



# Impact of Low Design Ambient Wet Bulb, with Bengaluru as Example

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## Introduction

Ambient design conditions indicated in ASHRAE Handbook are based on cumulative frequencies of parameter values involved. The ambient WBT value decided on this basis for Bengaluru is about 19°C. This is to be compared with WBTs of about 25°C that have been in use for several decades. The consideration involved in arriving at a design WBT, viz. using cumulative frequency data, impact of selecting low WBTs and plant performance at low WB depressions on air conditioning and evaporative cooling systems have been analyzed and reviewed. The study is based on WeDCo data – chiefly, the hourly values of parameters of interest. The study recommends use of 23-24°C for Bengaluru. Recommendations include study of differences between traditionally used design WBT values and ASHRAE/WeDCo values for other stations also like Mumbai, Pune, Kolkata, Hyderabad and Chennai – where differences are found to be significant. The major role that ISHRAE should play in tackling this issue has been emphasized.

## About the Author

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## The Background

The format and values for ambient design temperatures were changed, beginning with 1997 *Fundamentals* volume of ASHRAE Handbook. In the previous editions of the Handbook, summer ambient design temperatures were reckoned over a period of 4 months – 2920 hours (typically March, April, May and June in the USA and other Western countries), whereas in the 1997 edition, the entire year was considered as the relevant period. References to separate sets of ambient conditions for summer and winter were excluded entirely; instead, data for ambient design DB with mean coincident WB temperatures and data for ambient WBs with mean coincident DB temperatures were introduced, regardless of the season of the year. (See *Appendix 1*, which shows cumulative frequency distribution CFD presented in several forms, viz. as a table, as a curve and as a histogram. This will help us familiarize with the concept of CFD, which is used in the study of Weather Data). In this process, it was found that the ambient wet bulb design values introduced in the 1997 Handbook were significantly lower than those contained in the earlier editions of the *Fundamentals* volume. The differences were found to be so large in the case of some cities that the

industry in our country has not accepted them and practicing engineers have still not adopted the post-1997 data.

Bengaluru, Mumbai, Pune, Kolkatta, Hyderabad and Chennai were found to be amongst the several stations that belonged to this category. A Weather Data Review Committee was formed by ISHRAE in the year 2002 to go in to this matter. The Committee was headed by this author. It was composed of representatives from various parts of the country. The Committee arrived at the consensus (informally) that the most likely reason for the discrepancies was incorrect raw data. Several proposals to tackle the situation emerged, but no action was taken. And the industry, by and large, continues to use the old data. Those were the days when there was still no focus on energy calculations. Also, ECBC was nowhere on the horizon. In today's situation, characterized by the concern for Global Warming and Climate Change, the role of energy consumption has been duly highlighted. The need for calculations for estimating energy consumption has become more acute. Availability of reliable and authentic data for hourly values of necessary weather parameters assumes vital importance at this time. The only source of such data has been WeDco. WeDco data and ASHRAE data appear to be identical. WeDco data is based on the raw data of Indian Meteorological Department (IMD) processed thereafter by WeDco, and duly vetted by *ASHRAE Technical Committee – 4.2*. The WeDco and ASHRAE design ambient wet bulb for cooling vary from 19.6°C at 0.4% and 1% to 19.2°C at 2% for Bengaluru. The design wet bulb that has been in use for several decades and, in fact, is still in use is 24 to 25°C – substantially higher at 5-6°C. It is these considerations that have necessitated a revisit to this issue today.

#### Hourly Weather Data and Energy Consumption

The selection of a plant is about the capacity to meet peak load requirements – and it depends significantly on ambient design conditions. The energy consumption, on the other hand, depends on the variation of ambient temperature and humidity – and in addition, of course, to various other loads like appliances, lighting and occupancy. Normally, variation is evaluated periodically, say, at 15 minute, 30 minute and 1-hour intervals. In this study, an hourly basis has been adopted. For all DB and WB temperature variations currently in use, WeDco is the only source of data. There is no other data one can turn to – to serve either as an alternative or as a basis for comparison.

#### Study Based on Weather Data for Bengaluru

Of the several stations, in case of which significant discrepancies exist, Bengaluru is amongst the most conspicuous. Today, Bengaluru occupies an important place in the HVAC map of the country. Additionally, the author, being Bengaluru-based for more than 3 decades, can hopefully claim some familiarity with the city's climate. Hence the focus on Bengaluru.

Several topics are considered:

- Evolving an ambient design wet bulb temperature
- Impact on selection of cooling towers for air conditioning plants

- Impact on applicability considerations of evaporative cooling – with particular reference to Bengaluru
- Recommendations for action to be taken

### Evolving an Ambient Design Wet Bulb Temperature Definitions

The terms used in the discussions and calculations are defined below.

Summer: March, April, May and June

Cooling Season: February to October

Year Round: January to December

Working Hours: The number of hours per day the plant works

Base Hours: To help understand this term, consider the temperature band of 23-24°C as an example. When the Base Hours used are 24, WB temperature is scanned over the entire period of 24 hours a day, even though Working Hours are only 10 (9 AM to 7 PM). If, on the other hand, a 10-hour base is used, WB temperature is scanned during a 10-hour period. This will, of course, coincide with the Working Hours.

Cumulative Frequency: Number of hours a parameter value is exceeded.

#### Alternatives Studied

Nine alternatives have been worked out for different Working Hours/Base Hours patterns of 10/10, 10/24 and 24/24 for summer, cooling season and the year round period.

As an example, a calculation for summer season (only) has been shown in Table 1, 2 and 3.

Table 1: 10 working hours

Months	No. of days	No. of working hours (9am - 7pm)	Total possible cooling hours	Frequency of occurrence in the assigned temperature band					
				19-20°C	20-21°C	21-22°C	22-23°C	23-24°C	24-25°C
March	31	10	310	82	52	17	2		
April	30	10	300	68	59	44	18	11	
May	31	10	310	4	18	60	94	120	45
June	30	10	300	21	104	109	64	28	1
<b>Total</b>			<b>1220</b>	<b>175</b>	<b>233</b>	<b>230</b>	<b>178</b>	<b>159</b>	<b>46</b>
<b>Cumulative frequency above 19°C</b>				<b>1021</b>	<b>846</b>	<b>613</b>	<b>383</b>	<b>205</b>	<b>46</b>
<b>Percent cumulative frequency above selected temperature band/ total possible cooling hours</b>				<b>84</b>	<b>69</b>	<b>50</b>	<b>31</b>	<b>17</b>	<b>4</b>

Table 2: 24 working hours

Months	No. of days	No. of working hours (9am - 7pm)	Total possible cooling hours	Frequency of occurrence in the assigned temperature band					
				19-20°C	20-21°C	21-22°C	22-23°C	23-24°C	24-25°C
March	31	24	744	155	91	31	11		
April	30	24	720	154	122	86	47	16	4
May	31	24	744	52	118	186	184	150	45
June	30	24	720	192	249	151	71	28	1
<b>Total</b>			<b>2928</b>	<b>553</b>	<b>580</b>	<b>454</b>	<b>313</b>	<b>194</b>	<b>50</b>
<b>Cumulative frequency above 19°C</b>				<b>2144</b>	<b>1591</b>	<b>1011</b>	<b>557</b>	<b>244</b>	<b>50</b>
<b>Percent cumulative frequency above selected temperature band/ total possible cooling hours</b>				<b>73</b>	<b>54</b>	<b>35</b>	<b>19</b>	<b>8</b>	<b>2</b>

Table 3: 10 working hours

Months	No. of days	No. of working hours (9am - 7pm)	Total possible cooling hours	Frequency of occurrence in the assigned temperature band					
				19-20°C	20-21°C	21-22°C	22-23°C	23-24°C	24-25°C
March	31	24	744	82	52	17	2		
April	30	24	720	68	59	44	18	11	
May	31	24	744	4	18	60	94	120	45
June	30	24	720	21	104	109	64	28	1
<b>Total</b>			<b>2928</b>	<b>175</b>	<b>233</b>	<b>230</b>	<b>178</b>	<b>159</b>	<b>46</b>
<b>Cumulative frequency above 19°C</b>				<b>1021</b>	<b>846</b>	<b>613</b>	<b>383</b>	<b>205</b>	<b>46</b>
<b>Percent cumulative frequency above selected temperature band/ total possible cooling hours</b>				<b>35</b>	<b>29</b>	<b>21</b>	<b>13</b>	<b>7</b>	<b>2</b>

**WB value of 23-24°C Recommended**

Inspection of values arrived at in this example suggests that 19°C is too low and that focus on AWBT value in the range of 22°C to 25°C instead of 19°C approximately is sufficient to arrive at a more acceptable design ambient WB value, viz. in the 22-23°, 23-24° and 24-25°C temperature bands.

Table 4 suggests possible values for 3 different criteria of plant selection based on operation in (a) summer only, (b) cooling period and (c) year round operation.

	Hours pattern	No. of hours	%	% higher than 22°C	% higher than 23°C	% higher than 24°C	Remarks
Summer	10/10	1021	84	31	17	4	24°C okay. 23°C is too low. 24°C matches with ASHRAE 1993 1% value.
	24/24	2144	73	18	8	2	23°C may be okay. It matches ASHRAE 1993 2.5% value.
	10/24	1021	35	13	7	2	
Cooling Period	10/10	2373	87	21	8	2	23°C may be acceptable. 22°C is too low. ASHRAE 1993 does not apply to 9-month period. ASHRAE 1997 value not achievable.
	24/24	4893	75	12	4	1	
	10/24	2373	36	9	3	1	22°C too low. 23°C is okay. ASHRAE 1997 value not achievable.
Year Around	10/10	2609	71	15	6	1	23°C may be acceptable. 22°C is too low. ASHRAE 1997 value not achievable.
	24/24	5282	60	9	3	1	
	10/24	2609	60	6	3	1	22°C is okay. ASHRAE 1997 value not achievable.

ASHRAE DATA  
 ASHRAE 1993 – Summer Percentiles: 1% - 24°C, 2.5% - 23°C, 5% - 23°C  
 ASHRAE 1997 – Cooling DB/MCWB: 34.4/19.5°C for 0.4%, 33.6/19.4°C for 1%, 32.8/19.5°C for 2%

It will be seen that the recommended values are closer to 1993 ASHRAE Fundamentals than to the values in the subsequent editions.

ASHRAE 1997 Fundamentals volume explains the background and the rationale for the differing approaches in considerable detail. Relevant extracts from ASHRAE Handbook have been placed in Appendix 2. A study of the extracts will be helpful to place the above remarks in a proper perspective.

**Impact of Low Wet Bulb Temperature on Air Conditioning**

In an air conditioning plant, the maximum capacity of the chillers required could occur in the monsoon season (and not necessarily during the hot months) and accordingly, the plant would be selected on that basis. But, the ambient conditions corresponding to peak monsoon load will not coincide with the capacity required by the hottest months of the year. The paragraph in Appendix 2 under the title *Cooling and Dehumidification Design Conditions (summer)* relates to this point.

Furthermore, it is necessary to ensure that the cooling tower is selected for the WB corresponding to peak load (in the monsoon season) and not for the mean coincident wet bulb

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temperature (MCWB) corresponding to the peak load on the hottest days in summer (cooling DB), as the ambient design condition.

### Impact of Low Wet Bulb Temperature on Evaporative Cooling

In evaporative cooling, the design wet-bulb is also of vital importance. An underestimated value for this parameter will make this system appear attractive. If the underestimate turns out to be true, the occupants will be uncomfortable over a longer period in the year. In the present case, it is true that the design ambient WB temperature of 19°C approximately is exceeded during a very small number of hours during the hottest part of the year (4 months – in summer). However, the ambient certainly needs improvement during another 5 months in the year so that a total period of 9 months can be regarded as the cooling season. During the remaining 5 months, which represent the difference between the cooling period and the summer, the ambient WBT will be around 23°C. The dry bulb temperature that goes with this wet bulb temperature will be 27-30°C. These conditions prevail in daytime when it is not raining and that is a substantial number of hours. During these hours, DB will fall significantly – in fact, sufficiently to ensure that the higher RH will become all but irrelevant. If the weather-dependent loads predominate, the cooling load will also be lower; the evaporative cooling plant will continue to yield an acceptable performance level. If on the other hand, it is the internal loads that predominate – as indeed they do in the case of industrial cooling applications – the plant will turn out to be under-sized.

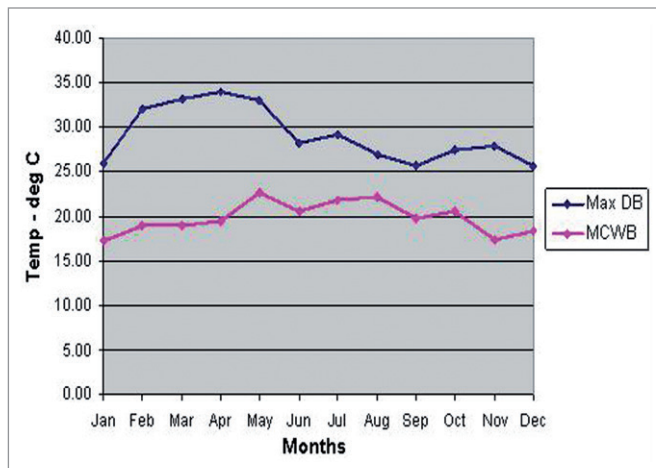


Figure 1: Maximum DBT on 21st of every month

Figure 1 shows a plot of maximum DB temperature on 21st day of each month as well as MCWB. It will be seen that WB temperature is 19°C and below during months (February,) March and April in the cooling season and fluctuates between 20 and 23°C till the end of October. This covers a large part of the monsoon season – during the hot months of the year – February, March, April and May. The DBs are high – 32°C in February, 28°C in June, 33°C in March,

34°C in April and 33°C in May. During this period the WB depressions are as under:

February : 13.2°C	March : 14.1°C
April : 14.5°C	May : 10.4°C

These are reasonably large. On the other hand, WB depressions during the monsoon period (June – October) will be significantly lower:

June : 7.6°C	July : 7.4°C
August : 4.7°C	September : 5.9°C
October : 6.8°C	

All these considerations go to show how a plant sized for WB depressions in the hot months can turn out to be undersized for monsoon months.

An implication to the designer is that he is probably safe in assuming a 19°C based depression and selecting a plant on that assumption provided the weather dependent loads are not significant. On the other hand, in cases where internal loads are very high – particularly the sensible gains – the plant would be substantially undersized. The heat gains in the monsoon would be about the same as in summer while on the other hand WB depressions available would be smaller.

Even those low WB depressions will not be available for large parts of a day; they are smaller most of the time.

### Recommendation

The impact of wet-bulb depression on plant performance has already been discussed. However, a large depression by itself does not always yield the desired inside temperature; the wet bulb temperature itself also has to be sufficiently low. If the WB temperature that materializes remains higher than the assumed value, the plant will not cool adequately. This underlines the importance of correct data availability. It has been seen that in the case of Bengaluru, the frequency of occurrence of wet bulb temperature higher than 19°C is much higher than the values required for it to warrant its selection as an ambient design value.

It may be recalled in this context that WeDCo data (which includes both the ambient design parameter values as well as hourly values) are based on IMD’s raw data and the processing by TERI has been vetted by ASHRAE. Assuming therefore, that the processing procedure adopted in the WeDCo publication is unobjectionable, the question arises as to whether the raw data is correct. We have already noted that besides Bengaluru, there are other cities also, for which similar discrepancies in data have been noticed. Mumbai and Pune are examples of cities in this category. It seems advisable to make necessary studies in the case of all such cities or at least as many cities as possible. An extensive and in-depth review of such studies may help build a consensus that could lead to action; ISHRAE would undoubtedly need to play a major role on this important issue and come forward with a solution.

## Appendix 1

Table 5 provides frequency of occurrence of ambient wet bulb temperatures from 19°C to 26°C during a year (8760 hours). This data is useful for plants working 24 hours/day, 365 days in the year. One comes across this kind of working pattern in many industrial applications and residential buildings. Because of the large number of applications of this kind in the industry, such data is readily available in ASHRAE Handbooks and can be used for reference and rough comparisons.

Table 5: Frequency of occurrence of ambient WBT from 19°C to 26°C during a year

Months	No. of days	No. of working hours (9am - 7pm)	Total possible cooling hours	Cumulative frequency of occurrence/ 8760 hours						
				19-20°C	20-21°C	21-22°C	22-23°C	23-24°C	24-25°C	19-20°C
January	31	24	744	30	9					
February	28	24	672	25	10					
March	31	24	744	155	91	31	11			
April	30	24	720	154	122	86	47	16	4	
May	31	24	744	52	118	186	184	150	45	1
June	30	24	720	192	249	151	71	28	1	
July	31	24	744	293	260	90	7			
August	31	24	744	157	248	211	95	20		
September	30	24	720	232	296	124	20	1		
October	31	24	744	235	226	141	57	1		
November	30	24	720	177	78	9				
December	31	24	744	79	7					
<b>Total</b>				<b>1781</b>	<b>1714</b>	<b>1029</b>	<b>492</b>	<b>216</b>	<b>50</b>	
<b>Cumulative frequency above 19°C</b>				<b>5282</b>	<b>3501</b>	<b>1787</b>	<b>758</b>	<b>266</b>	<b>50</b>	<b>1</b>
<b>Percent cumulative frequency above selected temperature band/ total possible cooling hours</b>				<b>60</b>	<b>40</b>	<b>20</b>	<b>9</b>	<b>3</b>	<b>1</b>	<b>0.011</b>

As can be seen from Table 5, the ASHRAE 0.4% value occurs at 25°C AWBT (instead of 19.6°C) while the 1% value occurs at 24°C

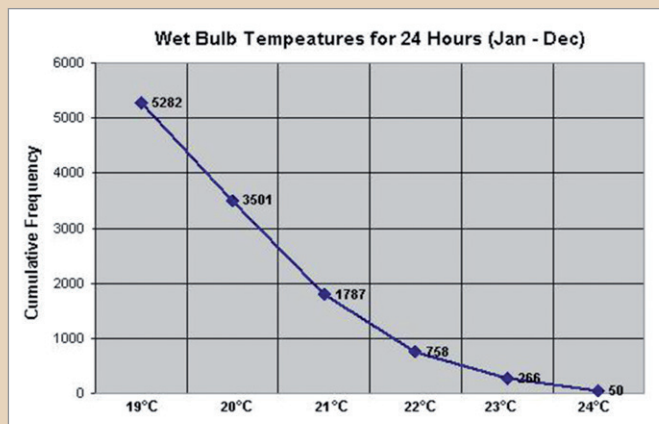


Figure 2: Cumulative frequency curve

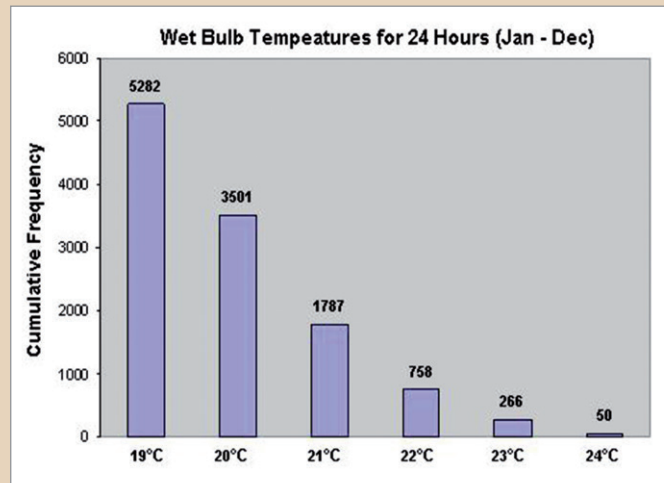


Figure 3: Cumulative frequency histogram

and above instead of 19.1 and 19.2°C. The 2% value is treated between 23 and 24°C AWBT.

Table 5 is followed by the cumulative frequency curve and the histogram (Figure 2 and 3).

## Appendix 2

### Extracts from Chapter 26 – Climatic Design Information – in the 1997 Edition of ASHRAE Fundamentals Handbook

1. The design conditions in this chapter are calculated on a different basis compared to the design conditions published in previous editions of this handbook. Previous design conditions were based on a 4-month summer period and a 3-month winter period in the United States, in the months of July and January in Canada, and the warmest 4-month period and coldest 3-month period in international locations. \*Although generally suitable as design values, the different periods resulted in design temperatures representing different annual probabilities of occurrence, depending on the country; and within countries, on the distribution of temperature and humidity conditions throughout the year typical of regional climatic zones. The design conditions in this chapter explicitly represent the same annual probability of occurrence in any location, regardless of country or general climatic conditions.
2. \*\*The annual cumulative frequency of occurrences representing the design dry-bulb temperatures generally correspond to the seasonal design temperatures in the following fashion for locations in the mid-latitude, continental locations (characterized by a hot summer and cold winter). The 0.4% annual value is about the same as the 1% summer design temperature. This 1% annual value is about 0.5K lower than the 2.5% summer design temperatures in the 1993 ASHRAE Handbook, and the 2% annual condition corresponds approximately to the 5% summer design temperature in the 1993 Handbook.

3. Applicability and Characteristics of Design Conditions

3.1 The sets of design values in this chapter represent different psychrometric conditions. Design data based on dry-bulb temperature represent peak occurrences of the sensible component of ambient outdoor conditions. Design values based on wet-bulb temperatures are related to the enthalpy of the outdoor air. Conditions based on dew point relate to the peaks of the humidity ratio. *\*\*\*The designer, engineer, or other user must decide which set(s) of conditions and probability of occurrence apply to the design situations. The addition of the psychrometric design conditions in this chapter allows for several viewpoints of operational peak loads. Additional sources of information on the frequency and duration of extremes of temperatures and humidity are provided later in this chapter.*

**Cooling and Dehumidification Design Conditions (summer)**

The 0.4%, 1.0% and 2.0% dry-bulb temperatures and mean coincident wet-bulb temperatures in Column 2 of Tables 1b, 2b and 3b often represent conditions on hot, mostly sunny days. These are useful for cooling applications, especially air conditioning.

Design conditions based on wet-bulb temperature in Column 3 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.

The design conditions based on dew-point temperatures in Column 4 of Tables 1b, 2b and 3b are directly related to....

**Author's Remarks**

*\*The sentences in italics need to be understood and analyzed in depth to decide on whether the perceived disadvantages and risks of adopting lower WBTs are to be accepted to gain the benefit of achieving the same annual probability of occurrence in any location, regardless of country or general climatic conditions.*

*\*\*It should be noted from this observation that it does not take cognizance of regions other than mid latitude continental locations. The impact of this sentence cannot be assessed satisfactorily.*

*\*\*\*Using cooling WB/MCDB may be more appropriate for evaporative cooling; nevertheless, discussions in this article centre around 19°C as the ambient design WB temperature, since calculations made by a large majority of engineers in our country use this value.*

**Conclusion**

This study recommends use of 23-24°C as ADWB for evaporative cooling, based on detailed consideration of weather data and different operating patterns. This agrees 'closely' with the value of 23.5°C recommended in WeDCo data under cooling WB/MCDB.

