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Investigation of Energy Performance and Usage Behavior of Domestic Refrigerator Freezer Using Clustering and Segmentation

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Abstract: This study carried out the field survey from house to house to garner the information of consumer behavior. In this study the energy consumption 104 refrigerators have been monitored as well. The energy consumption of 104 refrigerators is clustered and segmented to classify the refrigerators of same characteristic in the same group. The capacity of the refrigerator, frequency of door opening and position of refrigerator either near heat source or away from the heat source is considered for clustering and segmentation analysis. The clustering and segmentation in this survey reveal the effect of these factors on the energy performance of the refrigerator.

Key words: Domestic refrigerator, energy consumption, clustering, segmentation

INTRODUCTION

As refrigerator usage has become more common in household around the world, one area of concern is the energy consumption. Malaysia being a hot and humid country almost every house is equipped with one refrigerator. The energy consumption of refrigerator however, much depends on the consumer behavior. Therefore, a survey was carried out to get information the usage behavior and energy consumption of this appliance. Hasanuzzaman *et al.* (2008) conducted a series of experiments under conditions of different ambient temperature, cabinet load, thermostat set position and various compartment door-opening patterns. The investigation showed that the different environmental operating conditions have a significant influence on the energy consumption of the refrigerator-freezer. It is greatly affected by the number of door opening, cabinet load and ambient temperature. The open door energy consumption is greater by 40% compared to the closed door test. Liu *et al.* (2004) investigated the effect of door openings of refrigerator-freezers on the energy consumption and cabinet temperature variation by experimental approach. The testing was conducted under the ambient temperatures of 15 and 30°C in an environmental controlled chamber. From the test results, energy consumption of refrigerator-freezers with door opening was found to increase by 10%, compared to the same product without door opening. Author found that energy consumption increased with increasing the door opening frequency and duration of each door remains

open. Bjork and Palm (2006) investigated the influence of ambient temperature on energy consumption of the refrigerator-freezer. They found that with increasing the ambient temperature and a larger thermal load in the cabinet, the compressor running time increase as well as energy consumption increases. Meier and Jansky (1993) investigated the field performance of refrigerator compared with the laboratory test. Four hundred and thirty two refrigerator-freezers data were collected. Some technical problem and wide distribution of energy used, 209 refrigerator-freezers were compared with their labeled energy consumption. The mean measured energy use of the 209 refrigerators was 1009 kWh year⁻¹ where the mean labeled energy use was 1160 kWh year⁻¹.

Beside the laboratory study on the energy consumption, Gage (1995) investigated the effect of door openings and kitchen environment on the energy consumption of nine household refrigerator-freezers in the field. The door opening of the freezer compartment was varying from 2 times per day to 18 times per day. Energy consumption was found to correlate with kitchen temperature and the number of door openings. A similar study was carried out by Meier (1995) who investigated the refrigerator energy use in the laboratory and in the field, by comparing three different test procedures: the US Department of Energy Standard, the International Standard Organization (ISO) test and the Japanese Industrial Standard (JIS). Saidur *et al.* (2002) conducted an experiment to investigate the effect of single variables such as temperature, thermostat setting positions and door opening and their combined effect on energy

consumption. Room temperature has the higher effect on energy consumption, followed by door opening and thermostat setting position. Laguerre *et al.* (2002) conducted a customer survey to investigate the usage condition of refrigerator-freezer. Authors found that the number of door openings during breakfast, lunch, dinner and between meals are estimated about 19% (below 10 time day⁻¹), 43% (10 to 20 time day⁻¹) and 38% (over 20 time day⁻¹), respectively.

Masjuki *et al.* (2001) investigated the possibility of introducing the ISO 8187, ISO 8561 and ISO 7371 test standard for household refrigerator-freezer and found that these standards are applicable for testing and rating of Malaysian household refrigerator-freezers.

Cluster analysis helps grouping object of similar kind into respective categories in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. Segmentation is the process of partitioning a population into subgroups. Segmentation analysis helps identify population of sub-groups that exhibit certain common characteristics and can be expected to behave similarly with respect to an issue of interest.

So, the present research clustered and segmented the domestic refrigerator to get insight the energy consumption behavior based on three factors: Heat Source (HS), Capacity (C) and Frequency of Door Opening (FDO). It is being expected that this survey will enlighten consumers and the wide community in Malaysia about proper education on using their domestic refrigerators-freezers to its optimum operational conditions and consequently utilise their refrigerators efficiently. This information will also help policy makers to implement correct energy efficiency strategies such as test procedure, label, standard in establishing accurate, reliable and consumer's oriented measures.

MATERIALS AND METHODS

This research data has been collected using two approaches: field energy monitoring and questionnaire survey. The survey was conducted by Mechanical Engineering Department, University of Malaya in 2007.

Field energy monitoring: The aim of this monitoring was to measure actual refrigerator-freezers energy consumption. Energy monitoring was carried out by randomly visiting various types of residential dwelling such as double-storey, single storey, condominium and medium cost apartment at different locations of Malaysia. A Phoenix single phase electronic energy meter (model SM68, class 2.0) manufactured by Smart meters technologies (M) Sdn. Bhd. was used to monitor the daily

energy consumption. Specifications of the meter are: power range 0-1000 kWh, current range 0-12 amp and accuracy ± 0.001 .

Data collection through questionnaire: A questionnaire was prepared before the survey is being conducted. The survey was conducted from house to house with the questionnaire and power meter to monitor actual daily energy consumption. First permission was sought from the respondent before starting any survey. Once permission was granted, the survey was started with the questionnaire to get the pertinent information about the usage behavior of refrigerator-freezers and respondents profile. An explanation was provided to the respondent in case he/she is confused regarding any question. Once the questionnaire was filled completely, the power meter was connected with the refrigerator-freezers to monitor the actual energy consumption. Necessary data has been collected same way for the 104 refrigerator-freezers. The most important data that have been collected by this questionnaire is listed below:

- Personal profile of respondent
- Specifications of the refrigerator-freezer
- Usage pattern of the refrigerator-freezer (i.e., frequency of door opening, location of refrigerator)
- Age of refrigerator-freezer
- Type of refrigerator-freezer
- Food loading (whether empty, fully loaded, or half loaded)
- Income level of respondent

Multidimensional analysis such as clustering and segmentation were used to analyse and explain the relationship between the parameters. The energy consumption of the household refrigerator is clustered and segmented considering the factors such as position of the refrigerator i.e., near heat source or away from the heat source, capacity of the refrigerator and door opening frequency.

RESULTS AND DISCUSSION

Characteristic of respondents and refrigerator-freezers usage conditions: Data has been collected from both urban and rural area and among the respondent 68% was from urban and the rest is from rural area. Every household owns one refrigerator but only 9 out of 100 household own more than 1 refrigerator. There are 20 different brands of refrigerator-freezers among 104 refrigerators. The percentage of brands was shown in Fig. 1. Figure 2 shows the distribution of refrigerator types including type A (top refrigerator), type B (one door

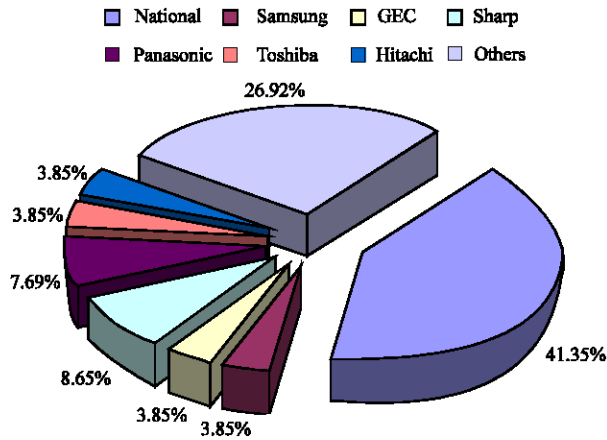


Fig. 1: Brands of refrigerator

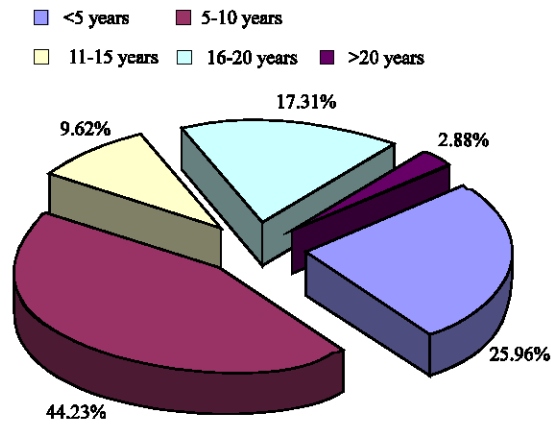


Fig. 4: Age of the refrigerator

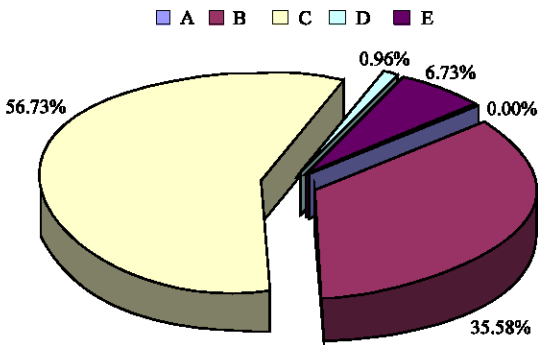


Fig. 2: Type of refrigerators

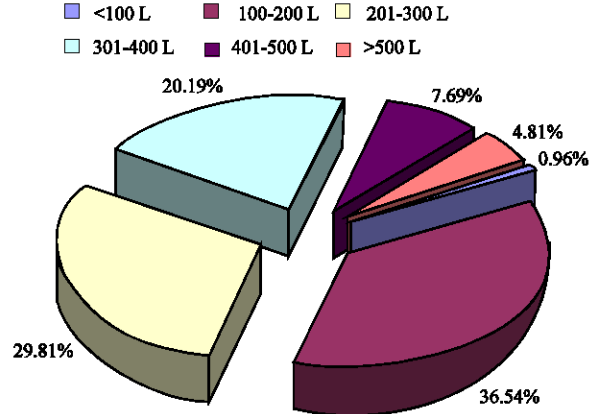


Fig. 5: Capacity of refrigerators

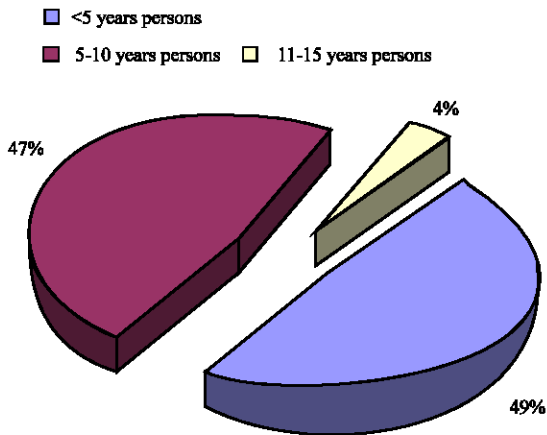


Fig. 3: Distribution of number of family members

refrigerator), type C (two door, top freezer), type D (side by side doors) and type E (unknown). Type A Refrigerator was not available in this survey.

In most of the houses the family member are less than 5 (Fig. 3). It was found that about 55% of the surveyed refrigerators were located near a heat source (oven, rice cooker, microwave, kettle, etc.). They usually placed their refrigerators in close vicinity of wall (i.e., almost in contact with the wall) in the kitchen which hinder the ventilation. Figure 4 shows that majority of the refrigerator used are from 5 to 10 years old.

Refrigerators of different brands and models have different capacity or volume. Most of the refrigerator's capacity is between 100 and 200 L.

It was noted that about 59% of the surveyed refrigerator-freezers are half-loading (Fig. 5). Figure 6 shows the food-loading distribution of refrigerators. Figure 7 shows the frequency of door openings. Most of the refrigerators consume 1 to 2 kWh (42.31%) and a small number of refrigerators consume more than 4 kWh which is shown in Fig. 8.

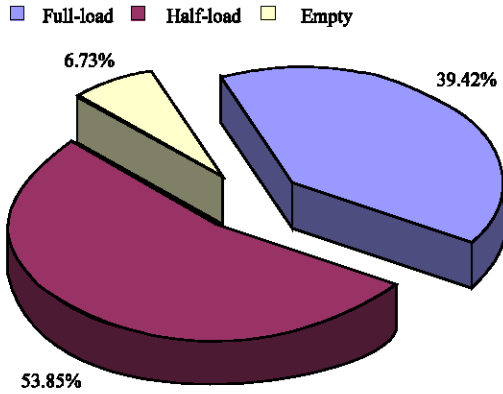


Fig. 6: Food-loading of refrigerators

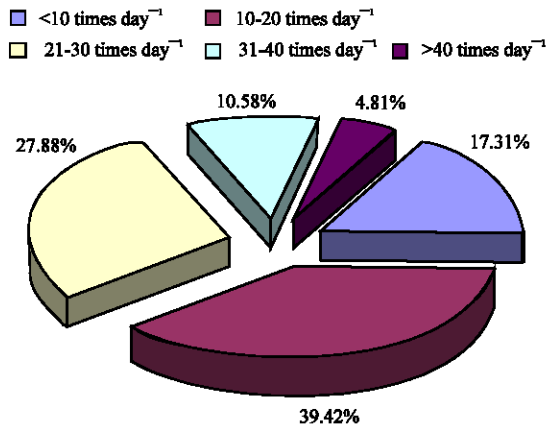


Fig. 7: Frequency of door openings

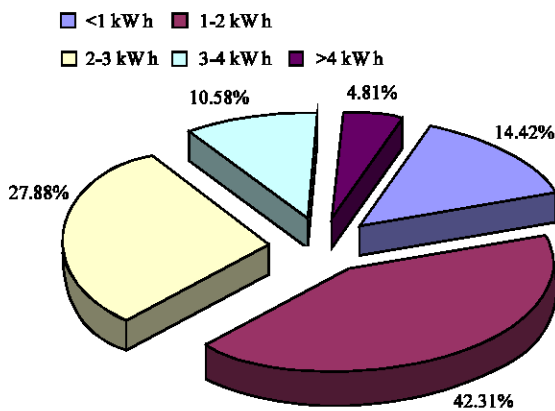


Fig. 8: Energy consumption of refrigerators

MULTIDIMENSIONAL STATISTICAL ANALYSIS

Clustering: The clustering helps grouping refrigerators with as many as common characteristics as possible.

Table 1: Representation of characteristics

Characteristics	Terms
Frequency of door openings (<20 times a day)	FDO 1
Frequency of door openings (>20 times a day)	FDO 2
Capacity of refrigerator (<200 L)	C 1
Capacity of refrigerator (>200 L)	C 2
Near to heat source	HS 1

Moreover, each group must have different common characteristics compared with the other groups; to the greatest extent possible. The term cluster analysis encompasses a number of different methods for grouping object of similar kind into respective categories. Cluster analysis is an exploratory data analysis tool which aims at sorting different object into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise.

Three factors which may have a major influence on energy consumption are: Heat Source (HS), Capacity of refrigerator (C) and Frequency of Door Openings (FDO). The refrigerators surveyed shows different characteristics in their usage behavior as well as energy consumption. The refrigerators in the same group shares common characteristics.

The number of refrigerators were first divided into 2 major groups which are the near to heat source and free to heat source. Then it was divided into smaller clusters. Under each group, it has been differentiated refrigerators which have capacity more than 200 L or capacity less than 200 L. Lastly, it has been grouped again according to the frequency of door opening more than 20 times a day or less than 20 times a day. The clustering diagram is shown in Fig. 9, it can be concluded that the common characteristics of the low energy consumption group are: capacity less than 200 L and door openings less than 20 times per day. The common characteristics of the high energy consumption group are: capacity more than 200 L and door openings more than 20 times per day.

Segmentation: Segmentation refers to the process of partitioning a population into subgroups. Segmentation analysis is typically used to identify population subgroups that exhibit certain common characteristics and can be expected to behave similarly with respect to an issue of interest (Table 1). The analysis is applied to group the energy consumption of refrigerator according to the frequency of door opening, Capacity of refrigerators and heat source (i.e., how these parameters influence energy consumption of refrigerator).

The refrigerators were divided into subgroups using explanatory variables (Fig. 10). The Frequency of Door Openings (FDO) was the best criterion enabling division of the 104 refrigerators into 2 subgroups. Subdivision was

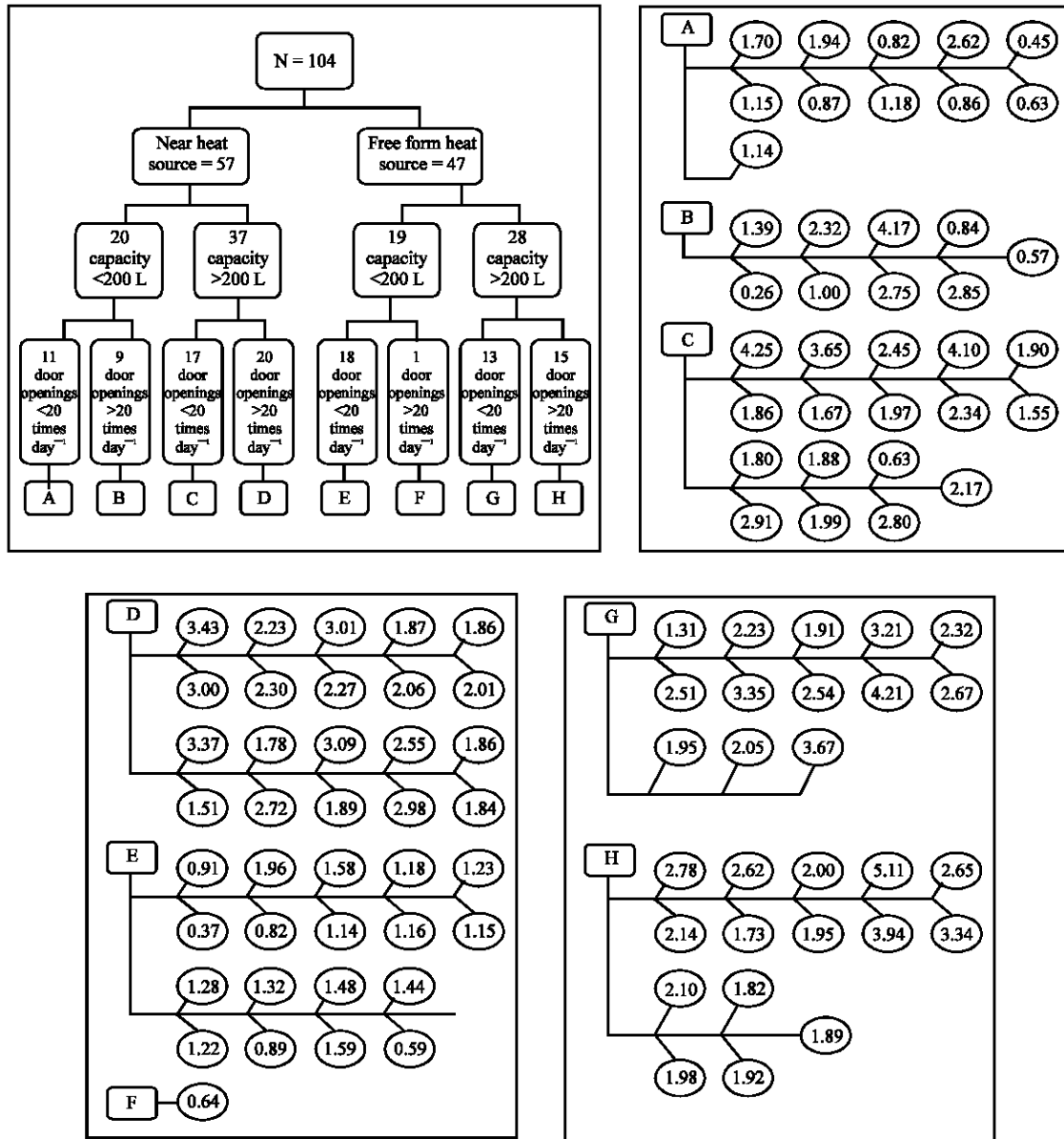


Fig. 9: Clustering of refrigerator, *All the values are in kWh day⁻¹

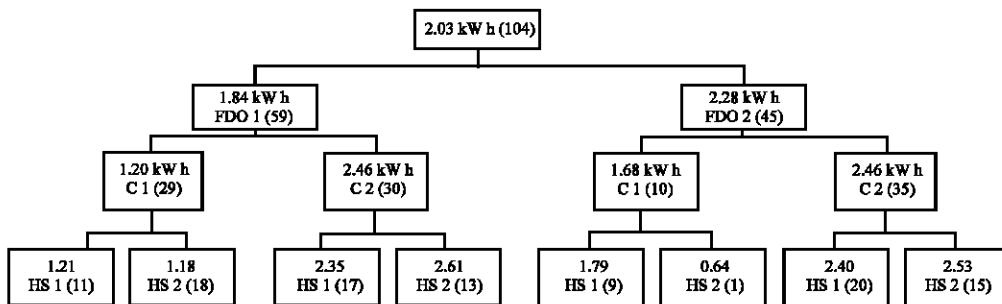


Fig. 10: Segmentation of refrigerators

then continued successively to the greatest possible extent. At the bottom level, the overall energy consumption and the number of samples are reported. The highest energy consumption groups ($2.61 \text{ kWh day}^{-1}$) has the number of door openings less than 20 times per day and capacity more than 200 L but free from heat source. The lowest energy consumption has the frequency of door opening more than 20 times per day, capacity less than 200 L and the refrigerator is not near a heat source.

CONCLUSIONS

The study covers the usage behavior and the power consumption of the domestic refrigerator. Throughout this study, the factors and usage behaviors which affect energy consumption of refrigerators has been surveyed and analyzed. It is found that the average energy consumption of the 104 household refrigerators surveyed is $2.03 \text{ kWh day}^{-1}$. This study shows that the combination of the usage conditions and factors (capacity of refrigerator, frequency of door openings and heat source) have a major impact on the refrigerator energy consumption. Energy consumption increases about 11.6% due to heat source near the refrigerator-freezer. It is also found that refrigerator-freezer energy consumption increases with increasing the number of door opening and volume. From the comparative evaluation of the surveyed data for the different parameter, it can be concluded that the factor considered here is great influence on energy consumption of refrigerator-freezer.

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