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Hong Kong

Report

on

Pilot Energy Management Opportunities Implementation Programme

in

Government Buildings

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1 Background of EMO Implementation Programme

Electricity is the most widely used form of energy in Hong Kong. The electricity consumption in Hong Kong is having an average annual increase of 5% from 1989 to 1998. The annual consumption in 1998 was 34,846 million kWh as compared with 22,386 million kWh in 1989.

The Energy Efficiency Office of EMSD was set up in 1994 to improve the energy utilisation in Hong Kong. Energy Audit Programme in government and public buildings is one of the initiatives and through this Energy Audit Programme, Energy Management Opportunities (EMOs) are identified and categorised into category 1, 2 or 3, depending on their complexity and the cost involved, with category 3 representing those that are relatively complex and require significant capital expenditure.

In 1995, the Secretary for the Treasury approved under delegated authority a non-recurrent commitment of $6 million for EMSD to carry out a 3-year Pilot EMO Implementation Programme (the Programme). The Programme was introduced to tackle category 3 EMOs in Government buildings over three financial years. The objective of this Programme was to examine the cost effectiveness of various advanced energy-efficient building service technologies under local conditions.

Two major types of energy-efficient equipment were installed under the Programme. They were electronic ballasts for fluorescent lamps and variable speed drives (VSDs) for air conditioning systems.

2 Electronic Ballasts for Fluorescent Lamps

2.1 Introduction

Due to the rapid development of modern electronic technology and the awareness of energy efficiency, the utilisation of electronic ballasts for the control of fluorescent lamps in commercial buildings is becoming more and more popular. A survey on technical performance of electronic ballast was conducted by Energy Efficiency Office prior to the commencement of the Programme. The purpose of the survey was to collect all available technical and performance data for electronic ballasts in Hong Kong. The result would then be used in the Programme for energy efficient lighting applications.

As the energy used for general lighting contributes over 25% of the total energy consumption of a modern commercial building, it is a major area to be considered as far as energy efficiency and conservation are concerned. Conventional ballasts, including low loss version, used for limiting and stabilising currents of fluorescent lamps are basically electromagnetic types, which consume a substantial amount of energy while in operation with the tubes. Modern technology in electronic ballasts operating at high frequency (25kHz to 45kHz) can eliminate most of the energy loss in conventional ballasts. Typical saving in lighting energy for direct replacement of conventional ballasts with HF electronic ballasts is more than 25%. The reduction of heat load from lighting will also save a substantial amount of energy in air conditioning.

This section of the report on electronic ballasts will highlight all relevant background information, technical details, test results and experience gained from our pilot EMO implementation projects carried out in government buildings.

2.2 Technical Information

2.2.1 Fluorescent Lamps

The fluorescent lamp, or low-pressure mercury vapour lamp, is by far the most widespread of all discharge lamp type used for general lighting nowadays. It is employed almost universally especially in office lighting. The introduction of compact fluorescent lamps has led to its application in domestic buildings too. The most common type of fluorescent lamp is tubular linear in shape ranged from 600mm (18W) to 1500mm (58W) in length. The discharged tube has an electrode sealed into each end and is filled with an inert gas and a small amount of mercury, the latter being present in both liquid and vapour form. The inside of the tube is coated with a mixture of fluorescent powders. These convert the ultraviolet radiation of the mercury discharge into longer wavelengths within the visible range. Different fluorescent powders or ‘phosphors’ are available for any desired colour temperature and colour rendering characteristics.

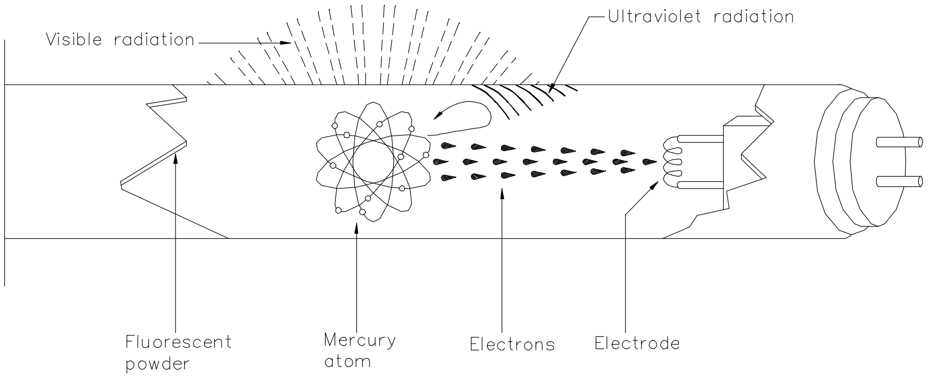


Fig. 1: Basic construction and operation of fluorescent lamp

Unlike an incandescent lamp, a fluorescent lamp cannot be connected directly to the mains. Some device to limit the electric current flowing through it must be included in the circuit. This device can be electromagnetic ballast (conventional or low loss) with starter switch or electronic ballast operating at high frequency. To facilitate starting, the electrodes of most fluorescent lamps are preheated prior to ignition, which is accomplished by means of a preheat voltage.

The linear tubular fluorescent lamp group can be sub-divided as follows:

a) T12 lamps with a diameter of 38mm (1.5”) and with a length dictated by the wattage (20W, 30W, 40W and 65W). These so-called ‘old’ or ‘fat’ lamps are stabilised by electromagnetic ballasts and have by now in most case been replaced by the modern T8 lamps.

b) T8 krypton-filled lamps with a diameter of 26mm (1”) and with a length dictated by wattage (18W to 70W). These so-called ‘thin’ lamps can be stabilised by both electromagnetic and electronic ballasts with extra benefit of improved efficacy and lumen maintenance.

c) T8 argon-filled high frequency (HF) lamps with a diameter of 26mm. The most common lamp type is 32W with 1200mm in length. These lamps are originally designed for optimum efficiency with electronic ballasts and are becoming more popular nowadays in Hong Kong.

d) A new range of T5 lamps with a diameter of 16mm (5/8”) has also been available in Hong Kong. T5 lamps were extensively used in table lamps in the past. The new lamps are now extended to the range of application currently using T8 lamps. Standard wattage of lamps is 14W, 21W, 28W and 35W. They are 50mm shorter than the equivalent standard types and are operated on high frequency electronic ballasts. The reason for the reduced length is that optimum compatibility with the most common ceiling systems could be obtained.

Table 1: Common Lamp Wattage of Fluorescent Lamps

Nominal Lamp Length	T12	T8	T8 (HF)	T5
600mm	20W	18W	17W	14W
1200mm	40W	36W	32W	28W
1500mm	65W	58W	-	35W

Table 2: Suitability of Ballast Types for various Fluorescent Lamp Groups

Lamp Group	Conventional Ballast	Low Loss Ballast	Electronic Ballast	Dimmable Ballast (Magnetic)	Dimmable Ballast (Electronic)
T12 (38mm)	{	{	%	{	%
T8 kryton-filled (25mm)	{	{	{	%	{
T8 argon-filled HF (25mm)	%	%	{	%	{
T5 (16mm)	%	%	{	%	{

2.2.2 Control Gear for Fluorescent Lamps

The optimum functioning of fluorescent lamps largely depends on the properties of the control gear used. They cannot function properly on the mains supply voltage and certain electrical devices have to be incorporated into the lamp circuit. The control gear performs a number of functions:

- To limit and stabilise the lamp current.
- To ensure lamp operating continuously during zero crossing of voltage at each half cycle.
- To provide ignition voltage for initial lamp starting.
- To supply controlled energy to pre-heat lamp electrodes during ignition.
- To fulfil other requirements such as ensuring high power factor, limiting harmonic distortion, suppressing EMI, limiting short-circuit and starting current, having long life, low losses and low noise level, etc.

2.2.3 Electromagnetic Ballasts

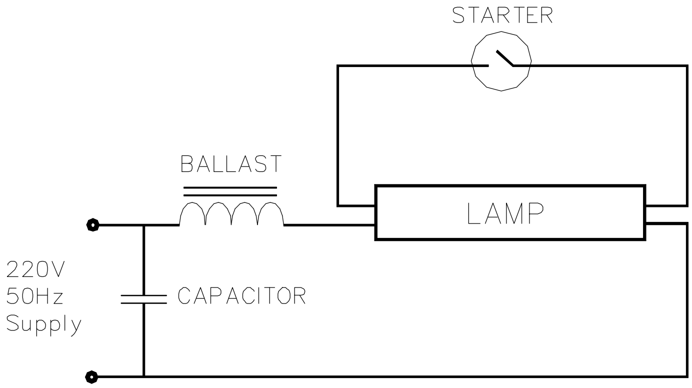


Fig. 2: Lamp circuit using electromagnetic ballast

With the electromagnetic control gear system, various separate components including ballast, glow starter switch, capacitor and filter coil fulfil all the above requirements together with the lamp.

This type of control gear involves a glow starter switch for preheating the filaments of the electrodes before discharge. When the supply voltage is applied, a small discharge occurs between the bimetal electrodes of the starter. The heat caused by this discharge curves the bimetal electrode and closes the contact to complete the circuit. The electrodes of the lamp are then preheated for a certain period before the starter cools down and opens the circuit. At that instant, a high induced voltage that occurs on the choke coil of the ballast causes the fluorescent lamp to ignite. If ignition of the lamp fails at the first attempt, the same process above will be repeated until ignition succeeds to start.

After starting of the lamp, the ballast will function as a current limiting device connected in series with the lamp. Iron and copper losses occur in the ballast dissipated as heat to the room space. Typical ‘warm’ loss of conventional and low loss ballasts operating a 36W fluorescent lamp is 13W and 10W respectively. Normally, one set of control gear is required to operate one fluorescent lamp.

2.2.4 Electronic Ballasts

The basic construction of typical electronic ballast involves a low-pass filter, rectifier, buffer capacitor and a high frequency oscillator. Although the electronic ballast system is integrated into one single ‘black box’, its different functions and requirements can be divided into a number of individual blocks. The basic operation principle is that after passing a low-pass filter, the mains voltage at 50Hz power frequency is rectified in an AC/DC converter. This converter also contains the buffer capacitor, which is charged with a DC voltage. In the HF power generator this DC voltage is transformed into a HF voltage, which provides the power for the lamp controller. The ballast controller controls all these functions.

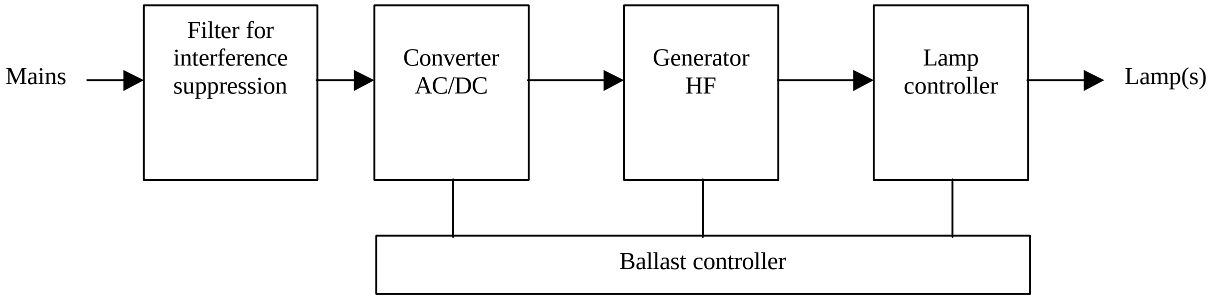


Fig. 3: Block diagram indicating main functions of electronic ballast

The ballast takes advantage of a characteristic of fluorescent lamp whereby greater efficacy is obtained at high operating frequency above 10kHz. The overall lighting system efficacy can be increased by 20 to 30 percents due to three main factors:

1. Improved lamp efficacy at high frequency operation.
2. Reduced circuit power losses.
3. Lamp operates closer to optimum performance in most enclosed luminaires.

Electronic ballasts could be designed for either warm start or instant start. The instant start electronic ballast uses high voltage in lieu of preheating electrodes for starting and is even more energy efficient. As the circuit design is simpler than warm start type, the cost of instant start electronic ballast is comparatively less expensive. However, it is not suitable for lighting requiring frequent switching which will shorten the lamp life.

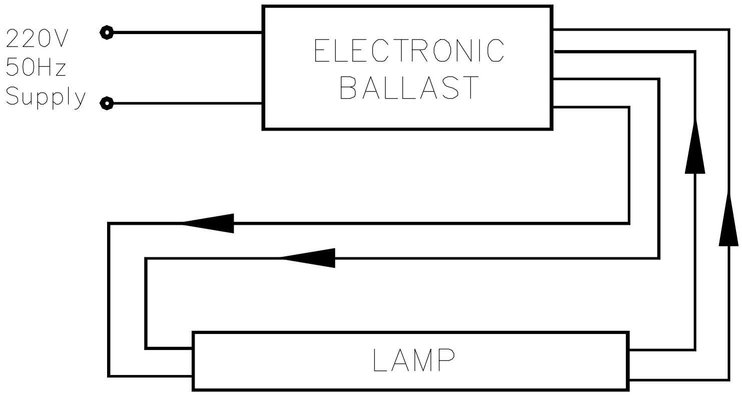


Fig. 4: Lamp circuit using electronic ballast

Efficacy due to high frequency operation is increased by about 10% thereby enabling the lamp to be operated at a lower input power than at 50Hz mains power frequency. For instance, a 36W 1200mm T8 lamp normally rated at 47W with conventional ballast can now be run at 34W for the same light output. The net effect is that same useful light output is maintained at lower power input in a typical luminaire.

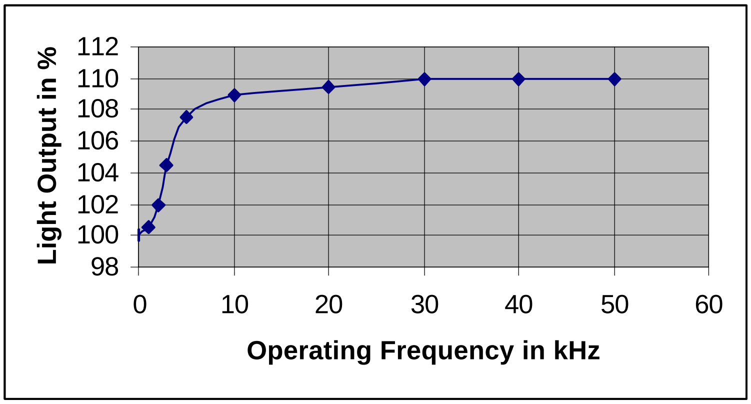


Fig. 5: Luminous flux of fluorescent lamp as a function of supply frequency at constant power

Ballast losses are reduced compared to electromagnetic ballast, as the solid state circuit contains no conventional copper windings. In the case of a twin 1200mm 36W lighting circuit the losses can be reduced from 26W to a mere 6W when using electronic ballast. The overall achievement in a suitable luminaire, therefore, is an energy reduction in the region of 20% to 30%. These energy saving features enable lighting levels to be maintained with a dramatic cut in electricity costs. With less heat generated, the cooling load on air conditioning equipment will also be reduced.

Other benefits electronic ballast offered include:

- Rapid or instant starting of lamp without flickering.
- Single ballast can be designed to drive one, two, three or even four lamps.
- Increased lamp life due to lower lamp operating current.
- Quiet operation without audible noise.
- Dimmable version is also available.
- No visible flicker during operation.
- No stroboscopic effect on high frequency operation.
- Most modern design has lower total harmonic distortion (THD) than conventional ballast.
- Higher power factor.
- Cooler ambient temperature inside luminaires for optimum operation of lamp, control gear, capacitor and batteries for emergency lighting.
- Low operating temperature and reduce carbonisation and blackening to luminaire and decoration in the vicinity.
- Less effect on variation of luminous flux due to mains supply voltage fluctuations.
- Much lighter in weight.

2.3 Survey and Testing

2.3.1 Survey on Electronic Ballasts

The Energy Efficiency Office (EEO) of Electrical and Mechanical Services Department conducted the survey on technical performance of electronic ballasts in 1996 as part of the Pilot Energy Management Opportunity (EMO) Implementation Programme. More than 40 lighting equipment suppliers and manufacturers in Hong Kong were invited to participate in the survey.

2.3.2 Product Summary

In accordance with the data on the survey forms returned by ballast suppliers, a summary sheet is produced below showing the availability of various types of electronic ballasts commonly used in Hong Kong from different manufacturers.

Table 3: Product Range available for Electronic Ballasts

Product Range of Electronic Ballasts Available for T8 Lamps										
1x18W	2x18W	3x18W	4x18W	1x32W	2x32W	1x36W	2x36W	3x36W	1x58W	2x58W

Most manufacturers claimed that their products are designed to comply with parts or all of the following national or international standards:

- IEC 928/EN 60928/GB 15143-94: A.C.-supplied electronic ballasts for tubular fluorescent lamps - General & safety requirements
- IEC 929/EN 60929/GB 15144-94: A.C.-supplied electronic ballasts for tubular fluorescent lamps - Performance requirements

- IEC 1000-3-2/EN 61000-3-2: Limits for harmonic current emission (equipment input current ≤ 16A per phase)
- EN 55015: Limit and method of measurement of radio disturbance characteristics of lighting and similar equipment
- FCC, 47 CFR Part 18: non-consumer equipment: conducted interference and radiated interference ≥ 30Mhz

2.3.3 Test Results

A lighting test rack was set up in EEO for mounting the standard reference kit of fluorescent luminaires complete with the reference fluorescent tubes. The test luminaire was first tested with conventional electromagnetic ballasts and then followed by the relevant electronic ballasts submitted by the suppliers. A digital luxmeter (Lutron LX-102) was used to measure illuminance in lux at a fixed test point directly underneath the luminaire. A power harmonics analyser (Fluke 41B) together with an IBM notebook were used to record all electrical parameters including active power, apparent power, power factor, voltage, current and total harmonic distortion, etc. during the tests. The test results of ballast performance for the operation of 3x18W T8, 2x36W T8, 2x32W T8 and 3x36W T8 tubes were summarised in the following tables and charts. Due to the agreement made between the manufacturers and EEO during the survey, all test results and information obtained must be kept in confidence. Ballast reference number is only given in the test results.

Table 4: Test Results for 600mm x 600mm Luminaire with 3x Philips ‘TL’D18W/84 lamps

Ballast	Current (A)	Power (W)	Power Saved (%)	Power Factor (%)	THD (%)	Measured Illuminance (lux)	Relative Lumen Output (%)
Conventional Ballast (CB)	0.66	97	N/A (reference)	66%	12.71%	1680	100.00% (reference)
EB1	0.32	66	31.96%	95%	27%	1720	102.38%
EB2	0.26	54	44.33%	97%	14.86%	1552	92.38%
EB3	0.25	51	47.42%	98%	29.42%	1315	78.27%
EB4	0.29	61	37.11%	98%	13.09%	1680	100.00%
EB5	0.27	55	43.30%	95%	18.02%	1625	96.73%

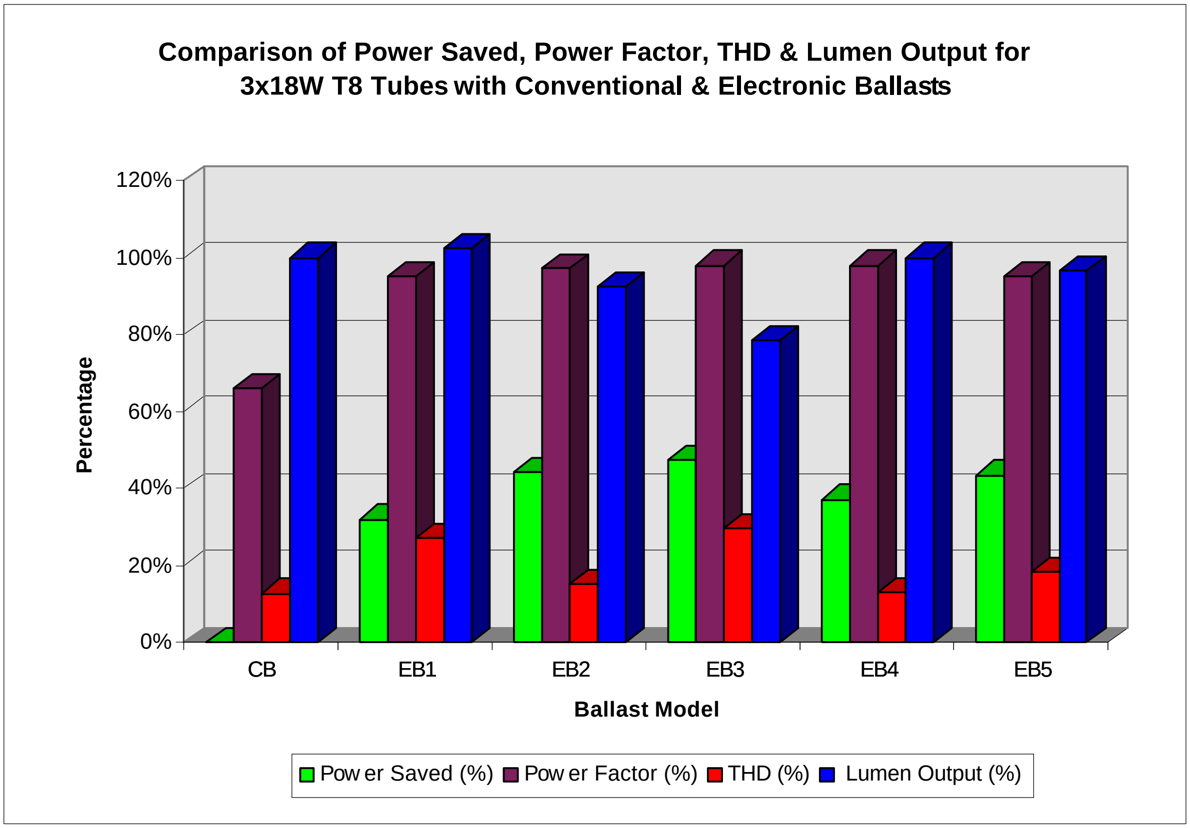


Fig. 6: Comparison of ballasts for 600mm x 600mm Luminaire with 3x Philips 'TL'D18W/84 lamps

Table 5: Test Results for 1200mm Luminaire with 2x36W 'GEC' Wattsaver Cool White lamps

Ballast Reference	Current (A)	Power (W)	Power Saved (%)	Power Factor (%)	THD (%)	Measured Illuminance (lux)	Relative Lumen Output (%)
Conventional Ballast CB	0.78	98	N/A (reference)	58%	9.95%	1124	100%
EB1	0.33	66	33%	93%	24.34%	1087	97%
EB2	0.32	63	36%	91%	35.49%	1006	90%
EB3	0.35	74	24%	97%	11.16%	1180	105%
EB4	0.34	75	23%	99%	11.33%	1166	104%
EB5	0.35	73	26%	97%	24.26%	1060	94%
EB6	0.35	72	27%	95%	13.85%	1085	97%
EB7	0.35	76	22%	99%	9.79%	1122	100%
EB8	0.34	73	26%	98%	11.04%	1164	104%
EB9	0.34	67	32%	92%	41.81%	1060	94%
EB10	0.35	74	24%	97%	11.00%	1160	103%
EB11	0.37	78	20%	95%	9.78%	1241	110%
EB12	0.34	71	28%	94%	13.18%	1140	101%
EB13	0.35	73	26%	95%	11.36%	1165	104%

Notes: a) The maximum allowable THD for lighting circuit is 20% for compliance with Electrical Energy Code

b) The acceptable relative lumen output shall be between 95% to 105%.

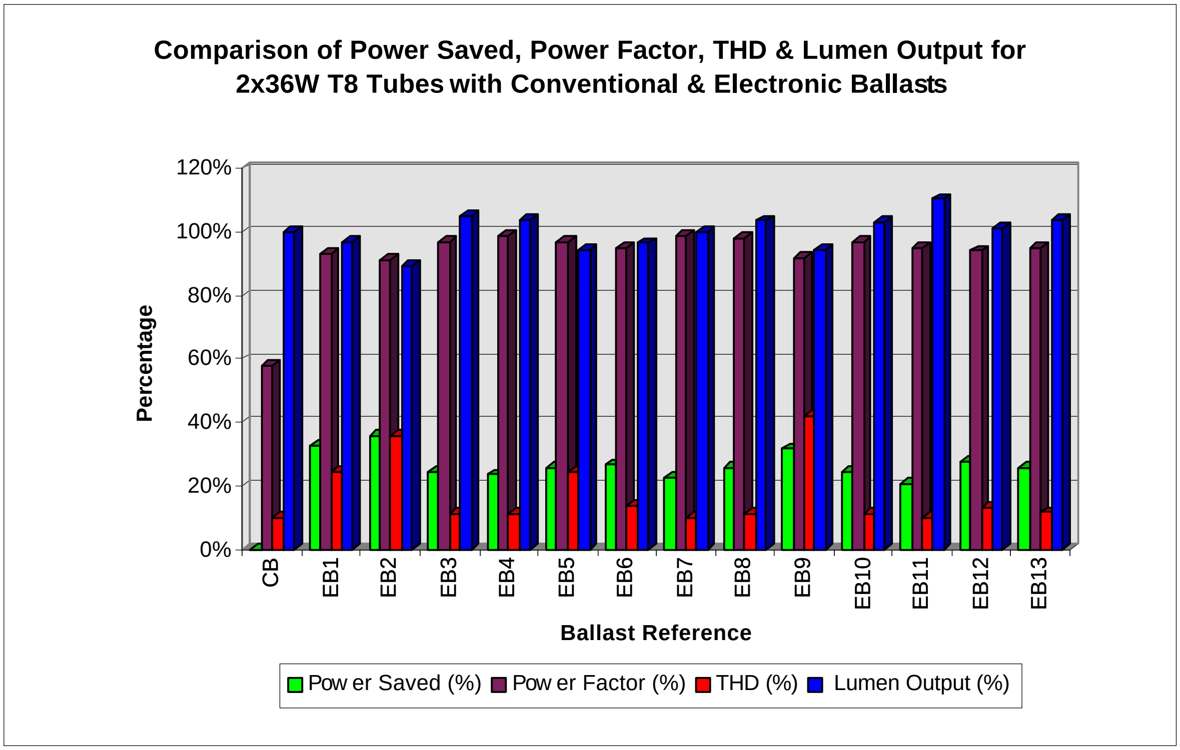


Fig. 7: Comparison of Power Saved, Power Factor, THD and Relative Lumen Output between Conventional Ballast and Electronic Ballasts for 2x36W T8 Tubes

Table 6: Test Results for 1200mm Luminaire with 2x32W Philips 'TL'D 32W/84 HF Electronic N6 lamps

Ballast	Current (A)	Power (W)	Power Saved (%)	Power Factor (%)	THD (%)	Reference Illuminance (lux)	Lumen Output (%)
2x36W Conventional Ballast (CB)	0.78	98	N/A (ref.)	58%	9.95%	1124	100% (ref.)
EB1	0.36	76	22%	99%	11.23%	1130	101%
EB2	0.31	63	36%	95%	25.34%	1089	97%

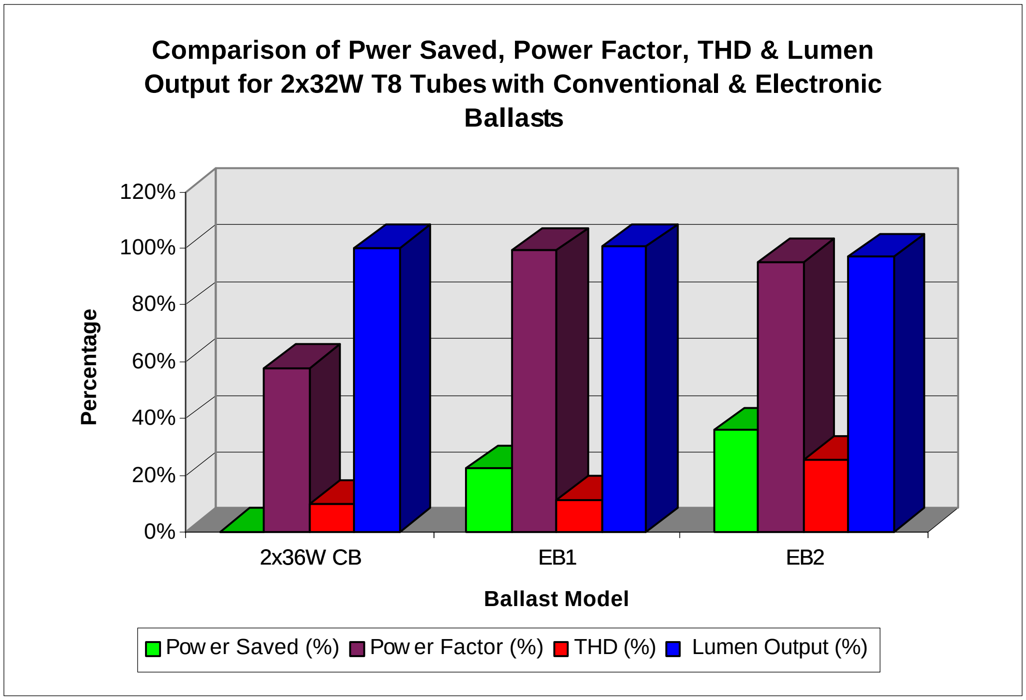


Fig. 8: Comparison of Power Saved, Power Factor, THD and Relative Lumen Output between Conventional Ballast and Electronic Ballasts for 2x32W T8 Tubes

Table 7: Test Results for 1200mm Luminaire with 3x36W 'GEC' Wattsaver Cool White lamps

Ballast	Current (A)	Power (W)	Power Saved (%)	Power Factor (%)	THD (%)	Reference Illuminance (lux)	Lumen Output (%)
Conventional Ballast CB	0.78	145	N/A (ref.)	58%	9.95%	1685	100% (ref.)
EB1	0.46	100	31.03%	98%	20.42%	1590	94.36%
EB2	0.52	108	25.52%	99%	9.79%	1747	103.68%
EB3	0.47	95	34.48%	93%	30.77%	1560	92.58%
EB4	0.48	104	28.28%	97%	8.58%	1710	101.48%

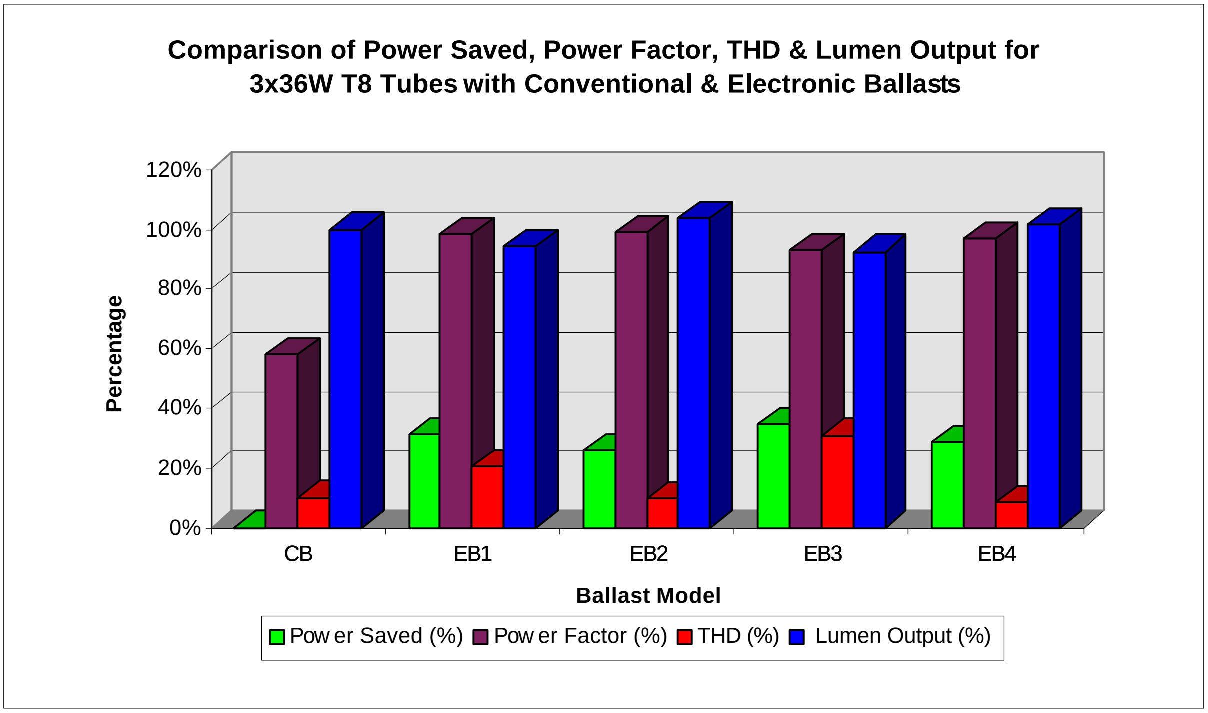


Fig. 9: Comparison of Power Saved, Power Factor, THD and Relative Lumen Output between Conventional Ballast and Electronic Ballasts for 3x36W T8 Tubes

According to the preliminary test results above, certain models of the following suppliers/brand names were tested to our satisfaction in term of energy saving, relative lumen output, total harmonic distortion, power factor, etc. This information is for general guidance only, reference should be made to manufacturers' test certificates for individual model issued by corresponding testing laboratories for compliance with relevant international standards for safety and performance of their electronic ballasts.

Table 8: Suppliers and Brand Names of Electronic Ballasts Tested by EEO

	Company Name	**Address**	**Telephone No.**
1	Billion Building Services Limited (Motorola)	8/F., Ming Tak Commercial Building, 101-103A Wanchai Road, Hong Kong	2511 0838
2	Brighten Trading Co. (BAST)	LG/F, Queen's Commercial Tower' 31 - 37 Lok Ku Road, Sheung Wan, Hong Kong	2545 3289
3	Clipsal Asia Limited (Clipsal)	3/F.,Wyler Centre I, 200 Tai Lin Pai Road, Kwai Chung, N.T.	2487 0261
4	Eurolite Co., Ltd. (OmniTroni (rapidTronic))	1006, 10/F, Kwong Sang Hong Centre, 152-153 Hoi Bun Road, Kwun Tong, Kowloon	2304 0712 2790 5385
5	Far East Trading Co. (Vossloh-Schwabe)	Room A12, 5/F, Kailey Centre, 12 Fung Yip Street, Chai Wan, Hong Kong	2889 8100

6	The General Electric Company of Hong Kong Limited (Micatron)	27/F., C C Wu Building, 302-308 Hennessy Road, Wanchai, Hong Kong	2919 8282
7	General Electric International Operations Co. (GE Lighting)	10/F, The Lee Gardens, 33 Hysan Avenue, Causeway Bay, Hong Kong	2100 6904
8	GLM International Ltd. (Tridonic)	Unit 5, 3/F, Kinox Centre, 9 Hung To Road, Kwun Tong, Kowloon	2398 3918
9	Helvar Electrosonic Co., Ltd. (Helvar)	Suite 603-5, Wilson House, 19-27 Wyndham Street, Central, Hong Kong	2525 1828
10	Hoye Lighting Limited (Hoye)	Unit 2710, 1 Hung To Road, Kwun Tong, Kowloon	2318 0621
11	HUAFUDA International Trading Co. (HUAFUDA)	Block A, 20/F, 379-381 King’s Road, North Point, Hong Kong	2566 8208
12	Leader Company (Hackett (Line Tek))	Room D, 6/F, Block 1, Tai Ping Industrial Centre, 57 Ting Kok Road, Tai Po	9308 8711
13	MagneTek Asia Limited (MagneTek, LEB)	Suite 1102, 11/F, Central Plaza, 18 Harbour Road, Wanchai, Hong Kong	2828 7988
14	Master House Development Ltd. (EMAT)	Unit 1903-05, 19/F, Tower B, Regent Centre, No. 63-73 Wo Yi Hop Road Kwai Chung, N.T.	2421 8730
15	Osram Prosperity Co., Ltd. (Osram)	Rm. 1409 Harbour Centre, 25 Harbour Road, Wahchai, Hong Kong	2511 2268
16	Pak Kin Electric Co., Ltd. (Power (Line Tek))	Unit 3, 4/F., Harry Industrial Building, 49-51, Au Pui Wan St., Fo Tan, N.T.	2602 0610
17	Philips Hong Kong Limited (Philips)	27/F., Hopewell centre, 17 Kennedy Road, Hong Kong	2821 5888 2821 5204
18	Prosperity Lamps & Components Ltd. (Motorola)	Room 1401, Harbour Centre, 25 Harbour Road, Wanchai, Hong Kong	2511 0022
19	Sinoland Technology Limited (Otte-tronics (Line Tek))	Unit D1, 6/F, Block 1, Taiping Industrial Centre, 57 Ting Kok Road, Tai Po, N.T.	2425 7893
20	Thorn Lighting (Hong Kong) Limited (Thorn)	19/F., Jardine Engineering House, 260 King’s Road, Hong Kong	2578 4303

As far as energy saving is concerned, the test results for different ballasts can be summarised in Table 9 below:

Table 9: Average Circuit Power Saved for different Wattage of Lamps

Fluorescent Lamp	18W T8 Lamp	36W T8 Lamp	32W T8 (HF) Lamp
Average Lighting Circuit Power (Conventional Ballasts)	30W	48W	–
Average Lighting Circuit Power (Electronic Ballasts)	20W	36W	32W
Lighting Circuit Power Saved	10W	12W	16W
% Lighting Energy Saved	33%	25%	33%

2.4 Pilot EMO Implementation Projects

The Electrical & Mechanical Services Department of the HKSAR Government have carried out seven pilot projects, for assessing the energy efficient performance, pay back period as well as other technical performance of lighting installations in government buildings using electronic ballasts. Details of all relevant pilot projects are given below.

2.4.1 Queensway Government Offices (QGO)

Queensway Government Offices (QGO) is one of the buildings selected for implementation of pilot EMO projects which include replacement of electronic ballasts, addition of variable speed drives for pumps/fans, addition of timers, etc. This section describes the replacement of the conventional ballasts with electronic ballasts for some of the fluorescent lamps in QGO.

The retrofit work consisted of replacement of the conventional ballasts with electronic ballasts for the fluorescent luminaires located around the core area, the essential lighting in the open hall area and Exit Signs on 38/F and 39/F. There were totally 192 nos. 1x36W luminaires for core and essential lighting and 10 nos. 1x18W Exit Signs involved in the project. All these luminaires are part of the essential and emergency lighting of the building and are mostly lit continuously.

The contractor for this retrofit work was Koon Wah Electrical Company. The project sum was HK$100,240.00 and works order issued to contractor in September 96. ‘Osram’ QTEC electronic ballasts were used and they were delivered to site in December 96. Site work took 3 successive weekends (Saturdays and Sundays), i.e. a total of 6 workdays and was completed in late December 96.

Separate kWh meters were installed for monitoring the energy consumption of the lighting circuits. The electricity consumption of the fluorescent lamps before and after the retrofit work was measured in a weekly basis. As the retrofit involved a small portion of the whole lighting installation, there were only very minor changes in power factor, THD and illuminance after the retrofit. The result of this pilot project is summarised in Table 10 below.

Table 10: Summary of Ballasts Replacement Works in QGO

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
266 kWh	13,860 kWh	$12,000	8 years	$500

No complaint has so far been received from the building users/maintenance staff and the products of ‘Osram’ electronic ballasts are regarded as reliable and performing well.

2.4.2 Eastern Law Courts Building (ELCB)

As this is only a pilot project, it was not intended to carry out full-scale improvement work for all existing luminaires in the building. In order to minimise interruption to the building users, public corridors and staircases in G/F to 12/F and roof were only chosen for this retrofit work and installation work was carried out after office hours.

This section describes the replacement of conventional ballasts with electronic ballasts for the existing corridor luminaires as well as the replacement of fluorescent luminaires in staircases. The luminaires involved are as follows:

(a) 184 nos. of type L3 3x18W recessed fluorescent luminaire in which 2 tubes to be operated by 2x18W electronic ballast.
(b) 133 nos. of type L4 4x18W recessed fluorescent luminaires to be operated by 2 nos. 2x18W electronic ballast (Note: 4x18W electronic ballast is not available at the time of tender).
(c) 62 nos. of type S2 1x58W staircase fluorescent luminaire to be replaced by new 1x18W batten luminaire with electronic ballast.

The contractor for this retrofit work was Logon Engineering Ltd. The contract sum was HK$138,684.00 and works order issued to contractor in January 97. ‘Osram’ QTEC electronic ballasts were used for the project. Installation commenced in late February 1997 and the project was completed in April 1997.

Separate kWh meters were installed for the corridor lights and the staircase lights. The electricity consumption of the fluorescent lights before and after the retrofit work was measured. Table 11 below shows the calculation of energy saving achieved from measurements of electricity consumption and readings were taken over a period of 1 month before and after retrofit of the light fittings.

Table 11: Calculation of Energy Saved in ELCB

Type of Luminaire	L3	L4	S2
No. of Retrofitted Luminaire	184	133	62
Operating Hours per day	9 hr.	9 hr.	12 hr.
Daily consumption in kWh before retrofit*	139.1	134.1	52.1
Daily consumption in kWh after retrofit*	109.3	91.0	16.4
Daily saving in kWh after retrofit	29.8	43.1	35.7
No. of days operating per year	270	270	365
Saving per year in kWh	8046	11637	13031

Note * : In calculating the daily consumption of electricity, an average of 22.5 days per month in which the light fittings are in operation is taken.

From the data above, the average electricity consumption of each luminaire with conventional ballast and that with electronic ballast can also be calculated and compared in Table 12.

Table 12: Energy Saved for various Luminaire Types in ELCB

Type of luminaire	L3	L4	S2
Watts consumed before retrofit (average)	84W	112W	70W
Watts consumed after retrofit (measured)	66W	76W	22W
Saving per luminaire in Watts	18W	36W	48W
Saving per luminaire in percentage	21%	32%	69%

As the retrofit involved a small portion of the whole lighting installation, there were only very minor changes in power factor, THD and illuminance after the retrofit. The result of this pilot project is summarised in Table 13 below.

Table 13: Summary of Ballasts Replacement Works in ELCB

Total Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast/Luminaire (Supply & Install)
32,714 kWh	$30,000	4.7 years	$365

No complaint has so far been received from the building users/maintenance staff and the products of ‘Osram’ electronic ballasts are regarded as reliable and performing well.

2.4.3 Harbour Building

Harbour Building was selected in 1997 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes pilot lighting and air conditioning improvement work. This section describes the replacement of the conventional ballasts with electronic ballasts for the existing fluorescent luminaires in the Labour Department Office (15/F and 16/F) as well as the replacement of fluorescent luminaires in all staircases.

The luminaires involved are shown as follows:

- 192 nos. of “Fitzerald” 1x18W Batten Luminaires for staircase lighting c/w “LEB” electronic ballasts
- 574 nos. of 2 x 36W “LEB” electronic ballasts for replacement in offices
- 11 nos. of 2x 30W “LEB’ electronic ballasts for replacement in offices
- 4 nos. of 2 x 18W “LEB” electronic ballasts for replacement in offices
- 175 nos. of 1 x 36W “LEB” electronic ballasts for replacement in offices
- 170 nos. of 1 x 18W “LEB” electronic ballasts for replacement of EXIT signs

The contractor for this retrofit work was United-Power Engineering Company Limited. The project sum was HK$469,120.00. Works order was issued to contractor in October 1997. Installation commenced in November 1997 and the project was completed in May 1998.

Separate kWh meters were installed in the meter rooms on 15/F and 16/F of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in power factor and THD of the lighting circuits after the retrofit. Illumination level in staircase areas was increased substantially with the new luminaires and electronic ballasts. The result of this pilot project is summarised in Table 14 below.

Table 14: Summary of Ballasts Replacement Works in Harbour Building

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
1,372 kWh	68,600 kWh	$62,000	7.5 years	$490

No complaint has so far been received from the building users/maintenance staff and the products of ‘LEB’ electronic ballasts are regarded as reliable and performing well.

2.4.4 Southorn Centre

Southorn Centre was selected in 1997 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes pilot lighting and air conditioning improvement work. This section describes the replacement of the conventional ballasts with electronic ballasts for the existing fluorescent luminaires on 22/F and 23/F.

The luminaires involved are as follows:

- 772 nos. of 3 x 18W “Thorn” electronic ballasts for replacement in offices
- 27 nos. of 1 x 36W “Thorn” electronic ballasts for replacement in offices
- 174 nos. of 1 x 18W “Thorn” electronic ballasts for replacement in staircase

The contractor for this retrofit work was Winner Link Engineering Company Limited. The project sum was HK$325,560. Works order was issued to contractor in October 1997. Installation commenced in December 1997 and the project was completed in March 1998.

Separate kWh meters were installed in the meter rooms on 22/F and 23/F of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 15 below.

Table 15: Summary of Ballasts Replacement Works in Southorn Centre

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
2.030 kWh	101,500 kWh	$91,000	3.5 years	$335

No complaint has so far been received from the building users/maintenance staff and the products of ‘Thorn’ electronic ballasts are regarded as reliable and performing well.

2.4.5 Mongkok KCRC G.O.

Mongkok KCRC G.O. was selected in 1997 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes pilot lighting and air conditioning improvement work. This section describes the replacement of the conventional ballasts with electronic ballasts for the existing fluorescent luminaires in staircase and offices on 4/F and 11/F.

The luminaires involved were:

- 250 nos. of 1 x 36W “Thorn” electronic ballasts for replacement in offices

- 38 nos. of 2 x 36W “Thorn” electronic ballasts for replacement in offices
- 66 nos. of 1 x 18W “Thorn” electronic ballasts for replacement in staircase
- 8 nos. of 2 x 18W “Thorn” electronic ballasts for replacement in offices
- 9 nos. of 1 x 58W “Thorn” electronic ballasts for replacement in offices

The contractor for this retrofit work was Winner Link Engineering Company Limited under the same contract as Southorn Centre. The project sum was HK$119,370. Works order was issued to contractor in October 1997. Installation commenced in December 1997 and the project was completed in March 1998.

Separate kWh meters were installed in the meter rooms on 4/F and 11/F of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 16 below.

Table 16: Summary of Ballasts Replacement Works in Mongkok KCRC G.O.

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
413 kWh	20,650 kWh	$18,500	6.5 years	$321

No complaint has so far been received from the building users/maintenance staff and the products of ‘Thorn’ electronic ballasts are regarded as reliable and performing well.

2.4.6 Kowloon East G.O.

Kowloon East G.O. was selected in 1997 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts for the existing fluorescent luminaires in staircase and offices on G/F, 2/F, 3/F, 6/F and 7/F.

The luminaires involved were:

- 37 nos. of 1 x 36W “Thorn” electronic ballasts for replacement in offices
- 330 nos. of 2 x 36W “Thorn” electronic ballasts for replacement in offices
- 33 nos. of 3 x 36W “Thorn” electronic ballasts for replacement in offices
- 86 nos. of 1 x 18W “Thorn” electronic ballasts for replacement in staircase
- 103 nos. of 1 x 58W “Thorn” electronic ballasts for replacement in offices
- 2 nos. of 2 x 58W “Thorn” electronic ballasts for replacement in offices

The contractor for this retrofit work was Winner Link Engineering Company Limited under the same contract as Southorn Centre. The project sum was HK$159,530. Works order was issued to contractor in October 1997. Installation commenced in December 1997 and the project was completed in March 1998.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 17 below.

Table 17: Summary of Ballasts Replacement Works in Kowloon East G.O.

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
814 kWh	40,700 kWh	$36,600	4.4 years	$270

No complaint has so far been received from the building users/maintenance staff and the products of ‘Thorn’ electronic ballasts are regarded as reliable and performing well.

2.4.7 Tsuen Wan G.O.

Tsuen Wan G.O. was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts and new 32W HF fluorescent lamps for the existing fluorescent luminaires in offices on 1/F, 5/F and 15/F.

The luminaires involved were:

- 602 nos. of 2 x 32W “Hoye” electronic ballasts and new 32W HF fluorescent lamps
- 54 nos. of 2 x 18W “Hoye” electronic ballasts for replacement in offices
- 26 nos. of 2 x 58W “Hoye” electronic ballasts for replacement in offices
- 31 nos. of 3 x 18W “Hoye” electronic ballasts for replacement in offices
- 132 nos. of 1 x 58W “Hoye” electronic ballasts for replacement in offices
- 164 nos. of 1 x 36W “Hoye” electronic ballasts for replacement in offices
- 21 nos. of 1 x 18W “Hoye” electronic ballasts for replacement in offices

The contractor for this retrofit work was Paul Y. – ITC (E&M) Contractors Limited under the same contract as Yuen Long G.O. The project sum was HK$220,000. Works order was issued to contractor in August 1998. Installation commenced in October 1998 and the project was completed in December 1998.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. The illumination level in the office areas was measured before and after the retrofit and an average increase of 20%

in lux level was found. There were some improvements in power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 18 below.

Table 18: Summary of Ballasts Replacement Works in Tsuen Wan G.O.

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
1270 kWh	63,500 kWh	$57,000	3.8 years	$214

The new lighting installations with new electronic ballasts and new 32W HF lamps were highly appreciated by the building users. No complaint has so far been received and the products of ‘Hoye’ electronic ballasts are regarded as reliable and performing well.

2.4.8 Yuen Long G.O.

Yuen Long G.O. was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts and new 32W HF fluorescent lamps for the existing fluorescent luminaires in offices on 9/F, 10/F and 11/F.

The luminaires involved were:

- 339 nos. of 2 x 32W “Motorola” electronic ballasts and new 32W HF fluorescent lamps
- 30 nos. of 2 x 18W “Motorola” electronic ballasts for replacement in offices
- 323 nos. of 2 x 58W “Motorola” electronic ballasts for replacement in offices
- 20 nos. of 1 x 36W “Motorola” electronic ballasts for replacement in offices

The contractor for this retrofit work was Paul Y. – ITC (E&M) Contractors Limited under the same contract as Tsuen Wan G.O. The project sum was HK$150,000. Works order was issued to contractor in August 1998. Installation commenced in October 1998 and the project was completed in December 1998.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were an average increase of 20% illumination in the office areas and some improvements in power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 19 below.

Table 19: Summary of Ballasts Replacement Works in Yuen Long G.O.

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
1000 kWh	50,000 kWh	$45,000	3.3 years	$210

The new lighting installations with new electronic ballasts and new 32W HF lamps were highly appreciated by the buildings users, District Lands Office. No complaint has so far been received and the products of ‘Motorola’ electronic ballasts are regarded as reliable and performing well.

2.4.9 Civil Engineering Building

Civil Engineering Building was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts and new 32W HF fluorescent lamps for the existing fluorescent luminaires in offices on 3/F, carpark, lift lobbies and library on LG1.

The luminaires involved were:

- 297 nos. of 1 x 32W “Hoye” electronic ballasts and new 32W HF lamps
- 98 nos. of 3 x 18W “Magnetek” electronic ballasts for replacement in lobbies
- 39 nos. of 2 x 36W “Magnetek” electronic ballasts for replacement in offices
- 249 nos. of 3 x 36W “Magnetek” electronic ballasts for replacement in offices
- 5 nos. of 2 x 58W “Magnetek” electronic ballasts for replacement in offices

The contractor for this retrofit work was K.M. Luk & Engineering Limited under the same contract as Tai Po and Sai Kung G.O. The project sum was HK$217,861. Works order was issued to contractor in July 1998. Installation commenced in December 1998 and the project was completed in February 1999.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 20 below.

Table 20: Summary of Ballasts Replacement Works in Civil Engineering Building

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
1670 kWh	83,500 kWh	$75,000	2.9 years	$316

The new lighting installations with new electronic ballasts and new 32W HF lamps were highly appreciated by the buildings users. No complaint has so far been received and the products of ‘Hoye’ and ‘Magnetek’ electronic ballasts are regarded as reliable and performing well.

2.4.10 Tai Po G.O.

Tai Po G.O. was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts, new prismatic diffusers and new T8 fluorescent lamps for the existing fluorescent luminaires in lift lobbies and offices on G/F, 3/F, 4/F and 5/F.

The luminaires involved were:

- 9 nos. of 1 x 18W “Magnetek” electronic ballasts for replacement in offices
- 9 nos. of 2 x 18W “Magnetek” electronic ballasts for replacement in offices
- 240 nos. of 3 x 18W “Magnetek” electronic ballasts for replacement in offices
- 75 nos. of 1 x 36W “Magnetek” electronic ballasts for replacement in offices
- 173 nos. of 2 x 36W “Magnetek” electronic ballasts for replacement in offices
- 32 nos. of 3 x 36W “Magnetek” electronic ballasts for replacement in offices
- 117 nos. of 1 x 58W “Magnetek” electronic ballasts for replacement in offices

The contractor for this retrofit work was K.M. Luk & Engineering Limited under the same contract as Civil Engineering Building and Sai Kung G.O. The project sum was HK$146.055. Works order was issued to contractor in July 1998. Installation commenced in December 1998 and the project was completed in February 1999.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in illumination level, power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 21 below.

Table 21: Summary of Ballasts Replacement Works in Tai Po G.O.

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
810 kWh	40,500 kWh	$36,500	4 years	$227

The new lighting installations with new electronic ballasts and new T8 lamps were highly appreciated by the building users. No complaint has so far been received and the products of ‘Magnetek’ electronic ballasts are regarded as reliable and performing well.

2.4.11 Sai Kung G.O.

Sai Kung G.O. was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts, new prismatic diffusers and new T8 fluorescent lamps for the existing fluorescent luminaires in District Land Offices on 3/F and 4/F.

The luminaires involved were:

- 2 nos. of 2 x 18W “Osram” electronic ballasts for replacement in offices
- 11 nos. of 1 x 36W “Osram” electronic ballasts for replacement in offices
- 13 nos. of 2 x 36W “Osram” electronic ballasts for replacement in offices
- 3 nos. of 1 x 58W “Osram” electronic ballasts for replacement in offices
- 371 nos. of 2 x 58W “Osram” electronic ballasts for replacement in offices

The contractor for this retrofit work was K.M. Luk & Engineering Limited under the same contract as Civil Engineering Building and Tai Po G.O. The project sum was HK$117,787. Works order was issued to contractor in July 1998. Installation commenced in December 1998 and the project was completed in February 1999.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. There were some improvements in illumination level, power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 22 below.

Table 22: Summary of Ballasts Replacement Works in Sai Kung G.O.

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
800 kWh	40,000 kWh	$36,000	3.3 years	$337

The new lighting installations with new electronic ballasts and new T8 lamps were highly appreciated by the building users. No complaint has so far been received and the products of ‘Osram’ electronic ballasts are regarded as reliable and performing well.

2.4.12 Immigration Tower

Immigration Tower was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts, new T8 32W HF fluorescent lamps for the existing fluorescent luminaires in Audit Commission Offices on 26/F.

The luminaires involved were:

- 2 nos. of 2 x 18W “Motorola” electronic ballasts for replacement in offices
- 75 nos. of 3 x 18W “Motorola” electronic ballasts for replacement in offices
- 440 nos. of 2 x 32W “Motorola” electronic ballasts for replacement in offices
- 40 nos. of 1 x 58W “Motorola” electronic ballasts for replacement in offices

The contractor for this retrofit work was BYME Engineering (HK) Limited under the same contract as Revenue Tower. The project sum was HK$136,280. Works order was issued to contractor in October 1998. Installation commenced in December 1998 and the project was completed in February 1999.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. The illumination level in the office areas was measured before and after the retrofit and an increase of over 10% in lux level was found There were some improvements in illumination level, power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 23 below.

Table 23: Summary of Ballasts Replacement Works in Immigration Tower

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
960 kWh	48,000 kWh	$43,200	3.2 years	$245

The new lighting installations with new electronic ballasts and new T8 lamps were highly appreciated by the building users. No complaint has so far been received and the products of ‘Motorola’ electronic ballasts are regarded as reliable and performing well.

2.4.13 Revenue Tower

Revenue Tower was selected in 1998 for Phase I Pilot EMO Implementation Programme in Government buildings. The retrofit project carried out in this building includes the replacement of the conventional ballasts with electronic ballasts, new T8 32W HF fluorescent lamps for the existing fluorescent luminaires in offices on 31/F and 33/F.

The luminaires involved were:

- 159 nos. of 3 x 18W “Micatron” electronic ballasts for replacement in offices
- 865 nos. of 2 x 32W “Micatron” electronic ballasts for replacement in offices
- 6 nos. of 3 x 32W “Micatron” electronic ballasts for replacement in offices
- 80 nos. of 1 x 58W “Micatron” electronic ballasts for replacement in offices

The contractor for this retrofit work was BYME Engineering (HK) Limited under the same contract as Immigration Tower. The project sum was HK$306,730. Works order was issued to contractor in October 1998. Installation commenced in December 1998 and the project was completed in February 1999.

Separate kWh meters were installed in the meter rooms of the buildings. The power and energy consumption of the lighting installations before and after the retrofit work was recorded. Individual sample ballasts (conventional and electronic) were also taken from site for testing and measurement for spot-checking. The illumination level in the office areas was measured before and after the retrofit and an increase of over 10% in lux level was found There were some improvements in illumination level, power factor and THD of the lighting circuits after the retrofit. The result of this pilot project is summarised in Table 24 below.

Table 24: Summary of Ballasts Replacement Works in Revenue Tower

Measured kWh Saving for 1 week	Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Unit Cost of Electronic Ballast (Supply & Install)
2,100 kWh	105,000 kWh	$94,500	3.2 years	$276

The new lighting installations with new electronic ballasts and new T8 lamps were highly appreciated by the building users. Several newly installed electronic ballasts were found faulty. They were replaced and the defective ballasts were returned to manufacturers for investigation. Feedback from the manufacturer indicated that some fuses in the ballasts were marginal to withstand the inrush current and circuit had been redesigned to rectify the problem.

2.5 Conclusions and Discussions

2.5.1 Owing to the increase of public awareness in energy efficiency, the market of electronic ballasts for fluorescent lamps is becoming more and more competitive nowadays as many manufacturers from all over the world came into the Hong Kong market. The variety of electronic ballasts available in the market is also increasing. A single electronic ballast can be made to drive one, two, three or even four lamps ranged from 18W(600mm) to 58W(1500mm). The unit cost of electronic ballast has been dropping rapidly from over HK$400 couple of years ago to less than HK$120 recently. The lower cost has made it more attractive for investment in either new project or major retrofit work resulting in much shorter payback periods. The trend is reflected from the above pilot EMO Implementation Programme. We have achieved to reduce the simple payback from 8 to 3 years and the unit cost for the supply and installation of electronic ballast from HK$500 to HK$250 during the 3-year Phase 1 EMO Implementation Programme.

2.5.2 Harmonic distortion is another major concern of electronic ballast application. As non-linear electronic converters and high frequency oscillator are major components of electronic ballast, harmonic filtering must be incorporated in the ballast to reduce the current harmonic distortion, especially third harmonic, in order not to affect the power quality of the existing power distribution system. Some previous models of electronic ballast created very high harmonic current (over 40%) and had adverse effects on power quality and distribution losses. Most modern design of electronic ballast nowadays has improved quality in harmonic distortion (e.g. below 10%).

2.5.3 The power factor of conventional and low loss ballasts can be as low as 0.4 without capacitor for reactive power compensation. Most electronic ballasts nowadays have power factor over 0.95. The inrush current is higher at starting for electronic ballasts. The maximum number of luminaires with electronic ballasts connected to a 10A lighting switch should not exceed 10 in order not to trigger the corresponding circuit breaker incidentally.

2.5.4 The replacement of conventional or low loss ballasts with electronic ballasts could save electrical power and could have instant effect of reduction in energy and demand charge in electricity bill.

2.5.5 For new building and major retrofit projects, it is recommended that electronic ballasts should be used in lieu of conventional or low loss ballasts for all fluorescent luminaires including emergency lighting and ‘EXIT’ signs.

2.5.6 Based on our experience gained on the application of electronic ballasts, a standard specification for electronic ballasts has also been drafted as below to ensure quality of the products.

2.5.6.1 The electronic ballast (hereafter referred to as EB) shall be a solid-state converter to convert single phase mains supply of 220V±6% and 50Hz±1Hz to a high frequency (HF) voltage output at its rated throughput power to suit the lamp(s) connected.

2.5.6.2 The EB shall conform to the following national or international standards:

(a) IEC 928/EN 60928/GB 15143-94A.C.-supplied electronic ballasts for tubular fluorescent lamps - General & safety requirements
(b) IEC 929/EN 60929/GB 15144-94A.C.-supplied electronic ballasts for tubular fluorescent lamps - Performance requirements
(c) IEC 1000-3-2/EN 61000-3-2 Limits for harmonic current emission (equipment input current ≤ 16A per phase)
(d) EN 55015 Limit and method of measurement of radio disturbance characteristics of lighting and similar equipment
(e) EN 61547 Equipment for general lighting purposes – EMC immunity requirements

2.5.6.3 Certificates of compliance with the above standards shall be issued by a recognised test laboratory for each standard rating of EB used in the Contract. The EB shall also be manufactured to ISO9001.

2.5.6.4 Full technical details of the EB shall be submitted by the manufacturer through the Contractor and shall cover technical guides on its applications, wiring diagrams, shop drawings of EB incorporating in luminaire if applicable, etc.

2.5.6.5 The EB shall incorporate a low-pass filter for limitation of harmonic distortion, radio interference, inrush current and high mains voltage peak, a full diode bridge rectifier, a power factor correction (PFC) part consists of a boost type converter (a choke, FET-transistor and diode) and an electrolytic capacitor, a high frequency (HF) oscillator and an internal control circuit. The HF oscillator circuit shall consist of a half bridge inverter oscillator driven by a toroid transformer and ignition capacitors.

2.5.6.6 The minimum energy efficiency of high frequency lamp-ballast circuits operating on EB shall not be less than 85% at the rated lamp power output.

2.5.6.7 For the fluorescent lamp(s) operated by the EB, the regulated light output shall be less than ± 2% over a supply voltage range of 220V ± 10% to the EB.

2.5.6.8 The Ballast Lumen Factor of the EB shall not be lower than 0.95 or higher than 1.05 with reference to standard conventional ballast.

2.5.6.9 The EB shall be warm start and the lamp operating frequency shall be above 20kHz. Instant start EB shall only be offered when non-frequent switching of the lighting circuit is specified.

2.5.6.10 The Total Power Factor (TPF) of the EB shall be higher than 0.95 and its maximum Total Harmonic Distortion (THD) shall be less than 20% when tested on a pure sinusoidal mains supply.

2.5.6.11 The complete EB shall be housed in a single front-access enclosure with appropriate terminal blocks for easy connection of wiring. The EB shall be suitable to operate at an ambient temperature range from 0°C to 50°C. The minimum case temperature of the EB shall be 70°C at the test point.

2.5.6.12 The EB shall go into a shutdown or low power stand-by state and switch the lamp off when the lamp becomes deactivated. In case of multi-lamps operating from a single EB, all lamps shall be switched off when a lamp fails. After relamping the EB shall start automatically.

2.5.6.13 The maximum inrush current of the EB shall not exceed 20A peak at starting and shall not last longer than a duration of 0.5 ms.

2.5.6.14 The rated life of the EB shall not be less than 50,000 hours at the maximum case temperature.

2.5.6.15 The failure rate of the EB shall be less than 1% per 4000 hours operation at the maximum case temperature.

3 Variable Speed Drives for Air Conditioning Systems

3.1. Introduction

In Hong Kong, most of the 3-phase ac motors in buildings are fitted to fans and pumps. The flow from most fans and pumps is either constant or controlled by restricting the flow by mechanical means, e.g. dampers are used on fans and valves are used on pumps. This mechanical constriction will control the flow and may reduce the load on the fan or pump motor, but the constriction itself adds an energy loss that is obviously inefficient. Hence if the flow can be controlled by reducing the speed of the fan or pump motor, more efficient means of achieving flow control could be offered

In fact the saving is greater than might initially be expected. As the speed of the fan or pump is reduced, the flow will reduce proportionally, while the power required by the fan or the pump will reduce with the cube of the speed. For example, if the flow can be reduced by 20%, the corresponding speed will be 80% of normal speed, the power required is 0.8^3 and is equal to 51.2%. This level of potential energy saving makes the use of Variable Speed Drive (VSD) to control flow one of the most important, cost-effective investments in energy efficiency which can be considered for motors.

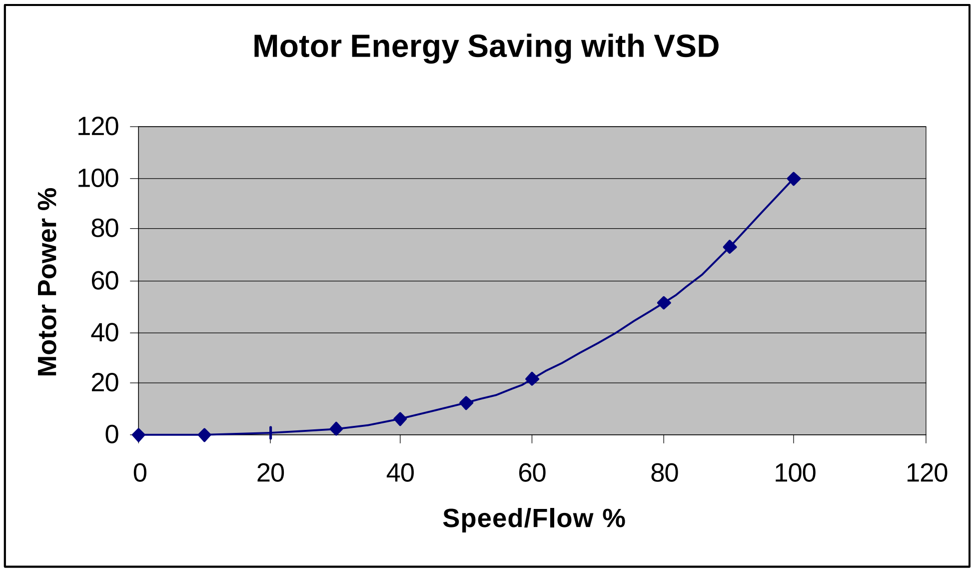


Fig.10: Percentage Motor Power Consumption as a Function of Variable Volume Flow
Note: The actual motor power consumption measured with VSD shall include power losses in VSD, motor and mechanical power transmission, etc.

3.2. Technical Information

3.2.1 Variable Speed Drive (VSD)

It has always been possible to control the speed of ac motors, but in the past this was only justified for exception cases due to the high cost and complexity of the system. In recent years, modern development in power semiconductors and microprocessors have allowed the introduction of electronic VSDs which have improved performance and reliability over earlier systems while reducing the equipment cost. Hence a range of motors in building services can now be considered for retrofitting with VSD based on the economics of energy saving.

A VSD can be regarded as a frequency converter rectifying ac voltages from the mains supply into dc, and then modifies this into a 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.

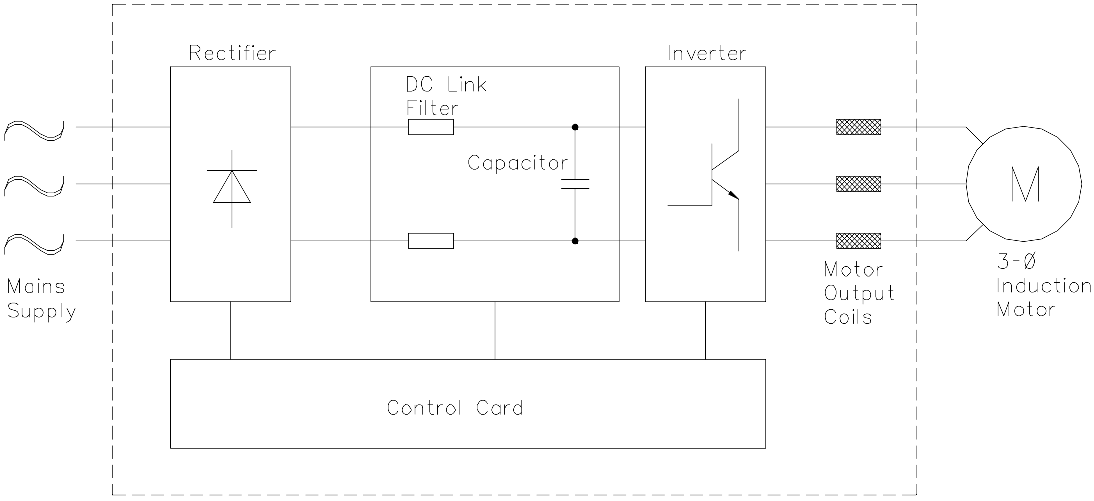


Fig.11: Basic Configuration of a typical Variable Speed Drive (VSD) system

3.2.2 Application of VSD in Primary Air-Handling Units (PAU)

Conventional fresh air supply introduced into a high-rise commercial building is normally fed via a Primary Air-handling Unit (PAU) at constant air volume. Fig 12 shows the arrangement of a conventional PAU.

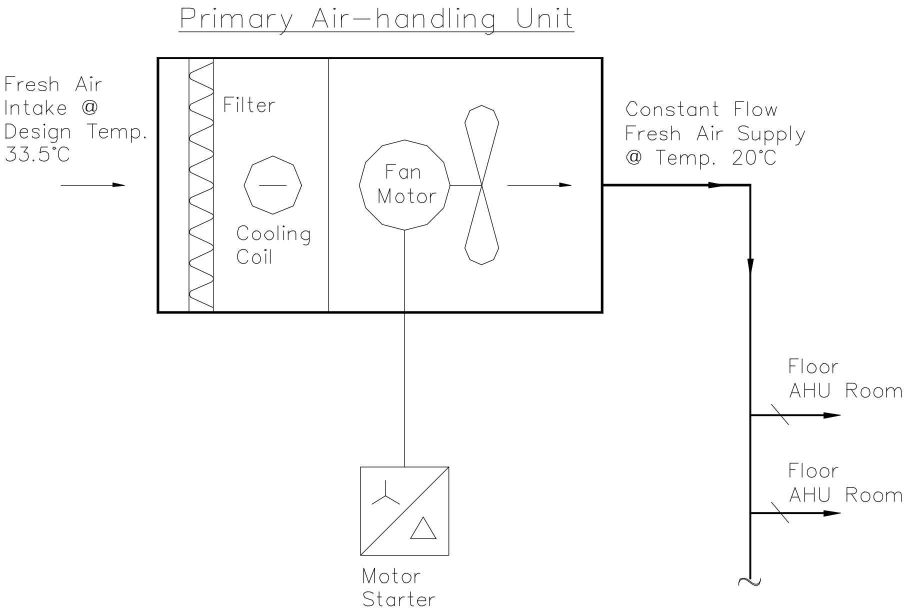


Fig.12: Basic Configuration of a Conventional PAU at Constant Air Flow

The conventional PAU is part of a central air conditioning system usually 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 brings outside air, at a designed temperature of 33.5°C, into filters prior to pre-cooling it to 20°C and delivers it via fans and ductwork to serve individual floors. This system is designed for “worst case” condition and end up wasting energy relative to the needs of the building for most of the operational life. No modulation method had normally been allowed in the design other than the original balancing of the system. The system is normally operated continuously from 8:00 am to 6:00 pm for general offices building.

Demand control on PAUs using carbon dioxide offers a unique opportunity for building services engineers and building owners to resolve the problem of how to reduce energy costs while optimising indoor air quality.

CO_2 control is best applied to spaces with variable or intermittent occupancy. These applications can include lecture halls/classrooms, conference/meeting rooms, theatres, waiting areas, and even office spaces. In space without variable occupancy, 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.

In a typical building, the amount of CO_2 exhaled by people is diluted by outside air introduced by mechanical ventilation, air leakage, and open windows. The lowest concentration of CO_2 measured in outside air in Hong Kong ranging from 400 to 500 ppm. The CO_2 concentration measured outside EEO office in Causeway Bay was found to be on the high side of 500 ppm. CO_2 is generally not considered a health-threatening contaminant at the 500 to 3,000 ppm levels typically found in most buildings. Many people have observed symptoms of stuffiness, sleepy, inattention, unpleasant odours, and a general feeling of discomfort as CO_2 levels rise about 1,400 ppm. It is important to note that these symptoms are not directly related to CO_2 or a corresponding lack of oxygen. Rather these reactions are more related to the build-up of other contaminants and irritants in the space when ventilation levels are low. CO_2 is therefore often considered a good surrogate indicator of indoor air quality.

According to ASHRAE Standard 62-1989 “ Ventilation for Acceptable Indoor Air Quality”, ventilation maintaining an indoor CO_2 content of 1000 ppm is considered ideal. CO_2 lower than 800 ppm is considered as over-ventilated. Some of the government office buildings investigated under the Pilot EMO Implementation Programme have average measured CO_2 concentration below 700 ppm. Therefore CO_2 based demand control ventilation has good potential to reduce energy consumption while optimising indoor air quality.

One of the simple ways of utilising VSD in PAU system is to set up the average CO_2 level profile of the building during the working day via detailed survey and statistical analysis of its indoor air quality. The potential of energy saving could be achieved by reducing the speed of the fan motor during the period of low CO_2 content by a simple timer control and VSD. The modification work is very simple without any major rewiring work. Fig. 13 indicates a possible arrangement of a variable flow PAU using VSD and timer control.

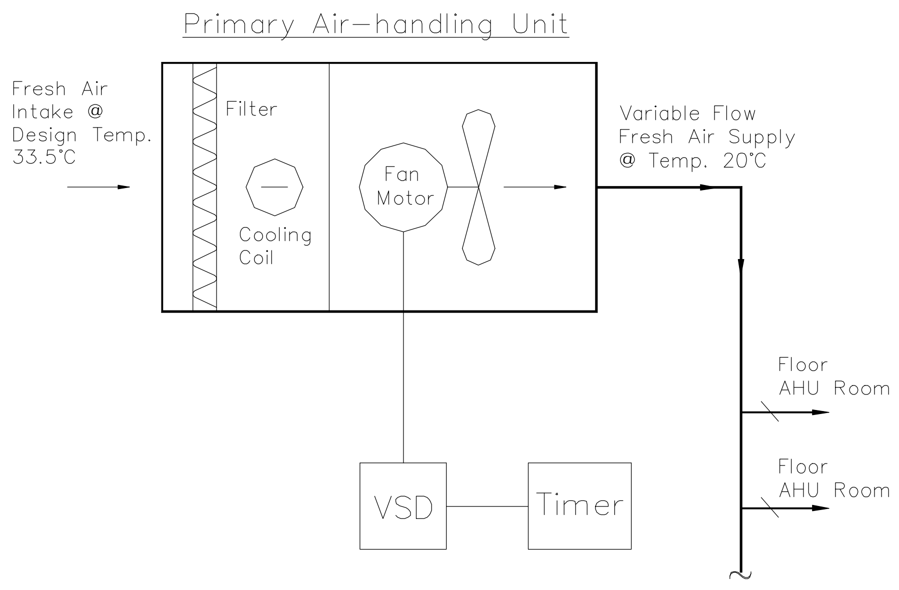


Fig.13: Basic Configuration of a PAU with VSD and Timer Control

The CO_2 based demand control can also be achieved by the direct application of CO_2 sensors for real time speed control of PAU. Recent innovations in gas sensor designs have considerably improved the long-term performance and cost of CO_2 sensors, making it one of the fast growing segments of the HVAC control industry. The CO_2 sensors should be located at some strategic location where "worst case" occurred. Fig. 14 indicates a possible arrangement of a variable flow PAU using VSD and CO_2 sensors.

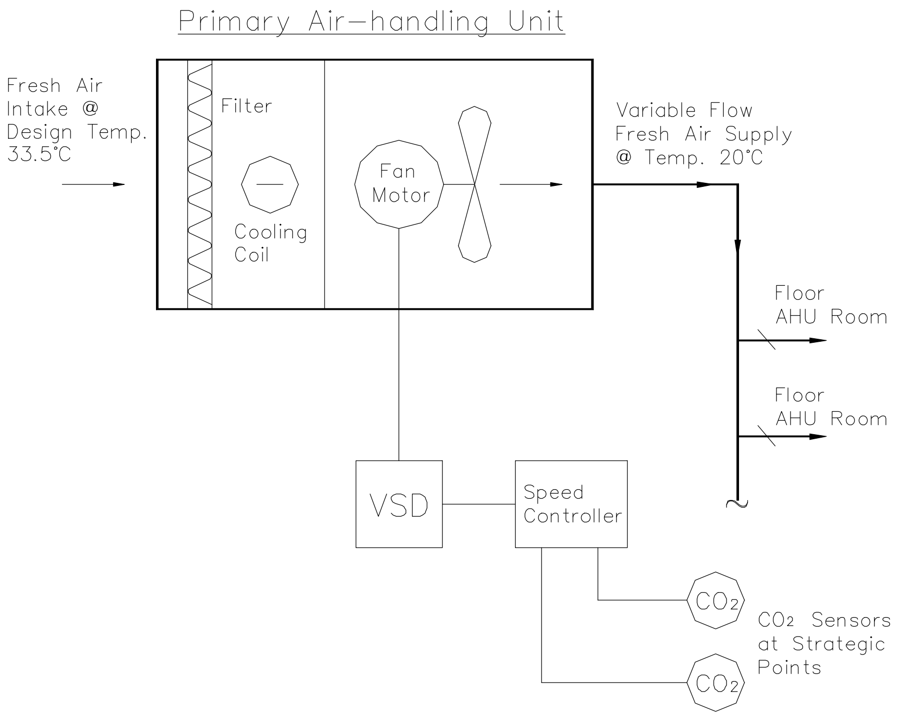


Fig.14: Basic Configuration of a PAU with VSD and CO_2 Sensors

3.2.3 Application of VSD in Variable Air Volume (VAV) Air-Handling Units

Variable Air Volume (VAV) systems typically bring conditioned air from PAU and returned air from the air-conditioned space into Air Handling Units (AHU) where the air temperature and humidity can be adjusted. Fans blow air across filter, cooling coils and volume control dampers or inlet guide vanes into ductwork, which distributes the air throughout the zones served. The air passes into each zone from the ductwork through individual VAV terminal boxes. A temperature sensor located in each zone is connected to its VAV box and opens or closes the VAV box to maintain the defined temperature setpoint. As the zone becomes satisfied, the VAV box modulates to a close position. The pressure in the ductwork would then begin to rise as the openings in the VAV box close.

Traditionally, inlet guide vanes or discharged dampers are installed in the AHUs to prevent this over pressurisation and save energy. These devices work by creating resistance and a pressure drop to the air entering the ductwork or reducing the efficiency of the fan. The more the VAV boxes in the system close, the more the dampers close to maintain static duct pressure. The dampers or inlet guide vanes for the fan are commonly controlled by a controller maintaining a fixed pressure in the supply ductwork downstream of the AHU. A typical configuration of this system is shown in Fig.15 below.

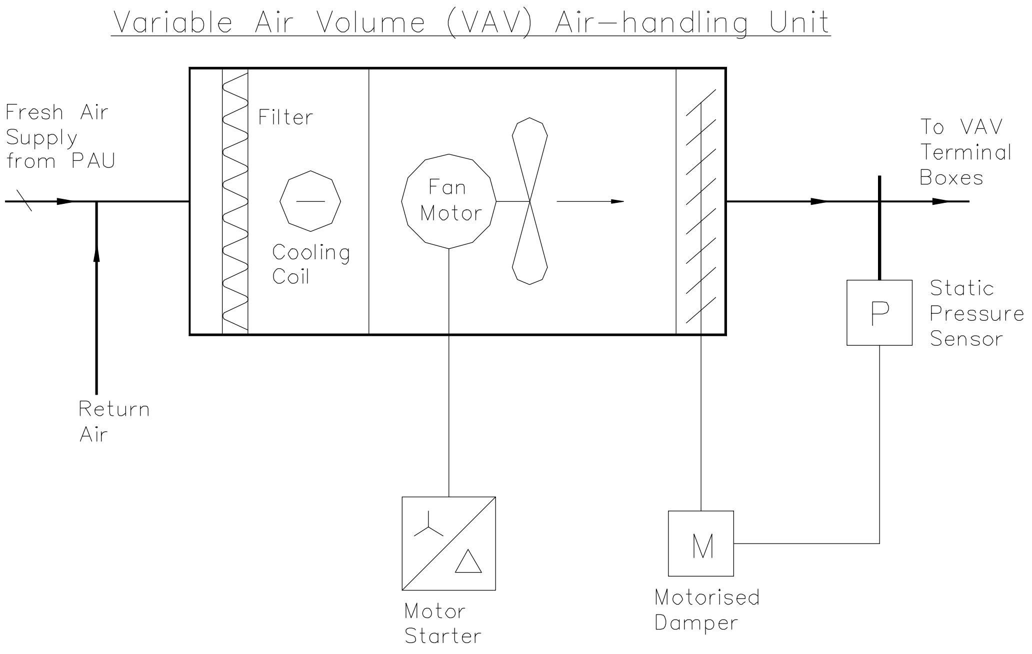


Fig.15: Basic Configuration of a VAV System with Dampers and Static Pressure Sensors

While dampers and inlet guide vanes work to maintain a constant pressure in the ductwork of a VAV system, the utilisation of VSD could save much more energy and reduce the complexity of the installation. Instead of creating an artificial pressure drop or causing a decrease in fan efficiency, the VSD decrease the speed of the fan to provide the flow and pressure required by the system. Fig 16 shows a modified VAV system with VSD in lieu of the conventional star-delta motor starter and motorised dampers for static pressure control in the ductwork.

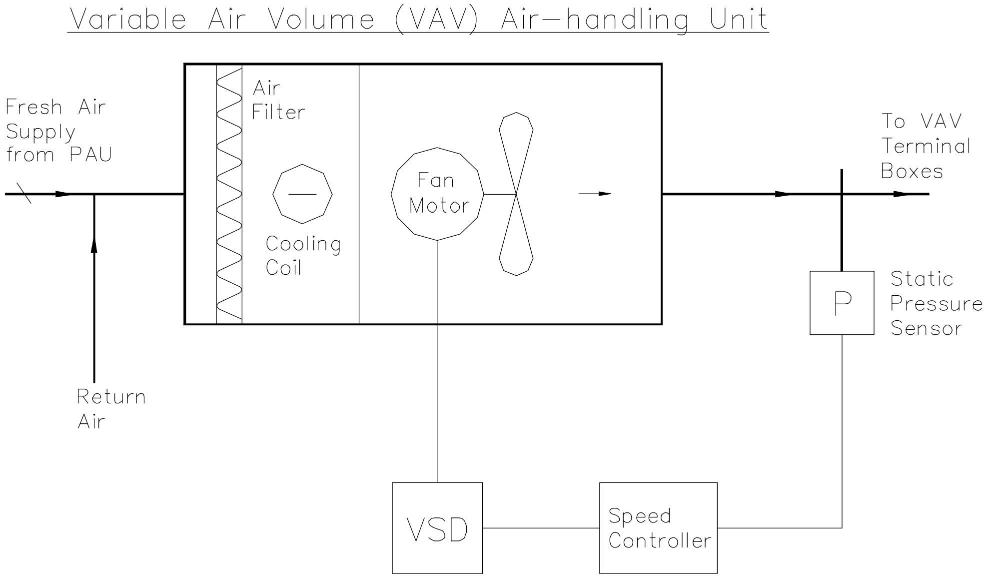


Fig.16: Basic Configuration of a VAV System with VSD, Controller and Static Pressure Sensors

3.2.4 Application of VSD in Secondary Chilled Water Circuit

Primary pumps in a primary/secondary pumping system, such as shown in Fig. 17, can be used to maintain a constant flow through chillers that encounter operation or control difficulties when exposed to variable flow.

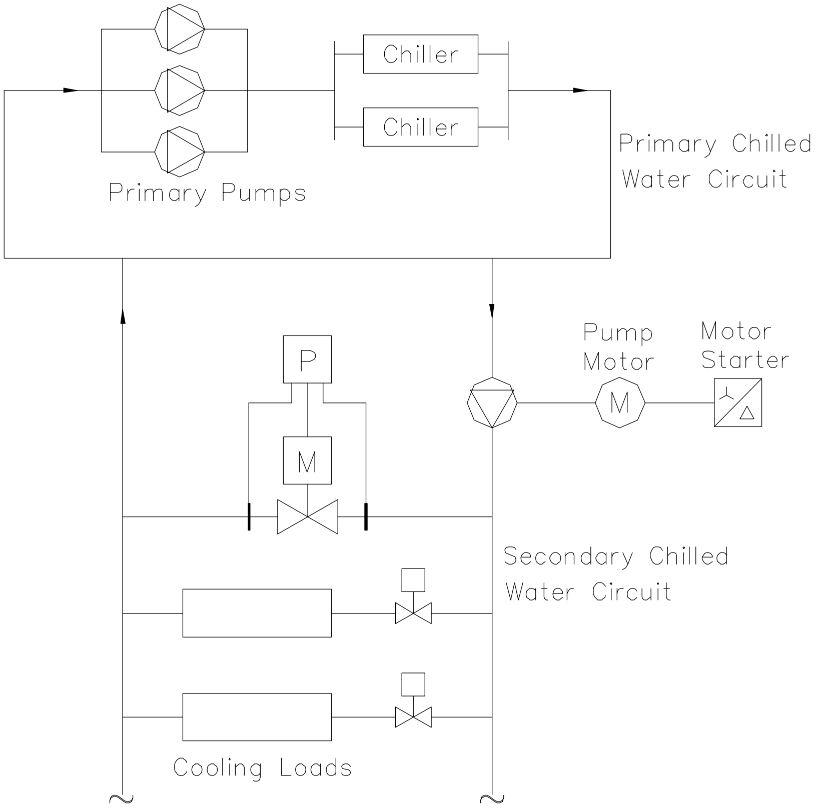


Fig.17: Basic Configuration of a Primary/Secondary Chilled Water System with By-pass Valve

In chilled water systems, the primary loop consists of primary pumps sized to handle the chillers designed flow rate at a discharge pressure just high enough to circulate the water through the chiller and the rest of the primary piping loop. The secondary chilled water loop is a variable flow system consists of secondary pumps sized to circulate chilled water to handle full capacity of the cooling loads connected on the circuit. During light load condition, most of the two-port control valves on the loads are not fully open resulting in pressure rise in the secondary chilled water loop. In a conventional system, a by-pass valve connected across the cooling loads will be used to by-pass the secondary water flow and regulate the flow to loads and balance the water pressure in the system. A differential pressure sensor normally controls the by-pass valve.

Fig. 18 shows a new arrangement of the secondary chilled water circuit with VSD in lieu of by-pass valve for regulation chilled water flow according to the actual loading requirement. Energy saving is achieved in pump motors in most of the time when the cooling loads are not at full capacity and maximum chilled water flow is not required.

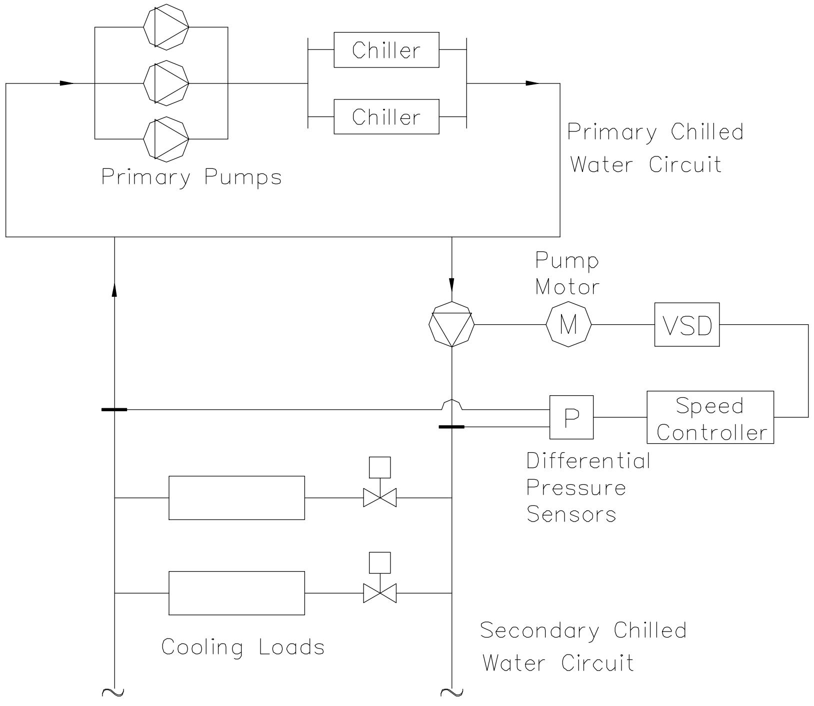


Fig.18: Basic Configuration of a Secondary Chilled Water Circuit controlled by VSD

3.3. <u>Pilot EMO Implementation Projects</u>

The Electrical & Mechanical Services Department of the HKSAR Government have carried out several pilot projects, for assessing the energy efficient performance, pay back period as well as other technical performance of air conditioning installations in government buildings using VSDs. Details of one of the pilot projects are given below.

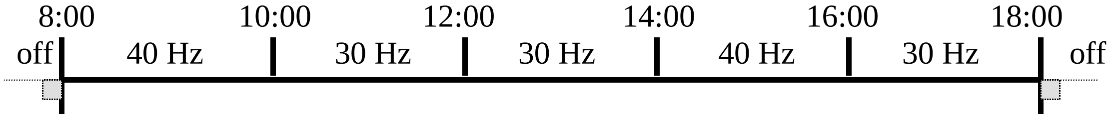
3.3.1 Queensway Government Office (QGO) - PAU

Queensway Government Offices (QGO) is the first building selected in September 1996 for implementation of pilot EMO projects using variable speed drives and timer for controlling the volume flow rate of fresh air supply to the building. This section describes details of the VSDs installation works in QGO.

The works consisted of the supply and installations of 4 nos. 15kW VSDs for the 4 nos. Primary Air-handling Units (PAU) on roof and 32/F complete with timers and the associated by-pass control panels. The configuration of the new system is the same as shown in figure 13.

The contractor for this retrofit work was Ryoden Engineering Co. Ltd. The project sum was HK$430,200 and works order issued to contractor in October 1996. ‘Danfoss’ 15kW VSDs were used in the project and they were delivered to site in December 96. Site work took 6 weeks and was completed in February 1997.

The motors of the PAUs were put to operate at different frequencies according to timer controls of the VSDs, which were set as per the following daily schedule:



Separate kWh meters were installed in the plant rooms on roof and 32/F for measurement of electricity consumption of the individual PAUs with and without the operation of the VSDs. The result of this pilot project is summarised in Table 25 below.

Table 25: Summary of VSDs Installation Works in QGO

Measured kWh Saving for 1 Working Day	Anticipated Annual (270 days) Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Total Package Cost for 4 x 15 kW VSDs
329 kWh	88,830 kWh	$80,000	5.4 years	$430,200

The table above is for saving of fan energy only. The reduction in cooling load for fresh air supply at 40 Hz can be assessed as follows:

Air flow rate measured at 50 Hz supply = 18.8 m^3/s
Air flow rate measured at 40 Hz supply = 15 m^3/s
Reduction in air flow rate = 3.8 m^3/s
Assuming average outdoor air temperature = 30°C
Designed off coil air temperature = 25°C
Reduction in cooling load = 3.8 x 1.2 x 1.012 x (30 – 25) kW = 23 kW
Assuming a COP of 4 for water-cooled chiller, saving in electrical power = 5.8 kW
Annual energy saved in cooling load, assuming 10 hours/day for 270days
= 15,600 kWh

For 4 nos. identical PAUs, total annual energy saved in chillers = 62,400 kWh
Having considered the energy saved in cooling load as well, the payback period can be reduced to 3.2 years

3.3.2 Queensway Government Office (QGO) – Chilled Water Circuit

Queensway Government Offices (QGO) is selected in March 1997 for implementation of pilot EMO projects using variable speed drives and differential pressure sensors for controlling the volume flow rate of secondary chilled water flow to the building cooling loads. This section describes details of the VSDs installation works in QGO.

The works consisted of the supply and installations of 3 nos. 37.5kW VSDs for the 3 nos. (2 duty, 1 standby) secondary chilled water pumps located in the AC Plant Room on 32/F of the building. The new system was complete with differential pressure transducers, controllers and the associated by-pass control panels. The configuration of the new system is the same as shown in figure 18.

The contractor for this retrofit work was ABB Industrial and Building Systems Ltd. The project sum was HK$329,350 and works order issued to contractor in June 1997. ‘Meiden’ 37.5kW VSDs were used in the project and they were delivered to site in August 97. Site work took 3 months and was completed in February 1998.

Separate kWh and hour meters were installed for each of the VSD in the plant rooms on 32/F for measurement of electricity consumption of the individual secondary chilled water pump. The measured result is analysed as follows:

Average power of pump motor measured without VSD = 37 kW
Average power of pump motor measured with VSD = 24.5 kW
Power saving in pump motor with VSD = 12.5 kW
Annual energy saved in pump motor, assuming 10 hours/day for 270days
= 33,750 kWh
Total annual energy saving for the 2 duty water pumps = 67,500 kWh

The final result of this pilot project is summarised in Table 26 below.

Table 26: Summary of VSDs Installation Works for Chilled Water Pump in QGO

Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Total Package Cost for 3 x 37.5 kW VSDs
67,500 kWh	$61,000	5.4 years	$329,350

The measured data was based on the weather condition in 1998 and is subject to change to various climatic conditions of the year. The energy saving in summer months was relatively smaller than the winter months as the building cooling loads was almost at its full capacity in summer.

3.3.3 Mong Kok KCRC G.O.

Mong Kok KCRC G.O. was selected in 1997 for the implementation of pilot EMO projects using variable speed drives for controlling the volume flow rate of Fresh Air-handling Units (FAU) and Variable Air Volume (VAV) air-handling units in the building.

The contractor for this retrofit work was Technicon Engineering Ltd. The project sum was HK$259,770 under the same contract as Southorn Centre. Works order issued to contractor in October 1997. ‘Allen-Bradley’ VSDs were used in the project and they were delivered to site in December 97. Site work took 3 months and was completed in February 1998.

The first part of the project consisted of the supply and installations of 2 nos. 22 kW VSDs for the 2 nos. Primary Air-handling Units (PAU) in roof plant room complete with 4 nos. CO_2 sensors, controllers and the associated by-pass control panels. The configuration of the new system is the same as shown in figure 14. All wall-mounted CO_2 sensors were located at critical locations where worse case condition occurred, such as waiting areas opened to public or GR offices. The CO_2 content in the other building areas was also spot-checked with a hand-held measuring device to ensure IAQ has not been adversely affected elsewhere. Signals from the CO_2 sensors were transmitted to VSD controllers for processing. Without VSD control, the speed of fan motor at 50Hz supply was about 1450 revolutions per minute (rpm). The minimum frequency setting for all VSDs installed was 35Hz (about 1700 rpm) and the average operating frequency throughout the day was found to be below 40Hz. The profiles of CO_2 content in PPM and the corresponding motor operating frequency are shown in Fig. 19 for information.

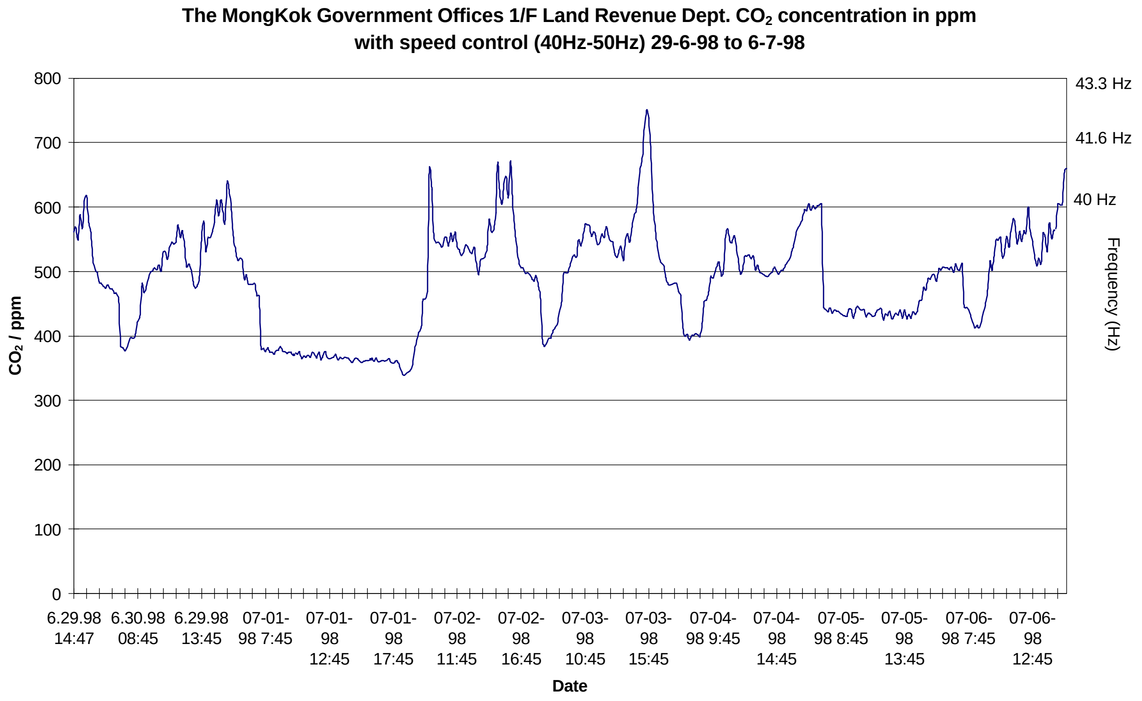


Fig.19: CO_2 Level Measured in Mok Kok GO with VSDs on PAUs

Separate kWh meters were installed for each of the VSD in the AC plant rooms on the roof floor for measurement of electricity consumption of the fan motors. The air volume flow rate of the PAUs was also measured over the same period of operating time with and without VSDs. The result of energy saving with VSDs and CO_2 sensors is summarised as follows:

Average power of PAU fan motor measured without VSD = 14 kW
Average power of PAU fan motor measured with VSD = 7.7 kW
(Note this measured power includes losses in VSD, motor and pulley at 40Hz)
Power saving in PAU fan motor power = 6.3 kW
Annual energy saved in PAU fan motor, assuming 10 hours/day for 270days
= 17,000 kWh
Air flow rate measured at 50 Hz supply = 18.8 m^3/s
Air flow rate measured at 40 Hz supply = 15 m^3/s
Reduction in air flow rate = 3.8 m^3/s
Assuming average outdoor air temperature = 30°C
Designed off coil air temperature = 25°C
Reduction in cooling load = 3.8 x 1.2 x 1.012 x (30 - 25) kW = 23 kW
Assuming a COP of 3 for air-cooled chiller, saving in electrical power = 7.7 kW
Annual energy saved in cooling load, assuming 10 hours/day for 270days
= 20,800 kWh
Total annual energy saving for PAU1 and PAU2 = 2(17,000 + 20,800)
= 75,600 kWh

The second part of the project included the supply and installations of 4 nos. 11 kW VSDs for the 4 nos. VAV Air-handling Units on 1/F and 3/F complete with static pressure sensors, controllers and the associated by-pass control panels. The configuration of the new system is the same as shown in figure 15. The static pressure sensor in the supply air duct was set at 900 Pa. Signals from the static pressure sensors were transmitted to VSD controllers for processing. Without VSD control, the speed of fan motor at 50Hz supply was about 1450 revolutions per minute (rpm). The average operating frequency was found to be 40Hz. The result of energy saving with VSDs on VAVs is summarised as follows:

Average power of VAV fan motor measured without VSD = 5.73 kW
Average power of VAV fan motor measured with VSD = 3.26 kW
(Note this measured power includes losses in VSD, motor and pulley at 40Hz)
Power saving in VAV fan motor power = 2.47 kW
Annual energy saved in fan motor, assuming 10 hours/day for 270days = 6,670 kWh
Total annual energy saving for the 4 VAVs = 26,680 kWh

The overall result of this pilot project is summarised in Table 27 below.

Table 27: Summary of VSDs Installation Works in Mong Kok KCRC G.O.

Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Total Package Cost for 6 nos. VSDs
102,280 kWh	$92,000	2.8 years	$259,770

3.3.4 Southorn Centre

Southorn Centre. was selected in 1997 for the implementation of pilot EMO projects using variable speed drives for controlling the volume flow rate of Fresh Air-handling Units (FAU) in the building.

The contractor for this retrofit work was Technicon Engineering Ltd. The project sum was HK$256,730 under the same contract as Mong Kok KCRC G.O. Works order issued to contractor in October 1997. ‘Allen-Bradley’ VSDs were used in the project and they were delivered to site in December 97. Site work took 3 months and was completed in February 1998.

The project consisted of the supply and installations of 3 nos. 22 kW VSDs for the 3 nos. Primary Air-handling Units (PAU) in roof plant room complete with 8 nos. CO_2 sensors, controllers and the associated by-pass control panels. The configuration of the new system is the same as shown in Fig. 14. All wall-mounted CO_2 sensors were located at critical locations where worse case condition occurred, such as waiting areas opened to public or GR offices. The CO_2 content in the buildings was also spot-checked with a hand-held measuring device. Signals from the CO_2 sensors were transmitted to VSD controllers for processing. Without VSD control, the speed of fan motor at 50Hz supply was about 1450 revolutions per minute (rpm). The minimum frequency setting for all VSDs installed was 35Hz (about 1,000 rpm) and the average operating frequency throughout the day was found to be below 40Hz.

Separate kWh meters were installed for each of the VSD in the AC plant rooms on the roof floor for measurement of electricity consumption of the fan motors. The air volume flow rate of the PAUs was also measured over the same period of operating time with and without VSDs. The result of energy saving with VSDs and CO_2 sensors is summarised as follows:

Average power of PAU fan motor measured without VSD = 16 kW
Average power of PAU fan motor measured with VSD = 11.7 kW
Power saving in PAU fan motor power = 4.3 kW
Annual energy saved in PAU fan motor, assuming 10 hours/day for 270days
= 11,610 kWh
Air flow rate measured at 50 Hz supply = 12.5 m^3/s
Air flow rate measured at 40 Hz supply = 9 m^3/s
Reduction in air flow rate = 3.5 m^3/s
Assuming average outdoor air temperature = 30°C
Designed off coil air temperature = 25°C
Reduction in cooling load = 3.5 x 1.2 x 1.012 x (30 – 25) kW = 21.3 kW
Assuming a COP of 3 for air-cooled chiller, saving in electrical power = 7.1kW
Annual energy saved in cooling load, assuming 10 hours/day for 270days
= 19,200 kWh
Total annual energy saving for 3 nos. PAUs = 3(11,610 + 19,200) = 92,430 kWh

The overall result of this pilot project is summarised in Table 28 below.

Table 28: Summary of VSDs Installation Works in Southorn Centre

Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Total Package Cost for 6 nos. VSDs
92,430 kWh	$83,000	3.1 years	$256,730

3.3.5 Harbour Building

Harbour Building was selected in 1997 for the implementation of pilot EMO projects using variable speed drives for controlling the volume flow rate of Primary Air-handling Units (PAU) and Variable Air Volume (VAV) air-handling units in the building.

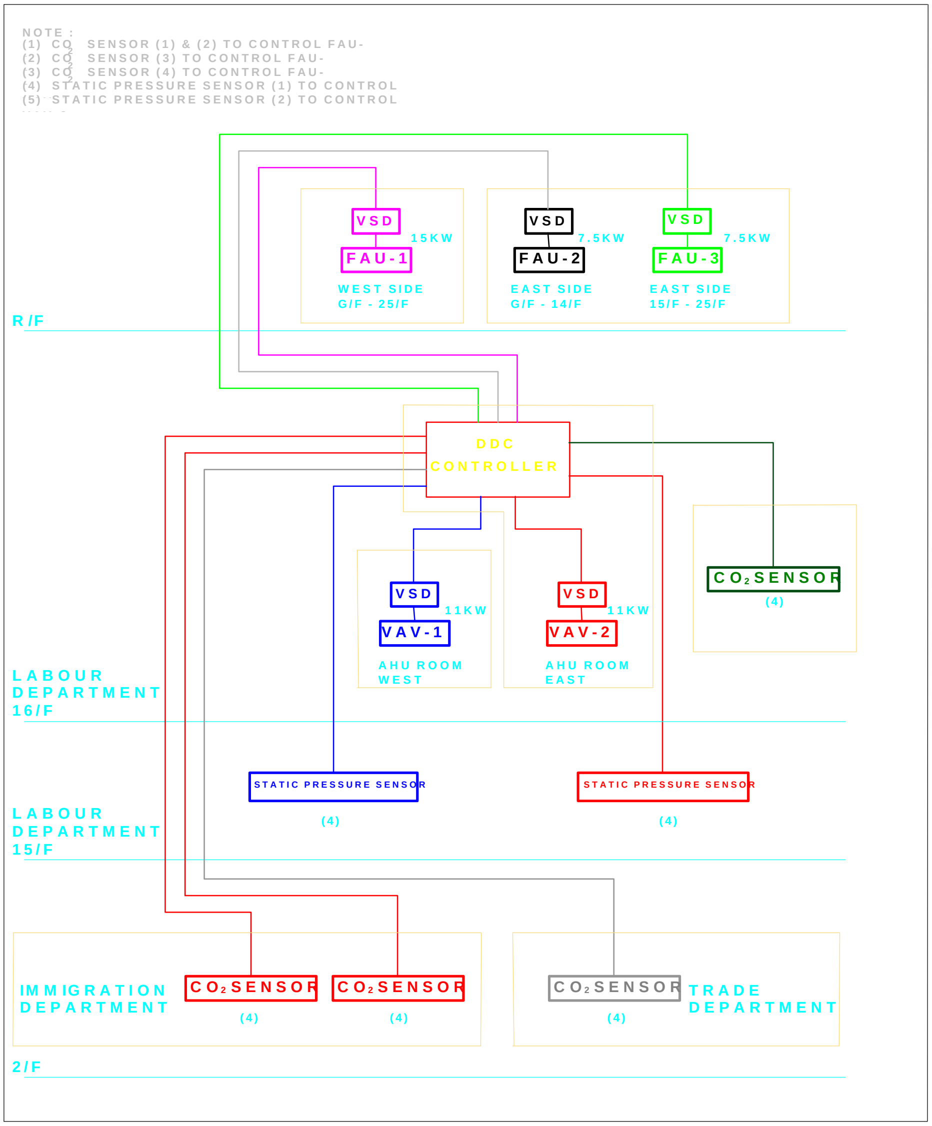


Fig.20: VSD Installations in Harbour Building

The contractor for this retrofit work was ATAL Engineering Ltd. The project sum was HK$575,000. Works order issued to contractor in October 1997. ‘Allen-Bradley’ VSDs were used in the project and they were delivered to site in December 1997. Site work took 3 months and was completed in February 1998. A schematic diagram showing the configuration of the installation work is shown in Fig. 20.

The first part of the project consisted of the supply and installations of 3 nos. 22 kW VSDs for the 3 nos. Primary Air-handling Units (PAU) in roof plant room complete with 4 nos. CO_2 sensors, controllers and the associated by-pass control panels. The general configuration of the new system is the same as shown in Fig. 14. All wall-mounted CO_2 sensors were located at critical locations where worse case condition occurred, such as waiting areas opened to public or GR offices. The CO_2 content in the buildings was also spot-checked with a hand-held measuring device. Signals from the CO_2 sensors were transmitted to VSD controllers for processing. Without VSD control, the speed of fan motor at 50Hz supply was about 1450 revolutions per minute (rpm). The minimum frequency setting for all VSDs installed was 35Hz (about 1000 rpm) and the average operating frequency throughout the day was found to be below 40Hz.

Separate kWh meters were installed for each of the VSD in the AC plant rooms on the roof floor for measurement of electricity consumption of the fan motors. The air volume flow rate of the PAUs was also measured over the same period of operating time with and without VSDs. The result of energy saving with VSDs and CO_2 sensors is summarised as follows:

Average power of PAU fan motor measured without VSD = 9 kW
Average power of PAU fan motor measured with VSD = 6 kW
Power saving in PAU fan motor power = 3 kW
Annual energy saved in PAU fan motor, assuming 10 hours/day for 270days
= 8,100 kWh
Air flow rate measured at 50 Hz supply = 9.8 m^3/s
Air flow rate measured at 40 Hz supply = 6 m^3/s
Reduction in air flow rate = 3.8 m^3/s
Assuming average outdoor air temperature = 30°C
Designed off coil air temperature = 25°C
Reduction in cooling load = 3.8 x 1.2 x 1.012 x (30 – 25) kW = 23 kW
Assuming a COP of 4 for water-cooled chiller, saving in electrical power = 5.8kW
Annual energy saved in cooling load, assuming 10 hours/day for 270days
= 15,660 kWh
Total annual energy saving for 3 nos. PAU = 3(8,100 + 15,660) = 71,280 kWh

The second part of the project included the supply and installations of 2 nos. 11 kW VSDs for the 2 nos. VAV Air-handling Units on 16/F complete with static pressure sensors, controllers and the associated by-pass control panels. The configuration of the new system is the same as shown in Fig. 15. The static pressure sensor in the supply air duct was set at 900 Pa. Signals from the static pressure sensors were transmitted to VSD controllers for processing. Without VSD control, the speed of fan motor at 50Hz supply was about 1450 revolutions per minute (rpm). The average operating frequency was found to be 44Hz. The result of energy saving with VSDs on VAVs is summarised as follows:

Average power of VAV fan motor measured without VSD = 9.3 kW
Average power of VAV fan motor measured with VSD = 7.6 kW
Power saving in VAV fan motor power = 1.7 kW
Annual energy saved in fan motor, assuming 10 hours/day for 270days
= 4,590 kWh
Total annual energy saving for the 2 VAVs = 9,180 kWh

The overall result of this pilot project is summarised in Table 29 below.

Table 29: Summary of VSDs Installation Works in Harbour Building

Anticipated Annual Energy Saving	Anticipated Annual Cost Saving @$0.9/kWh	Estimated Payback Period	Total Package Cost for 5 nos. VSDs
80,500 kWh	$72,400	8 years	$575,000

3.3.6 Tsuen Wan G.O., Tuen Mun G.O. and Revenue Tower

The three buildings were selected in 1998/99 for the implementation of phase 1 pilot EMO projects using energy efficiency motors and variable speed drives for Variable Air Volume (VAV) air-handling units in the buildings. The site installation works have completed recently and the energy consumption is still being measured on site to include the summer months. Energy consumption reports from contractor are not available yet. Details of these AC projects are summarised in Table 30 below.

Table30: AC Pilot EMO Implementation Programme for Tsuen Wan G.O., Tuen Mun G.O. & Revenue Tower

	Building	Cost HK$	Project Period	Description of Work
1	Tsuen Wan G.O.	85,900	Sep 98 – Mar 99	Retrofit of 6 nos. ‘ABB’ energy efficiency motor. 3 nos. 11kW for chilled water pumps and 3 nos. 4kW for AHUs in AC plant room on 5/F & 7/F. The contractor is Dah Chong Hong (Engineering) Ltd.
2	Tuen Mun G.O.	94,200	Sep 98 – Mar 99	Retrofit of 3 nos. ‘Meiden’ VSDs (1x11kW & 2x7.5kW) for VAV AHUs on 7/F complete with pressure sensors, transducers and controllers under the same contract as Tsuen Wan G.O.
3	Revenue Tower	168,000	Sep 98 – Mar 99	Retrofit of 4 nos. ‘Seimens/Danfoss’ 11 kW VSDs for VAV AHUs. The contarctor is Getwick Engineers Ltd.

3.4. Conclusions and Discussions

3.4.1 The application of variable speed drives (VSDs) for the purpose of energy saving by controlling the flow rate of conditioned air and chilled water in according to the actual demand of the building is proven in the Pilot EMO Implementation Programme. The overall energy saving of PAU with VSD and CO_2 control was found to be 27% under the following typical conditions:

	Constant Speed	**Variable Speed Control**
Motor Supply Frequency	50 Hz	40 Hz (daily average)
Fan Power	14 kW	7.7 kW
Air Volume Flow Rate	$18.8m^3/s$	$15m^3/s$
Average Outdoor Temperature	30°C	30°C
Off Coil Temperature	25°C	25°C
Fresh Air Cooling Load	18.8 x 1.2 x 1.012 x 5 =114 kW	15 x 1.2 x 1.012 x 5 =91 kW
COP for Air-cooled Chiller	3	3
Electrical Power Input to Chiller	114 kW/3 = 38 kW	91 kW/3 = 30.3 kW
Total Power for Fan & Cooling	52 kW	38 kW
Total Power Saved from Fan Power & Cooling	14 kW (27%)	

3.4.2 The CO_2 content found in some of the government office buildings at constant fresh air supply was ranged from 500ppm to 600ppm., which is much below 1,000 ppm as recommended by ASHRAE Standard 62-1989 “ Ventilation for Acceptable Indoor Air Quality”.

3.4.3 The lowest frequency set for all VSDs was 35Hz in order to maintain sufficient positive pressure within the building.

3.4.4 It would appear that the installation of variable speed drives coupled with CO_2 sensors to regulate fresh air supply to meet the actual requirements in the building is a viable option to be seriously considered for both retrofit and new projects.

3.4.5 This kind of Demand Control Ventilation systems can ensure the compliance with Clause 5.2.3.2 of the AC Code, in which the fan motor demands no more than 55% of the design wattage at 50% of design air flow for variable air volume fan system.

3.4.6 As far as harmonic distortion is concerned, the new VSDs used in these projects, supplied by most of the reputable manufacturers, comply with the THD requirement (Electrical Energy Code) of less than 35% 5^{th} harmonic current.

3.4.7 For new high-rise building projects involving CO_2-based demand control ventilation via central PAUs, it would be more appropriate to include individual duct-mounted CO_2 sensors at the return air ducts to control the amount of fresh air drawn from the main riser duct at the AHU rooms on each floor. The total demand of fresh air required to be handled by PAUs should then be control either via static pressure sensors in the main air duct or summation of individual fresh air requirement at each floor together with appropriate DDC controllers and VSDs. A typical configuration diagram of the system is shown in Fig. 21 in the following page.

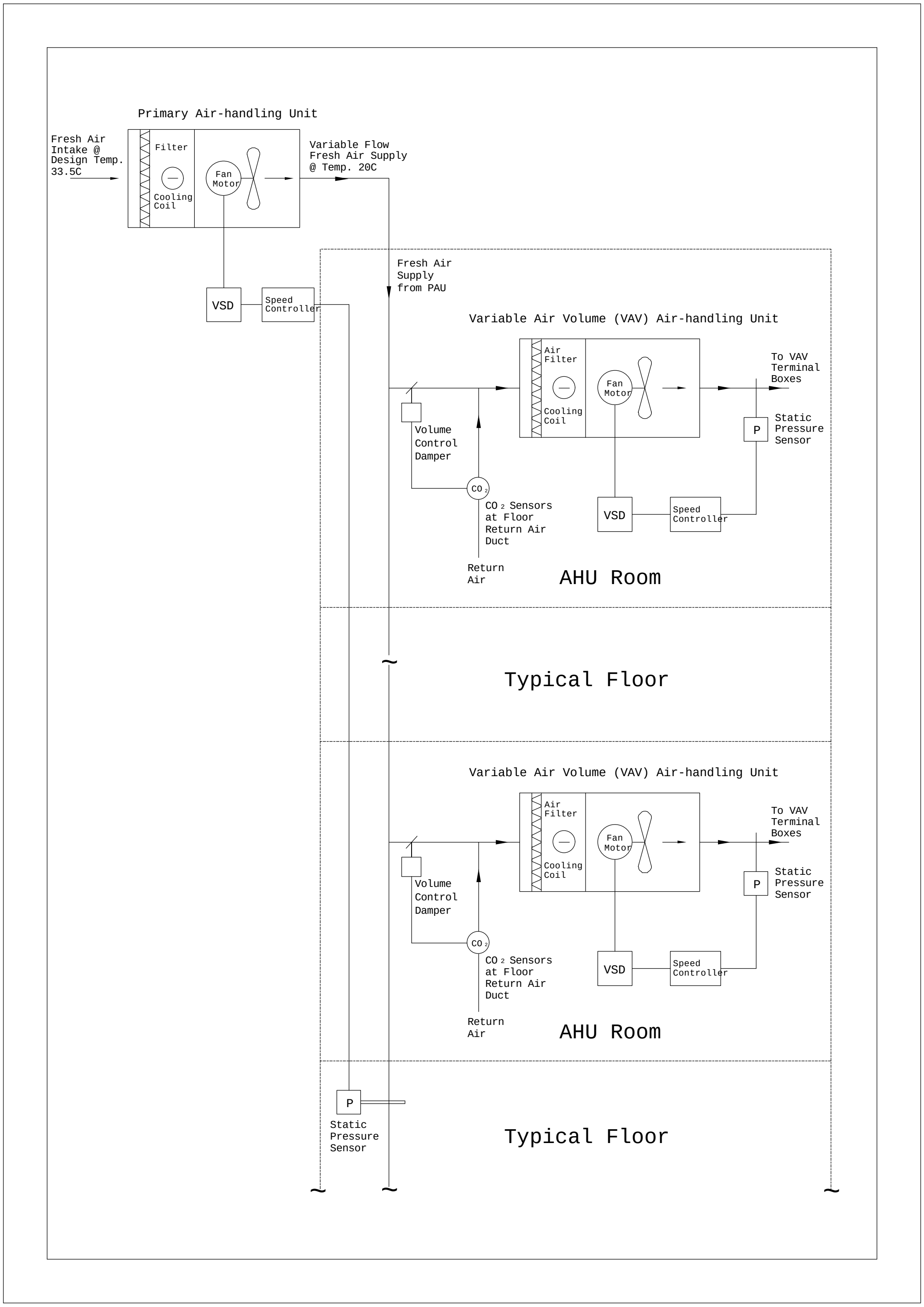


Fig.21: Typical Application of VSD in PAUs and VAV Air-handling Units

3.4.8 EEO had tried out many makes of variable speed drive products available in Hong Kong from most of the reputable manufacturers including Allan Bradley, Danfoss, Siemens, Meidensha, etc. Some of the VSDs have already been running continuously for over 2 years and no defects or adverse effects have so far been reported from our maintenance staff on sites. The site staffs also appreciate the extra benefits of soft motor starting and the comprehensive metering facilities included in VSDs. All VSD installations in the pilot scheme were connecting in parallel with the existing starter control gears with manual bypassing switch. In case of VSD failure, the original motor control can be restored by switching the selector switch to star/delta starter connection without any interruption to the services. With the improved reliability and availability of spare parts, VSDs could directly replace conventional motor starters in any future new and retrofit projects without the provision of bypassing panel.

3.4.9 When using VSDs, it is important to pay attention to the following practical considerations:

- Motor overheating:- The minimum speed control of VSD must be set to avoid motor overheating when the integrated cooling fan inside the motor enclosure is not adequate to cool down the motor windings.
- Increased speed and power:- VSDs present the opportunity of running at speed higher than the rated speed of motors. The maximum speed or operating frequency must be specified and pre-set in the VSDs.
- Electromagnetic compatibility (EMC):- Most manufacturers incorporate special filters to limit the amount of conducted emissions imposed on the main supply. The length of wiring from VSDs to motors should be kept to a minimum. Care should be taken with the layout and all motor side cables should have earthed armour or screens.