A fresh approach to Evaporative Cooling

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Starting from Climate and Comfort, the article takes an overview and analyzes concepts and detailed design of EC Systems. Topics covered include, Importance of Wet Bulb and Wet Bulb Depression, Revision of Concepts of Comfort, Plant Sizing, Room Air Movement, Use of Local Air Moving Devices like personal fans, Year-round Plant Performance, Energy Consumption Calculations, Comparative Studies Between Direct Evaporative Cooling, Indirect Evaporative Cooling and Air Conditioning - all with a fresh approach. The focus on energy saving is sharp throughout. The role that Evaporative Cooling can play in creating Energy Efficient Buildings and Green Buildings is emphasized. HVAC engineers have challenges and also opportunities to fashion EC in a fresh garb, using today's concepts, technology and tools for design and calculations.

Background

In Alternatives-to-Air Conditioning (A-to-AC), Evaporative Cooling (EC) is amongst the most widely applied system at the present time. Although it has been in vogue for several decades, there is scope for taking a re-look today at its applicability in relation to Climate, Comfort and Design. Availability of climatic information, new concepts of Comfort and availability of design and calculation tools...... helps us gain a better understanding of how it can be applied to more diverse applications of comfort cooling inspite of the limitations of the system.

About the Author

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Design conditions for HYDERABAD (CIV/MIL), India

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
HYDERABAD (CIV/MIL)	431280	17.45N	78.47E	545	94.95	5.50	IND	8201

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
12	14.0	15.3	3.0	5.0	29.9	5.0	5.8	29.7	6.1	24.5	5.3	25.1	0.2	20

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
5	11.0	40.3	22.0	39.2	21.9	38.0	21.8	25.7	31.8	25.1	30.9	24.6	30.3	3.5	320

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
24.2	20.4	27.9	23.7	19.8	27.2	23.2	19.3	26.7	82.9	32.1	80.1	31.2	78.3	30.4

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
8.4	7.6	6.3	29.0	41.9	11.3	0.9	1.5	42.5	10.2	43.1	9.3	43.6	8.5	44.2	7.4

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	31.4	18.2	34.9	18.3	38.2	20.4	40.7	22.2	42.1	21.9	40.5	22.0
1%	30.9	17.9	34.1	18.5	37.7	20.2	40.0	21.6	41.5	22.0	39.1	22.8
2%	30.2	17.7	33.5	18.4	37.1	20.0	39.3	21.5	41.0	22.1	38.0	23.1

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	34.0	23.4	32.0	23.9	33.2	23.2	33.3	21.1	31.2	20.1	30.0	17.9
1%	33.3	23.4	31.4	23.6	32.7	23.1	32.5	21.2	30.8	20.0	29.2	17.9
2%	32.7	23.5	30.9	23.5	32.1	23.1	31.9	21.3	30.2	20.0	28.8	17.9

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	21.3	27.1	23.1	28.7	24.2	30.5	26.3	35.8	27.0	35.2	26.4	31.5
1%	21.0	26.2	22.5	27.9	23.7	30.4	25.4	34.1	26.1	33.7	25.9	31.2
2%	20.6	25.7	22.1	27.3	23.2	30.3	24.8	33.1	25.6	33.4	25.5	31.0

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	25.4	30.2	25.2	29.2	25.2	29.4	25.3	29.2	23.5	27.5	21.7	25.4
1%	25.1	29.8	25.0	28.7	25.0	29.3	24.7	28.5	23.1	27.0	21.3	25.0
2%	24.7	29.4	24.7	28.4	24.7	28.9	24.4	28.1	22.8	26.6	21.0	24.7

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
11.0	11.8	12.3	11.5	11.0	8.4	6.5	6.0	6.9	8.2	9.8	11.2

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, m	StdP	Standard pressure at station elevation, kPa		
DB	Dry bulb temperature, °C	DP	Dew point temperature, °C	WB	Wet bulb temperature, °C
WS	Wind speed, m/s	Enth	Enthalpy, kJ/kg	HR	Humidity ratio, grams of moisture per kilogram of dry air
MCDB	Mean coincident dry bulb temperature, °C	MCDP	Mean coincident dew point temperature, °C	MCWB	Mean coincident wet bulb temperature, °C
MCWS	Mean coincident wind speed, m/s	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Table 1

Climatic Data

Sources :

Climate and the Comfort Level desired are the two most important factors in deciding on whether EC is a suitable system for any given project; they also influence the selection of the kind of EC system that is the best for the application.

Source for selection of Design Ambient Conditions is the ASHRAE Hand Book (Fundamentals Volume - 2005) and WeDCo. If the station (city) of interest is listed therein, data is presented in a CD supplied by ASHRAE as a part of the Hand Book (please see *Table 1*, which shows the design conditions for Hyderabad). Hourly data are available in WeDCo (also in a CD).

Choice of Ambient Design Conditions

The design ambient conditions for cooling applications are based essentially on the acceptable number of hours in the year that a particular ambient DB or WB is not exceeded in the entire year. This number of hours is expressed as percentage of total number of hours per year. Thus, 0.4% value means a value that is not exceeded for more than 0.004 x 8760 = 35 hours. This implies that a plant designed for 0.4% level will not cool adequately over a period of 35 hours over the entire year. Other levels are 1% (87.6 hours) and 2% (175 hours). The 35 hours (at 0.4% level) are not equally distributed over the seasons of the year or the months or the weeks or the hours. On the other hand, they do not all occur during the same month or week. Secondly, if the plant is serving an office or an establishment, which works 12 hours a day, the user may be interested in knowing how many hours of a day he will be deprived of the agreed comfort level. For eg. if all the 35 hours occur in a period of about 2 months and if the user stipulates that he can tolerate such deviation for just one hour of a 12 hour day, discomfort will be experienced over 8.3% of the time; further, if he opts for limit of half-an-hour, instead of one hour, it will go up to 16%. Similar considerations apply to monthly values also. It is useful and advisable for the engineer to understand how to interpret the climatic information suitably, so that the engineer and the user arrive at a mutually acceptable situation.

Relevant to the topic, is to note that ASHRAE data is presented in the following 3 groups:

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- Annual Cooling, Dehumidification and Enthalpy Design Conditions (Group A)
- Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures (Group B)
- Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures (Group C)

Group – A Data represent Annual Design Conditions for both a) Air Conditioning – cooling DB/MCWB and b) Evaporative Cooling – Evaporation DB/MCWB.

Group – B furnishes Monthly Ambient Data for Air Conditioning – Cooling DB/MCWB, while similar data – for Evaporative Cooling are presented in Group – C.

It will be noticed that all the groups contain data for all the parameters involved. The evaporation WB-MCDB data appear in Group-A, Group-B and Group-C as well. They are reproduced here for Hyderabad in *Table 2*.

	Cooling DB-°C	MCWB -°C	MCDB -°C	Evaporative WB - °C
Annual- Group A – 0.4%	40.3	22.0	31.8	25.7
Annual- Group A – 1%	39.2	21.9	30.9	25.1
Monthly/May – Group B – 0.4%	42.1	21.9		
Monthly/May – Group B – 1%	41.5	22.0		
Monthly/September – Group B – 0.4%	33.2	23.2		
Monthly/September – Group B – 1%	33.7	23.1		
Monthly/May – Group C – 0.4%			33.7	26.1
Monthly/May – Group C – 1%			35.2	27.0
Monthly/September – Group C – 0.4%			29.4	25.2
Monthly/September – Group C - 1%			29.3	25

Table - 2

It will be seen that the design ambient WB temperatures are most harsh in Group-C, while the values in Group-B are lowest. The lowest design ambient WBs occurs in Group-A.

From a practicing engineer's point of view, it is the Group-C data which is relevant for Evaporative Cooling. It is recommended that cooling load calculations are made for the months in the year, in which plant capacity required is expected to be highest. This could mean calculations for all the 12 months, as the capacity depends not only on the cooling load, but also on the wet bulb temperatures and the wet bulb depression.

It will be seen that the 0.4% value for May is 27°C WB with a MCDB of 35.2°C (Reference 1). The WB value seems to be on the high side. Designing for 0.4% Group-C values in the case of Hyderabad means applying 35.2°C MCDB and 27°C WB for ambient design values. The wet bulb depression for these values is 8.2°C. Compare this with WB depression of 20.2°C (42.1°C minus 21.9°C) for 0.4% Group-B values - which is generally used. The former is only 40% of the latter. Accordingly, it can be expected that the plants designed on Group-C value will be 2.5 times bigger. It is this result which conveys the impression that the WB shown in Group-C values are on the high side.

A study of the data for frequency distribution of WB temperatures in WeDCo shows temperatures in 8 bands. It will be noticed that the frequency of occurrence of in the last 2 bands i.e. 26°C and above, is zero. It is obvious that this should be checked for a possible error. It should also be noted at the same time that, what could be merely a numerical error, does not invalidate the calculation procedure adopted.

In the calculations made in this article, the value chosen (based on WeDCo data) is lower - 24.2°C (this is shown in the *Table 3* below).

WB -°C	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28
May-10 hrs	9	52	93	109	69	7	0	0
Cumulative	339	330	278	185	76	7		

Table 3

The table shows a frequency of occurrence of 76 for temperatures 24°C and above. This value comes down to 64 (19%) for a frequency of occurrence of temperatures above 24.2°C (this is not shown in the table). This means that the value of 24.2°C is exceeded in about 1.5 hours in every working day of 10 hours.

This may be compared with the discussion under the topic "Choice of Ambient Design Conditions" earlier in this article.

Confining ourselves to Evaporative Cooling, it appears that Group-C design ambients for the month of May for 2% level.

For the purposes of plant sizing and checking its adequacy for various months, Group – C data (2%) have been used for the months – May to October (monsoon months). It might appear that the plant will not be useful in cooler (winter) months. This will probably hold in case of residences and also, where more generally, the internal loads will be low; however, for commercial buildings and even offices, buildings which have significant internal loads especially – people, lighting and appliances, cooling may be required at least during some parts of the 12 hours day. The plant will therefore, be running at part load most of the year. This may be compared with the situation in air conditioning, where a plant is sized for cooling DB/MCWB and is running at part load under all other conditions.

Climatic Data for Energy Calculations

Energy calculations require hourly data. These have been taken from WeDCo data. In the energy calculations made in this article, the 10 hour day has been divided into 5 time segments of 2 hours each (from 8 AM to 6 PM). The hourly data for every time segment has been

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averaged. The 24.2°C ambient wet bulb temperature shown in the 2PM - 4PM segment in *Table 5** has been arrived at on the above basis.

No relation has been found between WeDCo's hourly data and the ASHRAE handbook data. WeDCo data, it may noted is based on IMD's raw data processed thereafter by WeDCo - and duly vetted by ASHRAE.

Climatic Data Vis-à-vis Cooling Loads and Air Flow Rates

Sizing an evaporative cooling plant is essentially; determining the maximum air flow rate required. The factors involved are

a) Cooling Load (SHG)
b) Supply Air Temperatures (SAT)
c) Room Temperature (Trm)
d) Room Temperature - supply air temperature (Trm – SAT)

Items b & d depend a great deal on the ambient wet bulb temperature and significantly, on the kind of equipment used and their efficiencies. Weather-dependent gains (envelope gains) on the one hand, and appliances, lighting and occupancy, on the other, are the major components of the Cooling Loads. The impact of these components on cooling loads and air flow rates are shown below:

• Weather Dependent Gains - High • Wet bulbs - Low • Internal Loads - Low	Evaporative WB load will be lower than Cooling DB load
• Internal loads - High • Wet bulbs - High • Weather dependent gains - low	Evaporative WB load will be higher than cooling DB loads
• High WB and low ΔTs in monsoon as compared to dry summer season.	High supply air temperature - high air flow rates

Table - 7

Thus, the Evaporation WB cooling loads could often be higher than the Cooling DB loads. Also to be remembered, is that larger cooling loads do not necessary result in higher air flow rates. This is because occurrence of such large loads may coincide with high WB depression. On the other hand, big air flow rates will be required even at smaller cooling loads, when ΔT is small - typically in monsoon. This is a complicating factor. Please see *Tables 5 & 6** and *Figure 2 & 3**. In air conditioning calculations on the other hand, a higher cooling load invariably means a higher TR – and a higher air flow rate.

Cooling DB/MCWB Vs Evaporative WB/MCDB

It is clear that Evaporative Cooling plant sized on the basis of Evaporative WB/MCDB will be bigger than of those sized on the basis of Cooling DB/MCWB - by as much as 2 to 3 times. The DB/MCWB plant, while it will turn out to be smaller, will work only for a few months (Feb to May) in the year, whereas the bigger Evaporative WE/MCDB will work for a longer period. The first cost will be obviously higher for the bigger plant, the cost can be spread over a larger part of the year that it will be in beneficial use. The question is; what higher cost will be acceptable, for how many extra months that the plant can be put to beneficial use? This will imply a study of 'what if' options, and what the market will accept. It is dealt with greater detail in this article, though not in an obvious manner.

We have been looking all along at Climate, one of the two most important factors in Evaporative Cooling. We can now turn our attention to Comfort, which is the other factor.

Comfort : AC – ET 20 to 21°C, A-to-AC - ET up to 27°C

In air conditioning, Comfort is usually taken to mean 23±1°C db and 50 to 60% RH. This translates to an ET** range of 20-21°C. i.e. a range of about 1°C. Humans

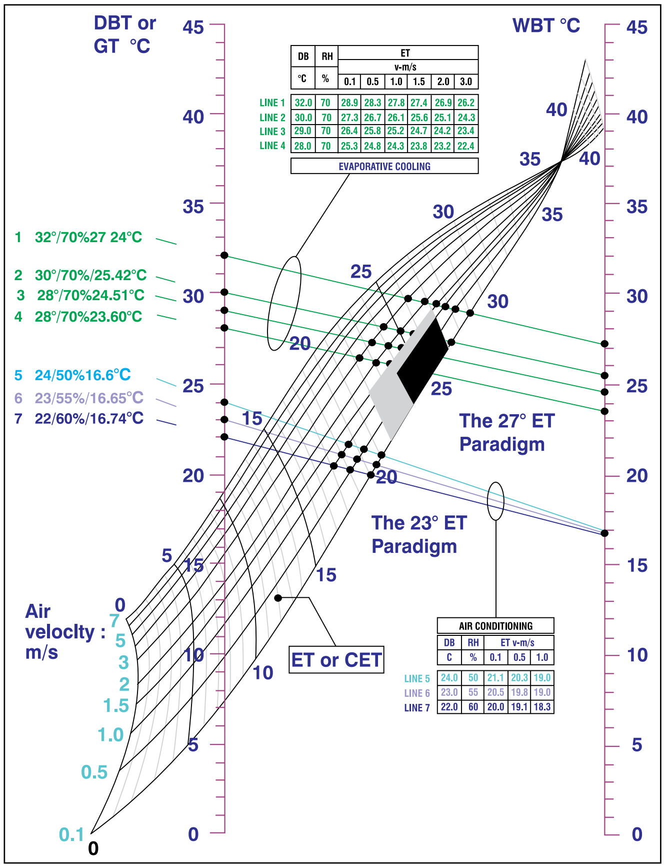

Figure 1 : ET Nomogram

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* *Refer note on last page of this article.*

** *Effective Temperature (ET) is the temperature of an environment with a relative humidity of 50% and air movement of about 0.1 m/s that would in the absence of radiation produce the same effect as the environment under consideration. Corrected Effective Temperature (CET or ET) includes radiation effects also.*

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however adapt themselves to significant climatic conditions. Accordingly, in tropical regions, ETs up to 27°C are found to be acceptable. A DB of 32°C at an RH of 70%, when supported by an air movement of 1 m/s, is representative of an ET of 27°C. Even lower ETs down to about 24.5°C can be achieved, if air movement is raised further, but especially for offices and indoor areas, which do not come under the category of Hot Industrial environments, the limit of air velocity (v) is kept down to 0.8-1.0 m/s and 1.5 m/s for office. Please see *Figure 1* ET Nomogram. Higher air movements are permissible, and in fact, preferred in hot industrial environments. Please see *Figure 1*.

Air Movement as a Comfort Factor

The improvement in ET by creating higher 'v' values recognizes air movement as a major parameter and a tool for enhancing comfort levels in tropical regions besides the DB and RH, which are the only two parameters identified conventionally with Comfort.

The enhancement of Comfort (lower ETs) due to air movement is explained as follows:

In air conditioning, heat is lost by the human (body) mainly by convection and radiation, both these processes facilitated by the fact that the body temperature 32-34°C is significantly higher, while the ambient is cooler 23±1°C typically. In EC on the other hand, the ambient is usually in a range of 28°C to 32°C. This temperature difference (say 3°C - 5°C) is not large enough for the body to loose heat comfortably to the environment. It does produce more sweat in order to overcome this difficulty. However, producing more sweat is not sufficient to produce relief. The sweat produced must also be evaporated. Evaporation depends upon the product of difference in vapor pressure of water vapor (saturated at skin temperature) and the ambient vapor pressure on one hand, and the air movement on the other. If the ambient is humid, a higher air movement over the skin is required in order to evaporate the same amount of sweat

The effect of air movement is to reduce the ET for the same DB. Thus, a room with adequate air movement will show the same DB as the same room with poor air movement. However, if a globe thermometer senses the conditions, the temperature shown by it will be close to the ET. The relation between, DB, WB, 'V' and ET can be seen from the ET nomogram – *Figure 1*. This nomogram also incidentally identifies the relative locations of the comfort zone in tropical regions as compared to the comfort zone identified usually with air conditioning.

The 27°C ET Paradigm and Room Air Movement

Support and recommendations of 27°C ET as an acceptable criticism for Comfort in tropical countries and with appropriate qualifications, as well as recognition of the role of air movement in enhancing comfort levels may be found in Reference-3 and Reference-5

A method of calculation of room air movement has been furnished in Reference-2 and Reference-5.

Air Flow Rate Vis-à-vis ΔT

In Evaporative Cooling, the temperature pick-up (ΔT) is usually 4-5°C and in Natural Cooling (or Natural Ventilation), it would be lower sat 2.5-3°C. It will be readily appreciated that with temperature pick-ups being so small, any supply air temperature that is lower or higher even by 1-1.25°C will have a heavy impact on comfort levels, plant sizing, costing etc. and eventually, in fact, even on the very choice of an Evaporative Cooling System.

In *Table 5* "Air Flow Rate & Other Data for Typical Day of Each Month - DEC", the WBT along with ΔT furnishes the basis for arriving at the Supply Air Temperature. Thus, for a WBT of 24.25°C (row 2, 2pm to 4 pm value) and a dry bulb of 30°C, the air washer leaving temperature is 25.79°C. Adding a temperature rise of 1°C yields a ΔT value of 3.21.

Using air movement to lower ET often implies a DB higher than by 2-3°C. Assuming ambient design conditions of 36°C/25°C and room temperature of 30°C, the DEC leaving temperature would be 9.5°C. Adding a temperature rise of 1°C, the ΔT will be 30 – 26.5 = 3.5°C.

Consider now, the consequence of revising room temperature to 31°C. This results in a ΔT of 4.21 instead of 3.21 i.e., an increase of slightly over 30%. This implies a corresponding reduction of air flow rate to 191910 l/s from 251442 l/s. This is a very substantial reduction in air flow for a room temperature revision of just 1°C. It may be noted in passing that, on the other hand, the impact of raising the room temperature to 31°C considered above is a relatively small reduction in the cooling energy requirements of just 986 KW from 1000 KW i.e., 14 KW (14/1000*100 = 1.4%).

Another point that may be noted is that if the room temperature is lowered to 29°C instead of being raised to 31°C, the ΔT will become so small that the air flow required will shoot-up spectacularly. This is because we are dealing in small values of ΔTs and a change of by 1°C represents 30 to 40% of its value. Hence, if the calculation that has been made initially shows a ΔT of 2.5-3°C, a further lowering of room temperature, resulting in a corresponding reduction of ΔT is not feasible. The room temperature can only be raised but not lowered in this case. Thus, in any case, it is clear that the air flow rate and accordingly the plant size is extremely sensitive to ΔT, which in turn, is dependent heavily on the WB temperature. This demonstrates the importance of the

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position that WB (through the WB depression) through its influence on the attainable room temperature and also on the required air flow rate through its involvement in ΔT (though its involvement is ΔT).

Room Db Vis-à-vis Cooling Load

Another point that may be noted is that, while calculating the cooling loads, the engineer need not bother too much about what room temperature he starts the exercise with. (Room rh in an Evaporative Cooling plant will be around 60 to 70% and its variation with room DB is negligible. In any case, it has no bearing on cooling load calculations). The room temperature itself is an important parameter for determination of plant capacity, but not the cooling load.

Wet Bulb, a Major Player in Evaporative Cooling

In air conditioning, WB is one of the many factors involved in arriving at the plant cooling load capacity - but a big factor, only whenever OA flow rates and OA enthalpies are high. However, its influence on the supply air temperature is relatively weak. In Evaporative Cooling, on the other hand, we have seen that it is the WB that is a major player influencing plant performance, though its impact on the cooling load itself is negligible.

In air conditioning, the supply air temperature is not influenced by the wet bulb temperature or any other uncontrollable variable. A plant can be designed for any supply air temperature - 10 to 15°C usually - which can be maintained constant, independently of all other influences. Such a situation does not prevail in EC due to the impact of wet bulb. In this way wet bulb introduces considerable constraints and great complexity in EC systems.

Instrumentation and Performance Testing

The performance of the Evaporative Cooling System is to be judged in terms of whether the desired ETs have been achieved. Performance testing therefore, involves measuring ETs. Parameters measured conventionally in AC and A-to-AC systems are temperature and humidity (db & rh or db & wb). In Comfort, it is necessary to include an instrument to measure Wet-Globe Temperature (WGT). The WGT measures environmental heat stress, which is related to WBGT and leads to ET through heat stress index. The measurement is made with a wetted globe thermometer called a Botsball (Reference 4), which consists of a 65mm black copper sphere covered with a fitted wet black mesh fabric, into which the sensor of a dial thermometer is inserted. A polished stem attached to the sphere supports the thermometer and contains a water reservoir for keeping the sphere covering wet. This instrument is suspended by the stem at the site to be measured. Any change in air temperature, humidity, wind or thermal radiation that causes the Botsball temperature to rise will increase human discomfort or stress. Conversely, any change in these conditions that lowers the Botsball temperature will alleviate discomfort or stress.

Controls and Operation of EC Systems

The Evaporative Cooling System – whether DEC or IDEC - needs and deserves - to be controlled the way air conditioning plants are. The EC System described in this article consists of fans, spray arrangements and cooling coils, dampers.... Necessary controls for all these devices must be duly installed. The operating logic, working pattern have to be taken care off in the control system operation. In short, BMS must be provided – which will enable realization of achievable goals of energy consumption caps.

Green Buildings and Energy Efficient Buildings

With the sharp focus on energy through out these discussions, EC Systems could become a part and parcel of the concept of a Green Building Designs and Energy Efficient Buildings. Consideration may be given to extend the concepts of adaptive approaches to comfort and elastic comfort zone.

Worked Example

A worked example is included as a part of the article. Calculations have been made for both DEC and IDEC systems. Besides, air conditioning is also included in the comparative study. The contents of calculations for the Worked Example are noted briefly below for ready reference:

Sl. No	Contents
Table 1	Design Conditions for Hyderabad
Fig 1	ET Nomogram
Table 4	Data Sheet *
Table 5	Air flow rates & other data in 2 hr time segments - DEC **(Sample)** *
Table 6	Air flow rates & other data in 2 hr time segments - IDEC **(Sample)** *
Fig 2	Monthly Cooling Load *
Fig 3	Air Flow Rate – DEC *
Fig 4	Air Flow Rate – IDEC *
Fig 5	Ambient and Room Temperature – DEC *
Fig 6	Ambient and Room Temperature – IDEC *
Table 9	Comparative Study of DEC, IDEC and AC Systems

The steps and the sequence followed in the calculations are about the same as the contents listed above. These calculations have been made for all the 12 months in the year for both DEC and IDEC systems. All calculations are in Spread sheets.

** Refer note on last page of this article.*

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Notes and Observations on Worked Example

The Comfort level in the room is adapted to the ambient conditions. Thus, ET values are set lower during the winter months and in dry summer, where as they are set higher during the rest of the year. The setting will also depend on the design, type of the system employed (DEC or IDEC) and even on the time of the day. The dependence on the system is reflected in *Tables 5 & 6** where room DB is 31°C if the former and 29°C in the latter. The adjustments can be either manually or by automatic controls.

Though the flow rates in both September and May are about the same, the ET is significantly (about 3-4°C) higher between April and October (*Figure 5**). The flow rate required to lower the ET to about 27°C during this period will be substantially higher.

Whenever the calculated and selected air flow rates happen to be the same, the common curve is shown in Green (*Figures 3 & 4**).

The area between the minimum flow rates and the calculated flow rates represents the quantum of the air flow rate required from Local Air Moving Devices (LAMDs). This is also a measure of the energy saved due to use of LAMDs. The energy saving is calculated on the basis of reduction in power consumption due to the difference between 2.6 l/s per W for delivery through IDEC and 100 l/s per W through LAMDs. The implication is that, when deficit in air movement is taken care off by LAMDs rather than by the DEC or IDEC equipments, the additional power consumption will be only 1/40 to 1/30 of the consumption, if the fans of the DEC or IDEC equipment were oversized instead.

Fixing the minimum air flow rate is governed by requirement of pressurization of space served or by other appropriate criterion.

The "DB of air leaving DEC" line is always above the "WB" line. (*Figure 5**). It is almost touching the "WB" line during the middle of June-July, August-September and (end of) October (*Figures 5 & 6**).

The "DB of air leaving IDEC" is almost touching the "WB" line in September and remains close to it during Aug-Sep and Sep-Oct (2 months); there-after the DB of air leaving IDEC is significantly lower than WB. This may be compared with DECs performance. While both the systems do not perform so effectively during some months, IDEC fares better. During such months, introducing a cooling coil down stream of the heat exchanger of the IDEC equipment is indicated. This makes a "hybrid system".

Room temperatures - (and therefore, ETs also) in

Sl. No	Description	DEC	IDEC	AC
1.0	Design & Performance			
1.1	Area - Sqm		9280	
1.2	Height - M		3.6	
1.3	Volume - Cum		33408	
1.4	Max. RSH for selected flow rate - KW	993	717	–
1.5	TR	–	–	493
1.6	Sqm/TR	–	–	18.82
1.7	Air Flow Rate - l/s	191717	201475	99772
1.8	Flow Rate / area			
a	l/s/sqm	20.66	21.71	10.75
b	cfm/sft	4.04	4.24	2.10
1.9	ACH	20.66	21.71	10.75
1.10	No. of Plants	12	12	
1.11	Capacity / plant - l/s	15976	16790	
2.0	Connected Power			
2.1	DEC			
a	Fan - KW	222		–
c	Pump - KW	3		–
2.2	IDEC			
a	Primary Fan - KW		222	
b	Secondary Fan - KW		30	
c	Pump - KW		Neglect	
2.3	Air Conditioning			
a	Chillers - 2 Nos X 300 KW each			600
b	Cooling Tower Fan - 2 Nos X 3.7 KW each			7.4
c	Chilled Water Pump - 2 Nos X 16.5 KW each			37
d	Condenser Water Pump - 2 Nos X 22 KW each			44
e	AHU Fans -8 Nos X 15 KW each			120
2.4	Total Connected Power - KW	225	252	808.4
2.5	Total Connected Power/Sqm	0.024	0.0272	0.0871
3.0	Energy Consumption			
3.1	Chillers - KWH	–	–	706559.28
3.2	Cooling Tower Fan - KWH	–	–	24710.4
3.3	Chilled Water Pump - KWH	–	–	98950.5
3.4	Condenser Water Pump - KWH	–	–	118844
3.5	AHU Fans - KWH			238838.50
3.6	Annual Energy Consumption - KWH	248786.88	311731.48	1187902.68
3.7	DEC/AC	0.21		
3.8	2-Stage Cooling/AC		0.26	
3.9	DEC/2-Stage Cooling	0.80		
3.10	KWH (row 3.6) /Sqm	26.81	33.59	128.01
3.11	Annual Water Requirement - m3	9546.75	6469.91	7909.21

Table 9 : Comparative Study of DEC, IDEC and AC Systems.

* *Refer note on last page of this article.*

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IDEC are lower than in DEC. The method of calculations adopted (in both cases viz., DEC & IDEC) makes it possible to appreciate the flexibility available in choice of room temperatures, ETs and air flow rates.

IDEC can run beneficially as long as room temperature minus DB of air leaving IDEC is considered acceptable, say 2-3 degrees. Alternately, where internal loads are negligible, the pumps can be switched off, when the ambient dry bulb falls below to say 21-23°C. On further fall in ambient temperature, the fans can also be shutdown, keeping the LAMDs on, if required.

Design, Performance, Connected Power and related details have also been presented in the form of a comparative study for these systems (and Air conditioning also) in *Table* 9.

Analysis of Table 9

The following points may be noted :

1. Connected power for Evaporative Cooling Systems considered viz., DEC and IDEC, is substantially lower than that required for Air Conditioning (31%).

2. The water consumption for the DEC system - 9500 m^3, is highest, with IDEC system, showing the lowest figure - 6470 m^3 (68% of DEC values). The value for Air Conditioning is 7910 m^3 (83% of DEC value) being between the two.

3. The Annual Energy Consumption figures show that DEC is lowest – 2,49,000 KWH (about 21% of consumption by the AC system) with the IDEC system being higher, consuming 311730 KWH. This represents 26% of the AC energy consumption. Of them all, the AC system is the highest consumer for energy - 11,88,000 KWH.

Thus the Evaporative Cooling Systems consume about 20-25% of the consumption in AC system.

Remarks on Choice Between DEC and IDEC

Between the DEC and IDEC Systems, the IDEC system is more expensive. However, they can sometimes be applied where DEC can not be applied at all. Where both the systems are considered for an application, IDEC's performance will be superior in terms of higher comfort levels achieved at an energy consumption level which is just 25 to 30% of the cost of energy consumption by air conditioning. The choice of any of these systems is finally governed by a feasibility analysis of and by due consideration of all other issues involved (which do not involve any technical issues).

Summary and Conclusions

As noted earlier, the concepts and calculations are characterized by a great deal of flexibility. Several methods and approaches are possible. It is necessary to analyze each and every project to take care of all the issues discussed. Larger the number of projects tackled in a comprehensive manner, the better will be the quality of the design and calculation procedures. Such projects should be at many locations in a given climatic zone and in all the climatic zones in our country. The feed back thus available will be of great help, if properly utilized. The design and calculations in this article are not definitive, nor is it expected that the practicing engineers will be all able to work in such detail for all projects, but their work should be informed by the concepts and procedures that are continually under evolution. Also, hopefully, the article will create an awareness of the nature of issues that require solutions. The situation offers both challenges and opportunities to the HVAC engineers.

** Note : Tables 4,5,6 and Figures 2,3,4,5 & 6 are available in a separate brochure which will be sent free of charge on request. Please contact by post or email to the Editor at* ***ishrae_m@vsnl.net***

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