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A COMPARISON STUDY FOR ACTIVE CHILLED BEAM AND VARIABLE AIR VOLUME SYSTEMS FOR AN OFFICE BUILDING

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Abstract

Comparison in terms of energy and cost is carried out between two different air distribution systems, namely, Variable Air Volume (VAV) and Active Chilled Beam (ACB) based on a virtual building. The cooling load calculation was performed to determine the total load demand and the system design was carried out to determine the system capacity. Energy and cost analyses were carried out to determine which system gives the better saving. From the results analysis, it shows that the ACB is more energy-saving than the VAV, especially at full load and normal part-load conditions because of the reduced AHU fan's capacity. In terms of cost, the ACB has a higher initial cost than the VAV where it is mainly contributed by the secondary chilled water pipe, heat exchanger and the beam itself. However, the operation cost is lower for ACB, and for long term use, the ACB is more cost-saving than the VAV.

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Keywords: Variable Air Volume; Active Chilled Beam; Cooling load; Energy-saving; Office building; Tropics

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1. Introduction

Chilled water-based system is designed to provide cooling for large commercial buildings such as office, shopping mall, hotel and hospital. Due to the fact that more than 40% of the building's total energy comes from air-conditioning, equipment and system efficiencies are often taken into serious consideration, be it at the design stage, or during operation [1]. Not only they consume large amounts of energy, resulting in high operating cost, they also represent a large amount of investment from the perspective of first cost, maintenance expenses and physical space required.

A chiller plant (chilled water-based system) comprises of two parts: water side and air side where the former refers to the chilled water distribution system and the latter refers to the air distribution system. The chilled water distribution system involves major equipment like chillers, cooling towers and pumps whereas air distribution system involves air handling unit (AHU), dedicated outdoor air system (DOAS), fan coil unit (FCU) and exhaust fan. Equipment that consumes the most energy is a chiller and most often, chiller efficiency is given the top priority, especially during equipment selection as wrong selection will end up high operating cost.

From chilled water side, there are two common types of system design, namely constant primary/variable secondary flow (P/S) and variable primary flow (VPF). The primary/variable secondary flow consists of 2 loops where the primary loop is constant flow serving the chillers and the secondary loop is variable flow serving the AHUs. On the other hand, VPF consists of only 1 loop and the flow is variable throughout. Comparing between these two systems, VPF is more efficient as the chillers and pumps operate in response to the load demand. Unlike VPF, the primary pump for P/S operates at full load all the time regardless of the load demand.

For air side, there are many types of air distribution system such as constant air volume (CAV), variable air volume (VAV), underfloor air distribution (UFAD), stratum ventilation and active chilled beam system (ACB). The constant air volume is the most conventional air distribution system and it is also the most inefficient system where the supply air flow is constant all the time regardless of the load demand. Meanwhile, VAV is the improved version of CAV where the supply air flow is varied in response to the load demand. This system is not new, but it has been used for some time especially for office buildings.

Whereas, UFAD is an entirely different system where the air supply is from the ground (floor plenum) instead of from the top, as what is commonly seen in a normal overhead system. It is designed to supply cooled air up to human height rather than filling up the whole room [2]. For Stratum Ventilation, the air supply is from the side (wall plenum) that provides cooling directly to the occupants, which is claimed to be more efficient than UFAD [3]. Nevertheless, due to the fact that the difference in terms of design is significant for both UFAD and stratum ventilation when comparing to the conventional overhead system, the consideration of using such system is often turned down as it affects significantly on the building layout in order to fit in the system. ACB is another air distribution system, comparably more energy efficient, but less common, especially in Asia Pacific region [4]. Unlike UFAD and stratum ventilation, the design of ACB is not far different from the overhead system and in fact, the ceiling height required is lesser than the conventional CAV. Therefore, it is believed that ACB could be the best substitute of the conventional CAV or VAV in the future compared to UFAD and stratum ventilation.

However, literature review reveals that research conducted on the investigation in terms of energy and cost savings between two different air distribution systems, namely, VAV and ACB in air-conditioning and mechanical ventilation (ACMV) systems is virtually none in the tropics. Therefore, the research is required be conducted, and the objective is to examine the two just mentioned systems in terms of design, control, energy efficiency and cost savings. For the present study, a virtual building layout located in Kuala Lumpur, Malaysia, has been selected as a case study.

Nomenclature

ACB	Active Chilled Beam
ACMV	Air-Conditioning and Mechanical Ventilation
AHU	Air Handling Unit

CAV	Constant Air Volume
DOAS	Dedicated Outdoor Air System
FCU	Fan Coil Unit
HAP	Hourly Analysis Program 4.9
PCB	Passive Chilled Beam
P/S	Primary/Variable Secondary Flow
VAV	Variable Air Volume
VPF	Variable Primary Flow
UFD	Underfloor Air Distribution

2. Theory relevant to the current research

The ACB details will be described first in sub-section 2.1. The VAV descriptions will be given later in sub-section 2.2. The cooling load calculation will be illustrated in sub-section 2.3.

2.1. Active Chilled Beam (ACB)

Generally, chilled beams can be separated into two types, namely, passive chilled beam (PCB) and active chilled beam (ACB). For PCB, heat exchange takes place between the coil and the entering air is by natural means where the air movement through the coil is caused by the difference in density between warm air and cold air. On the other hand, for ACB, the primary air is supplied by a mechanical device (air handler) where it induces the room air to pass through the secondary coil and mix with the primary air before entering the room as shown in Figure 1. Since it involves forced convection, ACB is better than PCB in terms of performance and efficiency ideally. For that reason, ACB is used to compare with VAV in the present project.

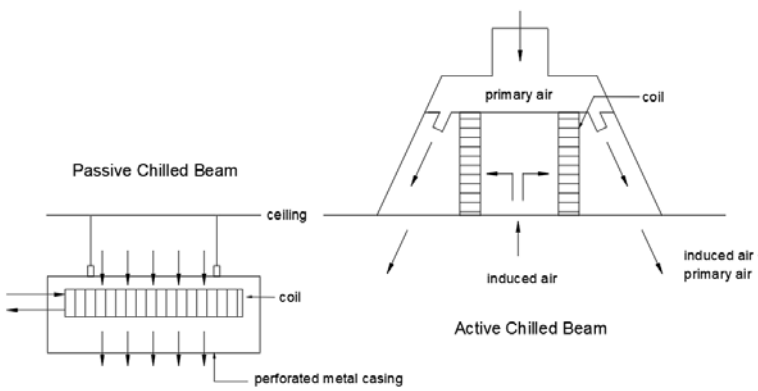

Fig. 1 Passive Chilled Beam and Active Chilled Beam re-drawn based on reference [5]

2.2. Variable Air Volume (VAV)

VAV system is composed of multiple VAV boxes that control the air supply of the respective zone by modulating the damper based on load demand. Temperature sensor or thermostat is used to determine the load demand where it will trigger the damper to open/close and consequently the fan to ramp up/down until the static pressure is maintained at its set-point. The reheat coil is to ensure the supply air temperature is maintained at its setpoint during part load condition when the damper's position can no longer be adjusted to meet the minimum ventilation rates [6].

There are two types of reheat: electric reheat and water reheat. Electric reheat uses electric element/coil to provide direct heating of the supply air, whereas water reheat uses hot water from external sources like a boiler or cooling tower to heat the air passing through the coil. There are many different types of VAV controller depending on the brands. Each brand has its own control logic.

2.3. Cooling load calculation

The cooling load is defined by the rate at which energy is removed from a room by mechanical means in order to keep the desired room temperature and humidity. It is often associated with heat gain where energy is transferred or produced within the room. Heat gains generally can be categorized into two components, namely, sensible heat and latent heat.

3. Research Methodology

Hourly Analysis Program 4.9 (HAP) is a computer tool for engineers to design HVAC systems for buildings. It can be used to estimate cooling load, design system, simulate energy use and calculate energy costs. However, in the present project, HAP is only used to estimate the cooling load. Note that, for VAV, both the zone load and system load are recorded, but for ACB, only the zone load is required.

In the current work, a virtual building layout is used for the numerical simulation where it consists of total 13 floors, including 2 sub-basements. Air-conditioning is provided from the ground floor up to Level 10 penthouse (L10) office. Since Levels 1 to 9 (L1-L9) are typical floors, the system layouts for both VAV and ACB are designed based on three distinct floors: Ground Floor (GF), L1-L9 and L10. A typical building layout for GF is shown in Figure 2.

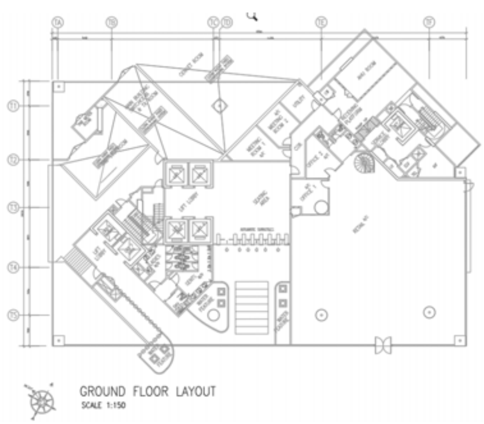

Fig. 2 Ground Floor System Layout

The virtual building is assumed to be located in Kuala Lumpur and the indoor and outdoor conditions are indicated in Table 1.

Table 1 Indoor and Outdoor Conditions

Indoor Conditions	Outdoor Conditions
Design Dry Bulb: 75 ^{o}F (24 ^{o}C)	Region: Asia/Pacific
Design Wet Bulb: 64 ^{o}F (17.8 ^{o}C)	Location: Malaysia
	City: Kuala Lumpur
	Latitude: 3.1^{o}
	Longitude: -101.6^{o}

	Elevation: 72 ft (21.9 m)
	Design Dry Bulb: 95 ºF (35 ºC)
	Design Wet Bulb: 82 ºF (27.8 ºC)

4. Results and Discussion

A detailed analysis on the energy and cost comparing between VAV and ACB is presented in this section. Both short-term and long-term savings are determined and justified. Energy comparison is performed in the overall building at three different load conditions: 100%, 75% sensible and 90% latent, and 50% sensible and 80% latent. At these three conditions, the system capacity and power consumption are determined. System capacity includes the capacity of AHU, pump, chilled beam, chiller and cooling tower. Likewise, the power consumption includes the equipment involved in the system and analysis is performed to determine which system gives a better saving.

For the entire building AHU capacity, VAV is higher than ACB at all three load conditions, namely, 50% at full load, 48% at part load and 45% at lower part load. ACB has the lower AHU capacity because part of the cooling load (room sensible) is catered by the chilled beams. Meanwhile, for overall building power consumption, VAV is higher than ACB at full load and normal part load conditions, with 345.0 kW and 262.1 kW compared to 284.5 kW and 226.1 kW respectively as shown in Table 2. However, at lowest part load condition, VAV has lower power consumption with 185.0 kW compared to 204.1 kW for ACB. The high power consumption for ACB at lowest part load condition can be explained by the use of a constant air volume diffuser at particular zones where the space available is too small for the placement of chilled beams. To improve the overall system, VAV can be used in spaces where chilled beams are not allowed. However, the penalty is the increase in initial cost as the cost of VAV boxes is comparably high against the normal CAV system.

Table 2 Total Power Input at Three Different Load Conditions for the Entire Building

		100%		**75% sensible**	**90% latent**	**50% sensible**	**80% latent**
LOAD & CAPACITY		**VAV**	**ACB**	**VAV**	**ACB**	**VAV**	**ACB**
Required Building & System Load	Zone Sensible Heat (kW)	1,029	1,029	772	772	515	515
	Zone Latent Heat (kW)	62	62	56	56	50	50
	Total Zone Load (kW)	1,092	1,092	828	828	564	564
System Capacity	ACB Water Capacity (kW)	-	536	-	380	-	403
	ACB Capacity (kW)	-	973	-	684	-	814
	AHU Capacity Sensible (kW)	1,095	448	821	336	547	224
	AHU Capacity Latent (kW)	264	239	237	215	211	191
	Total AHU Capacity (kW)	1,359	687	1,059	551	758	415
	AHU Air flow (l/s)	72,642	26,963	50,990	26,892	33,993	26,963
	AHU Chilled Water flow (l/s)	58.5	29.6	45.6	23.7	32.7	17.9
	ACB Chilled Water flow - Primary (l/s)	-	37.0	-	26.2	-	27.8
	ACB Chilled Water flow - Secondary (l/s)	-	23.1	-	16.3	-	17.4

	Condenser Water flow (l/s)	76.0	68.5	59.2	52.1	42.5	45.8
	Chiller Capacity (kW)	1,359	1,224	1,059	931	758	819
	Cooling Tower Capacity (kW)	1,766	1,591	1,376	1,210	986	1,064
Power Consumption							
Water side (Pump)	AHU Power Input (kW)	16.4	7.5	12.8	6.0	9.2	4.5
	ACB Power Input - Primary (kW)	-	9.3	-	6.6	-	7.0
	ACB Power Input - Secondary (kW)	-	5.8	-	4.1	-	4.4
Air side (Fan)	AHU Power Input (kW)	81.9	40.5	57.5	40.4	38.3	40.5
	Chiller Power Input (kW)	231.8	208.8	180.6	158.8	129.4	139.7
	Cooling Tower Power Input (kW)	15.1	13.6	11.7	10.3	8.4	9.1
	Total Power Input (kW)	**345.2**	**285.5**	**262.6**	**226.3**	**185.3**	**205.2**

5. Conclusions

The present numerical research has successfully investigated a sustainable air distribution system that provides long term savings based on the energy and cost analysis results comparing between ACB and VAV operating in a tropical building. From the results, it can be concluded that ACB is better than VAV in terms of total energy consumption and energy cost. In other words, for long term saving, ACB is recommended even if the initial cost is relatively high compared to VAV. However, in terms of system design, ACB is more complicated than VAV as it involves many specific design considerations at the design stage and sophisticated system control during operation.

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