Different Methods of Grading or Rating Refrigerator Freezers

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Abstract: As refrigerator-freezers are one of the major energy consuming appliances in the household environment, a great deal of attention has been paid to improve their efficiency throughout the world. In order to reduce their energy consumption, cost effective policy and strategies, such as energy efficiency standards and labels are in place for a number of countries and several other countries are in the processes of establishing these strategies. To attain standards and labels, an appliance grading or rating system must be established to demonstrate the products performance in the most comprehensive way. The grading or rating system provides a clear idea to consumers about the products' energy performance. This paper mainly focuses on different ways of grading or rating household refrigerator-freezers using current data in Malaysia.

Keyword: Refrigerator-freezers, grading, energy efficiency index, adjusted volume, standards.

Introduction

Refrigerator-freezers are one of the bulk energy users in the residential sector of Malaysia as this appliance has to operate 24 hours continuously, usually under hot tropical conditions. Ownership of this type of appliance has increased tremendously for the last several years due to rapid economic growth and the subsequent demand for improved living style and comfort [1-6]. A number of policies and strategies (i.e. standards and labels) are in place or under development for a number of countries in order to make this appliance more efficient by reducing its energy consumption. These energy saving policies have already proven to be cost effective for most of those countries who have already implemented standards, and labeling.

Along with the energy test procedure, energy efficiency standards and labels, grading or rating criteria for these appliances must first be established to get an accurate idea of a product's energy performance.

A number of papers have been published in international journals and conferences by several authors on energy test procedures, efficiency standards and labels and the associated potential energy savings and environmental benefits as a result of the introduction of these policies and strategies [6-8]. However, the different ways of grading or rating of these appliances has not been discussed to any extent. In this paper, the authors main intention is to present different rating systems in a simplified manner to contribute to better understanding of the different approaches.

Computation of Energy Efficiency Factor

1. Calculation of energy efficiency factor (EEF) and energy efficiency ratio (EER)

$$\text{EEF} = \frac{\text{Adjusted volume (litre)}}{\text{Energy consumption (kWh/24h)}}$$

Adjusted volume = $[FFV + FZV] * K * Fc$

FFV = fresh food compartment volume

FZV = freezer compartment volume

K = adjustment factor

F_c = frost free factor

$$K = \frac{\text{Test room temperature - Freezer compartment temperature}}{\text{Test room temperature - Fresh food compartment temperature}}$$

$$\text{EER} = \frac{\text{Energy consumption (kWh/year)}}{\text{Adjusted volume (litre)}}$$

Adjusted Volume: Refrigerator-freezer energy consumption depends on the appliance volume and on the temperature difference between the surroundings and the inside of the refrigerator-freezer. The adjusted volume is a measure of the refrigerator-freezers volume adjusted to reflect the various operating temperatures of different compartments [9-10].

2. Coefficient of performance (COP):

COP of a refrigerator can be defined as

$$COP = \frac{\text{Cooling effect}}{\text{Work input (to compressor)}}$$

COP of a refrigerator-freezer can be found using compressor calorimeter measurements which have been explained as below:

Nine-point calorimeter measurements can be used to determine the performance of compressors. In this procedure, compressor operating characteristics, including refrigeration capacity/cooling effect and COP of a compressor, are determined at each point in a matrix of 110°F (43.3°C), 120°F (48.9°C), and 130°F (54.4°C) condensing temperatures and -0°F (-28.9°C), -10°F (-23.3°C), and 0°F (-17.8°C) evaporating temperatures. Also specified in the test procedure is a 90°F (32.2°C, based on US standard and ISO) ambient temperature for the compressor, superheating of the suction gas to 90°F (32.2°C), and sub-cooling of the liquid refrigerant line to 90°F (32.2°C) before throttled expansion [11]. These have been shown in Table 1.

Table 1. Compressor calorimeter test result for a refrigerator – freezer compressor [10].

Evaporating temperature (^oF)	Condensing temperature (^oF)			
		110	**120**	**130**
0	Cooling. effect (kcal/hr)	222.4	245.9	269.1
	EER (kcal/hr- W)	0.987	1.104	1.225
-10	Cooling effect (kcal/hr)	160.2	178.8	202.7
	EER (kcal/hr-W)	0.816	0.928	1. 092
-20	Cooling effect (kcal/hr)	114.4	125.2	138.0
	EER (kcal/hr- W)	0.672	0.728	0.837

3. Calculating energy efficiency index using statistical analysis

The statistical method is based on market research of the given appliance. The statistical approach requires fewer data and less analysis. The data required are those that give a current characterization of the 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 that it is acceptable to eliminate from the current marketplace. This approach looks at the models available at a particular time and either performs a regression analysis to determine the dependence of energy use on volume/capacity (i.e. litre, kg etc) and then a regression line i.e. reference line is drawn. The minimum efficiency line or reference a regression line i.e. reference line is drawn. 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. This has been shown in Figure 1. The efficiency index can be explained by the following Equation:

$$Ieff = \frac{E_a}{E_{ref}} \quad (1)$$

An energy efficient appliance is located by a point below the reference line and therefore has in index lower than 1. A less efficient appliance has a point above the reference line and an index value greater than 1. This approach has been utilized in the European Union (EU) and in Australia. The principle used for defining the 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 in the time allowed before prohibition comes into force. In reality, poorly efficient units located above the reference points will be phased out and replaced by units with a higher efficiency index, below the line.

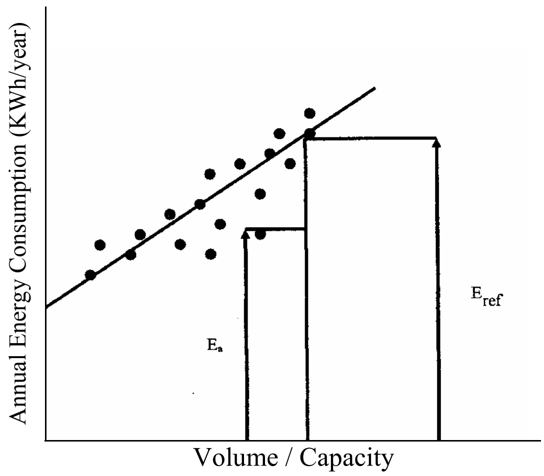

Figure 1. Energy consumption as a function of volume/capacity [13].

Hence, minimum efficiency standards are defined as a linear equation above which all units are less efficient and targeted to be phased out from the market. A plot of energy consumption versus volume/capacity is drawn for each product type. A regression analysis is done to calculate the reference line equation. This yields current average standards [12].

Data collection and analysis

Malaysia does not have well established test procedures, energy efficiency standards and labels which are key elements in getting reliable data. Recently though, the Malaysian government has provided due attention to energy efficiency in the residential sector along with other sectors. As a result, Malaysia is in the processes of developing these key elements for major energy consuming appliances. Different working committees have already been formed in collaboration with the Energy Commission of Malaysia, Malaysian Energy Centre, the Standards and Industrial Research Institute of Malaysia (SIRIM), manufacturer organizations and university professionals, in order establish energy policy measures for major energy consuming appliances. Currently it is very difficult to get accurate data that is needed for this purpose at this initial stage.. However, this data is helpful as a starting point to establish the energy efficiency policies.

The Energy Commission (ST) of Malaysia has formed a committee named “Sub-Working Group on Refrigerator-

Freezers" to establish energy labeling and rating criteria for these appliances. Several refrigerator-freezer manufacturers have already joined this committee [17] and signed a Memorandum of Understanding on Promotion of Energy Efficient Refrigerators (MUPEER) to cooperate in establishing energy efficiency policies for refrigerator-freezers. ST requested the manufacturers to supply necessary data so that a grading system can be established to show a products energy performance. A summary of the data collected from them is presented in Table 2.

Adjusted volume and EER, EEI and EEF has been calculated using raw data and presented in the Table as well. As a result ST has decided to establish grading or rating criteria based on existing data considering that manufacturers data will be verified when the test facilities are ready at SIRIM and the grading system will be revised accordingly.

Energy consumption as a function of adjusted volume has been calculated and plotted in figure 2 to get the average or reference energy consumption. Using E_a and E_{ref}, EEI has been calculated and shown in Table 2.

Table 2. Summary of Data.

Model Name	Adjusted Volume (L)	Energy consumption kWh/24hr	Energy consumption KWh/yr	EER	EEF	E_{ref}	EEI
AM1	245.33	0.96	351.86	1.43	254.49	463.30	0.76
AM2	280.13	1.06	388.00	1.39	263.53	487.27	0.80
AM3	536.12	2.00	730.00	1.36	268.06	663.57	1.10
AM4	586.12	2.00	766.50	1.31	293.06	698.00	1.10
AM5	770.35	2.40	876.00	1.14	320.98	824.88	1.069
AM6	829.09	2.50	912.50	1.10	331.64	865.33	1.05
AM7	270.82	2.60	949.00	1.09	334.93	894.07	1.06
AM8	770.35	2.40	876.00	1.14	320.98	824.88	1.06
AM9	829.09	2.50	912.50	1.10	331.64	865.33	1.05
AM10	870.82	2.60	949.00	1.09	334.93	894.07	1.06
AM11	770.35	2.40	876.00	1.14	320.98	824.88	1.06
AM12	829.09	2.50	912.50	1.10	331.64	865.33	1.05
AM13	870.82	2.60	949.00	1.09	334.93	894.07	1.06
BM1	417.33	1.33	483.88	1.16	314.80	581.76	0.83
BM2	451.78	1.47	535.82	1.19	307.75	605.48	0.88
BM3	5730.69	1.69	616.49	1.07	339.66	689.44	0.89
BM4	628.80	1.77	464.05	1.03	355.25	727.39	0.89
BM5	550.19	1.73	630.36	1.15	318.58	673.26	0.94
CM1	323.45	1.68	611.74	1.89	192.99	517.10	1.18
CM2	380.23	1.73	631.82	1.66	219.66	556.20	1.14
CM3	507.73	2.23	812.13	1.60	228.19	644.01	1.26
CM4	571.37	2.37	869.59	1.52	241.49	687.84	1.26
CM5	763.61	2.46	897.90	1.18	310.41	820.24	1.09
CM6	831.13	2.73	996.09	1.20	304.55	866.74	1.15
CM7	606.56	2.49	907.39	1.50	243.99	712.08	1.27
DM1	481.6	1.73	630	1.31	279.02	626.02	1.01
DM2	530	1.73	630	1.19	307.06	659.35	0.96
DM3	635.77	1.59	581	0.91	399.41	732.19	0.79
DM4	705.79	1.71	623	0.88	413.50	780.42	0.80
DM5	719.15	1.86	680	0.95	386.01	789.62	0.86
DM6	788.31	1.98	724	0.92	397.30	837.25	0.86
DM7	898.76	1.99	728	0.81	450.61	913.32	0.80
DM8	946.76	2.04	746	0.79	463.10	946.37	0.79

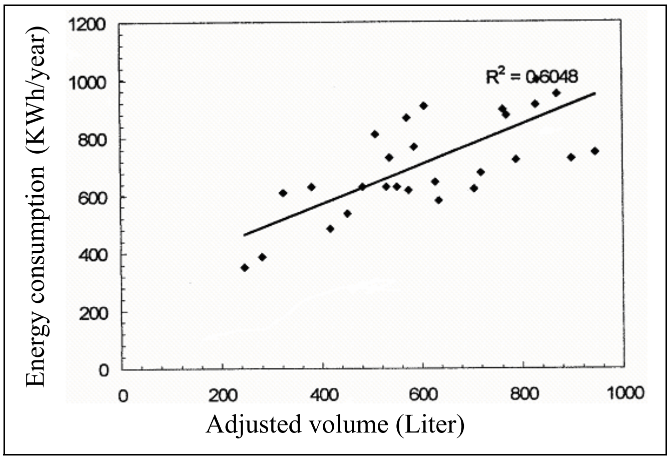

Figure 2. Energy consumption vs adjusted volume using actual data.

Star rating of the appliances has been classified for different EER, EEF and EEI and is presented in Tables 3, 4 and 5, respectively. It has been observed that the lower the EER and EEI, the better the performance, and, on the other hand, the higher the EEF the better the performance.

Table 3. Energy efficiency ratio and star rating.

Proposed Grading System (EER)	
1 Star	≥ 1.45
2 Star	1.23 ≤ ERR ≥ 1.44
3 Star	1.01 ≤ ERR ≥ 1.22
4 Star	0.81 ≤ ERR ≥ 1.00
5 Star	ERR ≤ 0.80

Table 4. Energy efficiency factor and star rating.

Proposed Grading System (EEF)	
1 Star	EEF < 250
2 Star	250 < EEF ≤ 300
3 Star	300 < EEF ≤ 350
4 Star	350 < EEF ≤ 450
5 Star	EEF > 400

Table 5. Energy efficiency index and star rating.

Energy Efficiency Index, I	Star rating
$I \geq 1.27$	1 star
$0.96 < I \leq 1.17$	2 star
$0.86 < I \leq 0.96$	3 star
$0.76 < I \leq 0.86$	4 star
$I \leq 0.76$	5 star

Conclusions

As a starting point, manufacturers in Malaysia will be given some time to upgrade their appliances. Rather than eliminating the inefficient product from the market, they are to be graded as low efficiency products (i.e. one star). Conversely, efficient product manufacturers can utilize the higher star rating to capture the market as part of their sales campaign.

Malaysia having a hot and humid climate, a 32^{o}C ambient test condition is suitable for testing of these appliances rather than the 25^{o}C specified for temperate climates.

Once the appliances are graded, it will pave the way for assessing the benefit/potential energy savings and environmental benefits associated with energy savings. Moreover, labeling will force the manufacturers to make their products more efficient, thus creating a competitive market.

EEF, EER, and EEI reflect the overall performance of a refrigerating appliance, whereas COP reflects only the compressors performance. In grading or rating, normally EEF, EER and EEI are used as they give the performance of the whole system.

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