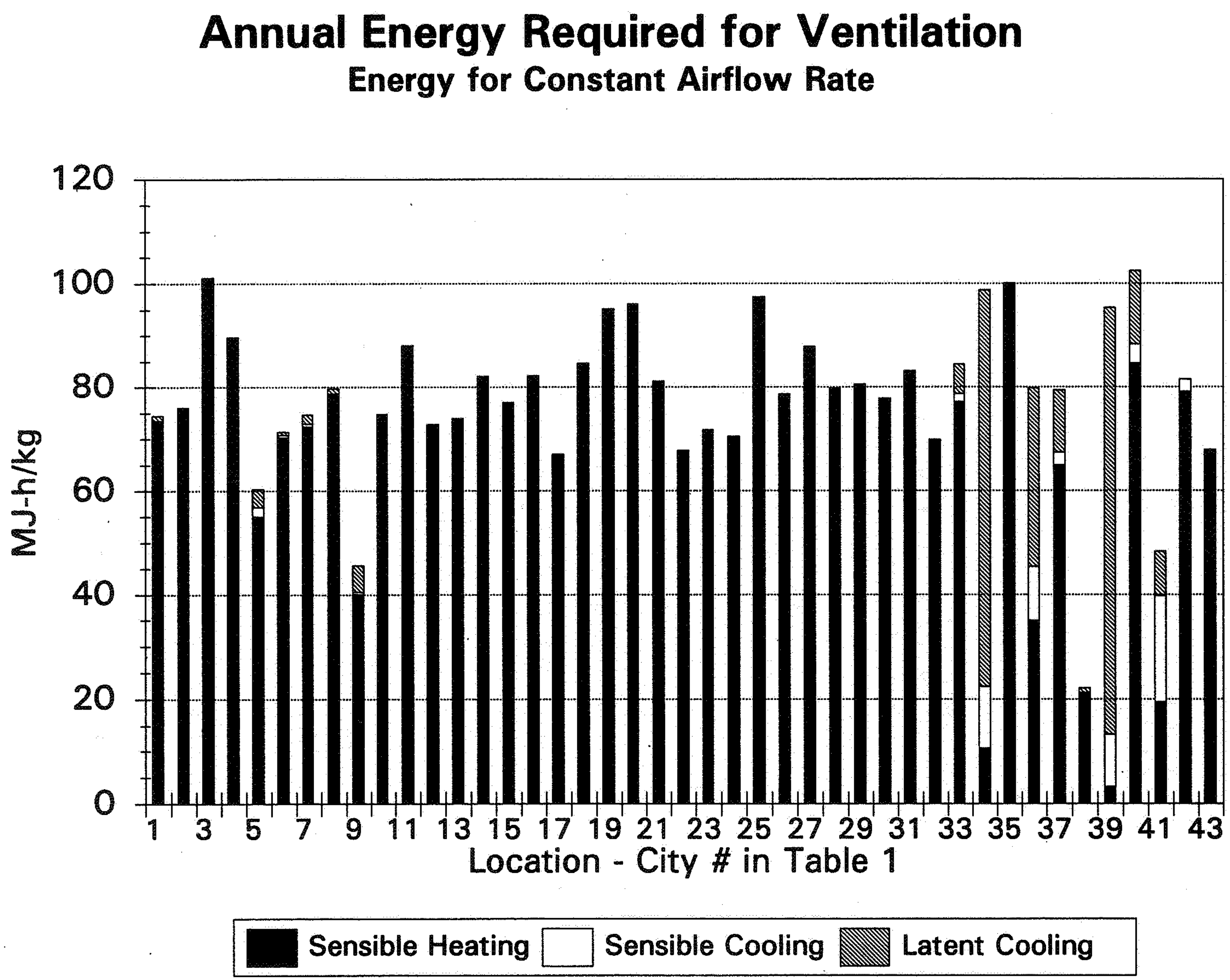

Figure 3. Total Energy Required for Ventilation Based Upon Constant Airflow Rate (Setpoints: Heating = 18 °C, Cooling 25.6 °C, 40%RH)

7. ACKNOWLEDGEMENTS

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8. REFERENCES:

[1] CEC. 1985. Test Reference Years TRY, Weather Data Sets for Computer Simulations of Solar Energy Systems and Energy Consumption in Buildings. Commission of the European Communities, Directorate General XII for Science, Research and Development. Brussels.

[2] COLLIVER, D.G., H. ZHANG., R.S. GATES, and K.T. PRIDDY. 1995. Determination of the 1, 2½, and 5% Occurrences of Extreme Dew-Point Temperature and Mean Coincident Dry-Bulb Temperatures (RP-754). *ASHRAE Transactions* 101(2) Paper No. 3904.

[3] COLLIVER, D.G. 1995. Energy Requirements for Conditioning Ventilating Air - AIVC Technical Note 47. Air Infiltration and Ventilation Centre. Coventry, Great Britain.

[4] CRITCHFIELD, H.J. 1983. *General Climatology, Fourth Ed.* Prentice-Hall.

[5] GATES, R.S., S.H. ZHANG, H. ZHANG and D.G. COLLIVER. 1994. Medium Temperature Psychrometric Routines in C^{++}. Biosystems and Agricultural Engineering Department, University of Kentucky, Lexington.

[6] IRVING, S.J. 1988. The CIBSE Example Weather Year. in Weather Data and Its Applications - A Symposium for Building Service Engineers. 9 March 1988. CIBSE. Balham, Great Britain.

[7] MüLLER, M. J. 1982. *Selected Climatic Data for a Global Set of Standard Stations for Vegetation Science*, *Tasks for vegetation science* 5. Dr. W. Junk Publishers, The Hague.

[8] NCDC. 1993. Solar and Meteorological Surface Observation Network 1961-1990 Version 1.0 (SAMSON). U.S. Department of Commerce, National Climatic Data Center, Ashville, NC and U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO.

[9] ZHANG, H., R.S. GATES and D.G. COLLIVER.1995. Development and Documentation of a Psychrometric Turning Machine. Dept. Publication 95--05-098. Biosystems and Agricultural Engineering Dept. , Univ of Kentucky, Lexington, KY.