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ENERGY SAVING OPPORTUNITY WITH VARIABLE SPEED DRIVE IN PRIMARY AIR-HANDLING UNIT

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ABSTRACT
As air-conditioning is one of the largest consumers of energy, we should aim to reduce the air-conditioning loads in buildings. In this study, the initial effect of addition of variable speed drives to primary air handling units in Kowloon City Law Courts Building is investigated. Since the fan motor running at nominal speed has supplied excess amount of fresh air at part loads. In order to increase the energy efficiency, the fan motors in primary air handling units are retrofitted with variable speed drives. The paper describes a method of energy saving in the building by using variable speed drives. It is evaluated and quantified the energy saving associated with variable fresh air supply flow rate and its cost to the Owner. An overview of such conservation measures, along with the potential energy and cost saving, implementation cost and pay back period are given.

KEY WORDS
Variable speed drives, Energy, Primary air-handling unit

1. Introduction

In Hong Kong, most of the 3-phase AC motors in buildings are fitted to fans and pumps. For example, in air conditioning applications, air flow requirements change according to the number of occupants, humidity and temperature in the room. The flow from most fans is either constant or controlled by motorized inlet guide vanes. This mechanical constriction will control the flow and may reduce the load on the fan, but the constriction itself adds an energy loss that is obviously inefficient. The mechanism for the guide vane system on the fans also required frequent adjustment.

Fresh air supply is fed into Kowloon City Law Courts Building via Primary Air-handling Units (PAU) at constant air volume. The PAU are used to supply fresh conditioned air via riser ductwork to the floors it served at constant rate, regardless of the actual needs of the zones served. The PAU bring outside air into filters prior to pre-cooling and deliver it via fans and ductwork to serve individual floors. This system was designed for possible maximum occupancy density or even designed with spare capacity to ensure have sufficient capability to cope with any new office configuration, which end up wasting energy relative to the needs of the building for most of the operational life. To maintain the system efficiency, variable speed drives should be used on the PAU. As the speed of the fans are reduced, the flow will reduce proportionally, while the power required by the fan will reduce with the cube of the speed [1]. Hence if the fresh air supply can be controlled by reducing the speed of the fan motor, more efficient means of achieving flow control could be offered.

2. Design Parameters of Fresh Air Supply System

Carbon dioxide (CO_2) has become an important measurement parameter for air-conditioning, heating and refrigerating engineers, particularly for demand control on PAU, using CO_2 offers a unique opportunity to resolve the problem of how to reduce energy costs while optimising indoor air quality. Although CO_2 is generally not of concern as a specific toxin in indoor air, it is used as a surrogate indicator of other contaminants and irritants in the space related to variable or intermittent human occupancy. In space without variable occupancy, indoor CO_2 concentration varies according to location and time of day, tending to increase during the day. Therefore, CO_2 control can ensure that the space is ventilated at the appropriate level for its occupancy, rather than being ventilated at an arbitrary rate determined sometime when the building was designed.

The CO_2 levels of typical office are in the range from 600 to 800 ppm [2]. According to ASHRAE Standard 62 [3], maintaining CO_2 concentrations below 1000 ppm (based on a differential of 700 ppm between indoor and outdoor CO_2 concentrations) usually results in conditions conductive to comfort and reduced odor from human-generated pollutants. In this project, the control system is set ensure minimum fresh air supply to space in order to maintain the CO_2 concentration below 800 ppm, while the lowest concentration of CO_2 measured in outside air in Hong Kong ranging from 400 to 500 ppm [4]. ASHRAE Standard 62 also recommends specific minimum outdoor air ventilation rates of 10 L/s per person to ensure adequate indoor air quality, which would result in a CO_2

concentration of 850 ppm at steady state conditions in the occupied space for normal occupancy and activities [3]. Some of the government office buildings investigated under the Pilot Energy Management Opportunity Implementation Programme have average measured CO_2 concentration below 700 ppm [4]. Therefore CO_2 based demand control ventilation has good potential to reduce energy consumption while optimising indoor air quality.

3. System Design

3.1 Variable Speed Drive

A variable speed drive (VSD) can be regarded as a frequency converter rectifying AC voltage from the mains supply into DC, and then modifies this into AC voltage with variable amplitude and frequency. The motor is thus supplied with variable voltage and frequency, which enables infinitely variable speed regulation of three-phase, asynchronous standard induction motors.

VSD are available for all power levels, from just a few watts up to several thousand kilowatts, but the variable speed drive system is not cost effective for small motor (up to 1 hp) [6]. The fan motor power supply is 380V in 3-phase at 50Hz and fan motor rating of PAU are shown in Table 1. There are 11 sets of new VSD and power analyzer for respective PAU to control the speed of respective fan motor and for monitoring the power consumption of the system. The IP 54 degree of protection for the VSD guarantees that they can work in dusty environment like the existing air conditioning plant rooms. Also, the VSD should be suitable for continuous operation without de-rating under ambient temperature of up to 40^{o}C. In order to keep up the serviceable life of the VSD and ensure the temperature inside the cabinets will not exceed the allowed limits, at least 200 mm space is allowed above and below the wall mounted units in this project, so that the air cooling fans of VSD can operate properly.

Table 1: Fan motor rating of existing primary air-handling units

PAU No.	PAU Motor Model	Motor Rating
PAU-201	ABB'QY13234A'	5.5 kW
PAU-202	ABB'QY90L2A'	2.2 kW
PAU-301	ABB'QY90L2A'	2.2 kW
PAU-401	ABB'QY90L2A'	1.5 kW
PAU-501	ABB'QY80L2A'	0.75 kW
PAU-U501	ABB'QY80L2A'	0.75 kW
PAU-601	Brook	0.75 kW
PAU-701	ABB'MU80A19-12'	0.75 kW
PAU-U701	ABB'QY160M4A'	1.1 kW
PAU-801	ABB'QY160M4A'	1.1 kW
PAU-R01	ABB'QY160M4A'	11 kW

Any motor control centre with VSD should also be equipped with appropriate power factor correction or harmonic reduction devices to improve the power factor to a minimum. The VSD in this retrofit work have built-in AC or DC chokes in order to full-fill the EMSD Code of Practice for Energy Efficiency of Electrical Installations [5] to which the VSD can give the maximum allowable fifth harmonic current distortion at the input terminals at full load is less than 35%. At part loads, the VSD have "Swinging Choke" feature which can reduces total harmonic distortion compared with that of conventional chokes.

3.2 Carbon Dioxide Sensors

The CO_2 based demand control can be achieved by the direct application of CO_2 sensors for real time speed control of PAU. The space CO_2 sensors installed in the Building are non-dispersive infrared analyzers designed for measuring environment CO_2 concentration in ventilation system and indoor spaces. Its measurement range of 0 to 2000 ppm makes in it compliance with ASHRAE and other standards for ventilation control. The technology makes use of the strong absorption band that CO_2 produces at 4.2 μm when excited by infrared light source [2]. While most non-dispersive infrared cell designs facilitate very rapid CO_2 sample diffusion, some of the instruments now in wide-spread use for indoor air quality measurement exhibit slower sensor response, resulting in stabilization times greater than 5 minutes and up to 15 minutes, which may complicate walk-through inspections.

In this project, two sensors are installed for one floor at some strategic location for monitoring the space CO_2 concentration to operate the respective VSD, so that the flow volume of fresh air of respective PAU will be regulated to maintain the indoor CO_2 concentration of the occupied space below 800 ppm.

3.3 Data Acquisition System

The data acquisition system is provided for carrying out measurement and verification of energy saving opportunity of VSD systems. The system is microprocessor base operated automatically to capture the operating data that can be delivered by the PAU, such as CO_2 concentration, fresh air volume flow, percentage of motor current etc. The workstation or data logger of the data acquisition system should be located inside the site office so as to facilitate monitoring and maintenance.

4. Energy Saving Calculation

The energy savings can be estimated if flow rates required over a repeatable cycle-time for the installation are recorded. This cycle might be a day, a week, a month, or whatever, as long as it approximates the real duty cycle of the system. Meanwhile, it is appropriate to estimate the fan power consumption if no VSD installation is taken, and then compare the power consumption for both of the conditions to determine potential savings.

To determine the potential savings from any VSD method, a load profile should be developed similar to that shown in Figure 1. The fan selected for this example is PAU-201 with a motor shaft power requirement of 5.5 kW. The air flow rates of a selected PAU are measured in every five minutes during typical office working days from 7:00a.m. to 7:00a.m. of the next day. Figure 1 shows the operation profiles of PAU-201 before and after VSD operation. PAU-201 starts at about 8:30a.m. and stops at about 5:30p.m. according to Figure 1. It maintains at constant air flow rate of 450 L/s approximately during office hours. However, the air flow rate of PAU-201 with VSD operation drops significantly at about 11:30a.m., then maintains at about 17% of the nominal air flow rate for two hours and then boost back to normal air flow rate. It is likely that the drastic changes are due to many people leave from office for lunch from 11:30a.m. to 1:30p.m. and the fresh air demand in office is low during lunch hours.

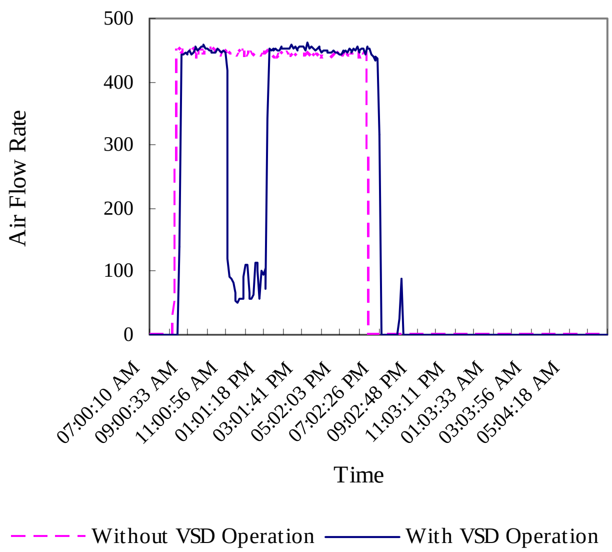

Figure 1: Measured air flow rate (in L/s) for PAU-201 during weekdays operation

The power consumption (in kWh) for PAU-201 at the same operation periods were also measured and shown in Figure 2 and the reduction of power consumption with VSD operation is about 248 kWh per day, which is equivalent to 20% of the original consumption.

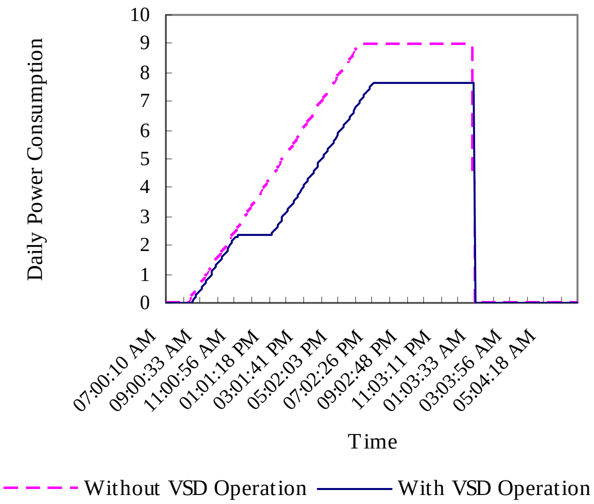

Figure 2: Measured daily power consumption (in kWh) for PAU-201 during weekdays operation

In assumption of 52 weeks per year, 5 working days per week and 8 working hours per day, the PAU will operate 2,080 hours per year. With VSD operation and at an energy cost of HK$0.93 per kWh, the predicted annual electricity cost for PAU-201 will be HK$58,221. Similarly, base on the estimated savings for PAU-201 and the fan motor rating of other PAU, a summary of the predicted energy and cost savings for other PAU are calculated and shown in Table 2.

Table 2 Predicted annual saving in energy consumption with variable speed control application

PAU No.	Predicted Annual Saving (kWh)	Predicted Annual Saving (HK$)
PAU-201	62,603	58,221
PAU-202	25,041	23,288
PAU-301	25,041	23,288
PAU-401	17,073	15,878
PAU-501	8,537	7,939
PAU-U501	8,537	7,939
PAU-601	8,537	7,939
PAU-701	8,537	7,939
PAU-U701	12,521	11,644
PAU-801	12,521	11,644
PAU-R01	125,206	116,441

5. Implementation Cost and Pay Back Period

The purchase cost for the VSD system is as HK$490,000 as shown in Table 3. The consulting services and measurement and verification work for the drive is HK$61,840, therefore, the total implementation cost of this drive system is HK$551,840. According to Table 2, the total annual electrical cost savings of HK$292,162 per year will pay for the implementation cost in approximately 2 years. This cost savings are based on the preliminary observed operating profile for the fan motor of PAU-201 and results will vary significantly when the operating profile varies.

Table 3: Schedule of rates of addition of VSD

Item No.	Description	Quantity	Price (HK$)
1.	Supply, deliver to Site and undertake one-year warranty of the brand new VSD of various ratings and associated accessories.	11 sets	77,000
2.	Supply, deliver to Site and undertake one-year warranty of the brand new CO_2 sensors and associated accessories.	20 nos.	51,500
3.	Supply, deliver to Site and undertake one-year warranty of the brand new power analyzers and associated accessories.	11 sets	44,000
4.	Supply of direct digital controllers, graphic generation & software program for central computer monitoring system workstation on VSD control and CO_2 control for PAU.	1 lot	35,000
5.	Provide labour, tools, equipment for the installation.	1 lot	270,000
6.	Testing and Commissioning (T&C) and perform the fine tune of the settings.	1 lot	7,500
7	Provision of as-fitted drawing, operation and maintenance (O&M) manual, equipment catalogue, recommended spare parts list, T&C report.	1 lot	5,000
		Total	490,000

Besides, motor efficiency is another decisive factor for cost saving. Without considering motor efficiency, the minimum pay back period for the VSD system will be 2 years. However, as shown in Figure 3, longer pay back period will be expected with lower motor efficiency. Therefore, it would be more economical if the PAU could originally equipped with VSD during construction stage of the Building, instead of retrofitting with VSD after several years of operation. Besides, using higher efficiency motors can save an average of 2-3% of energy consumption compared to standard motors [7].

Careful selection of the electric motor is important in increasing the efficiency of the ventilation system, as part of the overall fan selection. For example, motors are often rated well above the power levels at which they operate. Significant reductions in efficiency occur at 25% or less of full load. Avoiding over sizing will result in both capital and running cost savings [7].

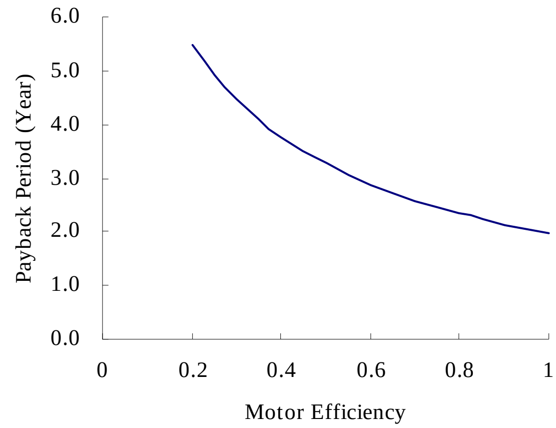

Figure 3: System pay back period against motor efficiency

6. Conclusion

The use of a variable speed drive for a speed control application offers an energy efficient solution. The primary air-handling units in Kowloon City Law Courts Building are retrofitted with variable speed drive and its system design is described. The initial effect and potential energy saving by using variable speed drive are studied based on the measured air flow rate and power consumption of a daily operation. With the application of variable speed drive controls, the motor will be allowed to operate at variable speeds that are based on load requirements. Energy savings are due to the decreased power required to operate the motor at reduced speeds, it is estimated that about 20% of power consumption and electrical cost of HK$292,162 per year can be saved in this case. The implementation costs and energy saving calculation is shown that the simple pay back period is expected in 2 years. It is an opportunity for energy savings, with subsequent economic savings, arises through the laws which govern the operation of fresh air supply fans in primary air-handling units.

Moreover, further investigation on the real duty cycle of the system, such as recorded flow rates and power consumption over a longer repeatable cycle-time for the installation will be beneficial. Besides, measured carbon dioxide levels of each floor should be studied so as to examine the performance of demand control on primary air-handling units.

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