IMPORTANCE OF DESIGN CONDITIONS FOR SIZING AIR-CONDITIONING PLANT

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ABSTRACT

Design conditions based on the meteorological data collected at two weather stations located less than 10 km away from each other within Kuwait City are presented for dry-bulb temperature (DBT) and wet-bulb temperature (WBT) prioritisation. The proposed design conditions specific to the location and the application are drastically different than currently used single design conditions for all applications and locations. Cooling load estimates for two buildings located in Kuwait have been analysed for the proposed and the current design conditions to highlight over- or under-sizing the air-conditioning (A/C) plant capacity. Finally, a number of recommendations are made for architects and designers to use proper design conditions to ensure year-round comfort and energy conservation.

Keywords: Design conditions, cooling capacity, cooling load.

INTRODUCTION

power/energy and to provide comfortable indoor environments throughout the summer. Over-sizing leads to higher initial investments and larger energy consumption by auxiliaries like pumps and fans while under-sizing results in discomfort during the peak summer season.

Choice of design conditions is one major factor controlling the capacity of the A/C plant. It is a common practice to define a single set of design conditions for a city irrespective of its size or topography (ASHRAE, 1987). Large cites or small countries, situated on the coastline, may have significant variations in weather conditions prevalent on the coastline and the interior region. Using a single set of design conditions for such places can result in either over-sizing or under-sizing the A/C plant capacity. It is, therefore, necessary to use their appropriate values. Another factor of importance is the choice of design conditions based on the prioritisation of the DBT the WBT. The WBT is the dominant parameter influencing the performance of an A/C system using a water-cooled (WC) condenser. Also, the estimates for the cooling load for the buildings with excessive requirements of ventilation are largely dependent on the WBT since the fresh air enthalpy is a direct function of the ambient WBT. Similarly, the performance of the A/C systems with air-cooled (AC) condensers and the estimates of cooling loads for general buildings are controlled by the DBT. As an example, the A/C system based on DBT prioritisation for a hospital building with high requirement of fresh air, located on the coastline, will not be able to meet the cooling demand during the hot and humid part of the summer. The matter will be worse if the A/C system is of WC type.

These concerns have been analysed in this paper in an actual situation for a small coastline country, Kuwait, wherein a single set of design conditions are currently being used for the entire country and for all types of A/C systems.

DESIGN CONDITIONS

Ambient design temperatures are

DBT and WBT are the two important design parameters for estimation of cooling load and selection of A/C equipment. Procedures, outlined in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 1981) publication, were used in an earlier study by the authors for estimating the design conditions for the coastal and interior areas of Kuwait, using the recorded data from two weather stations. In Kuwait, at present, a single set of design conditions, 46°C DBT and 28°C WBT, are used through the country for all applications.

The meteorological data over the past several years show an appreciable difference in weather conditions for the coastal and the interior areas, particularly during the summer season. Coastal areas experience hot and humid conditions, whereas the interior region is hot and dry (Shaban et al., 1998). Different sets of design conditions have been established, one prioritising the DBT and the other prioritising the WBT. For the first set of design conditions, the DBT values are established for different frequencies and the WBT values are then estimated by averaging the corresponding WBT values occurring simultaneously, and vice versa for the second set. Table1 presents these design conditions for the 2.5% frequency. The set of these design conditions are more appropriate as they are better representatives of the locations and applications.

Table 1. Design Conditions for Coastal and Interior Areas for Case Study

Location	DBT Prioritisation		WBT Prioritisation	
	DBT °C	WBT °C	DBT °C	WBT °C
Coastal Region	46.10	27.07	42.85	31.80
Interior Region	47.00	22.10	37.00	25.50

Source: Shaban et al., 1998, p. 10

ANALYSIS APPROACH

The estimates for the cooling load of a building (L) and the expected cooling output (C) of an A/C system are affected by the choice of design conditions. For a normal system, the two should match when the actual weather conditions coincide with the design conditions. Any deviation in the weather conditions from the design conditions affect these parameters differently. As an example, milder weather conditions will increase the C and reduce the L simultaneously and vice versa.

The current design conditions of 46°C DBT and 28°C WBT are used for estimation of the base values of L and C. They are termed as L_b and C_b, respectively. Likewise, for the proposed conditions as per Table 1, these are termed as L_c and C_c, respectively. The room conditions for all the cases are 24°C DBT and 50% Relative Humidity (RH).

Cooling Load of Building:

L_c , at any other design conditions is given by:

$$L_c = (\Delta h_c/\Delta h_b.\theta_1 + \theta_2 + \theta_3 + \Delta t_c/\Delta t_b.\theta_4)\, L_b \quad (1)$$

where:

Δh_b = (enthalpy at base design conditions) - (enthalpy at room conditions)

Δh_c = (enthalpy at other design conditions) - (enthalpy at room conditions)

Δt_b = (ambient DBT with base design conditions) - (indoor DBT; 24 °C)

Δt_c = (ambient DBT with other design conditions) - (indoor DBT; 24 °C)

θ_1 = ventilation-to-total cooling load ratio

θ_2 = internal-to-total cooling load ratio

θ_3 = solar-to-total cooling load ratio

θ_4 = transmission-to-total cooling load ratio

The first term of Eq. 1 is the latent load of the building, which is directly affected by the changes in the ambient WBT. The second and the third terms, which represent the internal and the solar gain, are independent of the weather conditions. The last term represents the sensible transmission load, which is dependent on the outdoor/indoor DBT. The deviation in cooling load (δ_{cl}) is defined as:

$$\delta_{cl} = (L_c) - (L_b) \quad (2)$$

Cooling Production:

The cooling production of the plant directly depends upon the temperature of the sink, which is DBT for the AC units and WBT for the WC units. Estimates of cooling output of the cooling plant can be made using the catalogue information. These data show that the cooling output deteriorates by 1.0% for the AC systems and by 1.2% for the WC systems, for one-degree centigrade rise in the outdoor DBT or WBT above the rated output at rated conditions (Al-Bassam et al., 1994). The deviation in cooling plant capacity (δ_{cap}) or cooling production is defined as:

δ_{cap} = (cooling production at design conditions) - (cooling production at base design conditions)

$$= C_c - C_b \quad (3)$$

The net deviation, δ_{net}, represented by the difference between the deviations in cooling production and in the cooling load is given by:

$$\delta_{net} = \delta_{cap} - \delta_{cl} \quad (4)$$

A positive value of the parameter δ_{net} indicates that the A/C system design based on base conditions is oversized and conversely, a negative value indicates that the A/C system is undersized.

CASE STUDY

Two Kuwaiti buildings, one on the coastal belt and the other in the interior area, were selected as example case studies. Kuwait, with an area of nearly 17,800 square kilometres and a population of only 2.5 million, can be treated as a large city. In line with the internationally accepted convention for large cities, Kuwait has been following the practice of a single set of design conditions specifying the DBT (46°C) and WBT (28°C) for the entire region. Brief outline of the buildings selected for the case study are :

Hospital Building:

The hospital building, located on the coastal site, is an eight-storey complex with 37,900 square meters as the air-conditioned floor area and a volume of 134,140 cubic meters. Using the base conditions, the building's cooling load was estimated to be 1,059 refrigeration ton (RT). The building, requiring 100% fresh air, has a ventilation load of 70%. The balance is attributed to 24% as internal load and 6% for the combined load of solar gain and transmission.

Office Building:

The office building, located in the interior area, is a four-storey complex with an air-conditioned floor area of 8,590 square meters. Using the base conditions, the building's cooling load was estimated to be 266 RT. Ventilation, internal load, solar gain and transmission account for 4%, 50%, 19% and 27% of the total load, in the same order.

RESULTS OF ANALYSES

Using the four sets of design conditions given in Table 1, the L and C for the two buildings were re-estimated considering possibilities of different locations and type of A/C systems. These values were compared with the original estimates based on the currently used single design conditions. Results for the re-estimated values of L and C and their respective deviations are presented in Table 2. Important observations from these results are:

1. For a hospital, WBT is the controlling parameter for the cooling load of the building as it has very large ventilation load. During the hot and humid summer season, the true cooling load for the hospital located in the coastal region is significantly higher compared with the base load. Also, there is a reduction in cooling production for a WC type of A/C system. Present design conditions are therefore inadequate, as there is a deficiency in the cooling of 30.6% and 38.2% with the AC and WC systems, respectively. However, during the hot and dry season, the situation is comfortable.

2. For a hospital building located in the interior region, the choice of base design conditions is equally harmful, as there is a surplus of cooling. A/C systems with smaller capacity, by as much as 28.8% and 22.8% would have been adequate to meet the cooling demand for the AC and WC systems, respectively.

3. The variations for the office building for different design conditions are marginal since ventilation load is not critical.

Table 2. Results of the Analysed Cases: Hospital ($C_b = L_b$ = 1,059 , Office ($C_b = L_b$ = 266)

Building Type	Hospital				Office			
Building Location	Coastal		Interior		Coastal		Interior	
Priority	DBT	WBT	DBT	WBT	DBT	WBT	DBT	WBT
Load (L_c) in RT	980	1,416	611	849	265	261	263	234
Deviation; Eq.2; in RT	-79	357	-448	-210	-1	-4	-3	-32
Plant Capacity (C_c); AC in RT	1,058	1,092	1,048	1,154	266	274	263	290
Deviation; Eq. 3; AC in RT	-1	33	-11	95	0	8	-3	24
Plant Capacity (C_c); WC in RT	1,071	1,011	1,134	1,091	269	254	285	274
Deviation; Eq. 3; WC in RT	12	-48	75	32	3	-12	19	8
Net Deviation AC in RT	78	-324	437	305	1	12	0	56
Deviation of AC in %	7.4	30.6	41.0	28.8	0.4	4.5	0.0	21.0
Net Deviation WC in RT	91	-405	523	242	4	-8	22	40
Deviation of WC in %	8.6	38.2	49.4	22.8	1.5	3.0	8.3	15.0

CONCLUSIONS

Conclusions of the present study are as follows:

1. Base design conditions are adequate to:

- Meet the worst of the Kuwaiti weather conditions for an office building in all locations,
- Select AC type A/C equipment in all locations,
- Select WC type A/C equipment for buildings located in the interior areas.

2. Base design conditions are inadequate to meet the cooling demand of buildings with high ventilation load and located in the coastal area. Likewise, for similar buildings in interior area, there is a surplus cooling capacity resulting in wasted equipment cost and hindered energy conservation

RECOMMENDATIONS

Following are the recommendations:

1. Single set of design conditions, currently used by the architects and designers, do not promote year-round comfort or energy conservation in air-conditioned buildings.

2. The architects and designers are advised to follow the following steps as indicated in Fig. 1:

- Identify location of the building as being coastal or interior,
- Estimate cooling demand using the design conditions from Table 1, both for DBT and WBT prioritisation and select the larger of the two,
- Select AC and WC type equipment using the design conditions from Table 1 with DBT and WBT prioritisation, respectively.

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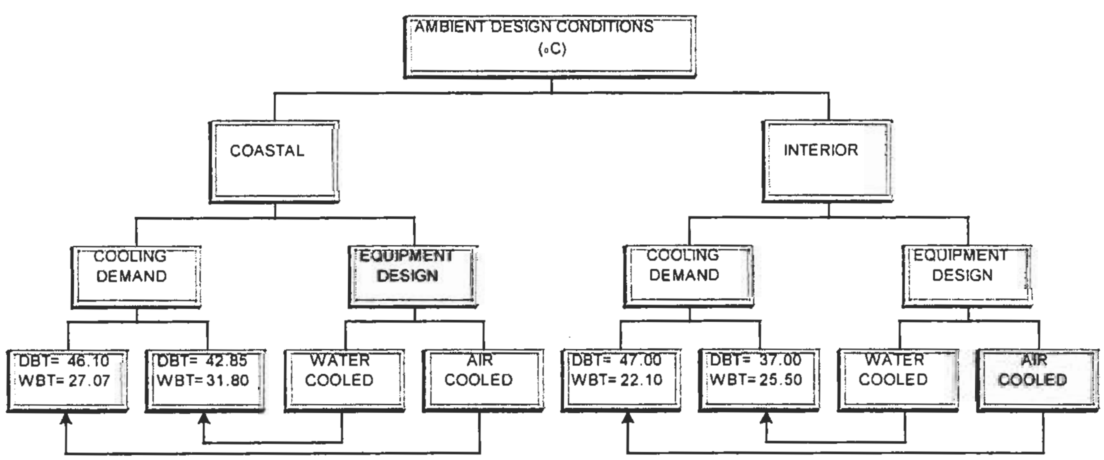

Fig.1. Ambient design conditions guidelines summary (at 2.5 % frequency)