J3.4 DESIGN TEMPERATURES FOR HEATING AND COOLING APPLICATIONS IN NORTHERN COLORADO -- AN UPDATE

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1. INTRODUCTION

Several values for “design temperatures” for heating and cooling applications for the Fort Collins area have been published in recent years. Each one was based on different data and each yielded, not surprisingly, somewhat different results. Accurate documentation of the data sources and data-handling methodologies has not been available.

Most recently, two sets of values were published by ASHRAE (ASHRAE, 2005). One is designated as AWOS data, WMO station #724769 for the period 1992 to 2001. This is believed to be from the Fort Collins-Loveland Airport weather station. The authors do not believe this location provides a good representation of Fort Collins climate due to the station location, the short data set, and the quality of data from this station. The second ASHRAE site is designated as SAWRS data, WMO station #724697 with coordinates 40.58N, 105.08W, elevation 1,524 meters, for the period 1982 to 1994. In addition to a short data period, there is ambiguity regarding the source of these data. Digital data have not been easily available from any weather station in the Fort Collins city limits during that period. Also, this WMO station number does not uniquely define a station.

City of Fort Collins asked the Colorado Climate Center to analyze a significantly longer temperature data set from a representative and well-documented source, in order to compute more reliable design temperatures for use by local engineers and contractors designing heating and cooling systems. The City was particularly interested in including recent temperature data because there have been several very warm years since 2000.

2. METHODS

2.1 *Data Source*

In this study, the heating and cooling design dry-bulb temperatures and Mean Coincident Wet Bulb (MCWB) temperatures were recalculated using the Fort Collins, CO campus weather station (NOAA Cooperative Station Number 05-3005-4) data for the 39-year period 1968 to 2006. The Fort Collins, CO weather station is located on the campus of Colorado State University, northwest of the Lory Student Center. It is considered to be representative of the urbanized (buildings, streets, etc.) but vegetated landscape that characterizes much of Fort Collins. The station has a rich history, with more than 117 years of climatological data. Since the 1950s, the weather station has experienced “urbanization,” with encroachment by buildings and pavement and growth of trees. The environment near the station has been fairly stable since Lory Student Center was completed in the early 1960s, but in 2002 the CSU Transit Center was built within 90 meters of the station. No significant changes in the local temperatures were noted at the time associated with this change, but this situation deserves continued monitoring. The weather station is currently situated on a vegetated/landscaped “island” in an effort to preserve an acceptable and representative climatological exposure. Long term data show a gradual warming trend which is most noticeable in winter.

The data from the Fort Collins National Weather Station Cooperative (NWS COOP) weather station are quality controlled before being digitized. Redundant and independent temperature measurement systems have been in use for many years. In addition to two pairs of traditional liquid-in-glass thermometers (wet bulb/dry bulb and maximum/minimum), the weather station utilizes a hygrothermograph, an electronic MMTS (Maximum/Minimum Temperature System) system, and electronic 10-minute temperature readings. This redundancy of measurements allows data to be cross-checked on a nearly continuous basis and assures a high degree of data integrity.

3.2 *Data Processing*

A summary of the current dataset is given in Table 1. In order to calculate heating and cooling design temperatures, the data needed to be compiled into usable forms. The ideal goal was to assemble complete 8760-hourly temperature data records for every year in the dataset, as the basis for frequency distribution analysis. In practice, subsets of different types of data were assembled into a proxy record that allowed accurate calculations. This was done as follows:

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Table 1: Description of temperature data compiled from the Fort Collins, CO campus weather station (Cooperative Station #05-3005-4) for this analysis.

Date Range	Data Source
1/1968 - 12/1977	Bi-hourly observations of dry-bulb/wet-bulb temperatures
1/1978 - 10/1986	Bi-hourly extreme temperatures only (<-12ºC/10ºF; ≥ 29ºC/85ºF) and wet bulb temperatures, digitized from hard copy files
11/1986 - 8/1994	Bi-hourly observations of dry-bulb/dew point temperatures
9/1994 -1/1996	Bi-hourly extreme temperatures only (<-12ºC/10ºF; ≥ 29ºC/85ºF) and relative humidity, digitized from hygrothermograph charts
2/1996 – 10/2006	Hourly electronic temperature data and relative humidity

- 1968 - 1977 and 1986 - 1984: Bi-hourly (once every two hours) manual observations during these periods had previously been digitized from the weather station data records. Missing data for these two periods were estimated by linear interpolation but only if the surrounding observations were greater than 29ºC /85ºF or less than -12ºC/10ºF. This assured that data were complete for both the warm and cold ends of the complete hourly temperature frequency distribution.

- 1/1978 -10/1986: Bi-hourly manual data had not previously been digitized. To save time while still considering these data for the calculation of design temperatures, only the extreme temperatures (<-12ºC/10ºF; ≥ 29ºC/85ºF) were digitized from the hard copy surface observations sheets. Missing observations during extreme temperature periods were filled using linear interpolation.

- 9/1994 - 1/1996: Data during this period were recorded on hygrothermograph charts. Again, only extreme temperatures (<-12ºC/10ºF; ≥ 29ºC/85ºF) were digitized.

- 2/1996 – 10/2006. During this period, data were recorded by an electronic temperature/humidity sensor. The data were reported every 10 minutes to the weather stations web site (http://ccc.atmos.colostate.edu/~autowx). These data were converted to hourly data by taking the last report from each hour (i.e. at 50 minutes past the hour), which is consistent with manual observation practices.

Both dry-bulb and wet-bulb temperatures were coincidentally available from direct weather station observations only during 1968-1977 and the extreme temperature data segments (≥ 29ºC/85ºF) that were digitized for the 1/1978 - 10/1986 period. During other portions of the data set, two other measures of moisture were observed: dew-point temperature or relative humidity. For the periods for which dew-point and relative humidity were available, the wet-bulb temperatures were derived using a software package called EZair Properties (Parks, 2002), using the equations in the ASHRAE Handbook of Fundamentals, 1993 edition. The calculations were spot-verified using a psychometric chart.

Additional quality control and processing steps were taken. Temperature values were graphed and visually inspected for suspicious data. Those data were investigated and removed if necessary (e.g. keying errors as data was digitized). If no cause could be found for erroneous data, one of two paths was followed. For observations during extreme temperature periods (<-12ºC/10ºF; ≥ 29ºC/85ºF), readings were linearly interpolated. For other observation times, the erroneous data were removed from the record. In a few instances it was found that data were mistakenly entered twice; redundant observations were removed.

3.3 *Dry-Bulb Design Conditions*

The calculation of the design temperatures was done following the methods of ASHRAE, reported by Thevenard and Humphries (2005). The data, observed to the nearest one-tenth degree Fahrenheit, were rounded to nearest whole degree in order to be comparable with the ASHRAE methods. Bi-hourly observations were double counted in order to create hourly data comparable to the hourly dataset from 1996-2005. The data were binned into one degree intervals and arranged into a cumulative distribution function (CDF), shown in figures 1 and 2 for the heating and cooling ends of the distribution respectively. As illustrated in the figures, the design temperatures can easily be derived from the CDF. The x% design condition is the condition that is exceeded, on average, x% of the time. In simpler terms, it relates to the number of hours per year, on average, that a temperature is exceeded. For example, the 1% annual design dry-bulb temperature is the temperature that is exceeded on average 1% of the year, or 87.6 hours per year (Thevenard and Humphries, 2005).

This dataset has many missing data points from the years where only extreme temperatures were digitized. However, the dataset is complete on the tails of the CDF (i.e. <-12C; ≥ 29C). Therefore, instead of working uni-directionally along the CDF, design temperatures were found by working in from the ends of the CDF. This method disregards the middle of the CDF where data is missing.

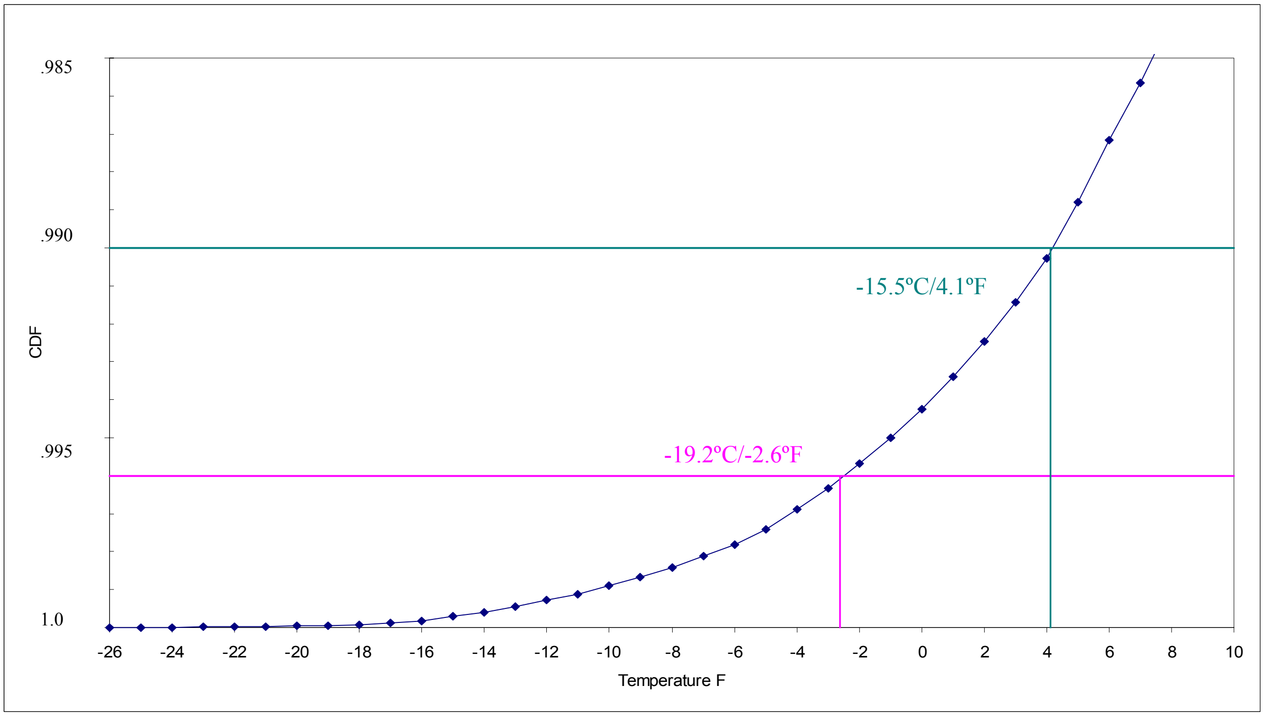

Figure 1: Low temperature end of the Cumulative Distribution Function using the entire 39-year dataset. The method for calculating the heating design temperatures is illustrated.

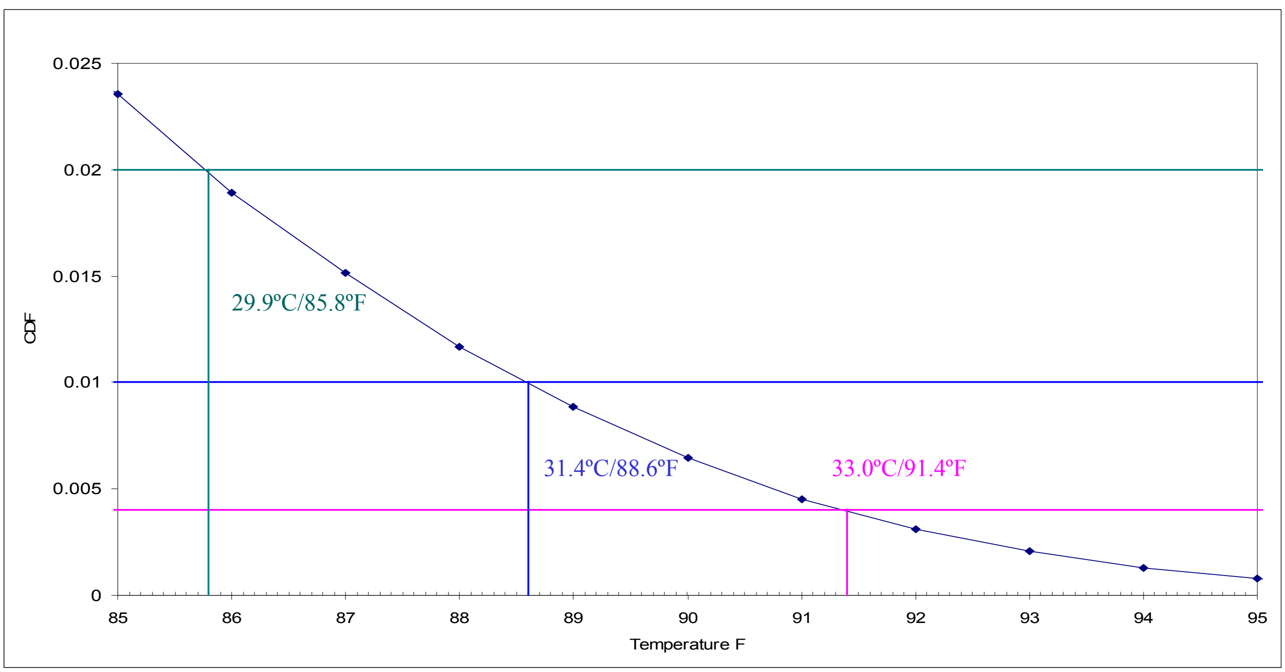

Figure 2: High temperature end of the Cumulative Distribution Function using the entire 39-year dataset. The method for calculating cooling design temperatures is illustrated.

3.4 *Mean Coincident Wet-Bulb Temperature*

Another important parameter published by ASHRAE for cooling system design is the Mean Coincident Wet-Bulb (MCWB) temperature. MCWB temperatures were calculated following the methods of ASHRAE, reported by Thevenard and Humphries (2005). All of the wet-bulb temperatures coincident with each one degree dry-bulb temperature bin are averaged. A MCWB is calculated for each temperature and graphed in Figure 3. From this graph the MCWB is found by finding the design temperature on the x-axis and reading the MCWB from the y-axis.

3. RESULTS

In order to calculate representative design conditions, long-term data sets are required. ASHRAE prefers to use up to 30 years of data to smooth out year to year variations. The years 1972-2001 were used for most stations in a recent ASHRAE summary (Thevenard and Humphries, 2005).

Fort Collins design conditions, based on the current analysis, are listed in Table 2. They were calculated for a variety of time periods. The first period was 29 years in length, including the three most complete temperature data subsets. The second period was the entire dataset of 39 years, including those years for which only the extreme temperatures were digitized. The other two time periods were simply the first and second halves of the 39-year dataset, to see how much design temperatures varied in successive time periods. The ASHRAE (2005) data for the Fort Collins SAWRS weather station is included for reference.

The calculated cooling design temperatures in this analysis show little variation with time period. In contrast, the heating design temperatures show slightly larger variations. The difference between the first and second halves of the 39-year dataset suggests that the recent winters are warmer (or at least have fewer persisting extreme cold periods) than previous winters. In order to better illustrate what is occurring, figures 4 and 5 show the number of hours each year greater than or equal to 32ºC/90ºF and the number of hours less than or equal to -18ºC /0 F, respectively. As can be seen, in recent years the number of hours greater than or equal to 32ºC/90ºF has increased, while the number of hours less than --18ºC /0 F has considerably decreased since the beginning of the dataset. This helps explain the relatively large differences in heating design temperatures from the first half of the record to the last. While we do not know if this trend will continue, it is a definite trait of the recent past.

The MCWB temperatures are also presented in Table 2 for each of the time periods. The MCWB stays nearly steady at approximately 16ºC/61ºF for each of the cooling design temperature levels (See Figure 3).

Of the various periods analyzed in this study, the authors recommend that results for the full 39-year dataset be used as the most representative characterization of the long-term Fort Collins climate.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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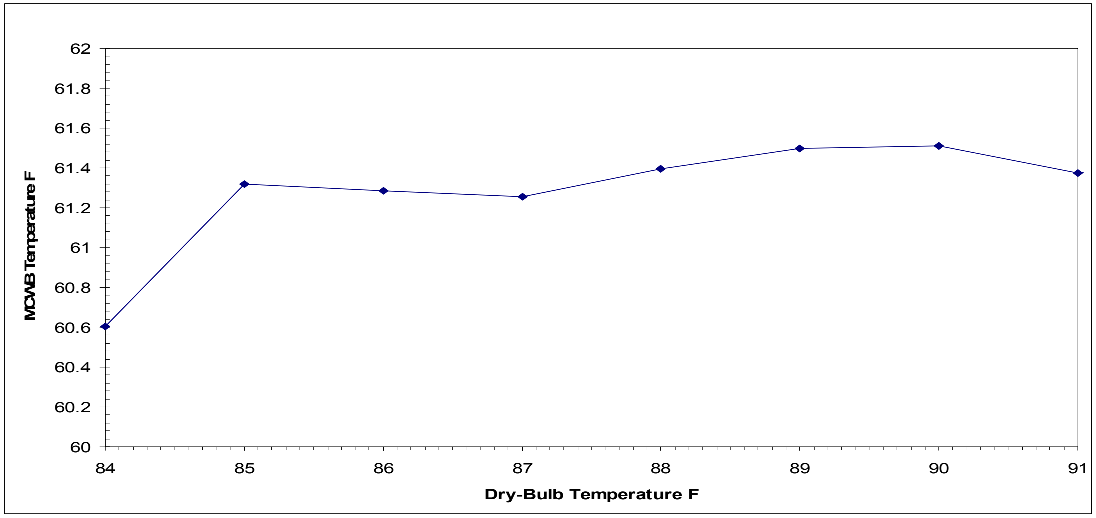

Figure 3: Mean Coincident Wet-Bulb Temperature.

Table 2: Design Temperatures for Fort Collins, CO (COOP 05-3005-4). Results from the current analysis are listed along with ASHRAE (2005) values for comparison.

			Design Temperatures (degrees Fahrenheit)				
			Heating		Cooling		
		Design Criteria (%) -->	99.6%	99.0%	2.0%	1.0%	0.4%
		Design Criteria Exceedance (hours/year) -->	8725	8672.4	175.2	87.6	35
Source and Weather Station	Years Included in Data Set	Parameter	ºC/ºF	ºC/ºF	ºC/ºF	ºC/ºF	ºC/ºF
ASHRAE (2005) "Fort Collins" (specific location ambiguous) SAWRS, WMO station # 724697	13 years: 1982-1994	Dry-bulb temperatures	-20.4/-4.8	-16.2/2.9	29.2/84.6	30.7/87.2	32.1/89.8
		Mean Coincident Wet Bulb temperature			15.9/60.7	16.0/60.8	16.2/61.1
Colorado Climate Center (2006) Colorado State University Campus NOAA Cooperative Station Number 05-3005-4	27 years: 1968-77, 1986-93, 1996-2006	Dry-bulb temperatures	-18.8/-1.9	-15.1/4.9	29.9/85.8	31.4/88.6	33.0/91.4
		Mean Coincident Wet Bulb temperature			16.3/61.3	16.4/61.5	16.3/61.4
	38 years: 1968-2006	Dry-bulb temperatures	-19.2/-2.6	-15.5/4.1	29.9/85.8	31.4/88.6	33.0/91.4
		Mean Coincident Wet Bulb temperature			16.3/61.3	16.4/61.5	16.3/61.4
	19 years: 1968-1986	Dry-bulb temperatures	-19.8/-3.6	-16.4/2.4	29.6/85.3	31.1/88.0	32.6/90.6
	19 years: 1987-2006	Dry-bulb temperatures	-18.4/-1.1	-14.3/6.2	30.1/86.1	31.7/89.0	33.2/91.8

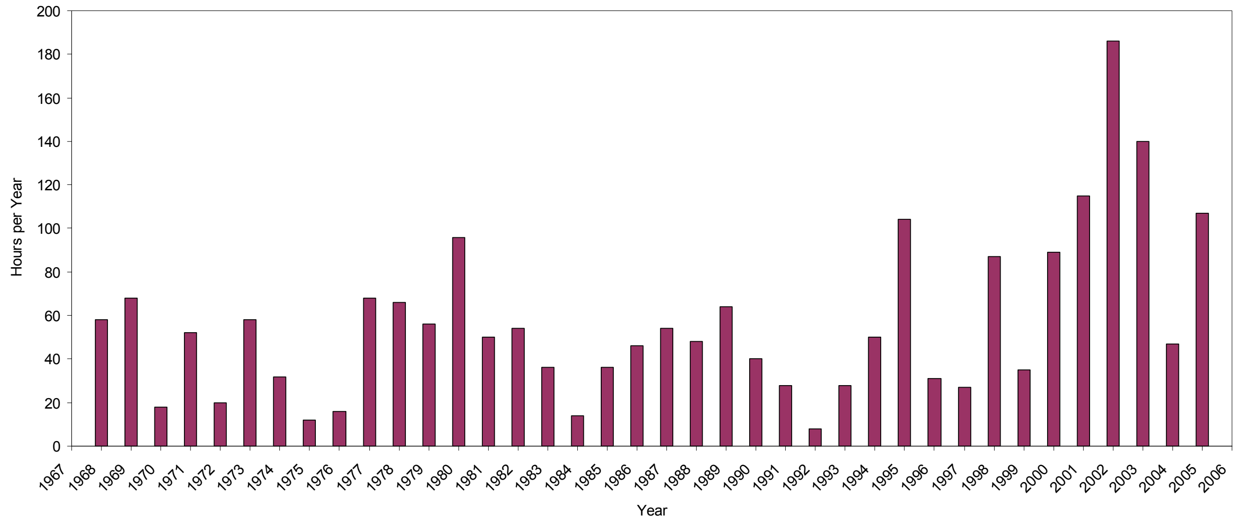

Figure 4: Number of hours greater than or equal to 32ºC/90ºF.

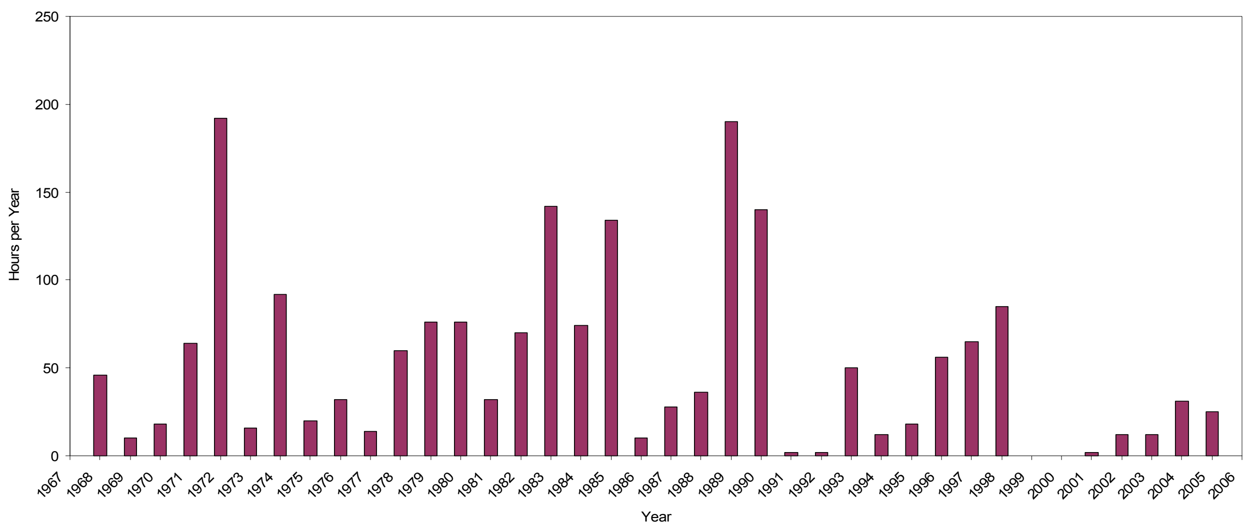

Figure 5: Number of hours less than or equal to -18ºC/0ºF.