Session 2.3 Advanced Building Elements

Remarkable Energy Retrofit for Existing Buildings by Advanced Fan Technology: Electronically Commutated Motor Plug Fan

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ABSTRACT

In Hong Kong, as of January 2013, 75.8% of commercial buildings and 90% of composite buildings were built before 1995 (ESP, 2015). The opportunities of energy consumption reduction for old existing buildings cannot be neglected to achieve deep energy saving target for Hong Kong by 2025 as per Energy Saving Plan launched by Hong Kong Special Administrative Region Environment Bureau. This paper presents a case study of adopting electronically commutated (EC) motor plug fan technology for replacing belt driven fan for AHU in an existing building.

EC motor plug fan technology offers high operation efficiency in HVAC air side system and be widely adopted in new building development in recent years. This advanced technology however was not common in existing building retrofit due to some hurdles such as initial cost, payback, spacing, installation approach and timing. This case study aimed to investigate the feasibility as well as performance of only replacing an old belt driven fan with external variable frequency drive (VFD) control by 4 nos. of EC motor plug fan with installed controlled electronics, but not involving the other operable components inside the air handling unit. It was estimated that more than 40% of fan energy reduction could be achieved, based on the hourly fan operation data via BMS, onsite fan power measurement and testing and commissioning (T&C) results of new fan installation. The life cycle cost and payback were also considered thus providing a full picture of this HVAC airside retrofit.

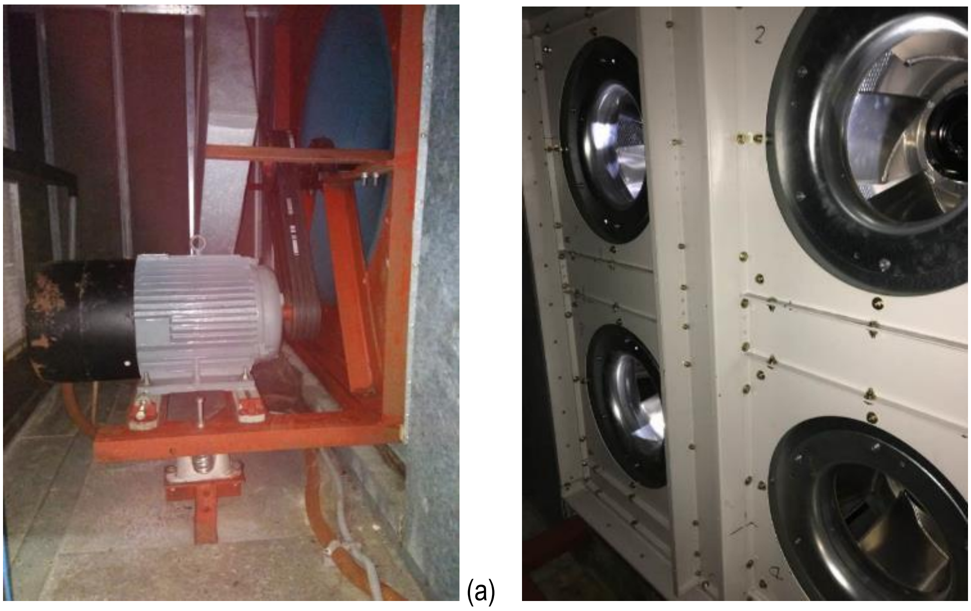
Keywords: *existing building retrofit, electronically commutated motor plug fan, energy saving*

1. INTRODUCTION

Fan uses nearly 40% of all electricity in HVAC systems of a commercial office building (Yik et al., 1998). Thus, adopting high efficiency fan technology is a good opportunity to achieve energy saving target for building. Recently, EC motor plug fan is one of the most effective fan improvement technologies available. There are some different types of EC motor plug fan available in the market, the most common one is a backward curved centrifugal impeller directly mounted on a brushless direct current (DC) motor. Its variable speed control can be achieved by varying the DC voltage delivered to the motor. This fan technology has significant advantage in terms of energy efficiency compared to alternating current (AC) motor belt driven fan, which is one of most typical HVAC applications in existing buildings, required on-going maintenance and frequent replacement of belts, pulleys and bearings. Failure to do so will lead to increased inefficiencies and motor and bearing failures which increase cost even further. For the purpose of improving energy efficiency and operation performance, this case study investigates the feasibility and effectiveness of adopting EC motor plug fans for replacing belt driven fan in an existing office building.

2. CASE STUDY

In this case study, a typical office floor (area: 1490 m^2) of a 22-year-old Hong Kong Island building was selected for fan retrofit. Air-conditioning system of variable air volume (VAV) powered by air handling unit (AHU) is adopted in this office floor. Static pressure control logic is applied for varying supply air volume. An old AHU belt driven fan of rated power 22 kW with external variable-frequency drive (VFD) control was replaced by 4 nos. of EC motor plug fan of rated power 5.05 kW (Figure 1). Table 1 lists the detail technical information of fans.



(a) (b)

Figure 1: (a) Belt driven fan and (b) EC motor plug fan

	Rotation Speed Control	Rated Input Power (kW)	Design Air Flow Rate (l/s)	Design Static Pressure (Pa)
Belt Driven Fan	External VFD (Previously set 25Hz to 45Hz)	22	10500	1125
EC Motor Plug Fans	Embedded rotation speed control (Set max. 85% speed)	20.2 (4 × 5.05 kW)	11200 (4 × 2800 l/s)	1200

Table 1: Technical information of fans

The retrofit work was commenced in early November of 2015. The old fan motor, fan blower, and its associated supporting frame were removed. The 4 nos. of new backward curved centrifugal EC motor plug fan were installed with new supporting steel frame, and an electrical panel for power supply to 4 nos. of fan was newly installed. The original building management system (BMS) control signal (0-10V) was split into 4 nos. of signal with 4 wires connecting to the new fans. Synchronized rotation speed operation was adopted in new fan system. Differential pressure sensor for air flow measurement and Modbus connection for high level interfacing between the new fans and existing BMS were installed for this case study, which provide useful operation data for fan performance analyses. The maximum rotation speed control of 85% of full speed was set for new fan system to deal with the predicted cooling demand according to the previous operation experience.

To facilitate the performance analyses, the portable power analyser and sound pressure level meter were utilised for the pre-retrofit on-site measurements in July and August of 2015 and post-retrofit new EC motor plug fans T&C in early 2016. Operation data of belt driven fan (pre-retrofit) and new EC motor plug fan (post-retrofit) which includes AHU air flow rate, fan input power, VFD control frequency and fan rotation speed were collected from BMS. Different data sources are summarized in Table 2.

	Data Collected by BMS (Recorded every 15 minutes)	**Data Measured by Portable Measurement Device** (Measured every 5 minutes)
Belt Driven Fan	• AHU air flow rate • VFD control frequency	• Fan input power and Harmonics (by power analyser) • Noise (by sound pressure level meter)
EC Motor Plug Fans	• AHU air flow rate • Fan rotation speed • Fan input power	• Harmonics (by power analyser) • Noise (by sound pressure level meter)

Table 2: Data sources

3. RESULTS AND DISCUSSION

Performance of belt driven fan and EC motor plug fans are compared in three aspects: electricity consumption, Harmonics and noise. Payback analysis is also conducted in this part.

3.1. Electricity consumption comparison

Belt driven fan input power and VFD control frequency were measured on-site and collected from BMS before the fan retrofit. Control setting from 25Hz to 45Hz was adopted to suit the cooling demand of office floor. Figure 2 displaces the relationship between fan input power and VFD control frequency. Electricity consumption of belt driven fan in July and August of 2015 is calculated by this equation with the BMS data of VFD control frequency. Compared with the electricity consumption of belt driven fan in July and August of 2015, electricity consumption of EC motor plug fan measured in July and August of 2016 is approximately 40% lower (Table 3) without considering the variations of weather condition and user demand between year 2015 and 2016.

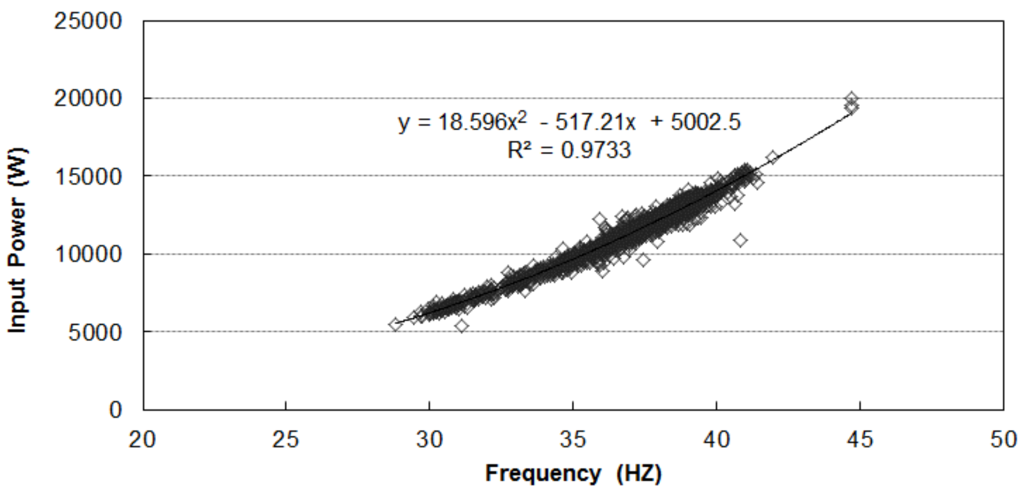


Figure 2: Belt driven fan input power vs frequency

Belt Driven Fan Electricity Consumption		EC Motor Plug Fan Electricity Consumption		Electricity Reduction after Retrofit
1 July 2015 to 31 July 2015	3595.99 kWh	1 July 2016 to 31 July 2016	2093.54 kWh	41.78%
1 August 2015 to 31 August 2015	3213.43 kWh	1 August 2016 to 31 August 2016	1936.71 kWh	39.73%
Total	6829.42 kWh	Total	4030.25 kWh	40.81%

Table 3: Energy consumption of fans

Based on data measured and collected from BMS in July and August of 2016, relationship between input power and air flow rate of EC motor plug fans is identified as shown in Figure 3. Annual consumption of belt driven fan and EC motor plug fans based on year 2015 operation profile were calculated by regression equations shown in Figures 2 and 3 respectively. Figure 4 shows the comparison result. It can be observed that, with the same quantity of air supply, EC motor plug fans require less energy in every month. This is mainly contributed by higher efficiency of EC motor plug fan. For belt driven fan with VFD, efficiency of VFD and belt drive can significantly influence the total fan efficiency. The VFD losses are typically 2% to 5% at the nominal torque and speed, and 10% to 30% at 25% torque and speed. The efficiency of a belt drive is 90% at medium power application (3 – 15 kW), but it can easily slip to 60% to 70% if the gear adjustment is incorrect (Brelih, 2012). For EC motor plug fan, the DC rotation speed control technology can maintain a relatively high efficiency from the rotation speed of 10% to 100%. The direct mounted impeller design can offer almost 100% of efficiency in transmission from motor to impeller.

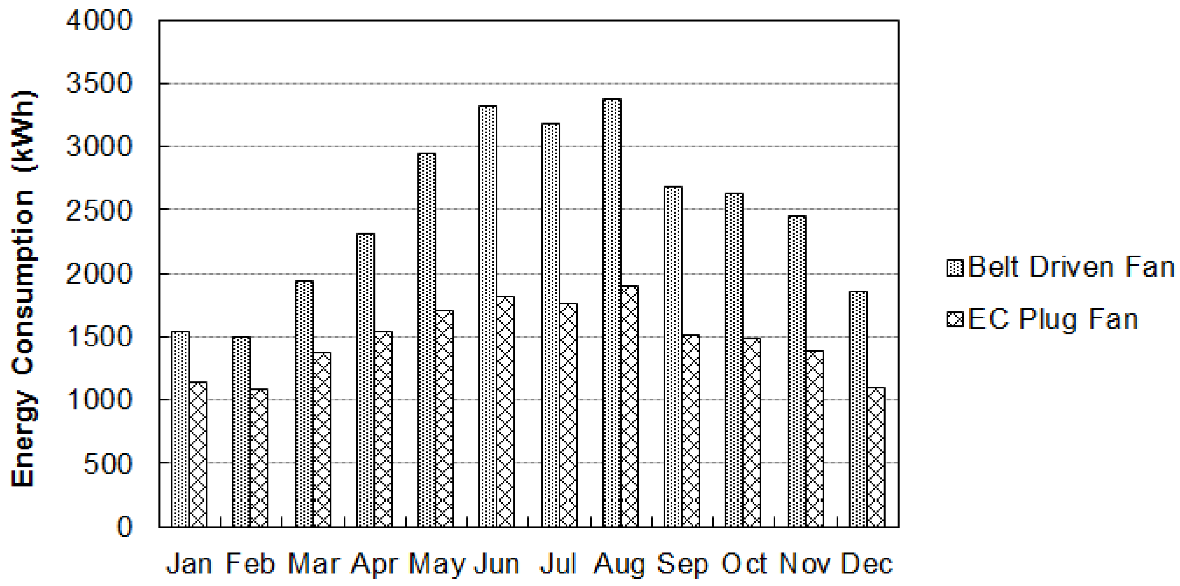


Figure 3: EC motor plug fan input power vs air flow rate

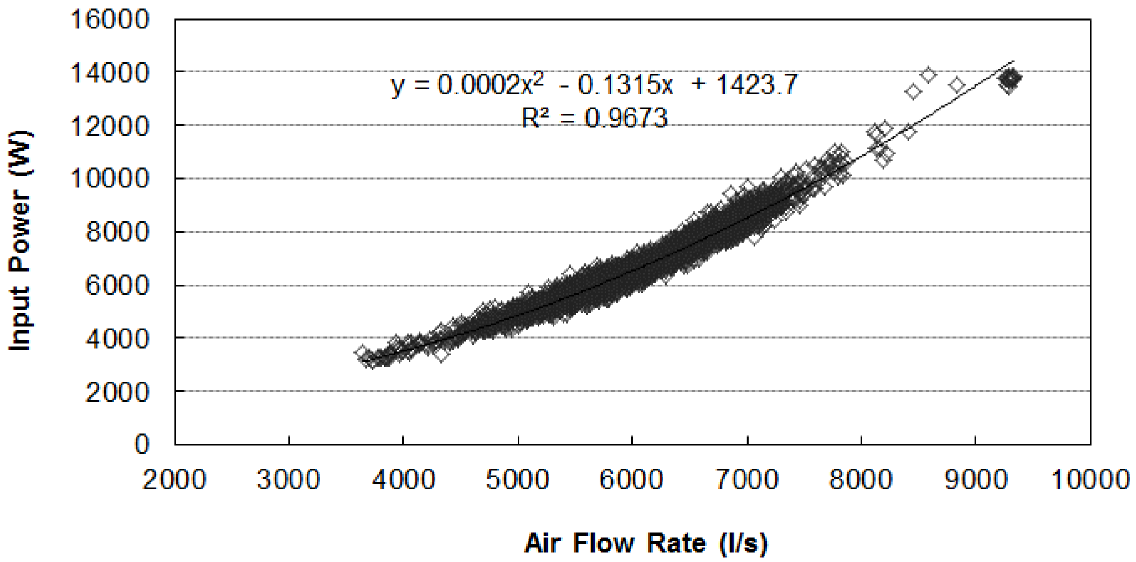


Figure 4: Energy consumption comparison: Belt driven fan vs EC motor plug fan

Based on year 2015 operation profile, electricity consumption estimation of fans in every month is summarised in Table 4. Adopting EC motor plug fans could save potential 40% of belt driven fan electricity consumption annually. This estimation assumes the both fan technologies operating under an identical real case operation profile (year 2015). These electricity saving estimations for July and August are slightly higher than that energy saving measurements identified in shown in Table 3 for approximate 4%.

2015	Belt Driven Fan (kWh)	EC Motor Plug Fan (kWh)	Saving
Jan	1534	1131	26.3%
Feb	1490	1089	26.9%
Mar	1939	1371	29.3%
Apr	2307	1541	33.2%
May	2944	1700	42.2%
Jun	3313	1809	45.4%
Jul	3175	1756	44.7%
Aug	3375	1891	44.0%
Sep	2679	1510	43.6%
Oct	2623	1486	43.3%
Nov	2455	1379	43.8%
Dec	1849	1101	40.5%
Total	**29537**	**17766**	**40.15%**

Table 4: Energy consumption of fans

3.2. Harmonics comparison

Harmonics induced by belt driven fan with VFD and EC motor plug fan were measured by portable power analyser before and after the retrofit. The measured variation range of current and total harmonic distortion (THD) for different fans are shown in Figure 5 and Figure 6. As Code of Practice for Energy Efficiency of Building Services Installation suggested when the design THD of current for a circuit at or below 40 A, THD should be lower than 20% (BEC, 2015). Obviously THD of current for the measured three-phase circuit connecting to both belt driven fan and EC motor plug fan is out of recommended range. It is thus suggested to install a harmonic filtering device to mitigate the THD when VFD or EC motor plug fan is adopted. For the fifth harmonic which may cause a counter electromotive force in motors acting in the opposite direction of rotation, current distortion induced by EC motor plug fans maintains 35% or below when the motor operates under the loading of 50% or less (single phase current of 15A or less). This conditionally meet the requirement of Code of Practice for Energy Efficiency of Building Services Installation that the maximum fifth harmonic current distortion at the VSD input terminals during normal operation within the variable speed range is less than 35% (BEC, 2015), given condition that the normal operation is larger than 50% of design loading. Harmonic filtering device is again recommended for low loading operation.

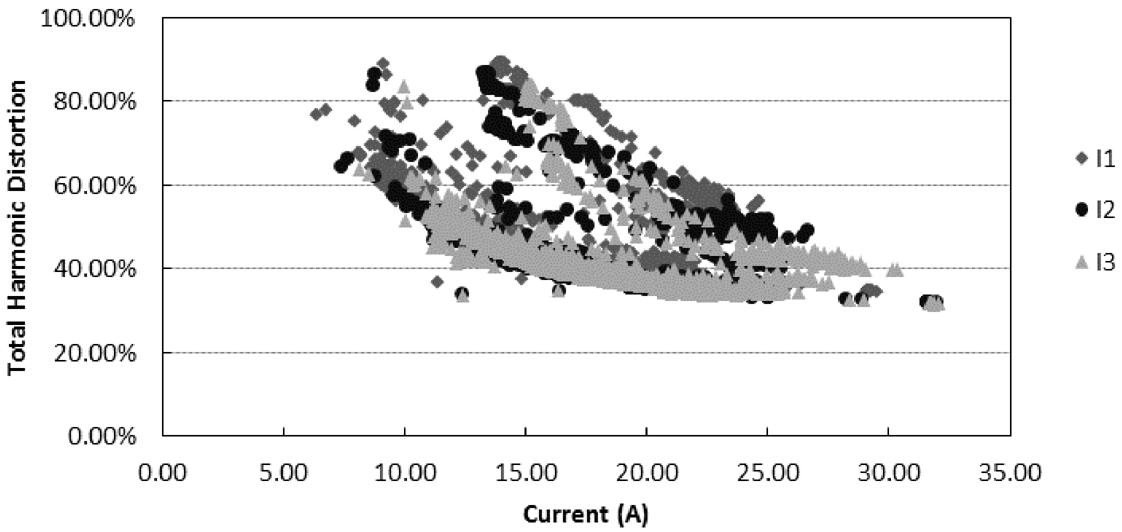


Figure 5: Belt driven fan with VFD Total harmonic distortion of current

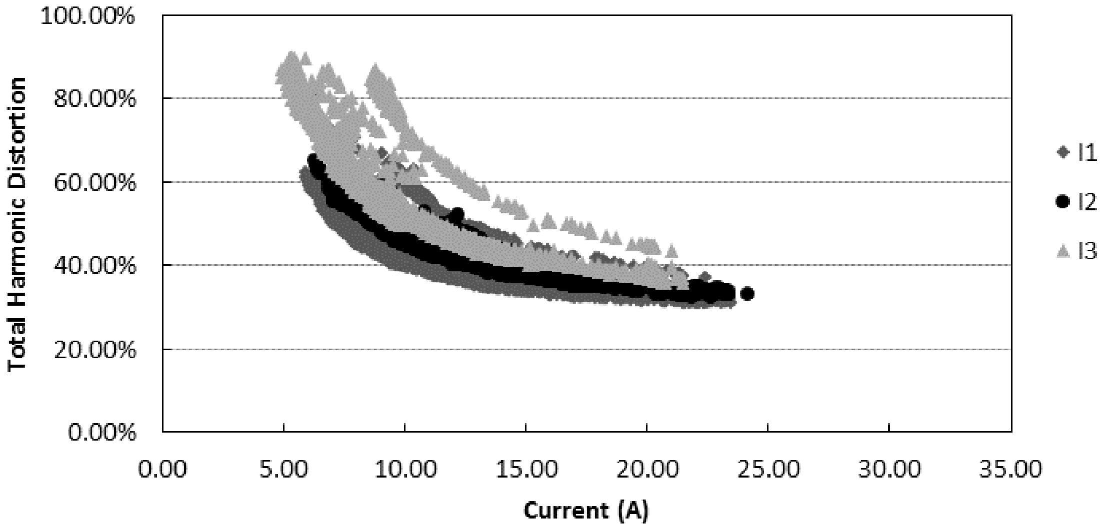


Figure 6: EC motor plug fan total harmonic distortion of current

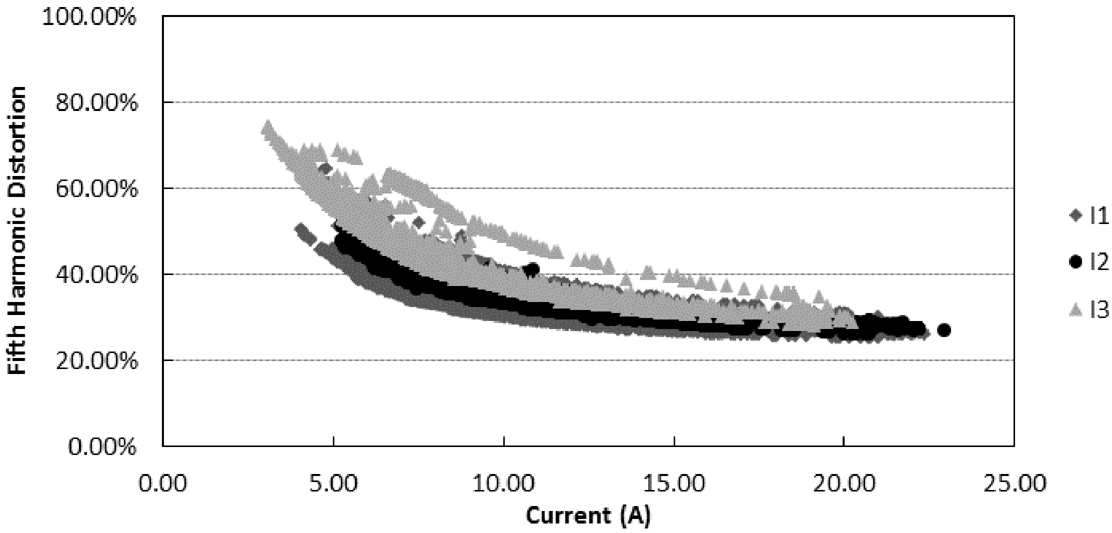


Figure 7: Fifth harmonic current distortion of EC motor plug fan

3.3. Noise test

To ensure the operation of EC motor plug fans will not affect office working environment, noise tests were conducted before and after the retrofit. Testing results are shown in Table 6. The highest sound pressure level under the normal air outlet was measured at a test point, which is located under one of the air outlets nearest to the AHU. According to BEAM plus Existing Building (version1.2, 2012), NC 40 is suggested for office type premises. For this AHU, air flow rate demand is in the range of 2500 - 8000 l/s during a year. Thus, the sound pressure level of office space can meet the requirement in most time of the year with EC motor plug fan.

	Belt Driven Fan			**EC Motor Plug Fan**		
Frequency	45Hz	30Hz	Off	-	-	-
Rotation Speed	-	-	-	2444rpm (94.0%)	1850rpm (71.2%)	1235rpm (47.5%)
Air Flow Generated	Approx. 8000 l/s	Approx. 4800 l/s	-	Approx. 9900 l/s	Approx. 7000 l/s	Approx. 2500 l/s
dB(A)						
Inside AHU Room (1m away from inlet)	71	62	48	74	71	50
Worst Case Test Point	46	41	37	48	45	37

Table 6a: Testing results

	Octave Band Center Frequency (Hz)								Noise Criterion
	63	125	250	500	1000	2000	4000	8000	
	Sound Pressure Levels (dB)								
Belt Driven Fan at 45Hz Worst Case Test Pt.	56.3	51.2	47.6	41.5	38.7	38.2	0.0	0.0	NC 40
EC Motor Plug Fans at 2444rpm Worst Case Test Pt.	59.7	55.3	49.1	45.0	41.0	37.0	0.0	0.0	NC 40

Table 6b: Testing results

3.4. Payback analysis

To answer the question whether the EC motor plug fan is worth the investment for building retrofit, a payback analysis was conducted. Table 7 shows the analysis result. Payback period for individual fan retrofit in this case study is relatively long (over 8 years). Weekend/ night-time installation, which aims to minimise the disturbance to office tenant, is also one of the reasons of high initial cost in this particular case. It is expected the cost of retrofit could be reduced by capturing the benefits of economy of scale, while engaging a large scale retrofit work with a significant quantity of fan replacement.

Item	**Cost (HKD)**
Fan and sensor supply	Approx. 80,000
Removal of belt driven fan	Approx. 20,000
EC plug fan installation	Approx. 80,000
EC plug fan control panel	Approx. 40,000
Test and Commissioning	Approx. 5,000
Total investment	Approx. 225,000
Electrical cost saving per year (1.4 HKD/kWh)	16,685
Maintenance cost saving per year (no belt and bearing replacement)	Approx. 9,000
Simple Payback	8.8 years

Table 7: Payback

4. CONCLUSION

This study investigates the performance and feasibility of adopting EC motor plug fan technology for replacing belt driven fan in an existing office building. It is found that EC motor plug fan can achieve more than 40% energy saving over belt driven fan yearly. Its modular and compact design makes installation easy. Its maintenance cost is lower because it is not necessary to frequently replace belts and bearings. Thus EC motor plug fan could be a good choice for new buildings or existing buildings which targets to achieve high performance in energy efficiency.

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