Effect of 1997 Handbook Summer Design Temperature Specifications on Enthalpy and Humidity Ratio

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ABSTRACT

The purpose of this paper is to provide a quantitative overall description of the differences in humidity ratio and enthalpy that are associated with the new extreme weather specifications presented in the 1997 ASHRAE Handbook—Fundamentals as compared to the traditional weather data specification. Differences between the new specifications and the traditional specification are presented for the 0.4% annual frequency of occurrence data. The effect of population distribution and the 2.0% annual frequency of occurrence are examined. Both specifications result in an increase in the total enthalpy for most locations. For 85%-86% percent of locations, this increase was in the range of 0-4 Btu/lbm da (0-9.3 kJ/kg). For 11% of locations, the dew-point specification results in the lower enthalpy than the traditional dry-bulb specification. For 47% of all locations, the dew-point specification results in a humidity ratio more than 30 grains/lbm da (4.3 g/kg) higher than that of the dry-bulb specification.

INTRODUCTION

In recent years there has been increasing interest in independent control of humidity in conditioned spaces for mainstream HVAC applications. One challenge faced by designers has been the difficulty in estimating moisture loads from outside air. The 1997 ASHRAE Handbook—Fundamentals addresses this issue by including design temperature specifications that will be helpful for estimating moisture loads in HVAC design. In addition to the traditional dry bulb-mean coincident wet bulb (db-mwb) specification, the 1997 Handbook adds for the first time wet bulb-mean coincident dry bulb (wb-md) and dew point-mean coincident dry bulb (dp-md) specifications. The Handbook describes the applicability of the three specifications as follows:

"[db-mwb] often represent conditions on hot, mostly sunny days. These are useful for cooling applications, especially air-conditioning [wb-md] represent extremes of the total sensible plus latent heat of outdoor air. This information is useful for cooling towers, evaporative coolers, and fresh air ventilation system design ... [dp-md] are directly related to extremes of humidity ratio, which represent peak moisture loads from the weather. Extreme dew-point conditions may occur on days with moderate dry-bulb temperatures resulting in high relative humidity. These values are especially useful for applications involving humidity control, such as desiccant cooling and dehumidification, cooling-based dehumidification, and fresh air ventilation systems. The values are also used as a check point when analyzing the behavior of cooling systems at part load conditions, particularly when such systems are used for humidity control as a secondary function."

The 1997 Handbook presented all temperature specifications in a slightly different format than in earlier editions. Instead of basing extreme temperatures on a four-month summer period with 1%, 2.5%, and 5% frequencies of occurrence, the 1997 Handbook uses 0.4%, 1%, and 2% annual frequency of occurrence. For “mid-latitude, continental locations” the Handbook compares the two presentations as follows:

"The 0.4% annual value is about the same as the 1% summer design temperature. The 1% annual value is about 1°F lower than the 2.5% summer design temperature in the 1993 ASHRAE Handbook, and the 2% annual condition corresponds approximately to the 5% summer design temperature in the 1993 Handbook.”

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Detailed descriptions of the methodology used in the preparation of the Handbook data are presented in Colliver et al. (1998) and in ASHRAE (1997). Issues relating to development of extreme dew-point specifications are also described by Colliver et al. (1995) but for the older 1%, 2.5%, and 5% seasonal specifications. Limited overall comparisons between the db-mwb and dp-mdb specifications are presented, and it is shown that the dp-mdb specification had a higher average humidity ratio for the 1% case and over the 239 U.S. locations considered. Further description of the 1997 Handbook data, as well as descriptions of other weather data sources, are presented by Harriman et al. (1997). Design implications are discussed.

The purpose of this paper is to provide a bird’s-eye view of the differences in moisture load and overall cooling load encompassed by the new weather specifications. Specific design procedures for a given location are well understood given appropriate data, and the specific effect for any particular location is simple to determine. For example, Figure 1 shows a plot on Tdb-humidity ratio coordinates of the positions for the three design temperature specifications for several U.S. cities for 0.4% frequency of occurrence data. The sea-level saturation line is also shown for reference. It is apparent that, in general, the sensible load decreases and the latent load increases for both the dp-mdb and wb-mwb specifications over what would be calculated from the db-mwb specification. It is not as clear how and to what degree the resulting enthalpy will be affected by the different specifications. In this paper an overall description of the magnitudes of enthalpy and humidity ratio differences between the various specifications will be provided, and the distribution of those differences as a function of magnitude will be examined.

**DISCUSSION OF RESULTS**

**Introduction**

The data from the United States (Table 1 of chapter 26 of the 1997 ASHRAE Handbook) provides temperature specifications for 509 cities around the United States. The purpose of this paper is to examine differences in humidity ratio and enthalpy for the three types of specifications. Therefore, the traditional db-mwb specification was used as a baseline, and examination of differences from that baseline is the focus of this paper. The data are drawn primarily from the 0.4% annual frequencies of occurrence, while some 2.0% data are presented for comparison. Most of the results are presented in terms of the percentages of total (out of 509) locations that fall into a given category. However, the locations with temperature information do not necessarily correspond well with the population distribution in the United States. For example, the weather data contain 35 locations for Alaska, with a population of about 0.6 million, while they have 18 locations for New York (≈ 18.0 million population) and 34 locations each for Texas (≈ 17.0 million) and California (≈ 29.8 million). Therefore, comparisons are also presented using percentages of total population rather than percentages of locations. These results are based on 453 cities or metropolitan areas for which population information was available. The population data were taken from the 1990 U.S. census. Enthalpy and humidity ratios were calculated from the given temperatures using the equations in chapter 5 of the 1977 ASHRAE Handbook—Fundamentals.

**Humidity Ratio**

Figure 2 shows the distribution of increase in humidity ratio for the wb-mwb (2a) and dp-mdb (2b) specifications over the humidity ratio given by the db-mwb specification. These are for the 0.4% frequency of occurrence data. The data for Figures 2-4 are also listed in Table 1. As suggested by Figure 1, all locations show some increase in humidity ratio for both specifications.

Figure 2a shows that 67% of all locations have an increase between 10 and 30 grains/lbm\(_{db}\) (1.4-4.3 g/kg). For the dp-mdb specification, 51% of all locations show an

**TABLE 1**

<table>
<thead>
<tr>
<th>Difference, grains/lbm(_{db})</th>
<th>wb-mdb (% of locations)</th>
<th>dp-mdb (% of locations)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.40% pop</td>
<td>2%</td>
</tr>
<tr>
<td>0 to 10</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>10 to 20</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>20 to 30</td>
<td>47</td>
<td>58</td>
</tr>
<tr>
<td>30 to 40</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>40 to 50</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Fig. 2a Fig. 3a Fig. 4a Fig. 2b Fig. 3b Fig. 4b

Min. diff. 0.0 0.0 1.9 -0.3
Max. diff. 74.2 49.8 80.7 59.9
Avg. diff. 27.0 28.6 17.7 32.3 33.6 22.1
increase between 10 and 30 grains/lbm$_{da}$ (1.4-4.3 g/kg), while for 47% of locations, the increase is greater than 30 grains/lbm$_{da}$ (4.3 g/kg). Thus, for nearly half of all locations, the dp-mdb specification results in a humidity ratio more than 30 grains/lbm$_{da}$ (4.3 g/kg) higher than what would be calculated with the traditional db-mwb specification. For nearly all locations (89% for wb-mdb, 92% for dp-mdb) the increase is between 10 and 50 grains/lbm$_{da}$ (1.4-7.1 g/kg).

Figure 3 shows the distribution of humidity ratio increase by population for the two specifications. The overall distributions are similar to those of Figure 2 except that the 20 to 30 grains/lbm$_{da}$ (2.9-4.3 g/kg) bin has grown significantly for both specifications. For both specifications, this increase has come more from the bins below 20 than from the bins above 30. The net result is a slight shift toward higher humidity ratio increases if population distribution is taken into account. This can also be seen by examining the population-weighted averages shown in Table 1, which are about 12 grains/lbm$_{da}$ (0.2 g/kg) higher than the averages for the unweighted data.

Figure 4 shows the distribution of humidity ratio increase by location for the 2.0% annual frequency of occurrence data. Compared to Figure 2 (which uses the 0.4% data) there is a large increase in the 10-20 grains/lbm$_{da}$ (1.4-2.9 g/kg) bin for both the wb-mdb and dp-mdb specifications. In Figure 4b, only 14% of locations have an increase greater than 30 grains/lbm$_{da}$ (4.3 g/kg) for the dp-mdb specification compared with 47% in Figure 2. The humidity ratio increase is still significant with 78% (wb-mdb) and 80% (dp-mdb) of locations falling into the 10-30 grains/lbm$_{da}$ (1.4-4.3 g/kg) range. However, it appears that the effect of the less extreme frequency of occurrence specification is to make, overall, a smaller difference between the db-mwb specification and the two new specifications.

In Figures 2-4 the distribution of the magnitude of increase in humidity ratio was expressed in absolute terms, i.e., the actual increase in units of grains/lbm$_{da}$. It is also useful to consider the relative increase in moisture in terms of percentage change. Figure 5 shows the same data as Figure 2, except that the percent difference (e.g., [wbw − wdb]/wdw) is shown rather than the absolute difference. For the wb-mdb specification (5a), 80% of locations show an increase greater than 20%. For the dp-mdb specification, 92% of locations show an increase greater than 20%.

**Enthalpy**

Table 2 shows the distribution of the increase in total enthalpy for the wb-mdb and dp-mdb specifications over the db-mwb specification. For the wb-mdb specification, there is always an increase in enthalpy, while for the dp-mdb specification, 11% of locations actually have a lower total enthalpy with the dp-mdb specification than with the db-mwb specification. In both cases, most locations (86% for wb-mdb and 85% for dp-mdb) have an increase in enthalpy between 0 and 4 Btu/lbm$_{da}$ (0.9-3.7 kJ/kg) and in both cases, the majority of these fall in the 2-4 Btu/lbm$_{da}$ (4.7-9.3 kJ/kg) range.
Table 2 also shows the increase in enthalpy distributed by population. The prominent feature apparent from a comparison of the 0.4% data with the population-weighted data is that the 4-6 Btu/lbm\(_{da}\) (9.3-14.0 kJ/kg) bin grew in both cases with an accompanying decrease in the lower ranges: the 0-2 Btu/lbm\(_{da}\) (0-4.7 kJ/kg) bin for the wb-mdb specification and the <2 Btu/lbm\(_{da}\) bins for the dp-mdb specification. The net result is that the difference in total enthalpy is more extreme if population distribution is taken into account. This is in agreement with the conclusions reached from Figure 3 for humidity ratio. Also, as with the humidity ratio, the change is reflected by an increase of 0.2-0.4 Btu/lbm\(_{da}\) (0.70-0.93 kJ/kg) in the population-weighted average enthalpy difference.

Table 2 also includes the distribution in the increase of total enthalpy for the 2% frequency of occurrence specification. Comparing the 2% data with the 0.4% data, it can be seen that there is a significant shift downward in the magnitude distribution. For the 2% data, 67% of locations fall in the <2 Btu/lbm\(_{da}\) range for the wb-mdb specification, and 89% fall in this range for the dp-mdb specification. This compares to 21% and 48%, respectively, for the 0.4% data. As indicated by Figure 3 for the humidity ratio increase, it appears that the less extreme frequency of occurrence results in less pronounced difference between the db-mwb specification and the wb-mdb and dp-mdb specifications.

**Latent and Sensible Enthalpies**

Table 3 separates the total enthalpy increase represented by the 0.4% frequency of occurrence specification into a sensible component and a latent component for the wb-mdb and dp-mdb specifications. In all cases for both specifications, the sensible component exhibited a decrease over the db-mwb specification (shown in Table 3 as a negative increase, for consistency with the other figures). This result might be expected from examination of Figure 1 and consideration of the various definitions. There is a greater decrease in sensible enthalpy for the dp-mdb specification with 78% of locations with a decrease greater than 2 Btu/lbm\(_{da}\) (4.7 kJ/kg), while with the wb-mdb specification only 19% of locations show a decrease greater than 2 Btu/lbm\(_{da}\) (4.7 kJ/kg). The concept of this trend, if not its magnitude, might also have been anticipated from consideration of Figure 1.

Table 3 also shows the latent component of enthalpy increase for the wb-mdb and dp-mdb. Again, as might be expected from the general relationship between specifications, the wb-mdb and dp-mdb specifications always show an increase in the latent component of the enthalpy over the db-mwb specification. The latent load increase is between 2 and 6 Btu/lbm\(_{da}\) (4.7-14.0 kJ/kg) for 79% of locations with the wb-mdb specification and for 71% of locations for the dp-mdb specification. It is greater than 4 Btu/lbm\(_{da}\) (9.3 kJ/kg) for 50% of wb-mdb specifications and for 70% of dp-mdb specifications. Thus, the dp-mdb specification results in greater decrease in sensible enthalpy and greater increase in latent component of enthalpy compared to the wb-mdb specification. The net result is a slightly lower total enthalpy increase for the dp-mdb specification (refer to Figure 6 where about 85% of locations are in the 0 to 4 Btu/lbm\(_{da}\) [0-9.3 kJ/kg] range for both specifications, but the dp-mdb specification has 11% below 0 Btu/lbm\(_{da}\) while the wb-mdb specification has 14% above 4 Btu/lbm\(_{da}\) [9.3 kJ/kg]).

**Average Effects**

Figure 6 summarizes the overall average differences between the three extreme temperature specifications by comparing the average enthalpy and average humidity ratio (for all locations at the 0.4% specification) on T\(_{db}\)-humidity ratio coordinates. The sea-level saturation line is included for reference. On average, the dp-mdb specification results in an increase of 32.3 grains/lbm\(_{da}\) (4.6 g/kg) in the humidity ratio and an increase of 1.9 Btu/lbm\(_{da}\) (4.4 kJ/kg) increase in the enthalpy. The corresponding increases for the wb-mdb specification are 27.0 grains/lbm\(_{da}\) (3.9 g/kg) for the humidity ratio and 2.9 Btu/lbm\(_{da}\) (6.7 kJ/kg) for the enthalpy. The trends are
identical for the 2% specification, although the differences are not as large.

Figure 7 shows the breakdown by region of the United States for the average increase in humidity ratio and enthalpy. The five regions were defined as follows:

**West Coast:** California, western Washington and western Oregon, Alaska, and Hawaii

**Southwest:** The intermountain West and the southwestern U.S. extending east to about Denver, Colorado

**Midwest:** Most of the Plains states and Great Lakes region, extending east to Cleveland, Ohio, and south to Paducah, Kentucky

**Southeast:** The southeastern U.S. extending north to Norfolk, Virginia, and west to New Mexico

**East:** The areas east of Cleveland, Ohio, and north of Norfolk, Virginia

Figure 7a shows that the greatest moisture differences in both specifications came in the Southwest. The smallest differences in both cases came in the West Coast. Identical trends are observed in Figure 7b for the enthalpy increase in the wb-mdb specification. However, the largest enthalpy increase for the dp-mdb specification is for the Midwest. The breakdown of enthalpy changes into latent and sensible components makes clear that the overall net enthalpy increase for both specifications is due to a greater increase in the latent component than the decrease in the sensible component. This is also seen by comparing the average values in the bottom row of Table 3. Nationwide, the largest increases in moisture and enthalpy for both specifications occurred in Yuma, Arizona, with relative humidity increases of 74.2 grains/lbm da and 80.7 grains/lbm da for the wb-mdb and dp-mdb specifications, respectively. The corresponding enthalpy differences were 8.1 and 6.9 Btu/lbm da. The minimum differences occurred in Adak, Alaska, and Hanford, Washington, with increases at or near zero in all cases.

**CONCLUSIONS**

The purpose of this paper is to quantify the overall resulting cooling load differences between the traditional db-mwb design temperature specification and the wb-mdb and dp-mdb specifications that were included for the first time in the 1997 ASHRAE Handbook—Fundamentals. This summary of the distribution of differences between the three specifications is not readily accessible from the temperature specifications themselves. For design engineers and project energy analysts, the information presented here may be of largely academic interest, since it is presented in terms of nationwide and regional summaries and averages and does not address the details of changes at individual locations nor of hour-by-hour conditions. The quantitative results may be of more practical use to policy planners and energy analysts who are dealing in potential nationwide impacts and trends. Since the new temperature specifications will be used for building design, an
accessible summary of the overall resulting design cooling and moisture load differences is useful.

In this paper it was shown that the wb-mdb and dp-mdb specifications always resulted in a decrease in the sensible enthalpy and an increase in the latent enthalpy as compared to the db-mwb specification. The increase in latent enthalpy as well as the decrease in sensible enthalpy were greater for the dp-mdb specification than for the wb-mdb specification. Both specifications resulted in an increase in total enthalpy over the db-mwb specification for most locations. For 85% to 86% of locations, this increase was between 0 and 4 Btu/lbm sub da (0-9.3 kJ/kg). For 11% of locations, the dp-mdb specification resulted in a decrease in total enthalpy as compared to the db-mwb specification. The humidity ratio was always higher with the wb-mdb and dp-mdb specifications than with the db-mwb specification. For 89% of locations for the wb-mdb specification and 92% of locations for the dp-mdb specification, this increase was between 10 and 50 grains/lbm sub da (1.4-7.1 g/kg). In relative terms, 80% of locations for the wb-mdb specification and 92% of locations for the dp-mdb specification had a humidity ratio increase of greater than 20% of the db-mwb humidity ratio. The effect of population was to shift the humidity ratio difference distribution and the enthalpy difference distribution upward, i.e., toward greater cooling loads. This shift was also reflected in the calculation of the population-weighted average for both humidity ratio and enthalpy. The effect of using a less stringent design specification (2.0% annual frequency of occurrence rather than 0.4% annual frequency of occurrence) was to reduce the differences between the various specifications for both humidity ratio and enthalpy. On a regional basis, the West Coast, including Alaska and Hawai'i, had the smallest average increases in both humidity ratio and enthalpy for both specifications. The intermountain West and the Southwest had the largest average increases in humidity ratio for both specifications and enthalpy for the wb-mdb specification. The Midwest, including the Plains and Great Lakes states, had the greatest increase for the dp-mdb specification.

REFERENCES


