Report on Study on International Efficiency (IE) Efficiency Classes for Low Voltage AC Motors

Executive Summary

In Hong Kong, the Code of Practice for energy efficiency of Building Services Installation (Code of Practice) specifies the minimum motor efficiency for single-speed three-phase totally enclosed motor. These requirements serve to determine the baseline energy performance on motor.

Internationally, there is a standard which stipulates the energy efficiency of low voltage AC motors, namely the International Efficiency (IE). The purpose of which is to promote higher energy efficiency to reduce the energy consumption and the energy cost of low voltage AC motors. To facilitate the procurement of new motors with higher energy efficiency, a study on the IE and its application was conducted.

In this paper, the IE standard for motors is introduced. In addition, with a view to better understand the availability of existing motor products in the market, a survey was conducted on the motor and its price of different classes from major suppliers in Hong Kong. A case study on calculating the energy saving of replacement of energy efficient motor is covered.

Background

In 1998, the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) developed three classes (i.e. EFF1, EFF2 and EFF3) to describe the energy efficiency of motors. It is a voluntary agreement between the electrical motor manufacturers and the European Commission. However, the agreement expired on 16 June 2011.

CEMEP's EFF has been adopted in Europe and some other countries around the world. In order to harmonize the standards describing motor energy efficiency, the International Electrotechnical Commission (IEC) has developed the International Efficiency (IE) classes through collaboration with the National Electrical Manufactures Association (NEMA), CEMEP, the Japan Electrical Manufacturers' Association (JEMA), the Institute of Electrical and Electronics Engineers (IEEE) and other international organizations.

The IE classes were initially developed in October 2008, namely IEC 60034-30:2008,

which has been recently updated in June 2014, namely IEC 60034-30-1:2014, for the purpose of expanding its scope of classification.

EFF Classification

The EFF has 3 classes, i.e. EFF1, EFF2 and EFF3 respectively. EFF1 is the most energy efficient, while EFF3 is the least energy efficient. In other words, the lower class number represents the higher motor efficiency. The testing method is based on IEC 60034-2-1:1996 – Standard methods for determining losses and efficiency from tests (excluding machines for traction power). The stray load loss, which varies with the load, is assumed at 0.5% of the motor's input power. However, it is lower than the real losses from motors of lower rated power.

IE Classification

The IE Classification is defined by IEC 60034-30-1. The latest version of IEC 60034-30-1 was published in June 2014. The IE classes are shown in Table 1

Table 1 IE Classes

Class Type	Class Number
Standard efficiency	IE1
High efficiency	IE2
Premium efficiency	IE3
Super premium efficiency	IE4

IE4 represents the highest energy efficiency whilst IE1 represents the least energy efficiency. In other words, the higher the class number, the higher the motor efficiency. IE5 is to be incorporated in the next edition of IEC 60034-30-1, with a goal to obtain an energy loss reduction of 20% relative to IE4. However, it should be noted that the drafting of the IE5 is in progress, thus, it is not available in the commercial market now.

The scope of classification is defined for single speed, single and three phase, and continuous duty electric motor with 2, 4, 6 or 8 poles. The rated output ranges from 0.12kW to 1,000 kW; the rated voltage is up to 1kV; and the frequency is between 50Hz and 60Hz. The scope also includes ambient temperature within the range of -20^{o}C to +60^{o}C and an altitude of up to 4,000m above sea level.

Some particular exemptions are highlighted as follows:

- Single-speed motors with 10 or more poles or multi-speed motors are excluded;
- Motors that are completely integrated into a machine, such as a pump, fan and compressor, and frequency-converters that cannot be tested for its efficiency individually shall be excluded from the IE standard;
- Brake motors, which is an integral part of the inner motor construction, cannot be removed nor supplied by a separate power source during the test shall be excluded; and
- Submersible motors and smoke extraction motors with a temperature class above 400°C shall be excluded.

In accordance with the Hong Kong electricity supply context, 50Hz motor is the focus. It is observed that the motors commonly used in Hong Kong are 4-poles. A graphical presentation of this type of motor is shown in Figure 1 while the minimum energy efficiency requirement of IE Efficiency Class of IE1 to IE4 of different poles is shown in Table 2. .

Figure 1 Minimum Energy Efficiency Requirement of IE Efficiency Class of 4 poles, 50Hz motor

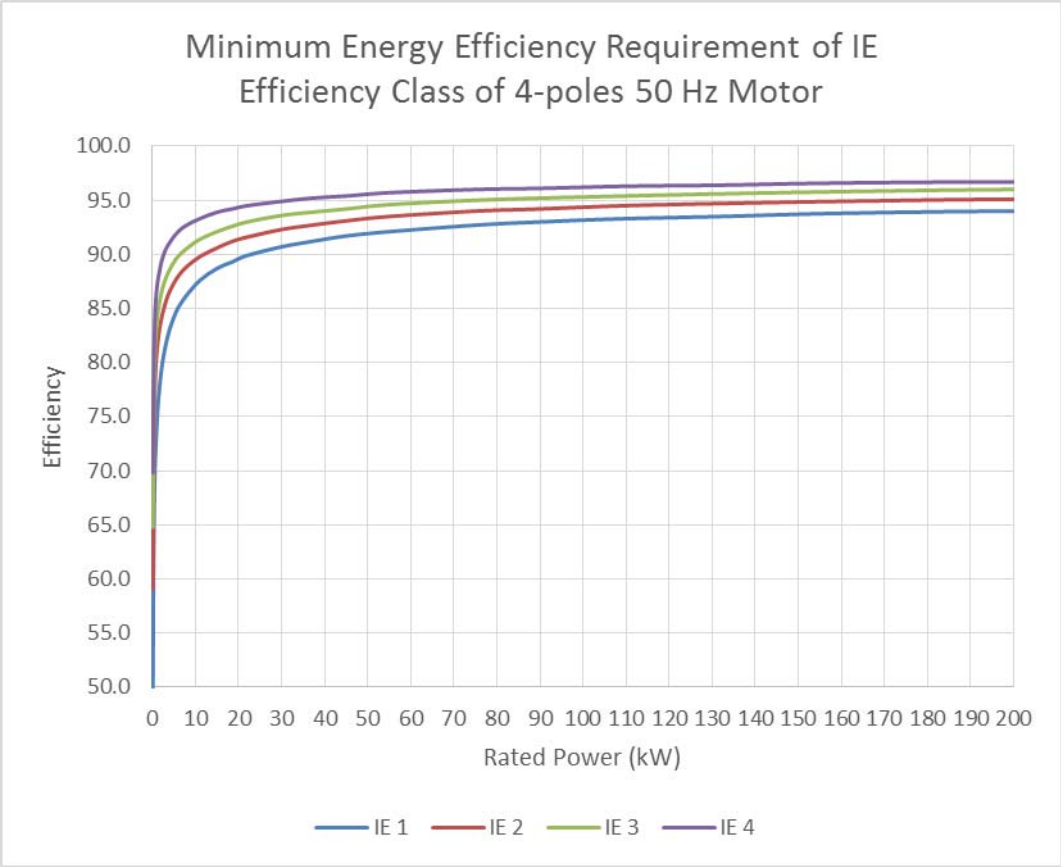

Table 2 Minimum Energy Efficiency Requirement of IE Efficiency Class IE1 to IE4 for 50 Hz motors

	IE1 (50Hz)				IE2 (50Hz)				IE3 (50Hz)				IE4 (50Hz)			
Rated Power (kW)	2-poles	4-poles	6-poles	8-poles	2-poles	4-poles	6-poles	8-poles	2-poles	4-poles	6-poles	8-poles	2-poles	4-poles	6-poles	8-poles
0.12	45.0	50.0	38.3	31.0	53.6	59.1	50.6	39.8	60.8	64.8	57.7	50.7	66.5	69.8	64.9	62.3
0.18	52.8	57.0	45.5	38.0	60.4	64.7	56.6	45.9	65.9	69.9	63.9	58.7	70.8	74.7	70.1	67.2
0.2	54.6	58.5	47.6	39.7	61.9	65.9	58.2	47.4	67.2	71.1	65.4	60.6	71.9	75.8	71.4	68.4
0.25	58.2	61.5	52.1	43.4	64.8	68.5	61.6	50.6	69.7	73.5	68.6	64.1	74.3	77.9	74.1	70.8
0.37	63.9	66.0	59.7	49.7	69.5	72.7	67.6	56.1	73.8	77.3	73.5	69.3	78.1	81.1	78	74.3
0.4	64.9	66.8	61.1	50.9	70.4	73.5	68.8	57.2	74.6	78	74.4	70.1	78.9	81.7	78.7	74.9
0.55	69.0	70.0	65.8	56.1	74.1	77.1	73.1	61.7	77.8	80.8	77.2	73	81.5	83.9	80.9	77
0.75	72.1	72.1	70	61.2	77.4	79.6	75.9	66.2	80.7	82.5	78.9	75	83.5	85.7	82.7	78.4
1.1	75	75	72.9	66.5	79.6	81.4	78.1	70.8	82.7	84.1	81	77.7	85.2	87.2	84.5	80.8
1.5	77.2	77.2	75.2	70.2	81.3	82.8	79.8	74.1	84.2	85.3	82.5	79.7	86.5	88.2	85.9	82.6
2.2	79.7	79.7	77.7	74.2	83.2	84.3	81.8	77.6	85.9	86.7	84.3	81.9	88	89.5	87.4	84.5
3	81.5	81.5	79.7	77.0	84.6	85.5	83.3	80.0	87.1	87.7	85.6	83.5	89.1	90.4	88.6	85.9
4	83.1	83.1	81.4	78.2	85.8	86.6	84.6	81.9	88.1	88.6	86.8	84.8	90	91.1	89.5	87.1
5.5	84.7	84.7	83.1	81.4	87	87.7	86	83.8	89.2	89.6	88	86.2	90.9	91.9	90.5	88.3
7.5	86	86	84.7	83.1	88.1	88.7	87.2	85.3	90.1	90.4	89.1	87.3	91.7	92.6	91.3	89.3
11	87.6	87.6	86.4	85.0	89.4	89.8	88.7	86.9	91.2	91.4	90.3	88.6	92.6	93.3	92.3	90.4
15	88.7	88.7	87.7	86.2	90.3	90.6	89.7	88.0	91.9	92.1	91.2	89.6	93.3	93.9	92.9	91.2
18.5	89.3	89.3	88.6	86.9	90.9	91.2	90.4	88.6	92.4	92.6	91.7	90.1	93.7	94.2	93.4	91.7
22	89.9	89.9	89.2	87.4	91.3	91.6	90.9	89.1	92.7	93	92.2	90.6	94	94.5	93.7	92.1
30	90.7	90.7	90.2	88.3	92	92.3	91.7	89.8	93.3	93.6	92.9	91.3	94.5	94.9	94.2	92.7
37	91.2	91.2	90.8	88.8	92.5	92.7	92.2	90.3	93.7	93.9	93.3	91.8	94.8	95.2	94.5	93.1
45	91.7	91.7	91.4	89.2	92.9	93.1	92.7	90.7	94	94.2	93.7	92.2	95	95.4	94.8	93.4
55	92.1	92.1	91.9	89.7	93.2	93.5	93.1	91.0	94.3	94.6	94.1	92.5	95.3	95.7	95.1	93.7
75	92.7	92.7	92.6	90.3	93.8	94	93.7	91.6	94.7	95	94.6	93.1	95.6	96	95.4	94.2
90	93	93	92.9	90.7	94.1	94.2	94	91.9	95	95.2	94.9	93.4	95.8	96.1	95.6	94.4
110	93.3	93.3	93.3	91.1	94.3	94.5	94.3	92.3	95.2	95.4	95.1	93.7	96	96.3	95.8	94.7
132	93.5	93.5	93.5	91.5	94.6	94.7	94.6	92.6	95.4	95.6	95.4	94	96.2	96.4	96	94.9
160	93.8	93.8	93.8	91.9	94.8	94.9	94.8	93.0	95.6	95.8	95.6	94.3	96.3	96.6	96.2	95.1
200	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.3	95.4
250	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.5	95.4
315	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.6	95.4
355	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.6	95.4
400	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.6	95.4
450	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.6	95.4
500-1000	94	94	94	92.5	95	95.1	95	93.5	95.8	96	95.8	94.6	96.5	96.7	96.6	95.4

European Union Practice

According to European Union, the IE classes are implemented progressively. Below is the summary of requirements of energy efficiency of motor in EU.

Table 3 Summary of requirements of energy efficiency of motor in EU

Commencement Date	Requirements
16 June 2011	IE2 is the minimum efficiency class allowed to be newly marketed in the European Economic Area. New motors of IE1 are no longer allowed.
1 January 2014	IE3 is the minimum efficiency class for motors with a rated output between 7.5kW and 375kW. IE2 is also allowed if motors are operated or equipped with variable speed drive (VSD).
1 January 2017	The scope of requirement of IE3 and IE2 with VSD will be expanded to motors with a rated output from 0.75kW to 375kW.

Comparison on EFF/ IE standards

The following comparison is based on the testing method of IEC 60034-2-1:1996 for EFF and IEC 60034-2-1:2014 for IE.

Study findings of the testing methods reveal that the determination of stray load loss is the major difference. For EFF, the stray load loss is assumed to be 0.5% of the total power output; whilst for IE, the stay load loss is determined by indirect measurement. It should be noted that in reality, the actual stray load loss is usually higher than 0.5% of the total power output, especially for motors of lower power. It is obvious that the energy efficiency of the motors with lower power were overestimated.

The EFF and IE classes could be aligned with each other. The motor of EFF1 could be considered as equivalent to that of IE2, and the motor of EFF2 could be considered as equivalent to that of IE1. Although discrepancies in energy efficiency requirements can be found between EFF1 and IE2 and EFF2 and IE1, they are due to the difference in the testing method as mentioned above. Table 4 describes the alignment of the energy efficiency of EFF and IE, and Table 5 compares the energy efficiency requirement of EFF and IE for 4-poles, 50Hz motor.

Table 4 Alignment of the energy efficiency standard of CEMEP and IEC

Efficiency Class	IEC	CEMEP
Super Premium Efficiency	IE4	-
Premium Efficiency	IE3	-
High Efficiency	IE2	EFF1
Standard Efficiency	IE1	EFF2
Below Standard Efficiency	-	EFF3

Table 5 Comparison of IE and EFF for 4 poles 50Hz motors

Rated Power (kW)	Comparison between IE2 and EFF1		Comparison between IE1 and EFF2	
	IE2	EFF1	IE1	EFF2
1.1	81.4	83.8	75.0	76.2
1.5	82.8	85.0	77.2	78.5
2.2	84.3	86.4	79.7	81.0
3	85.5	87.4	81.5	82.6
4	86.6	88.3	83.1	84.2
5.5	87.7	89.2	84.7	85.7
7.5	88.7	90.1	86.0	87.0
11	89.8	91.0	87.6	88.4
15	90.6	91.8	88.7	89.4
18.5	91.2	92.2	89.3	90.0
22	91.6	92.6	89.9	90.5
30	92.3	93.2	90.7	91.4
37	92.7	93.6	91.2	92.0
45	93.1	93.9	91.7	92.5
55	93.5	94.2	92.1	93.0
75	94.0	94.7	92.7	93.6
90	94.2	95.0	93.0	93.9

The IE standard is continuously developing for the future efficiency classes. As mentioned above, the IE5 is currently under preparation so the IE classification is expandable for future but the EFF classification is not.

Requirements in Hong Kong

In accordance with the latest Building Energy Code[1] (BEC), the minimum energy efficiency requirements of motors with rated output not exceeding 7.5kW and above 7.5kW are IE2 and IE3 respectively.

Application Area

Low voltage motors are widely installed in various E&M appliances, such as the compressors of chillers, AHUs, lifts and pumps. Installing energy efficient motors can help to reduce the electricity consumption.

During the procurement of the afore-mentioned electric appliances, apart from looking at the specific energy efficiency classes of the electric appliances, further attention could be paid to the energy efficiency of the motor. For example, when procuring a water pump, the energy efficiency of the motor equipped within the pump could significantly affect the overall energy efficiency.

However, it should be noted that the energy efficiency of motor may not be easily found during the procurement of the E&M product, as they may be integrated with the machine and a breakdown of the energy efficiency of its parts may not be provided, e.g. the motor of a chiller is installed in the compressor. During the procurement of the chiller, the energy efficiency provided could be the overall energy efficiency of the chiller, which is dependent on the different components of the chillers, but not solely the motor's. It is also mentioned in the IEC 60034-30-1:2014 that the energy efficiency of a motor that is fully integrated with a machine cannot be determined by the IEC standard. Therefore, specific energy efficiency classification for chiller, such as coefficient of performance (COP), is more applicable in describing the energy efficiency. As discussed above, the efficiency of motors would significantly affect the overall efficiency of the machine it serves. Therefore, it is recommended to consider the energy efficiency of the motor installed in the E&M appliances separately.

A Concise Review of Retail Price

There are various manufacturers manufacturing motors in accordance with the IE standard around the world. The listed price varies across brands for reasons such as the quality, material and other features.

[1] http://www.beeo.emsd.gov.hk/en/pee/BEC_2015.pdf

Some motor manufacturers were invited to submit the motor prices during the Study. A comparison of the prices collected in relation to IE2 with IE3 and IE4 motor was made. A ratio of the prices is tabulated in Table 6. The motors are divided into 2 groups in accordance with their rated power of 37kW due to the significant difference of their shaft bearing design.

Table 6 Price ration comparison of IE2, IE3 and IE4 4-poles motor

Rated Power	Price Ratio[1]		
kW	IE2[2][3]	IE3	IE4
≤37	1.00	1.17	1.32
>37	1.00	1.13	1.21

Notes:

[1] The listed prices are obtained from various manufacturers available in Hong Kong market in June 2015

[2] The listed price of IE2 4-poles 7.5 kW motor is around HK$6,000 in Hong Kong market.

[3] The listed price of IE2 4-poles 45kW motor is around HK$28,000 in Hong Kong market.

According to Table 6, the retail price of IE3 motor is higher than that of IE2 motor, with an average ratio 1.17:1 and 1.13:1 for motor at lower or equal to 37kW and higher than 37kW, respectively. The retail price of IE4 motor is costlier than IE2 motor with an average ratio of 1.32:1 and 1.21:1 for motor at lower or equal to 37kW, respectively. Detailed comparison can be found in Appendix A.

Market Available Products

The minimum requirement of energy efficiency of motor is rated at IE3 level (IE2 level for motors with rated output not exceeding 7.5kW). No IE1 nor EFF2 motor is available in the market. The IE2 and IE3 motors dominate the Hong Kong market due to its lower price tag in comparison to IE4 motors.

The number of manufacturers supplying IE4 motors is limited in Hong Kong and would have to be sourced from international motor manufacturers. Further, there are only a few projects in Hong Kong that have required the use of IE4 motors.

There are some other additional features and function of motors, such as flexible terminal box, corrosion proof and engineered-to-order, etc. These additional features shall be taken into consideration during the procurement of new motors.

Energy Saving by Energy Efficient Motor

The annual energy saving by upgrading to more efficient motor is calculated as the formula below:

$$Annual\ Energy\ Saving\ (kWh\ per\ Year) =$$
$$Annual\ Energy\ Consumption\ of\ Motor\ (kWh\ per\ Year) \times Percentage\ of\ Energy\ Saving\ (\%)$$

The percentage of energy saving can be calculated with the following formula:

$$Percentage\ of\ Energy\ Saving\ (\%) = \left(1 - \frac{Efficiency\ of\ Old\ Motor\ (\%)}{Efficiency\ of\ New\ Motor\ (\%)}\right) \times 100\%$$

If the annual energy consumption of motor is not available, it can be estimated with the following formula:

$$Annual\ Energy\ Consumption\ of\ Motor\ (kWh\ per\ Year)$$
$$= Rated\ Power\ of\ Motor + Labelled\ Energy\ Efficiency$$
$$\times Operating\ Hours\ per\ Day \times Operating\ Days\ per\ Year$$

Case Study

To demonstrate the calculation of energy cost saving and payback period, a case study is provided below.

For Company A, the information regarding the old motor and the operation pattern is shown in Table 7.

Table 7 Specification of old motor and operation pattern

Rated Power	37 kW
No. of Poles	4
Efficiency	91.2 (IE1)
Operating Hours per Day	10
Operating Days per Year	360

The Annual Energy Consumption is calculated below:

$$Annual\ Energy\ Consumption\ (kWh\ per\ Year) = 37kW + 91.2\% \times 10\ hours\ per\ day \times 360\ days\ per\ year = 146{,}053kWh$$

Therefore, the annual energy consumption of old motor is 146,052kWh.

Company A is going to upgrade the motor to an IE3 motor as per the specification shown in Table 3.4.

Table 8 Specification of new motor

Rated Power	37 kW
No. of Poles	4
Efficiency	93.9 (IE3)
Cost of Motor (including installation)	HK$40,000
Designed Lifespan	400,000 hours

The percentage of energy saving and the anticipated annual energy saving is calculated below:

$$Percentage\ of\ Energy\ Saving\ (\%) = \left(1 - \frac{91.2\%}{93.9\%}\right) \times 100\% = 2.88\%$$

$$Annual\ Energy\ Saving\ (kWh\ per\ Year) = 146{,}052kWh\ per\ year \times 2.88\%$$
$$= 4{,}206kWh\ per\ Year$$

Therefore, the percentage of energy saving and annual energy saving is 2.88% and 4,206kWh per year, respectively.

To evaluate the cost effectiveness, the payback period is calculated as follows:

$$Annual\ Energy\ Cost\ Saving\ (HK\$\ per\ Year) = 4{,}206kWh\ per\ Year \times HK\$1\ per\ kWh$$
$$= HK\$4{,}206\ per\ Year$$

$$Payback\ Period\ (Year) = HK\$40{,}000 + HK\$4{,}206\ per\ Year = 9.5\ Years$$

Therefore, the payback period is 9.5 years, which equals to 34,675 operating hours. In comparison with the designed lifespan of the motor (i.e. 400,000 hours), upgrading the motor from IE1 to IE3 is considered to be cost effective.

Conclusion

International Efficiency (IE) is a new trend around the world in describing the energy efficiency of motors. The IE classes IE1 to IE4 are well developed, while the IE5 is under preparation. The classification method allows for further improvement in the energy efficiency of motors. In Hong Kong, minimum energy efficiency requirements of motors

with rated output not exceeding 7.5kW and above 7.5kW are IE2 and IE3 respectively.

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Appendix A

Study Note on Market Availability of High Efficient Chillers and Unitary Air Conditioners in Hong Kong

Appendix A.1

Rated Power	Ratio Comparison of Listed Price of IE2 to IE4 Motor[1]								
	2-poles			4-poles			6-poles		
kW	IE2	IE3	IE4	IE2	IE3	IE4	IE2	IE3	IE4
0.37	1.00	N/A[2]	N/A[2]	1.00	N/A[2]	N/A[2]	1.00	1.19	N/A[2]
0.55	1.00	N/A[2]	N/A[2]	1.00	1.18	N/A[2]	1.00	1.19	N/A[2]
0.75	1.00	1.22	N/A[2]	1.00	1.22	1.48	1.00	1.19	N/A[2]
1.1	1.00	1.23	N/A[2]	1.00	1.23	1.38	1.00	1.19	N/A[2]
1.5	1.00	1.23	N/A[2]	1.00	1.23	1.35	1.00	1.12	N/A[2]
2.2	1.00	1.23	N/A[2]	1.00	1.19	1.33	1.00	1.12	N/A[2]
3	1.00	1.19	1.35	1.00	1.19	1.31	1.00	1.12	N/A[2]
4	1.00	1.19	1.34	1.00	1.19	1.32	1.00	1.12	N/A[2]
5.5	1.00	1.19	1.34	1.00	1.20	1.30	1.00	1.12	N/A[2]
7.5	1.00	1.20	1.35	1.00	1.20	1.31	1.00	1.12	N/A[2]
11	1.00	1.12	1.35	1.00	1.12	1.32	1.00	1.13	N/A[2]
15	1.00	1.12	1.35	1.00	1.12	1.29	1.00	1.10	N/A[2]
18.5	1.00	1.12	1.35	1.00	1.12	1.28	1.00	1.17	N/A[2]
22	1.00	1.12	1.33	1.00	1.12	1.26	1.00	1.11	N/A[2]
30	1.00	1.11	1.31	1.00	1.11	1.27	1.00	1.10	N/A[2]
37	1.00	1.11	1.31	1.00	1.10	1.24	1.00	1.10	N/A[2]
45	1.00	1.10	1.25	1.00	1.10	1.23	1.00	1.15	N/A[2]
55	1.00	1.10	1.24	1.00	1.10	1.22	1.00	1.15	N/A[2]
75	1.00	1.15	1.23	1.00	1.15	1.22	1.00	1.15	N/A[2]
90	1.00	1.15	1.22	1.00	1.15	1.21	1.00	1.15	N/A[2]
110	1.00	1.15	1.20	1.00	1.15	1.20	1.00	1.14	N/A[2]
132	1.00	1.15	1.20	1.00	1.15	1.21	1.00	1.14	N/A[2]
160	1.00	1.15	1.21	1.00	1.15	1.20	1.00	1.15	N/A[2]
200	1.00	1.14	1.21	1.00	1.15	1.20	1.00	0.97	N/A[2]

Notes:-

[1] The listed prices are obtained from various manufactures available in Hong Kong market in June 2015.

[2] N/A means that there is no available listed price from manufacturers