Energy efficient air-conditioning and air distribution system for improved indoor air quality

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ABSTRACT
The quality of air in the indoor environment is dependent on the nature and source of indoor pollutants and the performance of the ventilation system. Increased dilution in a tropical context implies a high energy penalty. This paper presents a novel method of addressing IAQ and energy issues. An innovative energy efficient method and means of air-conditioning for an independent control of temperature and humidity of two different air streams has been developed. The Single Coil Twin Fan (SCTF) air handling unit is further developed to incorporate a new method of air distribution for an independent control of ventilation air quantity at acceptable indoor temperature and humidity conditions. Recent findings from a prototype SCTF air handling unit and SCTF system are encouraging and significant energy savings are possible.

INDEX TERMS
Innovation, Dehumidification, Energy efficiency, Ventilation system, Tropics

INTRODUCTION

Tropical air-conditioning is dictated by the stringent requirements of cooling and dehumidification, which poses challenges involving cost effective design criteria that addresses thermal comfort, indoor air quality (IAQ) and energy issues. Although these issues are usually addressed by an attempt to eliminate the various sources of indoor pollutants, it is almost impossible to totally eliminate them. Several studies involving the role of ventilation in ensuring good IAQ have been done in the past and clear associations between the two have been established (Seppanen et.al., 1999; Wargocki et.al., 2000). Ventilation in the tropics is associated with high energy-penalty of cooling and dehumidification and requires special attention (Luxton and Marshallsay, 1998). The importance of effective ventilation distribution has also been investigated in the context of the fresh air being available at the occupied breathing zone (Sekhar et. al., 2000). Complaints of staleness and stuffiness are inevitable due to the inability of typical designs of variable air volume (VAV) systems to maintain adequate fresh air distribution to the dynamically changing occupancy and "other" space load profiles. This paper presents a novel method of addressing both the IAQ and energy issues.

THE SINGLE COIL TWIN FAN (SCTF) SYSTEM

A prototype unit was developed and installed to serve conditioned air to two rooms of an IAQ chamber in the Department of Building at the National University of Singapore. The concept involves two VAV systems employing a single cooling and dehumidifying coil, as shown in Figure 1. The fresh air is conditioned by its own air-conditioning system (VAV System 1) and distributed to the various VAV boxes that form part of the air distribution network. Each of these F/A VAV boxes is controlled by its own localized carbon dioxide (CO_2) sensors, which will

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ensure an adequate ventilation (F/A) provision at all times. As the main purpose of the F/A VAV box is to ensure adequate fresh air quantity based on occupant density, it helps in achieving energy conservation in the event of reduced occupant loads. The return air from the various zones of the same distribution network is conditioned by a separate air-conditioning system (VAV system 2) and distributed to a separate set of the various VAV boxes. Each of these R/A VAV boxes is controlled by its own localized zone thermostats, which addresses diversity in cooling loads, and consequently helps in achieving significant energy savings at part load operating conditions resulting from non-occupancy related factors. The conditioned Fresh Air and the conditioned Return Air travel in parallel ducts and do not mix until just before the supply air diffusers in the mixing chamber of the modified VAV box.

The compartmented coil is aimed at achieving the required psychromteric performance of the two separate air streams throughout the operating range based on the concept of two VAV systems but one cooling coil. The significant advantage over conventional means of achieving the requisite cooling and dehumidifying performance with two separate coils is the relative ease of operation of the compartmented coil, which is based on a single feed of the chilled water.

EXPERIMENTAL RESULTS AND DISCUSSION

The seven experiments presented in Table 1 represent different discrete points of operation of a VAV fan in a steady state condition. For example in experiment 1, which has a base thermal and ventilation load in both the rooms, the fresh air fan and the recirculated air fan are operated at 30% of their speeds, thereby simulating an operating condition that is representative of minimum cooling capacity requirements from both thermal and ventilation considerations. High ventilation loads are simulated by having eight occupants in Room 1 and high thermal loads are simulated by additional heat-emitting lights in Room1. Besides fixing the speed of the fans, all other operating characteristics of the air-conditioning and the air distribution systems are subject to dynamic variations whilst the BAS attempts to achieve the space temperature, carbon dioxide level and "off-coil" temperature set points.

The various experiments represent different steady-state conditions and the action of the VAV box dampers under different combinations of ventilation and thermal loads is noted. Room 2 is used as a control room with base thermal and ventilation loads throughout the seven experiments. Room 1 is the experiment room, in which the thermal and the ventilation loads are varied through the experiments. It starts with base thermal and ventilation loads, followed by a high ventilation load and then a high thermal load. The final experiments (4a and 4b) involve high ventilation loads in Room 1 (similar to experiments 2a and 2b) except that the chilled water modulation is now achieved by F/A "off-coil" set point temperature. The chilled water control in all the previous experiments was achieved by the R/A "off-coil" set point temperature.

It was observed that the F/A damper opens fully when 8 occupants are present in Room1 (exp 2a, 2b, 4a and 4b) which raises the actual CO_2 level in Room 1 beyond the set point of 550 ppm. It is to be noted that exp 2b and 4b are associated with experimental conditions in which the F/A fan is set to operate at 100% speed. The opening of the F/A damper in these two experiments is a clear indication that more fresh air is actually being provided to Room 1 to dilute the elevated CO_2 levels. It was also observed that changing the load characteristics of Room1 during exp 3a and 3b resulted in the F/A damper virtually closing in Room 1. The actual CO_2 level was now less than 550 ppm and it was the high thermal load (due to additional lights) that demanded more recirculated air, as seen by the R/A damper remaining fully open during these experiments.

The energy efficiency of the SINGLE coil with two compartments for the two air streams is considered on the basis of the psychrometric performance. As each of the two fans, the F/A and the R/A, would optimize its flow requirements based on the individual demand of "ventilation air" or "thermal air", the cooling coil would not be required to provide more cooling than required during the dynamically changing operating conditions of an air-conditioning system.

CONCLUSION

A new method of independent conditioning and distribution of fresh and recirculated air streams is developed. The SCTF system aims to achieve optimal cooling and dehumidifying performance of fresh and return air streams using a single coil with a single feed of chilled water flow BUT through a complete isolation of the two air streams. Such a design of the coil enables to derive the optimal energy efficiency of the coil while achieving the desired cooling and dehumidifying performance and is envisaged to be of immense benefit in maintaining good indoor air quality in tropical buildings.

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Table 1 : Simulated experimental conditions in the two chambers (Room 1 and Room2) and simulated fan operating characteristics

Exp	Steady state period	Fresh air (F/A) fan	Recirculated air (R/A) fan	Thermal load		Ventilation load	
				Room 1	Room 2	Room 1	Room 2
1	11.40 am – 12.15 pm	30%	30%	Base	Base	Base	Base
2a	12.15 – 12.35 pm	30%	30%	Base	Base	High	Base
2b	1.00 pm – 1.20 pm	100%	30%	Base	Base	High	Base
3a	2.00 – 2.15 pm	30%	30%	High	Base	Base	Base
3b	2.20 – 2.45 pm	30%	100%	High	Base	Base	Base
4a	3.15 – 3.40 pm	30%	30%	Base	Base	High	Base
4b	3.40 –4.10 pm	100%	30%	Base	Base	High	Base

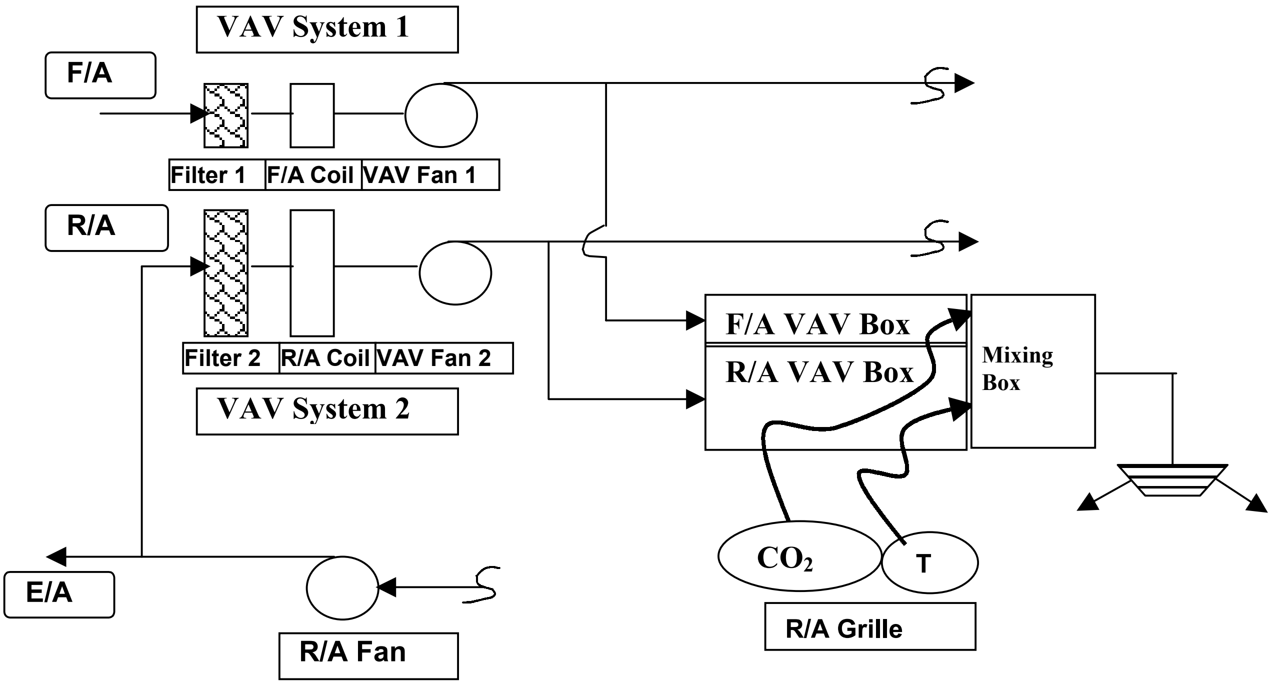

Figure 1 : **Compartmented Coil in a Single Coil Twin Fan (SCTF) system with zonal ventilation control**