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DEVELOPING ENERGY EFFICIENCY STANDARD AND ITS IMPACT ON REFRIGERATOR FREEZERS IN MALAYSIA

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ABSTRACT

Refrigerator-freezers are one of the major energy users in the residential sector of Malaysia. In line with the rapid economic growth, the ownership of household refrigerator-freezers increased rapidly for the last 10 years. There has been a tremendous increase in the use of household refrigerator-freezers (877749 units) from 1990 to 1999 and by the year 2020, there will be about 5623647 units. So, there is a huge saving potential by introducing cost-effective energy policy like energy efficiency standards. Energy efficiency standards are cost-effective approaches that can help to improve the efficiency of these appliances.

In the present study, six household refrigerator-freezers of different models and capacities have been tested in the energy conservation laboratory, Department of Mechanical Engineering, University of Malaya to investigate the energy consumption behavior of these appliances. The test has been carried out according to the ISO refrigerator-freezers test specifications. Using the experimental data of the ISO test conditions, a baseline standard has been developed by the statistical method. From the baseline standard, 5% and 10% standards as a function of adjusted volume have been developed. Impacts of energy efficiency standards have also been calculated and presented in this paper.

Key Words: *Energy efficiency standards, Refrigerator-freezers, Test procedure*

1.0 INTRODUCTION

Turiel et al. [1], Waide et al. [2], Nakagami and Litt [3] reported that the energy efficiency standard is a government approach that limits the energy consumption of a particular appliance. It prohibits the production of inefficient appliances from the market. The standards can be either mandatory or voluntary in nature. It also can be in the form of minimum allowable energy efficiency or a maximum allowable energy use. Standards can be performance based or prescriptive in

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nature. Performance types standards state the allowable energy use or energy efficiency whereas the prescriptive standards require the presence of some features. Mandatory Minimum Energy Efficiency Standards (MMEES) are generally the most effective means of rapidly improving the energy efficiency of household appliances. The MMEES is a government mandated standard that defines minimum levels of efficiency or maximum levels of energy consumption that must be met by all products sold in a particular jurisdiction [4-6].

Unlike many other initiatives, MMEES has the advantage because their benefits are comparatively simple to quantify. They treat all manufacturers, distributors, and retailers equally and the resulting energy savings can be comparatively guaranteed. Voluntary energy efficiency standards negotiated between the government and manufacturers are an alternative option to MMEES. They have the merit of being less controversial and hence easier to enact [7-8]. But they can be a disadvantage to signatory manufacturers in comparison with non-signatory manufacturers (typically domestic manufacturers as opposed to importers). The fact that voluntary standards are seldom universal and are not obligatory means that it is very difficult to persuade manufacturers to agree to a measure which will either reduce their profit margin or increase the purchase price of their goods. This arises because of the legitimate fear that competitors will not follow suit. For MMEES, a small increase in production cost is usually anticipated but because in principle, this applies to all manufacturers equally, it can be safely passed on the consumer without losing market share. If the MMEES are designed properly, the consumer will more than recoup the increased purchase cost through reduced operating costs, while manufacturer sales and profits should not be adversely affected [2].

With the ongoing increase in number of these appliances, residential energy consumption in Malaysia has also increased at an average rate of 13% over the year of 1990-2000 [9]. To mitigate the future demand for increased energy, the government either has to build up new power plants or introduce cost effective energy efficiency strategies like standards.

Unfortunately, because of the economic downturn in South East Asian countries in 1997, the government had to postpone the building up of the Bakun power plant, providing the emphasis on improving energy efficiency. Energy efficiency standards and labels are the cost-effective approaches that can help to improve appliance efficiency. This study is significant in the view that Malaysia is going to adopt energy efficiency standards for household electrical appliances.

2.0 STANDARD TEST PROCEDURE

The test has been carried out as per ISO refrigerator-freezers energy test requirements. The following is a brief overview of ISO test specifications for energy performance testing and rating of these appliances.

2.1 International Standard (ISO)

The International Organization for Standardization is a worldwide federation of national standard body. ISO 8187 [10], ISO 8561 [11] and ISO 7371 [12] are the relevant standards for testing the energy consumption of household refrigerator-freezers having two or more compartments. At least one compartment (the fresh food storage compartment) is suitable for storing unfrozen food, and at least one compartment (the food freezer compartment) is suitable for freezing fresh food and for the storage of frozen food at -18°C or colder.

According to the ISO standard, the test period shall be at least 24 hours long with no door openings. Relative humidity should be kept within 45%-75% inside the test chamber with freezer temperature. The room temperature should be maintained at 32°C based on tropical test condition. An excellent overview of these standards has been summarized in Ref. [13].

3.0 APPROACHES IN DEVELOPING ENERGY EFFICIENCY STANDARDS

There are three approaches to develop energy efficiency standards. These are: (i) Statistical, (ii) Engineering, and (iii) Consensus approach. These are outlined in the following:

3.1 Statistical Approach

This approach is also known as the short-term approach to establish energy efficiency standard as per European Union [21]. The statistical method is based on market research of the given appliance. The statistical approach requires fewer data and less analysis than the engineering/economic approach. The data required are those, which give a current characterization of marketplace for the products of interest. A standard level can then be selected after a decision is made as to the energy savings goal and or the number of models acceptable to be eliminated from the current marketplace. This approach looks at the models available at a particular tune and performs a regression analysis to determine the dependence of energy use on adjusted volume (*An adjusted volume is the sum of the volumes of the different compartments weighted by the difference in temperatures between interior of the compartment and the ambient temperature*). After the calculation of the regression line i.e. reference line, the desired goal such as 5% and 10% energy savings lines are drawn from the reference line. The minimum efficiency line or reference line is defined as the line of maximum efficiency index. The efficiency index of a model is the percentage that the energy is above or below the reference line. The efficiency index can be explained by the following equation:

$$I_{eff} = \frac{E_a}{E_{ref}} \tag{1}$$

An energy efficient appliance is located by a point below the reference line and therefore has an index lower than 1. A less efficient appliance has a point above the reference line and an index value greater than I as shown in Figure 1. This approach has been utilized in the European Union (EU) and in Australia. The principle used for defining minimum efficiency line is as follows.

Minimum efficiency standards will prohibit the least energy efficient units from the market. The manufacturers will have to improve or replace the energy efficiency of given models within the time allowed before prohibition comes into force. In reality, poorly efficient units located above the cloud points will be phased out and replaced by a unit with lower efficiency index.

Hence, minimum efficiency standards are defined as a linear equation above which all units are forbidden from the market [14].

Standard Energy Consumption Equations: With the current average standard, 5% standard, and 10% standard, energy consumption as a function of adjusted volume can be expressed by the following equations:

$$E_{max} = \alpha * V_{adj} + \delta \tag{2}$$

$$V_{adj} = \Sigma\, V_c \times W_c \times F_c \tag{3}$$

$$W_c = \frac{(T_a - T_i)}{(T_a - T_{rf})} \tag{4}$$

Significance of Using Adjusted Volume: Refrigerator-freezers' energy consumption depends on the appliance volume and on the temperature difference between the surroundings and the inside of the refrigerator-freezers. The adjusted volume is a measure of the refrigerator-freezers volume adjusted to reflect the various operating temperatures of different compartments.

3.2 Engineering Analysis

There are several parts to an engineering analysis, which have been widely used by Lawrence Berkeley Laboratory (LBL) for the U.S. Department of Energy. Firstly, an engineering analysis is carried out for each product type to determine manufacturing costs for improving the efficiency of a baseline model [1].

The following seven steps form the core engineering analysis:

(i) selection of appliance classes
(ii) selection of baseline units
(iii) selection of design options for each class

(iv) calculation of efficiency improvement from each design option
(v) combination of design options and calculation of efficiency improvements
(vi) developing cost estimates for each design option
(vii) generation of cost-efficiency curves.

Life Cycle Cast Analysis: One measure of the effect of proposed standards on consumers is the change in operating cost as compared to the change in purchase price, both resulting from standards. This is quantified by a difference in life cycle cost (LCC) between the base and standards case for the appliance analyzed. Life cycle cost is analyzed as a function of five variables: discount rate, fuel price, appliance lifetime, incremental price and incremental energy savings. The frequency of occurrence of the minimum LCC at each design option determines the optimum efficiency level [15].

The LCC is the sum of the purchase price and the operating expense discounted over the lifetime of the appliance. It can be defined by the following equation.

$$\textit{Life Cycle Cost (LCC)} = \textit{Purchase price} + \textit{NPV} \, {*}(\textit{Energy cost per year}) \quad (5)$$

where,

$$\textit{Net Present Value} = NPV = \frac{1}{r}\left\{1 - \frac{1}{(1+r)^N}\right\} \quad (6)$$

Payback Period: The payback period measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. Payback period (*PAY*) can be defined by following equation

$$PAY = \frac{\Delta PC}{\Delta OC} \quad (7)$$

The payback period is the ratio of the increase in purchase price (ΔC) from the base case to the standards' case to a decrease in the annual operating costs (ΔOC). A payback period greater than the lifetime of the product means that the increased purchase price is not recovered in reduced operating costs. A payback period greater than its lifetime is not economically viable for energy efficiency improvements [16].

3.3 Consensus Approach

In the consensus approach, two or more groups get together and decide on the standards through a joint process. These groups could be some combination of a government regulatory agency, environmental/consumers groups and appliance manufacturers. This approach was used in the United States in establishing the first national efficiency standards that were incorporated into law in 1987 [1].

4.0 ENERGY CONSUMPTION AS PER ISO TEST CONDITIONS

Standard energy consumption of 6 refrigerator-freezers as per ISO test specifications (details in Section 2.1) was investigated and calculated in kWh/year for models A, B, C, D, E, and F based on daily energy consumption. The yearly energy consumption of these models with adjusted volume is presented in Table 1. The specifications of these models are shown in Table 2.

5.0 SETTING EFFICIENCY STANDARDS

As this research is concerned with the statistical method of developing standards, the average standard, 5% standard, and 10% standard needs to be developed. These standards have been developed using principles described in the statistical method (Section 3.l) of establishing standards.

5.1 Current Average Standard

This standard is equal to the reference line, which is shown in Figure 2. This reference line was created using yearly energy consumption (i.e. energy consumption as per ISO test conditions) as a function of adjusted volume.

The standard energy consumption in the form of an equation can be expressed as:

$$E_{\max} = 1.23V_{adj} + 448 \qquad (8)$$

5.2 5% standard

The standard is set so that an average energy saving of 5% is achieved compared to average standard energy consumption. This standard is shown in Figure 2. The standard energy consumption in the form of an equation can be expressed as:

$$E_{\max} = 1.07V_{adj} + 457 \qquad (9)$$

5.3 10% standard

The standard is set so that an average energy saving of 10% is achieved compared to average standard energy consumption. The standard energy consumption in the form of an equation can be expressed as:

$$E_{\max} = 1.03V_{adj} + 418 \qquad (10)$$

6.0 IMPACT OF ENERGY EFFICIENCY STANDARDS

The purpose of this part is to forecast energy savings, bill savings, and emission reduction after the standard is enacted. In order to do so, the following input data must be considered [14 and 17].

1. Appliance ownership
2. Average unit energy consumption per year
3. Fuel price
4. Emission factor

Using the above input data, Baseline Annual Energy (BAE), Annual Energy (AE), Bill Savings (BS), CO_2 reduction for baseline standard (i.e. average standard), 5% standard, and 10% standard have been calculated and shown in Table 3. Average baseline unit energy consumption was multiplied with the number of appliances for a particular year to get the BAE. Average unit energy consumption for 5% and 10% standards was multiplied with the number of appliances for a particular year to get the AE (5%) and AE(10%). Annual Energy Savings (AES) was calculated by deducting AE frown BAE. AES was multiplied with the electricity price to get bill savings. CO_2 reduction was calculated by multiplying emission factor with the ASS. All the prediction data discussed above are shown in Table 3.

6.1 Appliance Ownership

Appliance ownership for the year 1990-1999 has been obtained from Wan [19] and shown in Table 4. Based on this data, appliance ownership for the year 2000-2020 has been predicted and shown in Table 3.

6.2 Average Unit Energy Consumption (AEC) Per Year

AEC or baseline energy consumption has been determined using the statistical approach. Once the base line energy consumption could be determined, efficiency level (i.e. 5%, 10% standards) could be reached by using the same methodology described in the statistical approach. Figure 2 shows the baseline standard, 5% and 10% standards. The baseline annual unit energy consumption is 946 kWh. Average unit energy consumption was obtained by summing up energy consumption of 6 units and then dividing it by 6. The average unit energy consumption for the 5% and 10% standards is 900 kWh/year and 851 kWh/year, respectively. The average unit energy consumption for different standards has been shown in Table 1.

6.3 Electricity Price

The value of energy savings (bill savings) is calculated using electricity price, which is 0.235 sen/kWh of energy in Malaysia [9].

6.4 Emission Factor

Emission factor is needed to calculate the CO_2 reduction due to implementation of standards. An average emission factor of 0.46 kg/kWh was used in this analysis [14 and 18]. Corresponding emissions reduction could be estimated by multiplying the emission factor with energy savings for each standard.

7.0 CONCLUSIONS

Energy efficiency standards are gaining tremendous success around the world. For example, in the USA energy consumption of 510 liter refrigerator-freezers were reduced from 1926 kWh/yr to 649 kWh/yr from 1972 to 1995 with the introduction of energy efficiency standards. Korea has reduced its energy consumption by 18% from 1992 to 1999 [20].

It would be more effective to implement energy efficiency standard as mandatory rather than voluntary because mandatory minimum energy efficiency standards are universal and must be abide by all manufacturers.

It is estimated that the energy efficiency standards will save 3978 GWh and 8216 GWh energy **(cumulative)** for 5% and 10% standards respectively, from 2003 to 2020 if the standard is enforced from the year of 2003. This means using the current average price (23.5 sen/kWh), the total bill savings will be RM 934 million (1 USD = 3.80 RM) and RM 1930 million for 5% and 10% standards respectively. The corresponding CO_2 reduction that could be achieved are 1830208 and 3779779 tons for 5% and 10% standards respectively. For a country like Malaysia, the above savings are quite significant. This will help to avoid building up of new power plants as well as preventing the country from environmental degradation.

The standards can be developed for other appliances such as washing machines. As the energy efficiency standards and labels are complementary, this study will help to establish energy guide labels for household appliances in Malaysia.

Finally, it is expected that by utilizing the success and experiences of the standards from the countries around the world and using the results of the present study, policy makers in Malaysia may introduce the standards so that the above savings could be achieved.

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NOMENCLATURE

α, δ Constants
E Annual energy consumption (kWh)
E_{max} Maximum energy consumption (kWh/year)
E_a Actual energy consumption (kWh/year)
E_{ref} Reference or baseline energy consumption (kWh/year)

F_c Constant: for frost free compartment, the value is 1.2, otherwise 1.0
I_{eff} Efficiency index
N Appliance life span in years
r Discount rate (%)
T_a Ambient temperature (°C)
T_i The related temperature of different types of freezer compartments (^oC)
T_{rf} The related temperature of fresh food compartment 5^oC
V_{adj} Adjusted volume (liter)
V_c Effective volume of a given compartment (liter)
W_c Coefficient of weighing factor

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Table 1 Yearly Energy Consumption as per ISO Standards

Model	Adjusted volume (V_{adj})(liter)	Yearly energy consumption (kWh/year)	Unit energy consumption (kWh/year)		
			Average	5% standard	10% standard
A	175	694			
B	183	650			
C	398	912.5	946	900	851
D	404	949			
E	619	1292			
F	665	1179			

Table 2 Technical specifications of different models

Specifications	Model A	Model B	Model C	Model D	Model E	Model F
Freezer capacity (liter)	40	40	80	80	142	130
Fresh food compartment capacity (liter)	110	115	220	220	350	330
Power rating (W)	115	90	160	160	190	165
Current rating (A)	0.67	0.60	0.9	0.9	1.35	1.3
Voltage (V)	240	240	220	220	220-240	240
Frequency (Hz)	50	50	50	50	50	50
No of door	1	1	2	2	2	2
Refrigerant type	134a (CF_3CH_2F)	134a (CF_3CH_2F)	134a (CF_3CH_2F)	134a (CF_3CH_2F)	134a (CF_3CH_2F)	134a (CF_3CH_2F)
Defrost system	Partial auto	Partial auto	Auto defrost	Auto defrost	Frost free	Frost free

Table 3 Prediction summary of impact of standards

Year	Refrigerator (No.)	BAE (GWh)	AE (10%) (GWh)	AE (5%) (GWh)	AES (10%) (GWh)	AES (5%) (GWh)	BS(10%) (RM million)	BS (5%) (RM million)	CO2 (10%) (Tons)	CO2 (5%) (Tons)
2003	3986776	3771	3392	3588	378	183	89	43	174222	84360
2004	4083062	3862	3474	3674	387	187	91	44	178429	86397
2005	4179349	3953	3556	3761	397	192	93	45	182637	88435
2006	4275635	4044	3638	3848	406	196	95	46	186845	90472
2007	4371922	4135	3720	3934	415	201	97	47	191052	92509
2008	4468208	4226	3802	4021	424	205	99	48	195260	94547
2009	4564495	4318	3884	4108	433	209	101	49	199468	96584
2010	4660781	4409	3966	4194	442	214	104	50	203676	98622
2011	4757068	4500	4048	4281	451	218	106	51	207883	100659
2012	4853354	4591	4130	4368	461	223	108	52	212091	102696
2013	4949641	4682	4212	4454	470	227	1105	53	216299	104734
2014	5045927	4773	4294	4541	479	232	112	55	220507	106771
2015	5142214	4864	4376	4627	488	236	114	56	224714	108809
2016	5238500	4955	4457	4714	497	240	116	57	228922	110846
2017	5334787	5046	4539	4801	506	245	119	58	233130	112884
2018	5431074	5137	4621	4887	515	249	121	59	237337	114921
2019	5527360	5228	4703	4974	525	254	123	60	241545	116958
2020	5623647	5319	4785	5061	534	258	125	61	245753	118996
TOTAL					**8216**	**3978**	**1930**	**934**	**3779779**	**1830208**

Table 4 Household refrigerator-freezers ownership in Malaysia

Year	Refrigerator-freezer (No.)
1990	2742514
1991	2830085
1992	2920183
1993	3012744
1994	3107788
1995	3205316
1996	3305327
1997	3407822
1998	3512801
1999	3620263

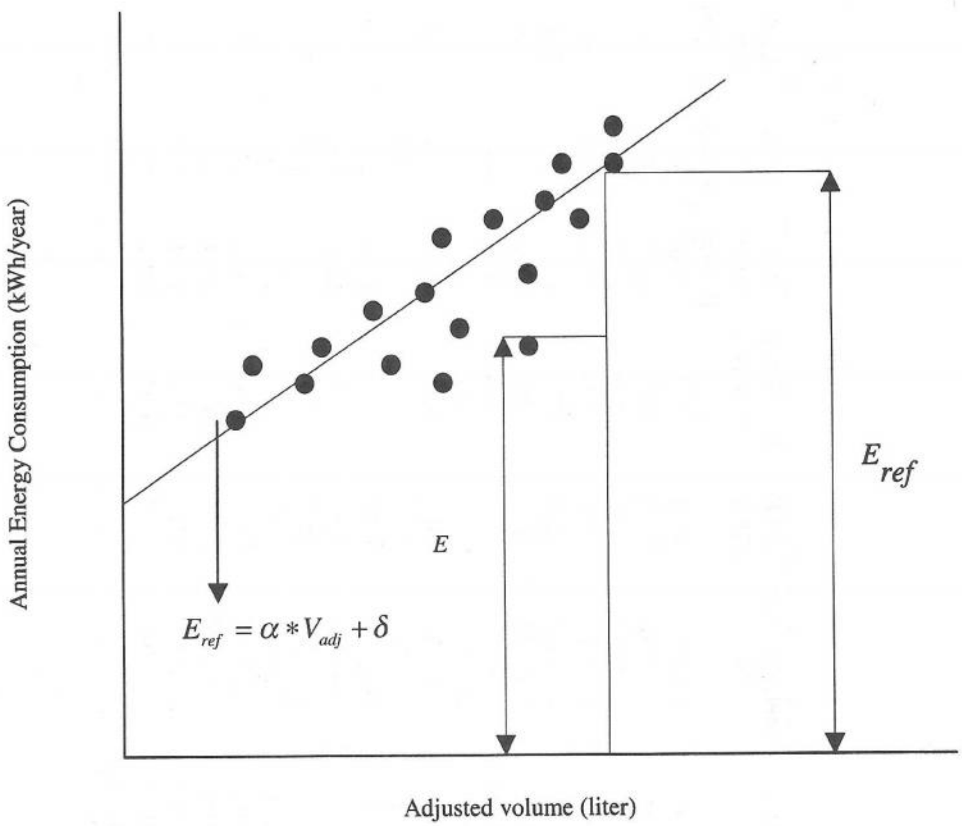

Figure 1 Refrigerator-freezer energy consumption as a function of adjusted volume

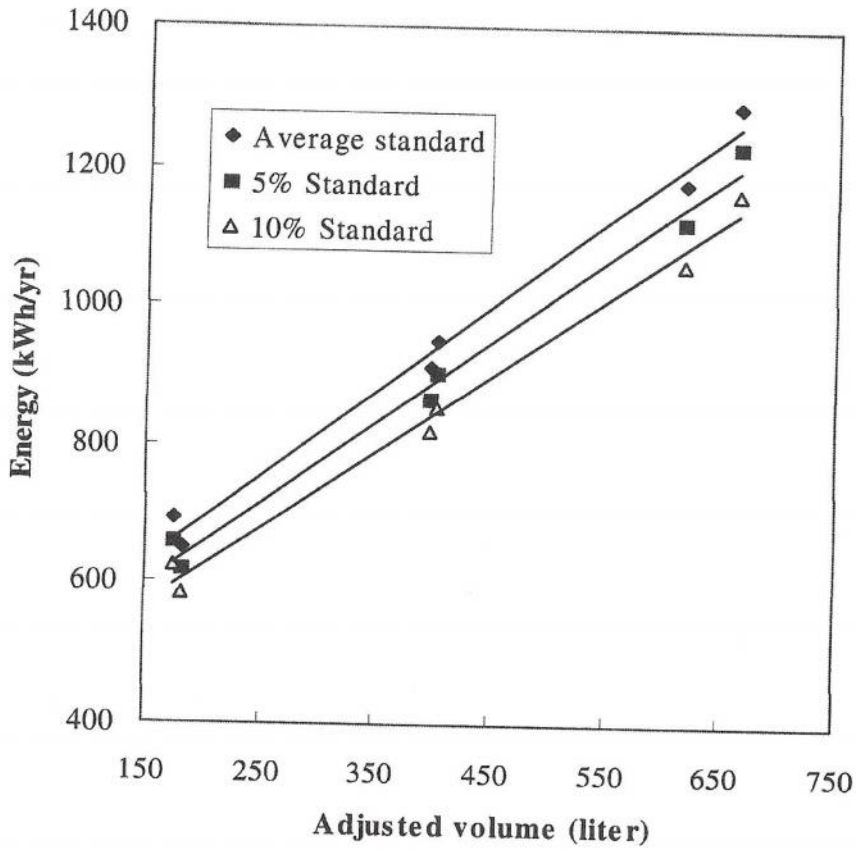

Figure 2 Annual energy consumption vs adjusted volume