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Investigation of Energy Consumption and Energy Savings of Refrigerator-Freezer During Open and Closed Door Condition

M. Hasanuzzaman, R. Saidur and H.H. Masjuki
Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

Abstract: This study presents the effects of different operating variables on energy consumption of refrigerator-freezer that had two phases. The first phase is to investigate the effects of the number of door opening, duration of each door remain open, ambient temperature, cabinet load and thermostat setting position on energy consumption during the open door conditions. The second phase is to investigate the effects of the ambient temperature, cabinet load, thermostat setting position and open surface water pan area inside the cabinet on energy consumption during the closed door conditions. All the experiments were conducted in the environmental controlled chamber. The result shows that there is a great influence of different variables on energy consumption and average consumption is about 3.3 kWh day^{-1}. The effects of number of door opening, ambient temperature and cabinet load are more compared to the others. The open door energy consumption is 40% more compared to the closed door test. It is found that the average of the maximum energy consumption is 27.3% more compared to average consumption and 55.6% more compared to average of the minimum consumption. If the users be serious, a significant amount of energy could be saved with the proper utilization of refrigerator-freezer.

Key words: Refrigerator-freezer, energy consumption, energy savings, usage condition, controlled chamber, ambient temperature

INTRODUCTION

Malaysia, like other developing countries, has experienced dramatic growth in the use of household refrigerator-freezers. The Malaysian economy growth rate is about 7%. The Gross Domestic Product is increased from RM 572.6 billion in 2006 to RM 625.1 billion in 2007. The per capita income is increased from RM 20,841 in 2006 to RM 22,293 in 2007 (DSM, 2007). Economic growth is the main driving factor for greater use of household appliances which leads to an increasing need for comfort and a high style of living that has consequently caused a substantial increase in household energy consumption. Household refrigerator-freezer ownership increased for several reasons: (i) increase in household income, (ii) more readily available electricity and (iii) refrigerator-freezers are more available and less expensive (Masjuki *et al*., 2001). Energy is one of the indispensable factors for continuous development and economic growth. The demand of energy is increasing in the developing countries due to automation, industrialization and urbanization. Rahman Mohamed and Lee (2006) investigated that the energy demand in Malaysia is increasing and the energy demand increased by almost 20% in 3 years (from 1999 to 2002). The energy demand is further expected to increase by approximately 60% within 8 years (from 2002 to 2010). Varman *et al.* (2005) predicted that residential electricity consumption will increase to 27,053 GWh in 2015. As a result, the installation capacity of energy is increased from 14,291 MW in 2000 to 19,227 MW in 2005. It is predicted that it will be 25,258 MW by 2010 (9th Malaysian plan). The installation capacity of energy is increased about 35% from 2000 to 2005. Refrigerator-freezers are one of the most energy consuming home appliances accounting for 14% of electricity consumption of US households in 2001 (EIA, 2004). Mahlia *et al.* (2001) conducted a survey on energy consumption and estimated that electricity consumption is increased from 326 GWh in 1970 to 9,471 GWh in 2000 and it will be 35,360 GWh in 2020 in the residential sector in Malaysia. Mahlia *et al.* (2004) investigated that the number of refrigerator-freezers has increased from 175,842 units in 1970 to 4,196,486 units in 2000 in Malaysia. In developing countries, the production of domestic refrigerator is rising steadily: total production (Worldwide) was 83.2 million and increased 30% in 2000 (Billiard, 2005). Liu *et al.* (2004) studied and revealed that the energy consumption of refrigerator-freezers

Corresponding Author: M. Hasanuzzaman, Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia Tel: +60379674448 Fax: +60379675317

is about 15 to 20% of total domestic electricity usage. Mahlia *et al.* (2003) investigated that refrigerator-freezers consume about 26% of residential electricity in Malaysia. Razali *et al.* (1993) conducted a survey to investigate household energy patterns and revealed about 76% of total residential homes are equipped with one refrigerator-freezer in Malaysia. Door openings would affect the increase of energy consumption and thus reduced food freshness, which make direct impact to refrigerator-freezer performance. Laguerre *et al.* (2002) conducted a customer survey and found that the number of door openings during breakfast, lunch, dinner and between meals are estimated that 19% (below 10 time day^{-1}), 43% (10 to 20 time day^{-1}) and 38% (over 20 time day^{-1}). Masjuki *et al.* (2001) investigated the effect of the ambient temperature, door openings, thermostat settings and food loading in order to develop refrigerator-freezer test standards and found that there is a great effect on energy consumption. Meier and Jansky (1993) investigated the field performance of refrigerator compared to the laboratory test and 432 refrigerators data were collected. Some technical problem and wide distribution of energy use 209 refrigerators and average energy consumption was 1160 kWh $year^{-1}$. Gage (1995) investigated the daily energy consumption of the nine units of refrigerator that is ranged from 1.7 to 5.3 kWh day^{-1}. It is consumed 1.4 kWh day^{-1} (12% increases) more energy in 26 door opening compare to no door opening. It is increased about 1.6 kWh day^{-1} by 1°C increasing the ambient temperature. Users pay attention to the refrigerator-freezer's ability to keep food fresh as well as its energy consumption. That is why, it is so important to investigate the effect of operating parameters during the open and closed door conditions and their comparisons.

In this research, energy consumption during the open and closed door conditions with different operating conditions have been investigated separately and shown the comparative evaluation of the experimental results as well as describing their effects.

MATERIALS AND METHODS

This research provides a description of the facilities developed for conducting experimental work on a domestic refrigerator. Experiment was conducted at Energy Conservations Laboratory, Mechanical Engineering Department, University of Malaya in the middle of 2007. The energy consumption during the different operating conditions that were divided into two phases. The first phase is to investigate the effects of the number of door opening, duration of each door remain open, ambient temperature, cabinet load and thermostat setting position on energy consumption during the open door conditions. The second phase is to investigate the effects of the ambient temperature, cabinet load, thermostat setting position and open surface water pan area inside the cabinet on energy consumption during the closed door conditions.

Test conditions: In the open door energy consumption test, the important variable are the number of fresh food and freezer door openings, duration of each door remains open, speed of door opening, the extent to which the door is opened, ambient temperature, ambient relative humidity, cabinet load, thermostat setting position. In this study, the considering variables were the number of fresh food and freezer door openings, duration of each door remains open, ambient temperature, cabinet load, thermostat setting position. The speed of door opening and the extent to which the door was opened, was constant. Automatic door opening mechanism was used to open and close the refrigerator and freezer door automatically. In general the environmental controlled chamber was maintained at temperature 25°C and relative humidity 70±5%. The thermostat setting was set at the setting point 3. The cabinet load during the experiment was 2 L of fresh water in the freezer and 4 L of fresh water in the fresh food cabinet. The door opening duration was 30 min for fresh food cabinet and 60 min for the freezer and the duration of both door remains open 20 sec. The tests were conducted by varying the number of door opening, duration of each door remain open, ambient temperature, cabinet load and thermostat setting position independently during the open door conditions. During the experiment, only one variable was changed and the other variables were kept constant. Number of door opening was varied from 8 to 32 of the fresh food cabinet and from 4 to 16 of the freezer cabinet. Duration of each door remain open varied from 10 to 30 sec. Ambient temperature was varied from 18 to 30°C in the environmentally controlled chamber. Fresh food and freezer cabinets load was varied from 0 to 8 and 0 to 4 kg of fresh water in the fresh food and freezer cabinet, respectively. The thermostat setting position was changed from 1 to 5 to reveal the effect of cabinet temperature.

In the closed door test, the tests were conducted by varying ambient temperature, cabinet load, thermostat setting position and open surface water pan area independently. During the experiment, only one variable was changed and the other variables were kept constant. Ambient temperature was varied from 18 to 30°C in the environmentally controlled chamber. Fresh food and

freezer cabinets load was varied from 0 to 8 and 0 to 4 kg of fresh water in the fresh food and freezer cabinet, respectively. The thermostat setting position was changed from 1 to 5 to reveal the effect of cabinet temperature. In the study, water pan area was varied from 324 to 1272 cm^2.

Instrumentation: The experiment was conducted in an environmentally controlled chamber. To measure the temperature inside as well as outside the test unit, T-type thermocouples were used. Humidity transmitter was used to monitor the relative humidity. Relative humidity measurement range = 3 to 95% and accuracy = ±0.2%. Heat pump was used to maintain the required temperature in the environmentally controlled chamber. The modes of operation of heat pump are heating, cooling and soft dry and the temperature range from 16 to 32°C. The temperature fluctuation was controlled by using a temperature controller. The controller was interfaced with the heat pump so that the desired temperature could be maintained within the chamber. To maintain relative humidity of the controlled chamber, dehumidifier was used and the range of dehumidifier from 0 to 90%. Electronic balance was used to weight the mass of evaporated water from the open surface water pans and cabinet load with weighing capability of 0.01 g up to 2 kg. Hewlett Packard data logger was used to store the data from the test unit to personal computer for calculation and analysis. The data logger supports direct measurement of temperature, AC voltage, DC voltage, AC current, DC current, resistance, frequency and period. Energy consumption was measured by the YOKOGAWA WT-130 digital power meter, which was interfaced with a PC through RS-232. Lab view software was installed into the PC for data storage and analysis. The accuracy of this power meter is ±0.2% of reading.

Automatic door opening mechanism: Automatic door opening mechanism (ADOM) was used to open and close the doors of the fresh food and freezer cabinet automatically. AC motor and reducing gear box is used to fabricate the ADOM. The fresh food and freezer cabinet doors are opened and closed separately by the ADOM. The freezer cabinet door ADOM is set on the top of the test unit and the other one is set on the ground beside the test unit that is shown in Fig. 1 and 2. Programmable Logic Controller (PLC) was used to control the door opening and closing. The PLC has an operating panel that send signal. According to the working schedule, total run time, opening and closing time was inserted into the operating panel. Automatic door opening mechanism was run according to the experimental requirement.

Fig. 1: Freezer cabinet automatic door opening mechanism

Fig. 2: Fresh food cabinet automatic door opening mechanism

Programmable logic controller: The door opening and closing processes were controlled by using the PLC (Micro Automation SIMATIC S7-200). This is a computer-based device which functions like a relay board and programming is achieved using relay ladder logic. There are four sensors which are connected with the motors of the ADOM and the PLC. The function of the sensors is to sense the position of the door (open or close) and to send the signal go the PLC. The Coros OP3 operator panel is used to input the data of experimental schedule such as total run time, duration of door opening, duration of each door remain open that is connected to the PLC.

Experimental setup: The refrigerator-freezer used was top mount freezer section, two doors and both doors hinged at right hand side. The specification of the test unit is shown in the following Table 1.

Figure 3 shows the schematic diagram with data logger, power meter, PLC, PC and ADOM of the experimental setup.

Location of thermocouples and humidity sensor: Thermocouples were used to measure temperature inside

Table 1: Technical specifications of refrigerator-freezer test unit

Specifications	
Freezer cabinet capacity (L)	130
Fresh food cabinet capacity (L)	330
Power rating (W)	165
Current rating (A)	1.3
Voltage (V)	240
Frequency (Hz)	50
No of door	2
Refrigerant type	134a(CF_3CH_2F)
Defrost system	Frost free

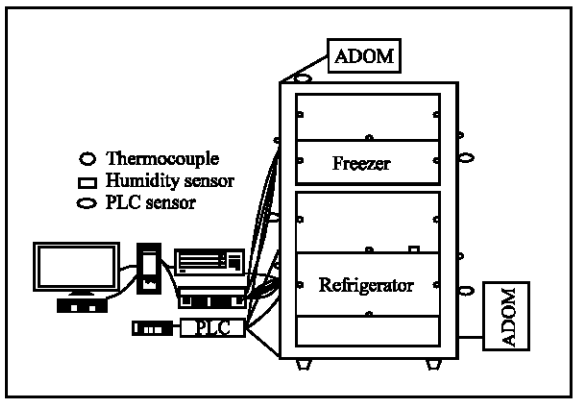

Fig. 3: Schematic diagram of the experimental setup

and outside of the walls and doors of refrigerator-freezer, inside the fresh food and freezer cabinet. Five thermocouples were used in freezer cabinets that were placed at both side walls and the cabinet separator. Another six thermocouples were used in fresh food cabinets that were placed at both side walls and the cabinet separators. To measure temperatures at outside of the walls and doors of the test unit, six thermocouples were used. Five thermocouples were set to monitor the ambient temperature inside the chamber. Humidity sensor was used to measure relative humidity inside fresh food cabinet. The location of thermocouples and humidity sensor are shown in the Fig. 4.

Location of cabinet load during open door test: Load was used both in the fresh food and freezer cabinet to make real situation during the open door test. Both the fresh food and freezer cabinets were divided into two shelves and each shelf contains equal load. The location of load both in fresh food and freezer cabinets are shown in the Fig. 5.

Location of load during closed door test: Load was used both in the fresh food and freezer cabinet to make real situation during the closed door test. Both the fresh food and freezer cabinets were divided into two shelves and each shelf contains same load. Open surface water pan was added in the fresh food cabinet that was made

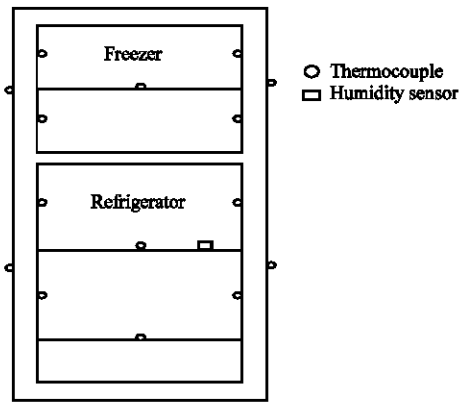

Fig. 4: Location of thermocouple and relative humidity sensor

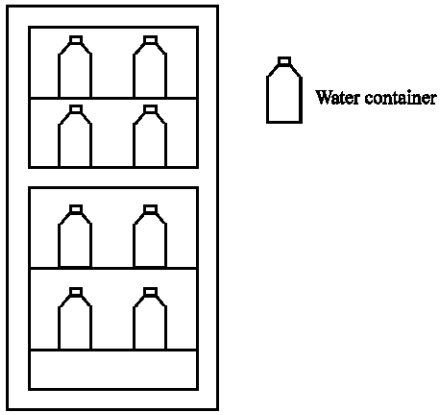

Fig. 5: Location of load during open door condition

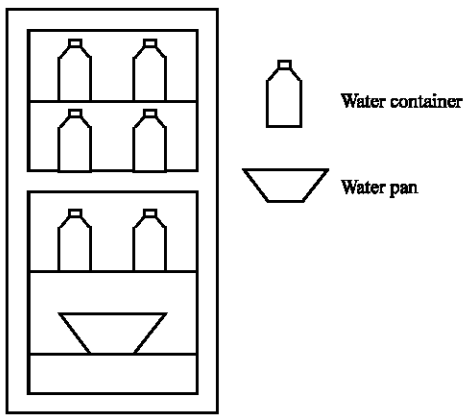

Fig. 6: Location of load during close door condition

the surface wet inside the refrigerator same as moist foods. The location of open surface water pan, load (water bottle) in fresh food and freezer cabinets are shown in the Fig. 6.

Data acquisition and processing: The information of the thermocouples and relative humidity sensor is necessary for calculation and analysis. The data logger supports direct measurement of thermocouples using ITS-90 software conversion. The data logger also supports direct measurement of DC voltage of the humidity sensor with a linearization factor to any DC voltage input. The output voltage was directly proportional to the relative humidity. The data was transferred to a personal computer to store on the hard disk drive. The data was recorded at an interval of 6 min for 24 h of closed door experiment. During the 8 h open door test, data was recorded at an interval of 2 min.

RESULTS AND DISCUSSION

Refrigerator-freezer consumes energy all day long to keep fresh food and vegetable fresh and freeze the perishable food. It consumes energy in both open and closed door conditions due to moisture transfer, heat transfer by conduction, convection, radiation, sensible and latent. This energy consumption is a significant amount of daily electric energy of a household.

Energy consumption during the open door condition: Refrigerator-freezer consumes energy due to heat and moisture transfer and bulk air exchange. Energy consumption is influenced by some environmental operating conditions during the open door condition that is described below.

Effect of number of door opening on energy consumption: The number of door opening has great effects on energy consumption. When it's door is opened, warm and moist ambient air mixes with the cabinet cool air. Moisture transfer increases with increasing the number of door opening. The warm and moist ambient air cool down and freeze at the freezer temperature. The ice is defrosted by the defrosting system. Energy is required two times to make frost and to defrost it again. Besides, convective heat transfer is increased with increasing the number of door opening. If the number of door opening increases, energy consumption increased obviously. Figure 7 shows the variation of energy consumption with number of door opening. Based on the results, it is found that it increases from 1.15 to 2.19 kWh/8 h when the number of door opening increases from 12 to 48. It increases by 28 Wh per door opening. Gage (1995) estimated the effect of door openings at 24°C of 26 door openings increased 1.4 kWh day^{-1} and 12% of energy consumption. Masjuki *et al.* (2001) investigated that about 10 Wh increase in energy consumption for each door opening of

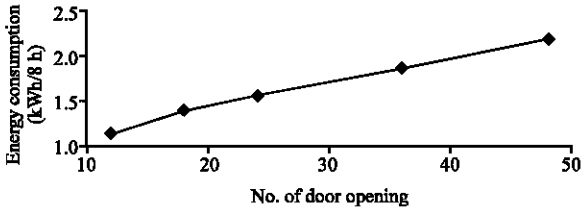

Fig. 7: Variation of energy consumption with number of door opening

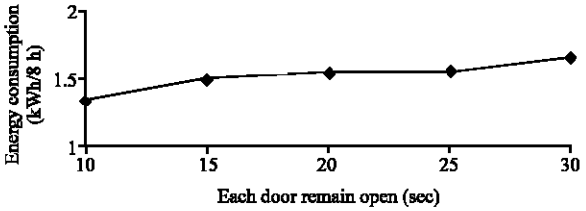

Fig. 8: Variation of energy consumption with each door remain open

the 150 L refrigerator-freezer. Saidur *et al.* (2002) conducted an experiment and found that about 12.4 Wh increase in energy consumption for each door opening of the 300 L refrigerator-freezer with 12 sec door opening. The increased energy consumption variation depends on the volume of the refrigerator-freezer. The present research increased energy consumption is about 28 Wh per door opening which is about 3 time of the findings of Masjuki *et al.* (2001) that shows good agreement.

Effect of duration of each door remains open on energy consumption: When the duration of each door remain open increases, the duration of the steady air flow, convective and radiative heat transfer increases. It imposes thermal load on the cabinets by increasing the heat and moisture transfer. So, energy consumption increases with increasing the duration of each door remains open to minimize the thermal load. Figure 8 shows the variation of energy consumption with increasing the duration of each door remain open. It increases from 1.34 to 1.66 kWh/8 h when the duration of each door remains open increases from 10 to 30. It increases by about 16 Wh/8 h for 1 sec increase in the duration of each door remains open.

Effect of ambient temperature on energy consumption: At higher temperature air can sustain more moisture. That is why, at the higher temperature air with more moisture enters into the cabinets during the door opening. Besides, when the ambient temperature increases, the temperature difference between the ambient and cabinet increases,

more convective and radiative heat during the opening and conduction heat through the walls is transferred. It imposes extra thermal loads of the cabinet and warm up. In addition, increasing the ambient temperature increases the sensible cooling load of the moisture that is entered into the cabinets. To maintain the desired temperature, the frequency of compressor off and on cycle and the duration of compressor run time increases. That is why, energy consumption increases with increasing the ambient temperature. Figure 9 shows the energy consumption with changing the ambient temperature. Based on the experiment, it increases 1.08 to 1.98 kWh/ 8 h when the ambient temperature increases from 18 to 30°C. It increases by about 75 Wh/8 h for a 1°C increase in the ambient temperature. From Fig. 9, it can be stated that there is a strong influence of ambient temperature on the energy consumption of the refrigerator-freezer.

Effect of cabinet load on energy consumption: In general, there are two types of energy loss due to the cabinet load. The primary energy loss is to cool down and make its temperature as cabinet temperature. This depends on the initial temperature of the food, cabinet temperature, mass, specific heat and latent heat. On the other hand, during the door opening it warms up and cools down again at the desired temperature. When the cabinet is more loaded, it is gained more thermal load. It causes more energy loss due to on-off cycle. So, energy consumption increases with increasing the cabinet load to control the desired temperature. Figure 10 shows the effect of cabinet load on energy consumption. It increases from 1.16 to 1.93 kWh/8 h when the cabinet load is increased from no-load to 12 kg of fresh water. It increases 64.2 Wh/8 h per kg of fresh water. Figure 10 shows that there is a strong influence of cabinet load on the energy consumption of the refrigerator-freezer.

Effect of thermostat setting position on energy consumption: Refrigerator-freezer cabinet temperature is controlled by setting the thermostat position that is an important factor to store foods. Warmest cabinet temperature causes to damage the food, coldest cabinet temperature can not improve the food storage but it causes the energy loss. When the cabinet temperature is very low, the temperature difference between the ambient and cabinet increases, the more heat is transferred by convection, radiation during the opening and conduction through the walls. It imposes extra thermal load of the cabinet and warms up. In addition, decreasing in cabinet temperature increases the sensible cooling load of the cabinet load and moisture that is entered into the cabinet. To maintain the desired temperature, the frequency of

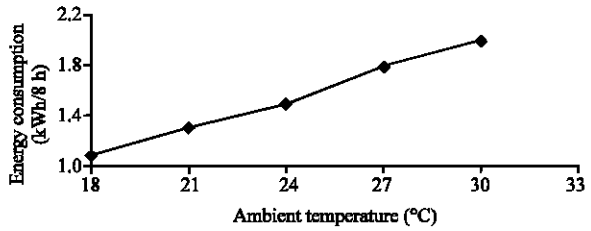

Fig. 9: Variation of energy consumption with ambient temperature

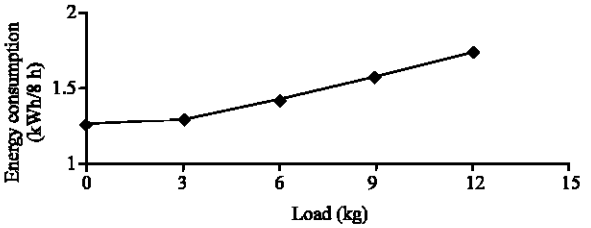

Fig. 10: Variation of energy consumption with cabinet load

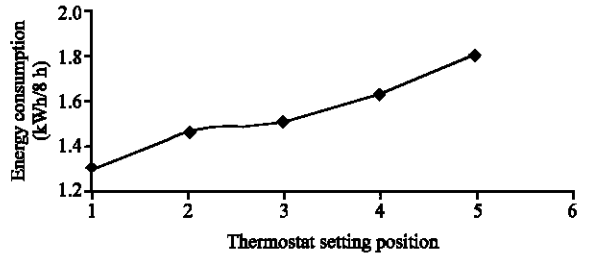

Fig. 11: Variation of energy consumption with thermostat setting position

compressor on and off increases and duration of compressor run time increases, as a result energy consumption increases. Figure 11 shows the effect of thermostat setting position on energy consumption. Based on the experiment, energy consumption increases from 1.3 to 1.8 kWh/8 h when the thermostat setting temperature is set from position 1(-12°C) to 5(-14.6°C). The result shows that it increases 192 Wh/8 h when 1°C decreasing the freezer temperature. It is found that about 8% increases in energy consumption occurs for 1°C reduction in freezer temperature.

Effect of different variables on energy consumption: Energy consumption of the refrigerator-freezer during the open door condition is strongly influenced by the operating environmental conditions. Figure 12 shows the maximum, minimum and average energy consumption during the open door test with the difference operating conditions. From the Fig. 12, it is revealed that there are

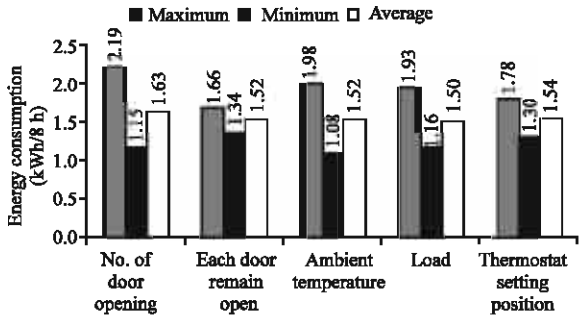

Fig. 12: Effect of different variables on energy consumption

greater effects of number of door opening, ambient temperature and cabinet load on energy consumption compared to the other variables. Duration of each door remains opening and thermostat setting position effect is low compared to the others but there is a moderate influence on moisture transfer. On the other hand, the Fig. 12 also indicates that the average energy consumption is almost same except the number of door opening. So, user should optimize the usage condition to save energy.

Energy consumption during the closed door condition: Energy consumption during the closed door conditions is mainly caused due to heat loss through the walls, moisture transfer and cabinet load. It is influenced by the some factors that are described as:.

Effect of ambient temperature on energy consumption: Ambient temperature has a great effect on energy consumption of refrigerator-freezer. When the ambient temperature is high, the temperature different between the ambient and cabinet increases, the more heat is transferred trough the walls of the refrigerator-freezer. It imposes extra thermal load of the cabinet and warms up. On the other hand, with increasing the ambient temperature increases the sensible cooling load of the cabinet load and moisture that is entered by gasket diffusion. To maintain the desired temperature, the frequency of compressor on and off cycle increases and duration of compressor run time increases to cool the cabinets. Figure 13 shows the energy consumption with changing the ambient temperature. Meier and Jansky (1993) stated that energy consumption varies from 1.25 to 2.6 kWh day^{-1} for an 11°C increase in temperature. Masjuki *et al.* (2001) investigated that energy consumption increases around 40 Wh day^{-1} for 1°C increase in temperature. Saidur *et al.* (2002) found that energy consumption increases around 53 Wh day^{-1} for

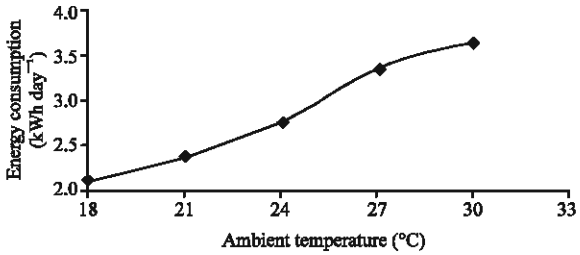

Fig. 13: Variation of energy consumption with ambient temperature

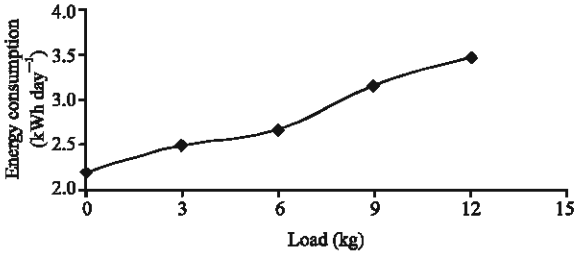

Fig. 14: Variation of energy consumption with load

1°C increase in temperature. In the experiment, energy consumption increases from 2.13 to 3.64 kWh day^{-1} when the temperature increases from 18 to 30°C. It increases around 126 Wh day^{-1} for 1°C increases in the ambient temperature. Figure 13 shows that there is a strong influence of ambient temperature on the energy consumption of the refrigerator-freezer.

Effect of cabinet load on energy consumption: Cabinet load plays an important role for energy consumption. The thermal load is imposed to cool down to the cabinet load that depends on the initial temperature of the food, cabinet temperature, mass of the cabinet load, specific heat and latent heat. The cooling load is directly proportional to the mass of cabinet load. On the other hand, during the off cycle, it is warmed up after that it cools again during the on cycle. Therefore, energy consumption increases with increasing the cabinet load. Figure 14 shows the effect of cabinet load on energy consumption. In the experiment, it increases from 2.2 to 3.5 kWh day^{-1} when the load increases from no-load to 12 kg of fresh water. It increases by 108 Wh day^{-1} per kg of fresh water. It increases by about 60% when it is loaded at 12 kg of fresh water. Figure 14 shows that there is a strong influence of cabinet load on the energy consumption of the refrigerator-freezer.

Effect of thermostat setting position on energy consumption: Refrigerator-freezer cabinet's temperature is

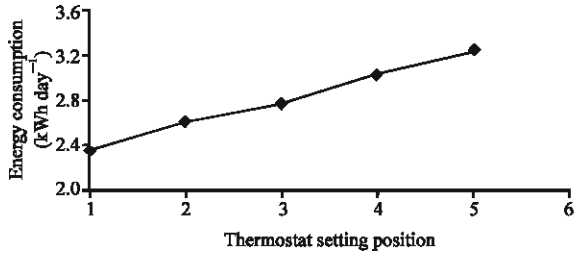

Fig. 15: Variation of energy consumption with thermostat setting position

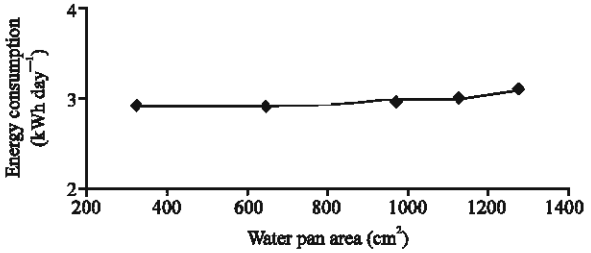

Fig. 16: Variation of energy consumption with water pan area

an important factor for energy consumption. When the thermostat is reset at the coldest temperature, heat loss by conduction through the walls, sensible cooling load by cabinet load, cabinet breathing and gasket diffusion increases. It is concluded that energy consumption increases with decreasing the cabinet temperature. Saidur *et al.* (2002) showed that energy consumption increases about 7.8% for each degree reduction in freezer temperature. Figure 15 shows the effect of thermostat setting position on energy consumption. Based on the experiment, energy consumption increases from 2.3 to 3.2 kWh day^{-1} when the thermostat is set the position from 1(-13°C) to 5(-18°C). The result shows that it is increased 180 Wh day^{-1} when 1°C decreasing the freezer temperature. It is found that about 8% increases in energy consumption for 1°C reduction in freezer temperature that is good agreement with Saidur *et al.* (2002). Figure 15 shows that there is a strong influence of thermostat setting position on the energy consumption of the refrigerator-freezer.

Effect of open surface water pan area on energy consumption: Open surface water pan is used to create the real situation of food loading moisture transfer. The cabinet breathing (water evaporation) increases when the water pan area increases. The evaporated water is cooled down, formed ice and defrost it again. As a result, energy consumption increases with the increasing the water pan area. Figure 16 shows the effect of water pan area on energy consumption. The result shows that, when the water pan area increases from 324 to 1272 cm^2, the energy consumption increases from 2.9 to 3.1 kWh day^{-1}. It is also found that it increases by 21 Wh day^{-1} for a 100 cm^2 increasing in water pan area. About 7% energy consumption is increased when the water pan area is increased 948 cm^2.

Effect of different variables on energy consumption: Refrigerator-freezer energy consumption fluctuates by the operating environmental conditions. Figure 17 shows the

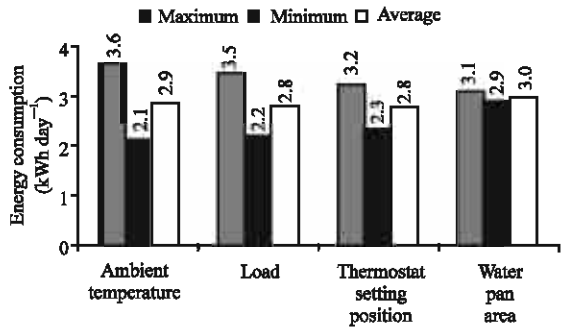

Fig. 17: Effect of different variables on energy consumption

maximum, minimum and average energy consumption during the closed door test with different operating environmental conditions. From Fig. 17 it can be concluded that there is very strong influence of ambient temperature and cabinet load on energy consumption compared to the thermostat setting position and open surface water pan area. Thermostat setting position effect is low compared to ambient temperature and cabinet load, but there is a strong influence on energy consumption.

Actual usage of refrigerator-freezer in the residents: Refrigerator-freezer is used in the residents to keep the fresh food (fruit, beverage, vegetable etc.) fresh and to store the perishable food (fish, meat etc.). Laguerre *et al.* (2002) conducted a survey and investigated that it is mainly opened for breakfast, lunch and dinner. In general, people work in the office or outside of resident for 8 h and take rest 8 h in a day. In the research, to investigate real effect of different variable on energy consumption the schedule is as 8 h open door and 16 h closed door condition. From the comparative evaluation of the experimental results for the different operating conditions, it is found that the average energy consumption is about 3.3 kWh day^{-1}. It is greatly affected by the door opening compared to the closed door as well as the environmental operating conditions. Open door energy consumption is

Table 2: Energy consumption of the refrigerator-freezer

Test condition	Duration (h)	Average of the maximum (kWh)	Average of the minimum (kWh)	Average (kWh)
Open door condition	8	1.9	1.2	1.5
Closed door condition	16	2.3	1.5	1.8
Energy consumption	24	4.2	2.7	3.3

about 1.5 times compared to the closed door. Table 2 shows that the variation of energy consumption and the effect of door opening. Based on the result, it is found that the average energy consumption is 1204 kWh year^{-1} that are the good agreement with the result of Meier and Jansky (1993).

Energy savings: Energy savings is the key issue for the environmental pollutions, energy demand, limited energy resources and future demand of energy. Energy demand in Malaysia increases rapidly as well as increases the greenhouse gases. The installation capacity of energy increases from 14,291 MW in 2000 to 19,227 MW in 2005. It is targeted that it will be 25,258 MW in 2010 (9th Malaysian plan). The installation capacity of energy increases about 35% from 2000 to 2005. Emissions of all greenhouse gases from fuel combustion activities are increasing to fulfill the energy demand. So there is a high impact on the environment as well as the global warming potential. Based on the experimental investigation, it is found that the energy consumption of the refrigerator-freezer is greatly influenced by the operating environmental conditions. It is more affected by the number of door opening, ambient temperature, cabinet load and effect is 46, 32 and 29% more compared to the average energy consumption, respectively during the open door conditions. On the other hand, the effect of the ambient temperature, cabinet load is 36 and 30% more compared to the average energy consumption respectively during the closed door conditions. It is also found that open door average energy consumption is 40% more compared to the closed door test. From the comparative evaluation of the experimental results for the different operating conditions, the maximum average energy consumption is 27.3% more compared to average consumption and 55.6% more compared to minimum average energy consumption. If the users of the refrigerator-freezer will be serious, they will optimize the usage conditions. As a result, the energy consumption will reduce by the proper utilizing of the refrigerator-freezer. When the energy saving step is taken very seriously, about 328 kWh year^{-1} energy will be saved out of 1204 kWh year^{-1}. The energy saving steps should be taken very seriously which will help to reduce the emissions and keep the country green as well as for future green world.

CONCLUSION

It is found that the different environmental operating conditions have a significant influence on the energy consumption of the refrigerator-freezer. Energy consumption is greatly affected by the number of door opening, cabinet load and ambient temperature during the open door conditions. The thermostat setting position and duration of each door remain open also have significant effects. The effect of ambient temperature and cabinet load on energy consumption is more significant during the closed door conditions. The average actual energy consumption is about 3.3 kWh day^{-1}. The open door energy consumption is greater by 40% compared to the closed door test. So, the energy saving step should be taken very seriously. When the users will be aware to optimize the usage condition, a significant amount of energy will be saved. If the users will be serious, at least about 328 kWh year^{-1} out of 1204 kWh year^{-1} could be saved with the proper utilizing of the refrigerator-freezer.

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