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Space temperature difference, cooling coil and fan—energy and indoor air quality issues revisited

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Abstract

In designing an energy-efficient air-conditioning system that also simultaneously addresses the needs of adequate ventilation and acceptable indoor air quality, several factors begin to play an important role. Among several others, the cooling coil, the fan and the temperature difference between the space and the supply air (commonly known as the Space ΔT) can be considered to be crucial. For a given space cooling load, the choice of a particular Space ΔT has an implication on the amount of supply air required, which further has an impact on the performance of the cooling and dehumidifying coil as well as the fan. Inherent in these implications are issues related to energy, ventilation and indoor air quality. This paper investigates these implications and quantifies them by considering a hypothetical building in a tropical climate and subjecting the design to several parametric variations involving different Space ΔTs for a given space temperature and humidity condition. The total power requirements, comprising additional cooling, reheating and higher fan power, for a design involving a Space ΔT of 5 °C can be as high as a factor of 2.2 of the total power for a design with a Space ΔT of 8 °C. The implication of higher supply air flow rates on duct design is qualitatively discussed. For a given space cooling load and a given Space ΔT, the implication of increased design ventilation rates to address part-load ventilation requirements can lead to an additional installed cooling capacity of 17.5%. Finally, emerging technologies that are aimed at addressing both energy efficiency and IAQ are discussed.

Keywords: Cooling coil; Supply air temperature; HVAC system; Energy; Ventilation; Indoor air quality

1. Introduction

The optimal design of an air-conditioning system and its successful implementation and operation in a building is obviously a great challenge, especially when both energy and indoor air quality (IAQ) issues are of equal importance. It is, indeed, the designer's knowledge and understanding of the dynamically varying system characteristics as a dynamic response to the inevitably varying cooling load characteristics that will ultimately prove to be crucial in the design of an optimal and successful system. Often, some of the fundamental principles in psychrometrics are likely to be either overlooked at design or accepted as limiting constraints in current state-of-the-art technology that lead to designs, which may be considered as the best compromise. Among several factors concerning energy consumption and IAQ that are intertwined in conventional design practice, it is often economics, and particularly, the capital cost, that become the governing criterion in the selection of a design. In recent times, the need for a life cycle costing approach towards the selection of air-conditioning and air-distribution systems is strongly advocated, considering that the economic life span of such systems are reasonably long and are, typically, in the range of 10–15 years [1–3]. This paper revisits some of the fundamental thinking in the design considerations of two of the most important and critical components in an air-conditioning system:

- Cooling and dehumidifying coil
- Fan

Having estimated the cooling loads in a building, the volume flow rate of air supplied to the various zones is then a function of the space dry bulb temperature (DBT) and the supply air DBT. The difference in these temperatures, called the Space ΔT, is a critical design parameter as it has implications in terms of both the cooling coil capacity and its performance and the amount of supply air necessary for handling the space cooling loads. The implication includes both energy and IAQ and is prevalent throughout the entire operating range of the air-conditioning system. For example, a small Space ΔT for a given space DBT would not

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only result in a high air flow requirement but would also make it impossible for the cooling and dehumidifying coil to maintain space humidity levels within the desired comfort range without resorting to overcooling and reheating. This is particularly relevant in tropical designs which experience warm and humid climates and would naturally lead to an energy penalty. In the absence of any permissible reheating provisions, a low Space ΔT design will lead to the space DBT gradually getting colder than desired and eventually leading to thermal discomfort. Zaheer-Uddin and Zheng [4] have observed that an optimal supply air temperature exists in a climate with high relative humidity and a high recirculation rate. Ke and Mumma [5] investigated supply air temperature reset controls from ventilation and energy perspectives and concluded that optimization is the only solution. Ke et al. [6] studied eight ventilation control strategies in VAV systems of which three of the strategies considered were changes in supply air temperature, leading to a conclusion that supply air temperature and supply air flow rate were two key parameters for optimization on the air-side.

2. Problem definition

A hypothetical building of about 1200 m^2 with a total space cooling load of 100 kW and a Room Sensible Heat Ratio (RSHR) of 0.75 is considered. The air-conditioning system being considered is of the variable air volume (VAV) type. The implication of different temperature differences between the space condition and the supply air temperature is investigated both in terms of the cooling coil performance and the associated fan performance. A qualitative discussion on the implication of higher air flow rates on duct design is also presented. A psychrometric overview of the various cases studied is presented in Fig. 1. If the VAV fan at part load is expected to provide minimum fresh air requirements to the critical zones, a higher percentage of fresh air needs to be designed for peak or design load. The implication of such designs in terms of increased energy consumption for cooling coil and fan is evident and an attempt is made in this paper to quantify the energy implication. If lower space temperature differences, which are quite typical in several tropical designs, are to be considered in conjunction with higher fresh air quantities at design load, the overall increase in energy consumption is phenomenal. A standard coil selection program is used in the selection of coils and in exploring the performance characteristics to satisfy the total space cooling load of 100 kW and RSHR of 0.75 [7].

3. Results and discussion

For a given space condition, the energy consumption under scenarios of different supply air temperatures resulting in different Space ΔTs is investigated on the basis of both the cooling coil and the fan performance. The results of the coil selection are first presented to be followed by those of the fan selection.

The basis of the coil selection is to ensure the leaving conditions of the air to be commensurate with the required dew point temperature that would result in the space condition to be held constant both in terms of the DBT and the relative

Space ΔT	Case	Coil Entering Air Condition
8°C	BASE	D
7°C	Case 1	C
6°C	Case 2	B
5°C	Case 3	A

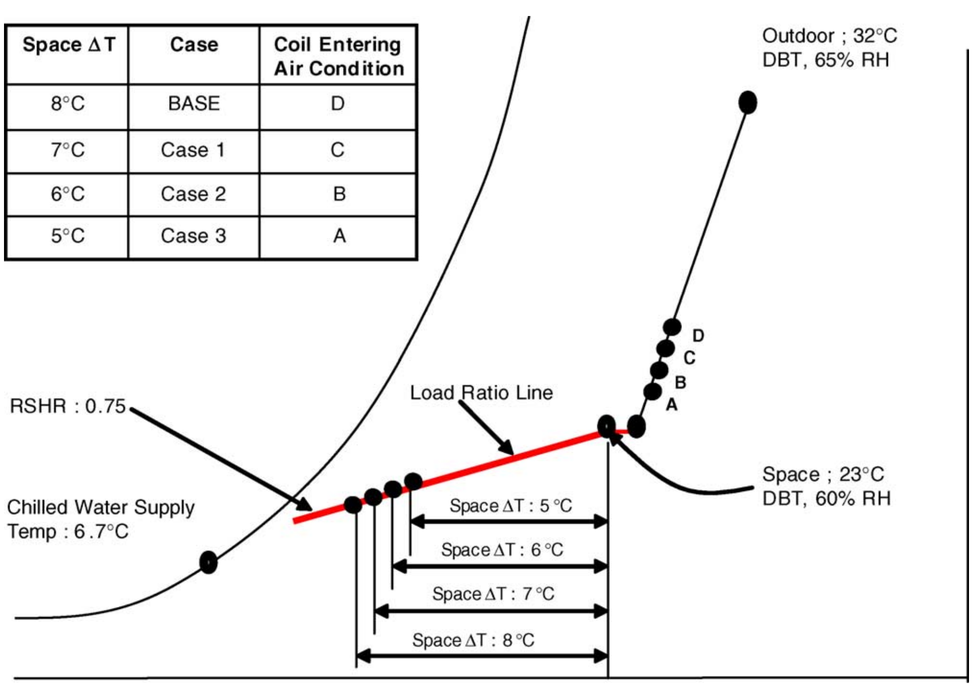

Fig. 1. A psychrometric overview of the cases studied.