Effect of Different Operating Variables on Energy Consumption of Household Refrigerator

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Abstract- **This research work presents the experimental investigation of the effects of number of door opening; duration of door remaining open, ambient temperature and thermal load on the energy consumption of a household refrigerator. The experiments were conducted under the condition that number of door opening varied from 2 to 8 times per hour whereas the duration of door remaining open varied from 10 to 40 sec. The test has been carried out under the condition that the ambient temperature varied from 20 to 33^{0}C at different thermal loads varying from 0.001 m^3 to 0.007 m^3 of fresh water; each experimental run time was 6 hours. From the test results, energy consumption of refrigerator with door opening was found to increase compared to the same product without door opening. Depending on the number of door opening about 7% to 30% more energy consumption has been observed as compared to closed door condition. The test result also shows that a significant amount of energy consumption increases because the time of door remaining open increases. Depending on the time of door remaining open the energy consumption varied from 3% to 20%. The experimental result also confirms that the energy consumption increases by about 15% to 53% because the ambient temperature increases from 20 to 33^{0}C. The test result also proves that a significant amount of energy consumption increases because cabinet load (thermal load) increased. Depending on the different thermal loads about 18% to 59% more energy consumption has been observed as compared to non-load condition. If the users be serious, a significant amount of energy could be saved with proper utilizing of the refrigerator-freezer.**

Keywords- Household Refrigerator; Door Opening; Ambient Temperature; Thermal Load; Energy Consumption

I. INTRODUCTION

Refrigerators are generally the largest end-uses of electricity in households due to their widespread use and continuous operation. At present household refrigerator –freezer ownership increased for several reasons such as increase in household income, more readily available electricity and refrigerator-freezers are more available and less expensive (Masjuki et al., 2001). Refrigerator-freezers are one of the most energy consuming home appliances accounting for 14% of electricity consumption of US households in 2001 (EIA, 2004). Liu et al. (2004) studied and revealed that the energy consumption of refrigerator-freezers is about 15% to 20% of domestic electricity usage. Mahlia et al. (2003) investigated that refrigerator-freezers consume about 26% of residential electricity in Malaysia. In this situation a number of countries have introduced energy labeling programs [Vine et al., 2001] and minimum energy efficiency standards (Waide et al, 1997; Turiel, 1997) of different appliances and equipments to minimize the energy consumption. Scientists, engineers and researchers in the field of refrigeration and air conditioning are now involving themselves to develop different technical options for improving the energy efficiency and reducing different system losses of household refrigerators.

Household refrigerator-freezer energy consumption depends on different variables like (i) number of door opening (ii) duration of door remaining open (iii) ambient temperature (iv) cabinet load (v) thermostat setting position etc. Very few experimental and theoretical studies have been carried out on the operating variable of household refrigerator-freezer. Laguerre et al. (2002) conducted a customer survey and found that the number of door openings during breakfast, lunch, dinner and between meals is estimated to be 19% (below 10 times per day), 43% (10 to 20 times per day) and 38% (over 20 times per day). Masjuki et al. (2001) investigated the effect of the ambient temperature, door opening, thermostat settings and food loading in order to develop refrigerator-freezer test standards and found that they have 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. Due to some technical problems and wide distribution of energy use 209 refrigerators were selected and energy consumption was 1160 kWh year^{-1}. Gage (1995) investigated the daily energy consumption of the nine units of refrigerator that ranges from 1.7 to 5.3kWh day^{-1}. It consumes 1.4 kWh day^{-1} (12% increases) more energy in 26 door opening compared to no door opening. It increases about 1.6 kWh day^{-1} with the ambient temperature increasing by 1^{0}C. Saidur et al. (2002) conducted an experiment and found about 12.4 Wh increase in energy consumption for each door opening of the 300 L refrigerator-freezer with 12 sec door opening. They also found that energy consumption increases around 53Wh day^{-1} for 1 ^{0}C increase in temperature. M. Hasanuzzaman et al. (2008) experimentally investigated the effect of different variables on energy consumption of household refrigerator. Their 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 other variables. The open door energy consumption is 40% more compared to the closed door test. Users pay attention to the refrigerator-freezer ability to keep food fresh as well as its energy consumption.

That's why, it is so important to investigate the effect of operating variables on energy consumption of household refrigerator-freezer.

II. EXPERIMENTAL METHODOLOGY

A conventional one chamber household refrigerator is used in this experiment. The specification of the refrigerator is as follows: refrigerator internal capacity 51.0 litre, refrigerant R-134a, Power rating, current rating, voltage and frequency of compressor, 60 Watt, 1.3 ampere, 240 volt, 50 hertz respectively. The experimental Set-up comprised a refrigerator, thermocouple, digital energy meter, and data acquisition system. Fig. 1 shows the schematic diagram of the experimental set-up and Fig. 2 shows position of thermocouple of the setup. Temperatures at various locations (compressor, condenser, evaporator and cabinet) are measured with K-type (copper–constantan) thermocouples having 0.0005 m diameter as shown in Fig. 2. The uncertainty of the temperature measurements by the thermocouples is estimated to be ±2.78% with respect to a high precision (0.002^0C) thermometer (Begman thermometer). A K-type thermocouple is used for the measurement of the air temperature within the cabinet, which is located at the center of the cabinet space. A thermostat is used to drive the compressor cycling; the thermocouple of the thermostat is located at the centre of the cabinet. The experimental set-up is equipped with a data acquisition system linked to a personal computer which allows a high sampling rate and the monitoring of all the measurements made by means of the thermocouples. Energy consumption was measured by the digital power meter. The accuracy of this power meter is ± 0.2% of reading. The experiments have been carried out in a room where the temperature and humidity are maintained constant with the aid of air conditioner.

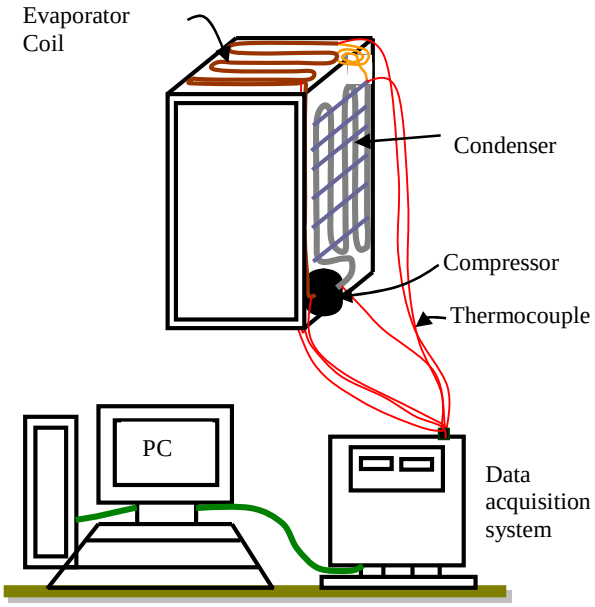

Fig. 1 Schematic diagram of the experimental set-up

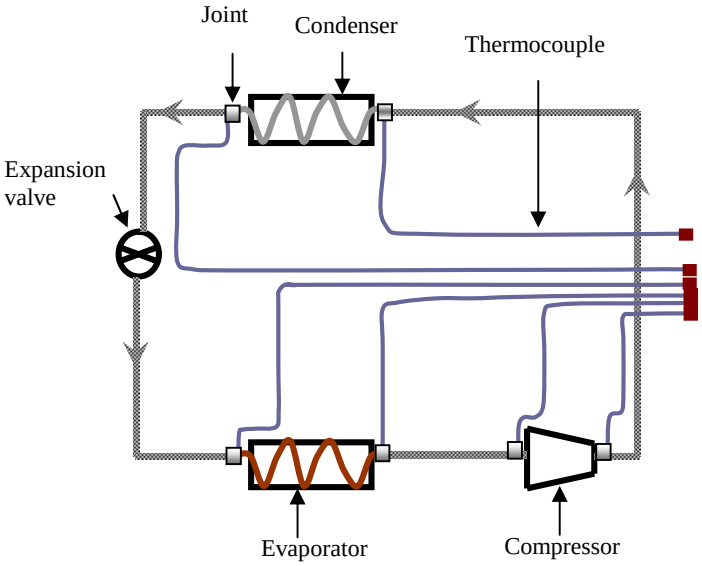

Fig. 2 Location of thermocouple

III. EXPERIMENTAL CONDITIONS

The energy consumption of household refrigerator depends on the different variable are the number of freezer door opening, duration of each door remaining 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 considered variables were the (i) number of door opening, (ii) duration of each door remaining open, (iii) ambient temperature and (iv) cabinet load. During the experiment, only one variable was changed and the other variables were kept constant. (i) Number of door opening varied from 2 to 8 times per hour. In this experimental time the duration of door remaining open was 20 sec and the cabinet load was 0.003 m^3 of fresh water, both two variables were kept constant. (ii) Duration of door remaining open varied from 10 to 40 sec, during this experiment no. of door opening was kept constant 2 times per hour and cabin load was 0.003 m^3 of fresh water. (ii) Ambient temperature varied from 20 to 32^0C in the environmentally controlled chamber. During this experiment no. of door opening was kept constant 2 times per hour, duration time 20 sec and cabin load was 0.003 m^3 of fresh water. (iv) Cabinet load was varied from 0.001 m^3 to 0.008 m^3 of fresh water. During this experiment no. of door opening was kept constant 2 times per hour, duration time 20 sec.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

This experiment has been conducted at different operating variable conditions. The effects of these variables on energy consumption of household refrigerator-freezer are discussed below.

A. Effect of Nnumber of Door Opening on Energy Consumption

Figs. 3 and 4 show the effect of number of door opening on energy consumption and percentage of energy consumption of a household refrigerator. It is clearly shown from that figure that huge amount of energy has been consumed because number of door opening increased.

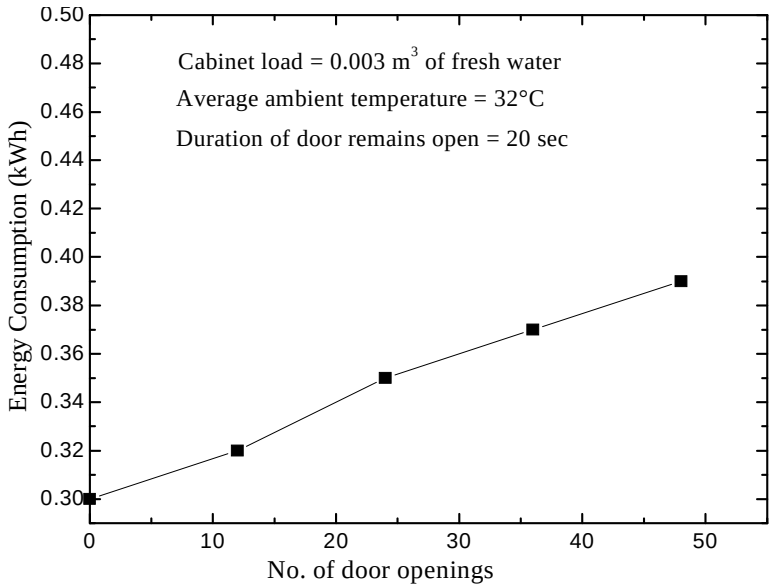

Fig. 3 Variation of energy consumption with number of door openings

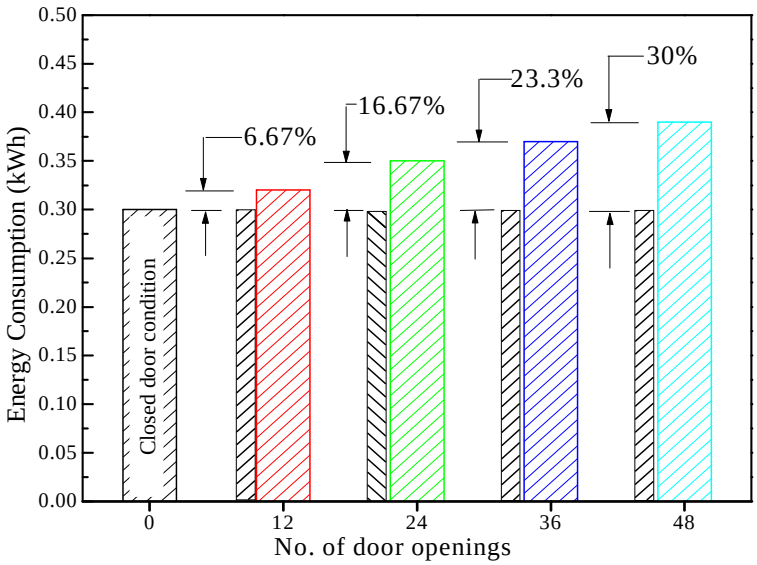

Fig. 4 Comparison of energy consumption at different door opening condition with closed door condition

Depending on number of door opening for 12 to 48 times per 6 hours about 6.67% to 30% energy consumption increased as compared to closed door condition. Based on the experiment, it is found that it increases by 1.43 kWh when the number of door opening increases from 12 to 48. It increases by 39 Wh per door opening. The number of door opening has great effects on energy consumption. When door is opened, hot and humid ambient air mixes with the chamber cold air. That's why moisture transfer increases with increasing the number of door opening. The hot and humid surroundings air cool down and freeze at the freezer temperature. Then double energy is required to make frost and to defrost it again. Whereas if the number of door opening increase, the convective heat transfer will increase. That's why, if the number of door opening increases, energy consumption will increase obviously.

B. Effect of Duration of Each Door Remaining Open on Energy Consumption

Figs. 5 and 6 show the effect of duration of door remaining open on energy consumption and percentage of energy consumption of a household refrigerator.

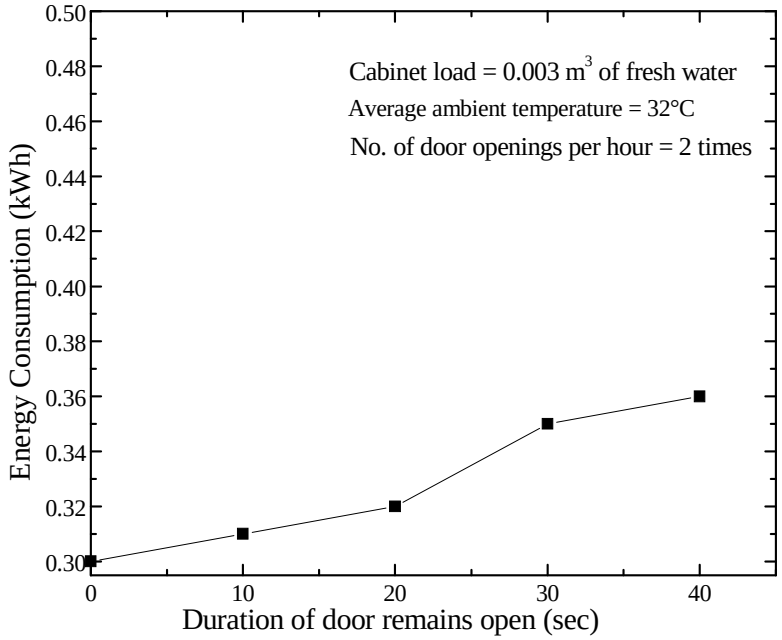

Fig. 5 Energy consumption Vs duration of each door remains open

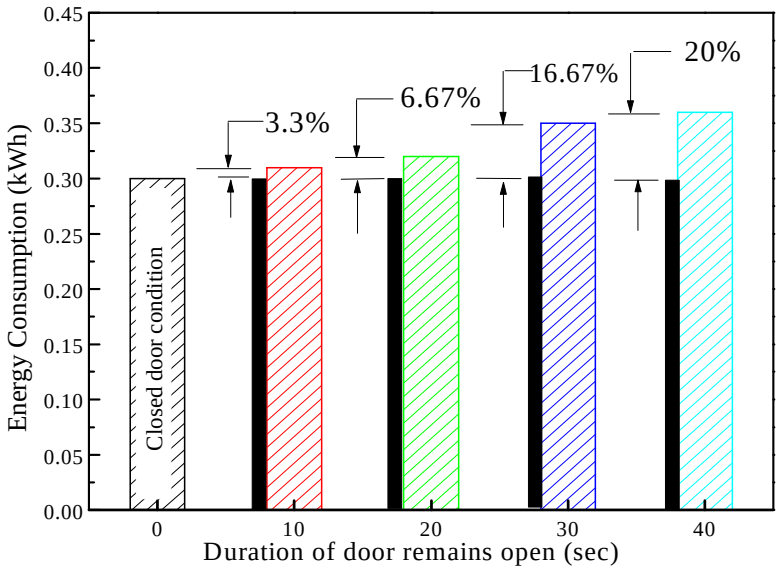

Fig. 6 Comparison of energy consumption at different duration of door remains open condition with closed condition

It is clearly shown from that figure that huge amount of energy has been consumed because duration of door opening increased. Depending on duration of door remaining open for 10 to 40 seconds about 3.3% to 20% energy consumption increased as compared to closed door condition. Based on the experiment, it is found that it increases by 1.34 kWh when the duration of each door remaining open increases from 10 to 40 seconds. It increases by about 44 Wh for 1 sec increase in the duration of each door remaining open. When the duration of door remaining open increases, the duration of the stable air flow, convective and radiative heat transfer increases. It imposes thermal load on the chamber by increasing the heat and humidity transfer. So, energy consumption increases with increasing the duration of each door remaining open to minimize the thermal load.

C. Effect of Ambient Temperature on Energy Consumption

Fig. 7 shows the energy consumption due to the increased ambient temperature. It is clearly shown from that figure that huge amount of energy has been consumed due to the increased ambient temperature. Depending on ambient temperatures for 25 to 33^{0}C about 14.3% to 52.38% energy consumption has been increased as compared to 20^{0}C ambient temperature. Based on the experiment, it increases by 1.32 kWh /6 h when the ambient temperature increases from 20 to 33°C. It increases by about 101 Wh /6 h for a 1°C increase in the ambient temperature.

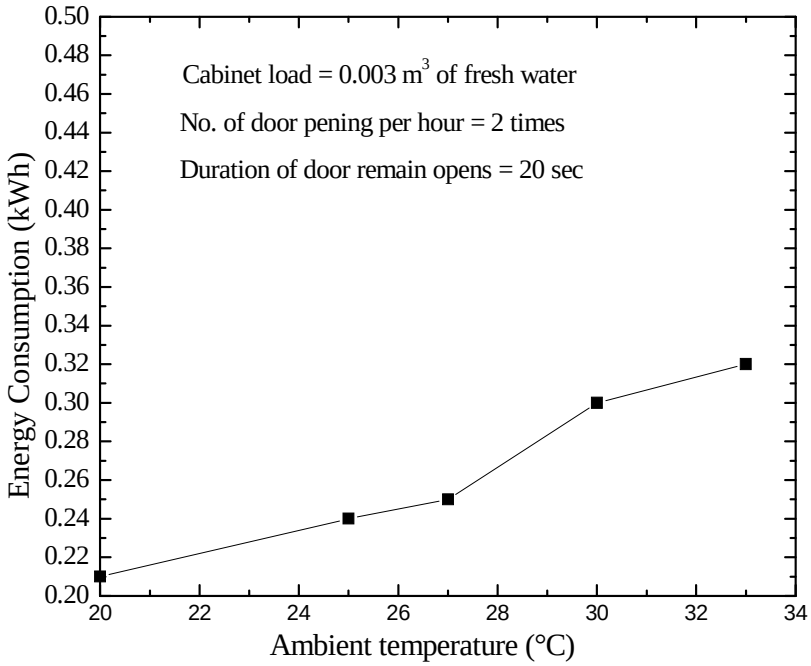

Fig. 7 Energy consumption Vs ambient temperature

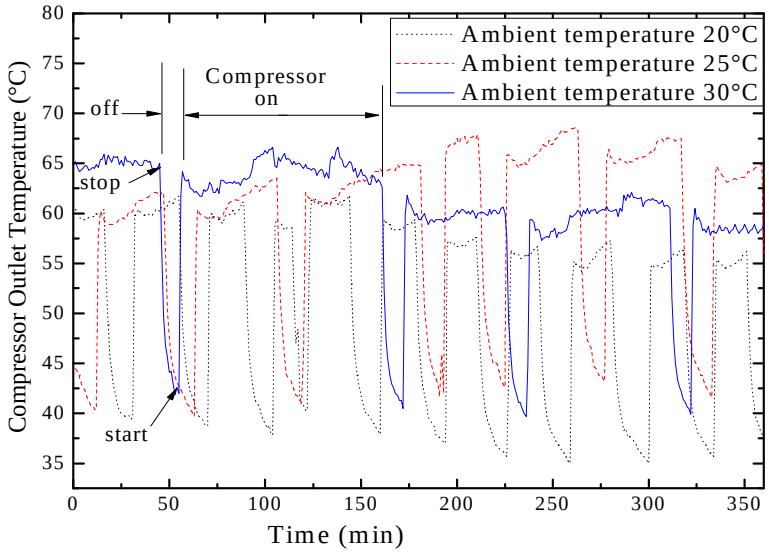

Fig. 8 Compressor outlet temperature Vs time at different ambient temperatures

Fig. 8 shows time vs compressor outlet temperature at different ambient temperatures. In this figure the point where the compressor outlet temperature just starts to decrease from its peak is identified as the moment of compressor just off, and the point where the compressor outlet temperature just starts to increase from its lower value is recognized as the moment of compressor just on.

From this figure it is clearly shown, that compressor running time is increases with increasing the ambient temperature also increased the ratio between the compressors running time to the total cycle time. Hence compressor consumed more energy with increasing the ambient temperature than that low ambient temperature.

Ambient temperature is strongly affected on the energy consumption of the refrigerator-freezer. At higher temperature air can carry on extra moisture. That's why at the higher temperature air with extra moisture enters into the chamber during the open door condition. 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 warms up. In addition, increasing the ambient temperature increase 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.

D. Effect of Cabinet Load on Energy Consumption

Figs. 9 and 10 show the effect of different cabinet loads on energy consumption and percentage of energy consumption of a household refrigerator. It is clearly shown from that figure that huge amount of energy has been consumed due to cabinet loads. Depending on cabinet loads for 0.001 to 0.007 m^3 volume of water about 17.65% to 58.82% energy consumption increased as compared to no cabinet load condition.

Based on the experiment, it is found that it increases by 0.94 kWh/ 6 h when the cabinet load increases from 0.001 to 0.007 m^3 of fresh water. It increases 238 Wh/6 h per liter of fresh water.

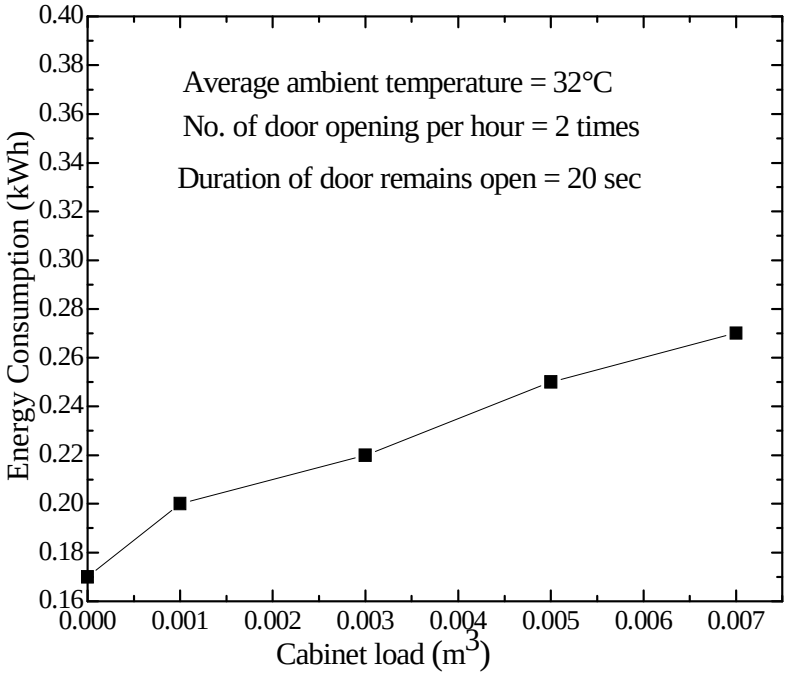

Fig. 9 Energy consumption Vs cabinet loads

Cabinet thermal load is strongly influenced by the energy consumption of the refrigerator-freezer. During the door opening it warms up and cools down again at the desired temperature. When the cabinet is more loaded, it gains 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.

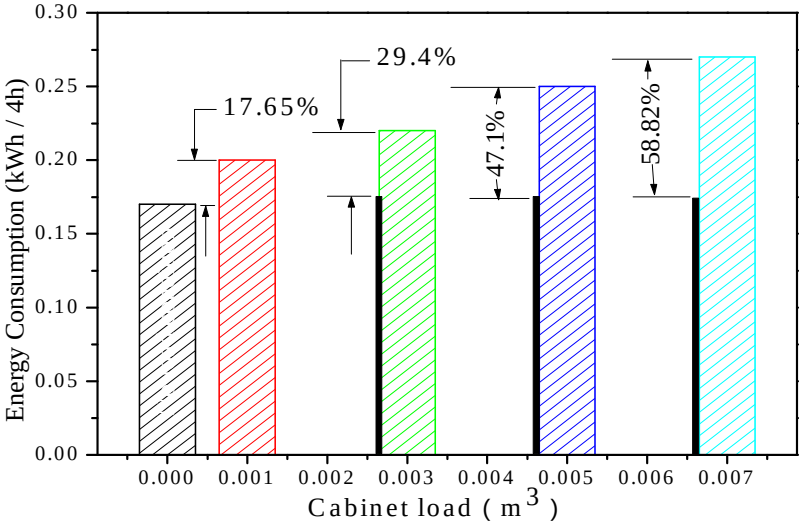

Fig. 10 Percentage of energy consumption at different cabinet loads compared with no load condition

V. CONCLUSIONS

Effect of different operating variables on energy consumption of a household refrigerator has been investigated and following are the specific conclusions:

1) The number of door opening has great effects on energy consumption. Depending on number of door opening about 6.67% to 30 % energy consumption increased as compared to closed door condition.

2) The energy consumptions have been increased with increasing the duration of door remaining open. It increases by about 44 Wh/6 h for 1 sec increase in the duration of each door remaining open and up to 20% energy consumption increased as compared to closed door condition.

3) The ambient temperature has the strong influence on the energy consumption. It increases by about 101 Wh/6 h for a 1^0C increase in the ambient temperature.

4) Also the cabinet load has the strong influence on the energy consumption. It increases 238 Wh/6 h per liter of fresh water and up to 58.82% energy consumption increased as compared to no load condition.

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