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Energy Efficiency of Air Conditioners in Developing Countries: A Malaysian Case Study

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Abstract. Growing demand for air conditioner (AC) in developing countries has hit an alarming point. Enforcing higher efficiency standards for cooling appliances is one of the easier initiatives that governments can implement to reduce energy consumption and emissions of potent greenhouse gases. Malaysia has adopted the Minimum Energy Performance Standards (MEPS) in 2013 to regulate the energy performance of five common household appliances including ACs. This work sheds light on the overall improvement of AC's energy performance after MEPS implementation. A rigorous data collection exercise was conducted to build a comprehensive sales and technical database of MEPS-compliant ACs covering the years 2013-2015. In 2015, the average energy efficiency ratio (EER) of ACs sold in the local market is 3.4, and the cumulative electricity saving and CO₂ emission reduction after MEPS implementation are 1,764 GWh and 1,178 ktCO₂eq respectively. The results from this study will contribute significantly to the review of the effectiveness of MEPS implementation in developing countries.

Keywords: energy efficiency; emissions reduction; minimum energy performance standards (MEPS); air conditioner; inverter.

1. Introduction

Air conditioner (AC) has become an essential comfort feature in modern homes, particularly for households in tropical and desert climates. Statistics have shown that the use of AC is escalating especially in developing countries in line with their rapid economic development and increased living standards [1]. Taking China for example, the adoption of room ACs in urban households had increased from less than a percent in 1990 to 112% in 2011, an astonishing increment of more than 300 times in just twenty years [2]. A survey conducted in several economically developed Chinese provinces also found that room AC ownership increases almost linearly with the increase of per capita annual income [3]. Many other countries echo similar circumstances [4]. **Figure 1** shows the growth of AC usage in 150 developing countries and emerging economies. The total number of stock AC in these countries is poised to hit 1.5 billion in 2030, which is about 94% of the amount of AC presently in use across the globe [5].



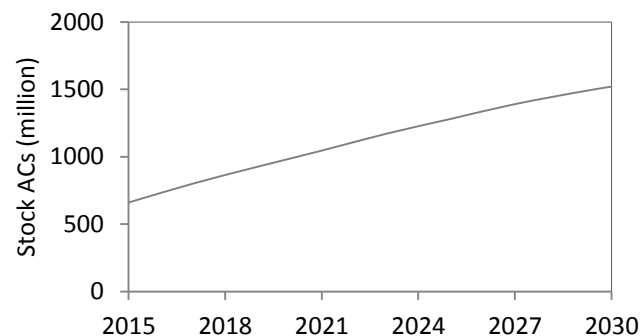


Figure 1: Projection of AC usage in developing countries (*Source: U4E Country Assessments*)

Modern AC nowadays does not merely cool the air, but is also equipped with nano-technology and smart air-purifying devices that are able to remove moisture and improve the indoor air quality by filtering airborne bacteria and viruses. Unfortunately, as good as it may sound, AC is also energy intensive; amounted to 1 trillion kilowatt hours of global energy consumption [1], therefore putting a strain on energy demand in many countries. Furthermore, the coolant or refrigerant widely used in AC, hydrofluorocarbons (HFCs), is a serious climate threat. A recent investigation by United Nation on 150 developing countries has found that AC alone was responsible for 640 million tonnes of carbon dioxide equivalent (CO_{2e}) emissions, which accounts for about 2% of the global energy-related CO_2 emissions in 2014 [6]. Under these circumstances, there is a growing emphasis on accelerating the adoption of more energy efficient and environmental friendly ACs.

If all developing countries adopted energy efficient products with proper standard settings and labelling, there would be massive energy saving and overall energy efficiency improvement of home appliance stock. A proper enforcement of energy efficiency standards is therefore necessary to increase penetration of high efficiency products into developing countries. The minimum energy performance standard (MEPS) is customarily used to specify the maximum amount of energy that a particular electrical device could consume in performing a certain task. MEPS has effectively brought significant economic and environmental benefits [5, 6] in more than 70 countries. In ASEAN countries, regulators and regional bodies are working diligently to advance their energy policies, strategies and actions to phase-out inefficient products especially AC and lighting.

2. AC Utilization in Malaysia

As a member of ASEAN countries, and one of the world's emerging economies, Malaysia is no exception to the rising AC usage. Malaysia has a tropical forest climate [7], with 13 out of its 35 cities identified as "mildly dry" to "dry"[8]. With rising economy and relatively warm temperature all year round, AC ownership in Malaysian household has increased from 31% in 2009 to 38% % in 2012 [9]. In 2013, the Energy Commission of Malaysia has implemented MEPS to standardize the energy performance of ACs. Standard and Industrial Research Institute of Malaysia (SIRIM) Berhad was tasked to develop the mandatory national standards. SIRIM has established *MS 2597:2014 Minimum Energy Performance Standards (MEPS) for Air Conditioner* which specifies the requirements for room ACs, classified as "single-phase, non-ducted, single split wall mounted type vapour compression air conditioners with cooling capacity up to 7.1 kW". Centralized and built-in ACs are currently excluded from the scope of the MS 2597:2014.

The Energy Efficiency Ratio (EER) and the Seasonal Energy Efficiency Ratio (SEER) are the two main types of metrics in use internationally to rate the energy efficiency of ACs. The EER metric is currently adopted in Malaysia to measure the ratio of the cooling capacity and the power consumed

when measured at full load. Testing may be done locally at SIRIM or abroad at test laboratories recognized by the Department of Standards Malaysia. Based on the tested EER, star rating will be assigned to the product model in accordance to MS 2597:2014. The MEPS star rating for the rated cooling capacity (RCC) are tabulated in **Table 1**.

Table 1: MEPS Star Rating for AC

(i) RCC < 4.5 kW			(ii) 4.5 kW ≤ RCC ≤ 7.1 kW		
Star Rating	Tested (BTu/h)/W	EER	Star Rating	Tested (BTu/h)/W	EER
5	>11.94		5	>10.71	
4	11.16 - 11.93		4	9.83 - 10.70	
3	10.37 - 11.15		3	8.94 - 9.82	
2	9.56 - 10.36		2	8.03 - 8.93	
1	9.00 - 9.55		1	7.50 - 8.02	

Before MEPS, there is no established performance monitoring and quantification of the EER for ACs in Malaysia. Quantifying how much energy have been saved from MEPS program is of increasing national interest, especially with increasing environmental concerns and rising energy demand. This need has led the authors to conduct a study to assess the effectiveness of MEPS implementation in Malaysia.

3. Methodology

3.1. Data Collection Method

The authors conducted a rigorous data collection of MEPS-compliant AC sales covering the years 2013-2015. The sales data were acquired from major manufacturers and distributors that hold Certificate of Approval (COA) by the Energy Commission, with 95% coverage of the data set of all MEPS-compliant appliances (1,150 COAs out of the 1,215 COAs issued by 2015). Technical data on cooling capacity and power input were also collected and all information consolidated into a comprehensive database.

3.2. Energy Efficiency Ratio (EER)

The EER is the metric adopted in Malaysia to assign energy efficiency rating for MEPS-compliant AC.

$$EER = \frac{\text{Cooling Capacity (W)}}{\text{Power Input (W)}} \quad (1)$$

Where 1 W = 3.412 Btu/hr

3.3. Annual Electricity Consumption (AEC)

To calculate annual electricity consumption for each AC model, the following equations are used as recommended by SIRIM for both AC types assuming 8 hours running time per day;

For non-inverter type,

$$A = \frac{365 \text{ days} \times 8 \frac{\text{h}}{\text{day}} \times \text{Power Input measured (W)}}{1000} \quad (2)$$

For inverter type,

$$A = \frac{365 \text{ days} \times 8 \frac{\text{h}}{\text{day}} \times ((0.4 \times \text{Power Input}_{\text{full-load}} \text{W}) + (0.6 \times \text{Power Input}_{\text{half-load}} \text{W}))}{1000} \quad (3)$$

Where A [kWh] is the annual electricity consumption for each AC model.

The power input $_{\text{half-load}}$ and the tested cooling capacity (Btu/hr) are reported in SIRIM's test report. To calculate total annual electricity consumption, the total annual electricity consumption of ACs determined previously was multiplied by the number of models sold in that year.

$$AEC_{total,year} = \sum (AEC_{model} \times NUS_{model,year}) \quad (4)$$

Where $AEC_{total,year}$ [kWh] is the total electricity consumed by MEPS-compliant ACs in a particular year while AEC_{model} [kWh] is the annual electricity consumption for each model $NUS_{model,year}$ is the number of units sold for a model in that same year.

3.4. Annual Electricity Saving (AES)

The maximum potential electricity saving was estimated by comparing the calculated annual electricity consumption with the annual consumption of the lowest 2-star rating model of the same equipment type, a similar approach applied by Energy Commission in the National Energy Efficiency Action Plan (NEEAP) [5]. By using the tested cooling capacity and EER as reference, the electricity consumption per year for the lowest 2-stars rating model measured (kWh) can be calculated by using Equation 5 and 6 below.

i) For cooling capacity of $\leq 4.5\text{kW}$, $EER_{\text{Lowest 2-star model}} = 2.80$,

$$B = 365 \text{ days} \times 8 \frac{\text{h}}{\text{day}} \times \frac{\text{Tested cooling capacity (kW)}}{2.80} \quad (5)$$

ii) For cooling capacity of $4.5\text{kW} \leq \text{cooling capacity} \leq 7.1\text{kW}$, $EER_{\text{Lowest 2-star model}} = 2.35$,

$$B = 365 \text{ days} \times 8 \frac{\text{h}}{\text{day}} \times \frac{\text{Tested cooling capacity (kW)}}{2.35} \quad (6)$$

Where B [kWh] is the annual electricity consumption for each AC model in reference to 2-stars rating model.

The amount of energy savings compared to the lowest 2-stars rating model was then calculated using equation 7 given below;

$$\text{Energy savings per model} = A - B \quad (7)$$

Thus, the total annual energy saving, gained for both AC types can be estimated using equation 8 as below;

$$AES_{total,year} = \sum (AES_{model} \times NUS_{model,year}) \quad (8)$$

Where $AES_{total,year}$ [kWh] is the total electricity saving by MEPS-compliant ACs in a particular year while AES_{model} [kWh] is the annual electricity saving for each model and $NUS_{model,year}$ is the number of units sold of a model in that same year.

3.5. CO₂ Emission Reduction (CER)

As for the annual carbon emission reduction, $CER_{total,year}$ [ktCO₂eq], it is determined based on the total annual electricity saving, $AES_{total,year}$ [GWh] times by the grid emission factor, GEF_{region} [tCO₂eq/MWh].

$$CER_{total,year} = AES_{total,year} \times GEF_{region,year} \times GA \quad (9)$$

Where GA [%] is the grid allocation.

Malaysia is served by three electricity grids; the TNB grid for Peninsular Malaysia that serves about 90% of the electricity demand, the SEB grid for Sarawak and the SESB grid for Sabah. Sabah and Sarawak are states on the East Coast of Malaysia. Since each grid has different profiles for generation capacity, the grid emission factor is also different for each grid as tabulated listed in **Table 2**.

Table 2: Grid Emission Factor by Region

Grid emission factor (tCO ₂ /MWh) **	2013	2014	2015
Peninsular Malaysia (TNB Grid)	0.742	0.694	0.659
Sabah (SESB Grid)	0.533	0.536	0.572
Sarawak (SEB Grid)	0.430	0.335	0.421

Source: Compiled from [10]; [11];[12]

The annual carbon emissions reductions are allocated amongst the three grids using the same ratio adopted in NEEAP, whereby 90% of the carbon emissions reductions is allocated to Peninsular Malaysia, while Sabah and Sarawak are allocated 5% each.

4. Results and Discussion

4.1. Energy Efficiency Performance

Figure 2 indicates the energy performance of ACs sold in the local market from year 2013 to 2015. The average energy efficiency measured as the Energy Efficiency Ratio (EER) increases very slightly from 3.34 in 2013 to 3.40 in 2015. The average annual efficiency increment is close to 1%. However, the range of available EER sold in the market does show an interesting yearly improvement. The MEPS implementation has raised the bar for minimum EER by 8% from 2.38 in 2013 to 2.56 in 2015. In the meantime, the maximum EER shows higher improvement with a dramatic increase from 4.57 in 2013 to 5.24 in 2015, constituting a 14% increment. The Malaysian market average of EER is found to be comparable to India which has average EER range between 3.0 – 4.0 [6]. It is also slightly higher than China's minimum efficiency for AC which is 3.2 in 2009 [1]. Since China plays a major role as the world's top AC manufacturer and exporter, China's minimum EER can be regarded as the current best practice.

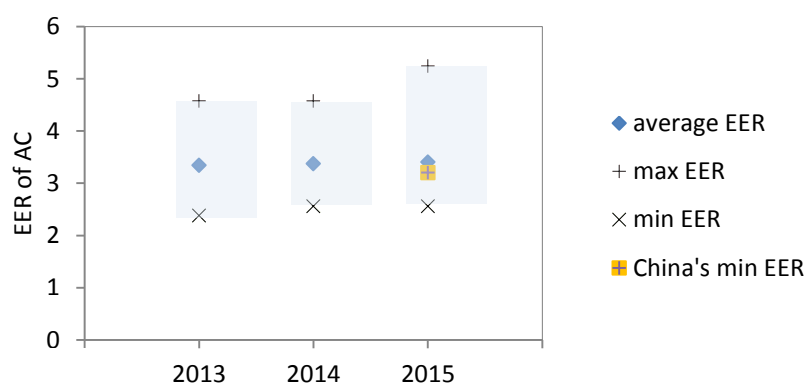


Figure 2: Energy performance of ACs after MEPS implementation.

4.2. Annual Electricity Consumption and Saving

The annual electricity consumption and saving by MEPS-compliant ACs are shown in **Figure 3**. Generally, both of them increase every year with average annual increment of 12% and 38%

respectively. Higher rate of annual electricity saving can be observed as it leaps from 404 GWh in 2013 to 762 GWh in 2015, caused by increased adoption of more efficient ACs especially the inverter type. Based on our analysis, inverter type AC consumes about 30-40% less electricity than the non-inverters. Inverter type AC in general has the flexibility to vary the compressor's speed and power in accordance to the cooling requirement of the room. On the other hand, regular type AC will have to run at full capacity and peak power requirement every time the compressor is running hence consuming more energy. In order to further improve AC's energy efficiency, innovative technologies could also be applied to fans, heat exchangers, expansion devices, and refrigerant fluids. The potential saving that could be gained if all these technologies were applied together in an AC unit is between 60 – 72 per cent of energy compared to non-inverter model [6].

Meanwhile, the annual electricity consumption of ACs also steadily increases every year reaching 3,128 GWh in 2015. Even though the government has attempted to reduce energy consumption per appliance through MEPS, the total energy consumption still increases every year due to increased sales volume of ACs. The average sales growth of AC from 2013 to 2015 is about 13% annually, most likely due to increased population and per capita annual income. Besides that, improved efficiency could also influence people to buy more AC unit for their house since the efficient models consume less electricity hence saves money, producing what is known as the rebound effect.

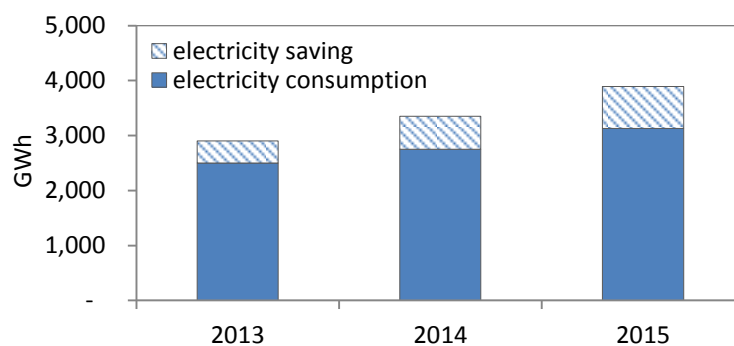


Figure 3: Annual electricity consumption and saving of MEPS-compliant ACs.

4.3. CO₂ Emission Reduction

Figure 4 shows the resulting annual emissions reductions from the increase of AC's energy efficiency. Assuming that emission reduction will carry over annually after the purchase of ACs in a given year, the total cumulative amount of emissions reduction after MEPS implementation on AC in 2015 is 1,178 ktCO₂eq.

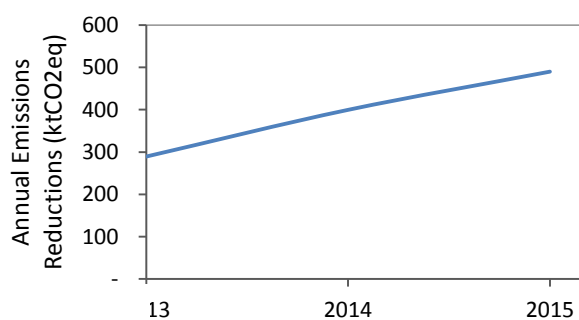


Figure 4: Annual emissions reductions after MEPS implementation.

5. Conclusion and Future Works

Increased energy use has become a critical global issue. Setting higher energy efficiency standards for household electrical appliances has been proven to reduce the rising energy demand. The increase of the market average of EER proves that MEPS has increased the diffusion of efficient ACs into Malaysian market. EER is typically the metric chosen when MEPS is being implemented in a country for the first time. However, many developed countries including Singapore has already transitioned to the Seasonal Energy Efficiency Ratio (SEER) metric which is actually a derivative of EER with more complicated formula to weigh in the different part load periods and variable speed systems. Malaysia could adopt SEER for AC with variable speed system in the future as it is more representative of the seasonal performance of AC, and also better at estimating the potential energy savings. Besides SEER, since Malaysia falls into the tropical climate zone, the Cooling Seasonal Performance Factor (CSPF) metric could also be adopted as it takes into account the ratio between the annual amount of heat removed and the amount of energy consumed. So far, CSPF has been adopted by Republic of South Korea and Vietnam.

As one of developing countries with manufacturing capacity, Malaysia is already a member of ASEAN SHINE, which is a platform for harmonizing energy efficiency initiatives in ASEAN. Harmonization of the energy efficiency standards and testing method and should be able to path the way to an integrated regional policy approach so that the diffusion of highly efficient products could be accelerated and sustained by the domestic market. Focusing on ASEAN SHINE initiatives for ACs, ASEAN member countries have agreed to a uniform testing method derived from ISO5151-2010 and to a minimum EER of 2.9W/W or CSPF of 3.08W/W by 2020 as mandatory MEPS for all fixed and variable drive ACs below 3.52kW capacities.

The large annual increment of total energy consumption of ACs also alludes to a rebound effect that may counteract the MEPS policy measures to reduce energy consumption in the residential sector. Rebound effect occurs when behavioural or a systemic response negates the savings achieved through technological improvements. As AC prices are likely to decrease due to economies of scale, the ownership of AC would accelerate even more. As a consequence, the energy saving target could not be achieved. For that reason, complementary efforts to educate consumers on smart purchasing and smart behavior when utilizing ACs are also important to minimize rebound effect.

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