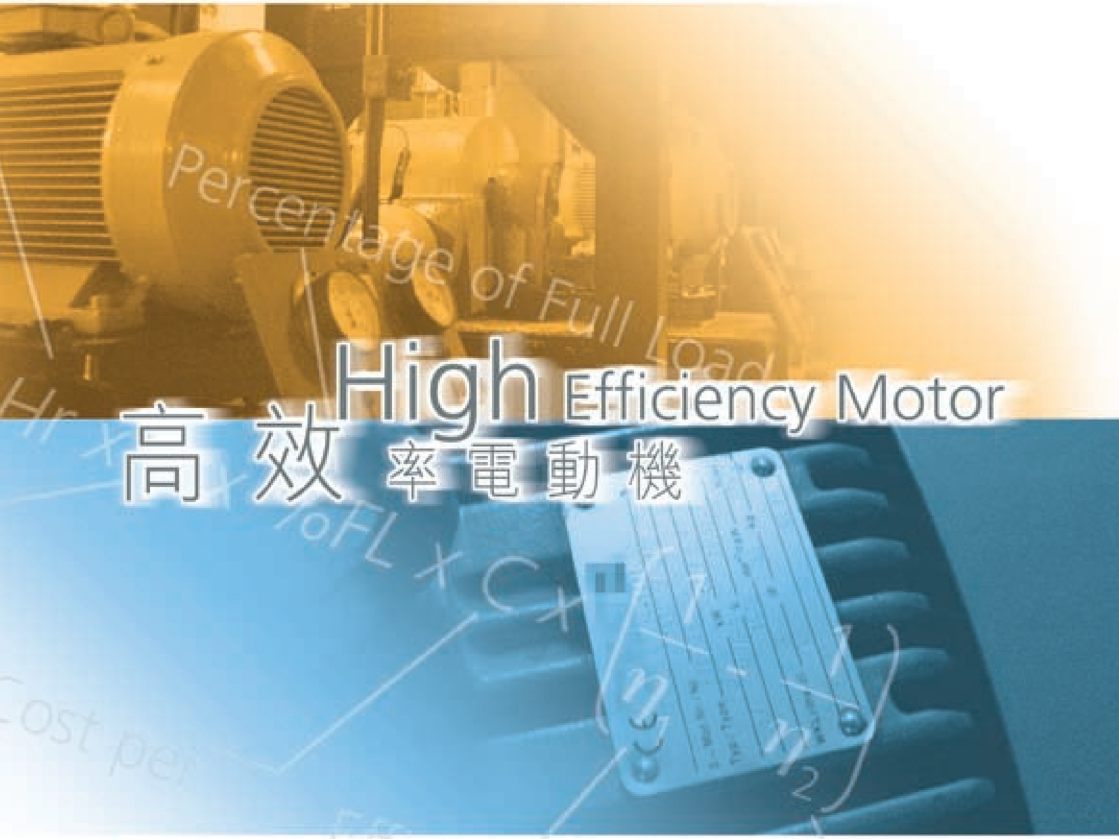


High Efficiency Motor
高效率電動機

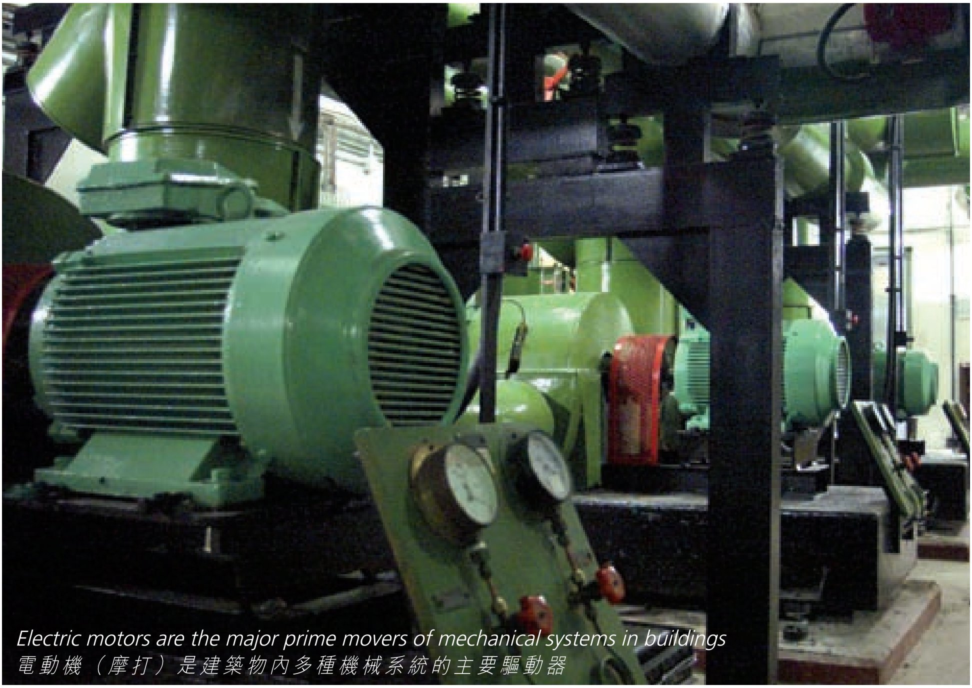
機電工程署
EMSD

Why Using High Efficiency Motors

Electric motors are the major prime movers of various mechanical systems such as the HVAC systems, water pumping systems and other industrial machines etc. According to EMSD's Energy End Use Database, HVAC consumes nearly 48% of the electricity in the office segment in the year 2004 while industrial machines can consume up to 79% electricity of the industrial segment. Improvement in motor efficiency can no doubt help reducing energy consumption.

為何要採用高效率電動機

電動機（俗稱摩打）是多種機械系統（如空調系統、泵水系統及其他工業用機器）的主要驅動器。根據機電工程署編訂的能源最終用途數據庫，空調系統在2004年消耗的電力佔辦公室組別耗電量差不多48%，而工業用機器消耗的電力則佔工業組別耗電量高達79%，因此改善摩打效率肯定有助減少耗電量。



Electric motors are the major prime movers of mechanical systems in buildings
電動機（摩打）是建築物內多種機械系統的主要驅動器

What contributes to Improved Motor Efficiency

Motor efficiency measures how well electrical energy is converted into mechanical energy. Compared with conventional standard motors, which are usually a compromise design between performance and cost, high efficiency motors are more efficient in converting electrical energy into mechanical energy. The improvement in energy efficiency is a result of the following:

- Increasing the use of copper in the motor's rotor to reduce copper winding resistance losses and improving temperature performance of motor
- Improving the design of stator and rotor with thinner laminated and higher quality steel.
- Reducing the air gap between the stator and rotor to increase the intensity of magnetic flux.
- Improving the overall design to reduce windage losses and stray load losses.

怎樣可以改善摩打效率

摩打效率，是指摩打能將多少電能轉換成機械能。與傳統標準摩打（在設計上通常須在表現與成本之間取得妥協），高效率摩打能更有效把電能轉換成機械能。以下的設計及製造方案皆有助提升摩打的能源效益：

- 在摩打的轉子多用銅料，以減少銅繞組的電阻損耗，並改善摩打在不同溫度的表現；
- 改良定子及轉子的設計，採用較薄的高品質鋼片；
- 縮小定子和轉子之間的空隙，以增加磁通量密度；
- 改良整體設計，以減少空氣阻力及雜散負荷帶來的損耗。

How are Motor Efficiency Classified

The two major markets, i.e. the European and the North American, have adopted different designation schemes for classifying efficiency of electric motors.

In the North American market, the Energy Policy Act (EPAct) of 2005 mandated the use of National Electrical Manufacturers Association (NEMA) Premium efficiency electric motor as the motors of choice for federal procurement. Since the motors in the North American market are working on 60 Hz supply line which is not compatible with the local electricity supply networks, the details of the EPAct requirement will not be covered in this pamphlet.

In the European market, members of the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) signed a voluntary agreement relating to motor efficiency. The classification scheme under the voluntary agreement provides customers and users a clear designation of motor efficiency class as highlighted in the table below:

怎樣劃分摩打效率

兩個主要市場（即歐洲及北美洲）已透過不同的標籤計劃來劃分電動機（摩打）的效率。

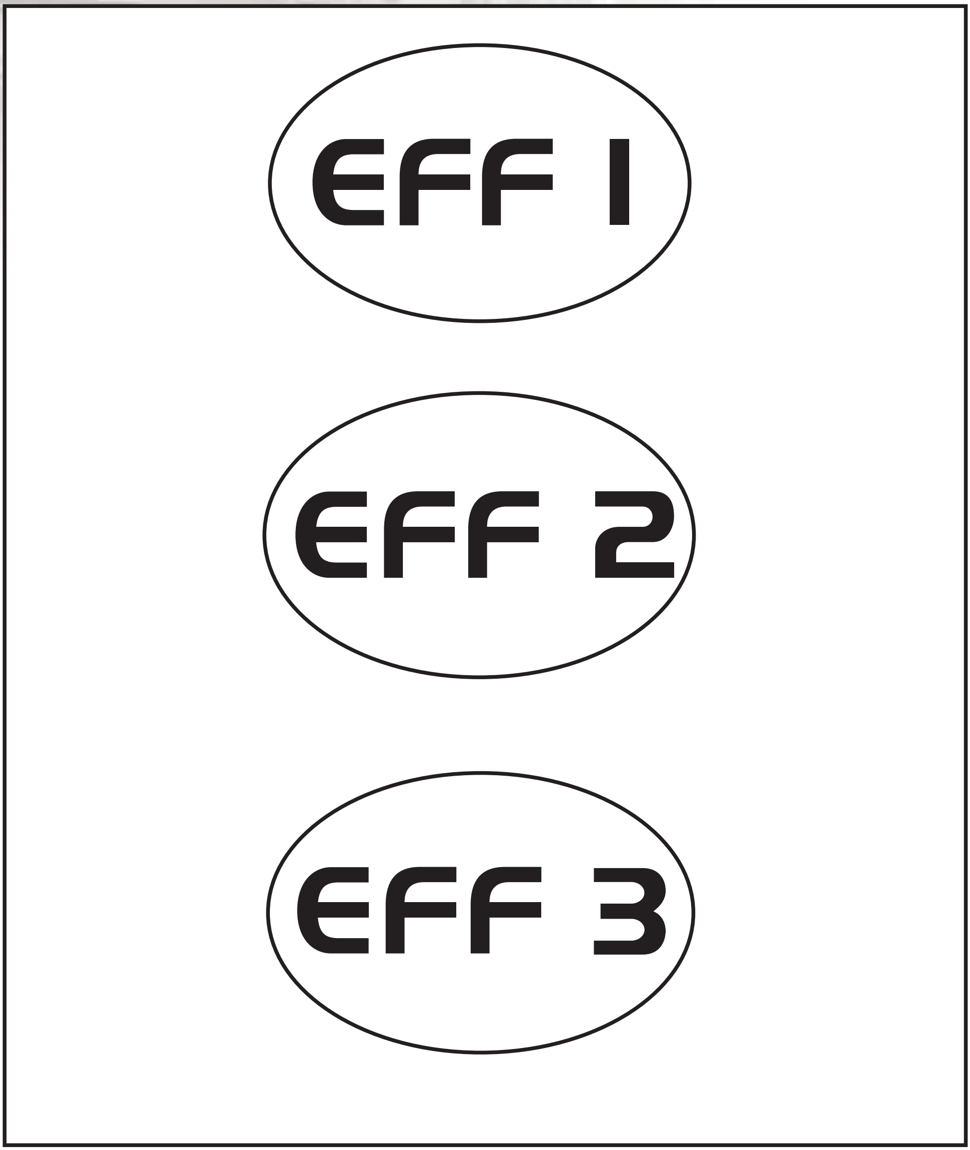
在北美洲市場，2005年的Energy Policy Act (EPAct) 規定國家必須選擇購買National Electrical Manufactures Association (NEMA) 的Premium級摩打。北美洲市場的摩打由60赫茲的電源供電，由於該等頻率與本港供電網絡的標準不同，因此本單張不會談及EPAct的詳細規定。

至於歐洲市場，European Committee of Manufacturers of Electrical Machines and Power Electronics（CEMEP）的成員已簽署一份有關摩打效率的自願性質協議，該協議定出的分類計劃為消費者及使用者釐訂清晰的摩打效率級別，詳情見下表：

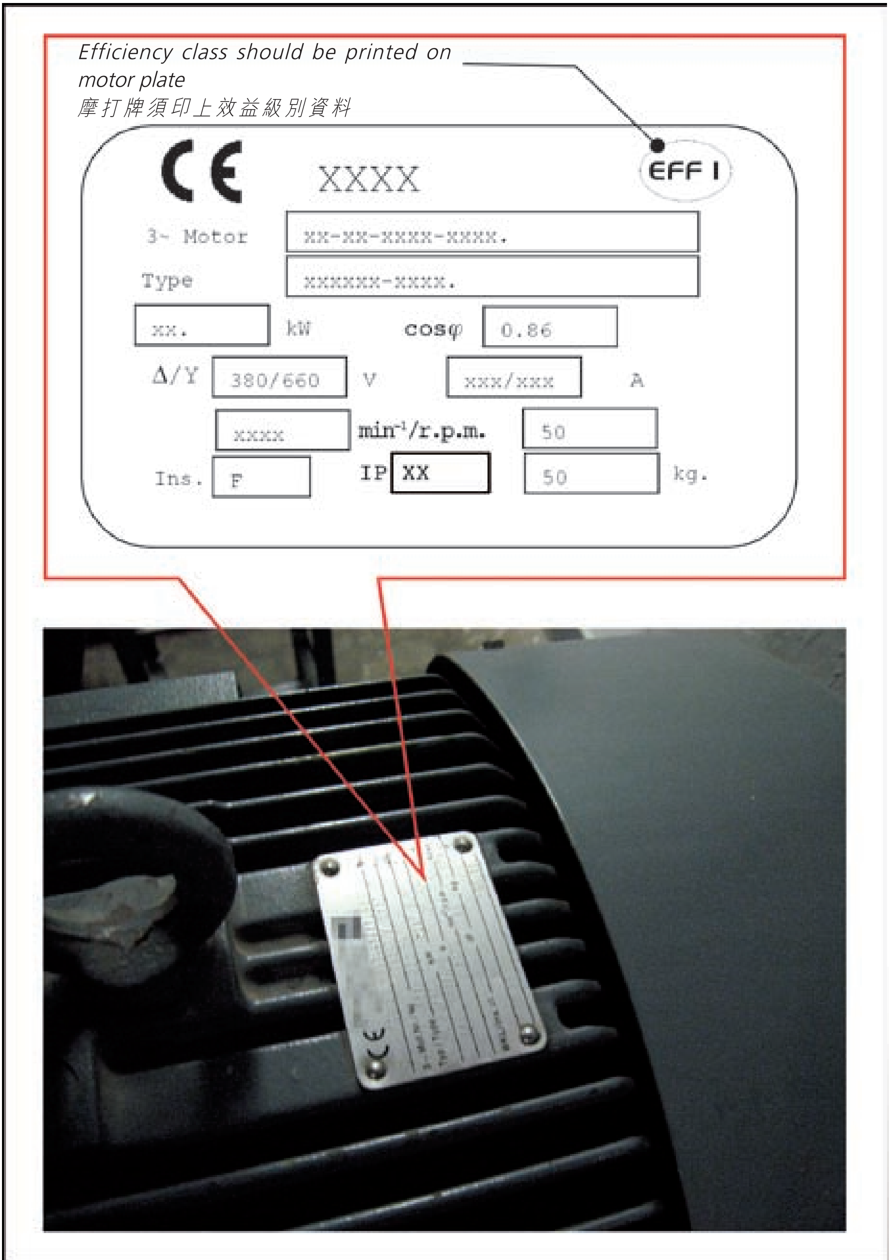
Coverage 適用範圍	Motor Type 摩打類型	• 3 Phase AC squirrel cage Induction Motor 三相交流電鼠籠式感應摩打 • S1 Duty class (continuous duty) 連續工作制（S1） • Totally Enclosed Fan-Cooled (TEFC) 全密封並用風扇冷卻
	Rated Motor Voltage 額定摩打電壓	Low Voltage ≤ 400V, 50Hz 低壓 ≤ 400伏特，50赫茲
	Motor Power 摩打功率	1.1kW - 90kW 1.1千瓦—90千瓦
	Number of Poles 極數目	2 poles and 4 poles 二極及四極
Energy Efficiency Classification 能源效益分類	Class 級別	EFF1, EFF2 and EFF3
	Measurement Standard 量度標準	EN 60034-2
Designation Requirements 標誌規定		• Efficiency class on motor rating plate 在摩打額定值牌顯示能源效益級別 • Efficiency at full load and 3/4 part load declared in product document such as product catalogues 在產品文件（如產品目錄）説明全負載及四分之三負載時的效率
Certification 認證		Manufacturer declaration 製造商聲明

Under the agreement, manufacturers will indicate efficiency designations on motor rating plate. The appearance of the designation label is shown below:

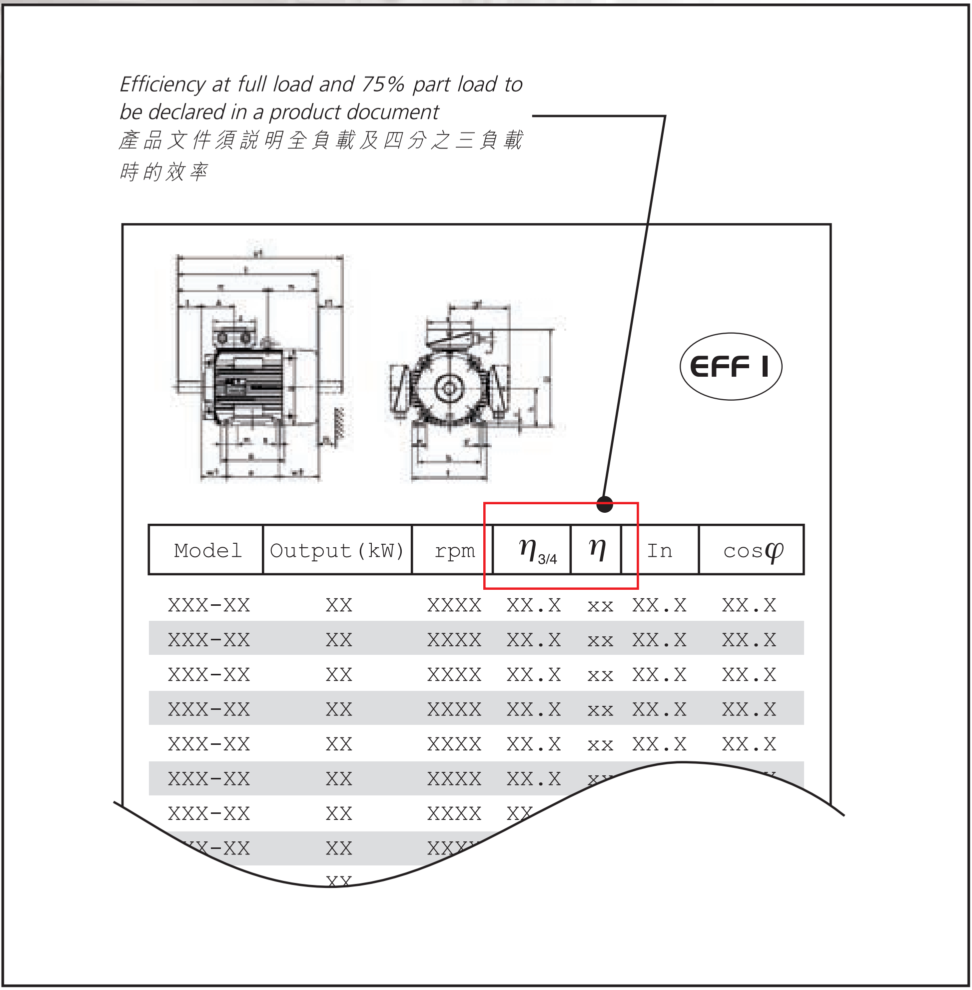
根據該協議，製造商會在摩打額定值牌顯示能源效益級別。有關標誌的式樣如下：



Efficiency Class Designations
能源效益級別標誌



Example: Efficiency class information printed on motor rating plate
例子：在摩打額定值牌印上能源效益級別資料



Example: Efficiency at full load and 75% part load declared in a product document
例子：產品文件說明全負載及四分之三負載時的效率

The efficiency of EFF1, EFF2 and EFF3 motors are as follows, with EFF1 being the most energy efficient and EFF3 the least energy efficient:

EFF1、EFF2及EFF3摩打的效率如下（EFF1最具能源效益，而EFF3則最低能源效益）：

For *4-pole* motors

四極摩打

kW 千瓦	EFF3 - motors EFF3摩打 η_N (%)	EFF2 - motors EFF2摩打 η_N (%)	EFF1 - motors EFF1摩打 η_N (%)
1,1	< 76,2	≥ 76,2	≥ 83,8
1,5	< 78,5	≥ 78,5	≥ 85,0
2,2	< 81,0	≥ 81,0	≥ 86,4
3	< 82,6	≥ 82,6	≥ 87,4
4	< 84,2	≥ 84,2	≥ 88,3
5,5	< 85,7	≥ 85,7	≥ 89,2
7,5	< 87,0	≥ 87,0	≥ 90,1
11	< 88,4	≥ 88,4	≥ 91,0
15	< 89,4	≥ 89,4	≥ 91,8
18,5	< 90,0	≥ 90,0	≥ 92,2
22	< 90,5	≥ 90,5	≥ 92,6
30	< 91,4	≥ 91,4	≥ 93,2
37	< 92,0	≥ 92,0	≥ 93,6
45	< 92,5	≥ 92,5	≥ 93,9
55	< 93,0	≥ 93,0	≥ 94,2
75	< 93,6	≥ 93,6	≥ 94,7
90	< 93,9	≥ 93,9	≥ 95,0

For *2-pole* motors

兩極摩打

kW 千瓦	EFF3 - motors EFF3摩打 η_N (%)	EFF2 - motors EFF2摩打 η_N (%)	EFF1 - motors EFF1摩打 η_N (%)
1,1	< 76,2	≥ 76,2	≥ 82,8
1,5	< 78,5	≥ 78,5	≥ 84,1
2,2	< 81,0	≥ 81,0	≥ 85,6
3	< 82,6	≥ 82,6	≥ 86,7
4	< 84,2	≥ 84,2	≥ 87,6
5,5	< 85,7	≥ 85,7	≥ 88,6
7,5	< 87,0	≥ 87,0	≥ 89,5
11	< 88,4	≥ 88,4	≥ 90,5
15	< 89,4	≥ 89,4	≥ 91,3
18,5	< 90,0	≥ 90,0	≥ 91,8
22	< 90,5	≥ 90,5	≥ 92,2
30	< 91,4	≥ 91,4	≥ 92,9
37	< 92,0	≥ 92,0	≥ 93,3
45	< 92,5	≥ 92,5	≥ 93,7
55	< 93,0	≥ 93,0	≥ 94,0
75	< 93,6	≥ 93,6	≥ 94,6
90	< 93,9	≥ 93,9	≥ 95,0

What are the Savings in Using High Efficiency Motors

使用高效率摩打可節省多少能源及金錢

Motor with higher efficiency (e.g. EFF1 motor) can reduce electricity consumption to deliver the same amount of work done currently driven by EFF3 or EFF2 motor. The annual electricity cost saving by replacing an existing motor with a high efficiency motor can be roughly estimated by the following equation:

高效率摩打（例如EFF1摩打）可減少耗電量，但輸出的作功與EFF3或EFF2摩打一樣。我們可利用下列方程式粗略估計以高效率摩打取代現有摩打後每年所節省的電費：

Annual Electricity Cost Saving
每年節省的電費

$$= Hr \times R \times \%FL \times C \times \left(\frac{1}{\eta_1} - \frac{1}{\eta_2}\right)$$

- Hr: Annual Operating Hours 每年運行時數
- R: Motor Rating (kW) 摩打額定值（千瓦）
- %FL: Percentage of Full Load 滿載百分比
- C: Electricity Cost per KWh 每千瓦小時電費
- η_1: Efficiency of Existing Motor 現有摩打的效率
- η_2: Efficiency of New Motor 新摩打的效率

However, the cost of EFF1 motor is significantly higher than EFF3 and EFF2 motor due to better materials and improved overall design. The incremental cost of EFF1 motor can be as high as 50% thus giving users a first impression that they are too expensive to use. However, it should be noted that from a life cycle perspective, the initial cost constitutes only a very small proportion of the life cycle cost. Thus in typical applications with reasonable operating hours each year, the annual saving will generally offset the incremental cost within a short period of time. The following worked examples illustrate all this. The calculation is based on discount cash flow analysis because the time horizon is long:

不過，由於EFF1摩打所用的材料較佳，整體設計亦有所改善，因此成本較EFF3及EFF2摩打高許多。EFF1摩打的附加成本可高達50%，故一些摩打使用者可能會覺得這種摩打過於昂貴。然而，從生命周期的觀點來看，初步成本只佔生命周期成本一小部分。因此，在一般應用中，若每年有相當的運行時數，每年節省得來的款項通常很快便可抵銷附加成本，而下列例子正好說明這點。由於摩打壽命較長，計算方法會以折扣現金流量分析為基礎。

Example 1: Proportion of motor cost out of the life cycle cost

例子1： 摩打成本在生命周期成本中所佔的比例：

Assuming the followings:
假設

Capital Cost of Motor 摩打的資本成本	: $6,000 (元)
Motor Rating 摩打額定值	: 30 kW (千瓦)
Efficiency 效率	: 90.0% (EFF3)
Annual Operating Hours 每年運行時數	: 3000 hours (小時)
Electricity Cost 電費	: $0.9/kWH (元/ 千瓦小時)
Expected Life Span 預計使用年期	: 10 years (年)
Discount Rate 折扣率	: 10%

Discount Factor for 10 years with discount rate 10%
10年的折扣因子，折扣率為10%

$$= \sum_{i=1}^{10} \frac{1}{(1+10\%)^i} = 6.14$$

Annual Electricity Cost
每年電費

$$= \frac{30\text{kW (千瓦)} \times 3000 \text{ hours (小時)}}{90\%} \times \$0.9/\text{kWH (元/ 千瓦小時)} = \$90{,}000 \text{ (元)}$$

Life Cycle Cost = Annual Electricity Cost x Discount Factor + Capital Cost
生命周期成本 = 每年電費 x 折扣因子 + 資本成本
= $90,000 (元) x 6.14 + $6,000 (元)
= $558,600 (元)

Proportion of Capital Cost Within Life Cycle Cost
資本成本在生命周期成本中所佔的比例

$$= \frac{\$6{,}000 \text{ (元)}}{\$558{,}600 \text{ (元)}} = 1.07\%$$

It can be seen from the example that the capital cost of the motor only constitutes about 1.07% of the life cycle cost. Thus the life cycle cost itself is not sensitive to the capital cost of the motor.

這個例子顯示摩打的資本成本只佔生命周期成本大約1.07%，因此摩打的資本成本對生命周期成本的影響不大。

Example 2: Savings in using high efficiency motor

To appreciate the benefits in using EFF1 motor in lieu of the EFF3 motor in Example 1 above, the life cycle cost and payback period for EFF1 are worked out based on the following:

例子2： 使用高效率摩打所能節省的用電和金錢

如在例子1中以EFF1摩打取代EFF3摩打，將會令使用者受惠。現按下列數據計算EFF1摩打生命周期成本及回本期：

Capital Cost of Motor 摩打的資本成本	: $10,000 (元)
Motor Rating 摩打額定值	: 30 kW (千瓦)
Efficiency 效率	: 93.2% (EFF1)
Annual Operating Hours 每年運行時數	: 3000 hours (小時)
Electricity Cost 電費	: $0.9/kWH (元/千瓦小時)
Expected Life Span 預計使用年期	: 10 years (年)
Discount Rate 折扣率	: 10%

Discount Factor for 10 years with discount rate 10%
10年的折扣因子，折扣率為10%

$$= \sum_{i=1}^{10} \frac{1}{(1+10\%)^i} = 6.14$$

Annual Electricity Cost
每年電費

$$= \frac{30\text{kW (千瓦) x 3000 hours (小時)}}{93.2\%} \text{ x \$0.9/kWH (元/ 千瓦小時) = \$86,910 (元)}$$

Life Cycle Cost
生命周期成本

= $86,910 (元) x 6.14 + $10,000 (元)

= $543,627 (元)

From the above two examples, the annual saving in using high efficiency motor is $90,000 - $86,910 = $3,090/year. The incremental capital cost for upgrading to EFF1 motor from EFF3 motor is $10,000 - $6,000 = $4,000. Thus the pay back period for the incremental capital cost can be calculated as follows:

根據上面兩個例子，每年可節省的金額是90,000元 - 86,910元 = 3,090元，把EFF3摩打改為EFF1摩打的附加資本成本是10,000元 - 6,000元 = 4,000元，因此以下列方式計算出附加資本成本的回本期：

$$\frac{\$4{,}000\ (元)}{\$3{,}090\ (元)} = 1.3\ \text{years}\ (年)$$

What else to be Considered when Upgrading Existing Motors To High Efficiency Motors

把現有摩打改為高效率摩打時還須考慮些什麼？

Operating Speed

For induction motors, the operating speed is always less than the synchronous speed (i.e. the rotating speed of the magnetic field). The difference is called slip. The equation defining the operating speed is shown below:

運行速度

感應摩打的運行速度總是低於同步速度（即磁場的轉動速度），兩者的差叫轉差。計算運行速度的方程式如下：

$$\text{Operating Speed (rpm)} = \frac{120x\ f}{n} - \text{slip}$$

運行速度（每分鐘轉數）

f: Supply Frequency (Hz) 供電頻率（赫茲）

slip 轉差

n: Number of Poles 極數

Some motor loads are very sensitive to the operating speed of motor. Examples of these loads are: centrifugal pumps, fans, and etc. *A slight increase in operating speed may induce a large increase of energy consumption. High efficiency motors may have a higher rotating speed (smaller slip) due to improved design. This will offset the energy efficiency improvement, or sometimes consume even more energy than the existing motor due to increased loading.* During the upgrading process, the following processes are recommended:

- Check the type of motor load to ascertain the sensitivity to operating speed
- Measure the existing operating speed.
- Specify the operating speed in addition to the nominal speed in procuring the new high energy efficiency motor.
- If a close match of the operating speed is not achieved with the procured new high efficiency motor, some adjustment to the drive train (e.g. belt drive pulley) or modification of the load component (e.g. trimming of a pump impeller) may be necessary.

有些摩打負載（例如離心泵及風扇）很受摩打運行速度影響。*摩打運行速度稍為增加，可能會令耗電量大增。由於高效率摩打的設計有所改善，轉速可能較高（轉差較小），這樣會抵銷節省到的能源，有時甚至因負載增加而較使用現有摩打消耗更多能源。*我們建議在改用高效率摩打時，應注意以下各點：

- 檢查摩打負載的種類，以確定負載受摩打運行速度的影響有多大；
- 量度摩打現時的運行速度；
- 在採購新的高效率摩打時除指定標稱速度外，還須指定運行速度；
- 如購得的高效率摩打的運行速度與負載的運行速度並不配合，就可能需要調節驅動鏈（例如傳動帶驅動的滑輪）或更改負載部件（例如縮小泵的葉輪）。

Starting Current

High efficiency motors may have higher starting current which may result in nuisance circuit breaker tripping during motor start up. This may occur in the case of motors with direct-on-line starting. For motor upgrading, the starting current has to be checked and the circuit breaker settings may need to be adjusted, if required, to accommodate the increased starting current. During the motor procurement process, the starting current may be included in the specifications for product selection.

起動電流

*高效率摩打可能需要較大的起動電流，*因此可能在起動過程中令斷路器不必要地被啟動，使用直接起動式摩打就更容易出現這種情況。如改用高效率摩打，須檢查起動電流。如有需要，可調整斷路器的設定值，以容許增大起動電流。在採購摩打的過程中，可將起動電流納入選購產品的規格內。

Starting Torque

High efficiency motors may sometimes have lower starting torque than standard motors. Motor loads within buildings are usually not very sensitive to starting load, but some motor load may be sensitive to starting torque and thus has to be checked to ensure that the high efficiency motor can provide the required torque during starting. Documentation of the existing motor may contain information about the start torque of the motor. As for the starting current, the starting torque may be included in the specifications for product selection during the procurement.

起動扭矩

*高效率摩打的起動扭矩有時可能較標準摩打的起動扭矩小。*建築物內的摩打負載通常很少受起動負載影響，不過部分摩打負載可能受起動扭矩影響，因此須檢查有關摩打負載，以確保高效率摩打在起動時可以發出所需的扭矩。現有摩打的說明文件可能載有摩打的起動扭矩資料。在採購摩打的過程中，可像起動電流一樣將起動扭矩納入選購產品的規格內。

Annual Operating Hours

Annual Electricity Cost Saving =

Motor Rating (kW)

Electricity

KWh

機電工程署 EMSD

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