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An Experimental Investigation of Door Opening Effect on Household Refrigerator; the Perspective in Bangladesh

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ABSTRACT

In this study presents the experimental investigation of the effects of number of door openings on the energy consumption of a household refrigerator. The experiments were conducted under the different number of door opening conditions. 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 7-30% more energy consumption has been observed as compared to closed door condition. Experimental results also show that the compressor on-off cycling increases by about 2-5 times because of the number of door opening increase which ultimately increases the system loss of the refrigeration system. The test result also proved that the temperature fluctuation inside the cabin is increased with increasing the number of door opening which ultimately damage the quality of the food. If the users in Bangladesh be serious, a significant amount of energy could be saved and reduce the system losses with proper utilizing of the refrigerator freezer.

Key words: Household refrigerator, door opening, energy consumption, system loss, food quality

INTRODUCTION

Bangladesh, like other developing countries, has experienced dramatic growth in the use of household refrigerator and freezer. The Bangladeshi economic growth rate is about 7% of The World Bank Group (2013). Bangladeshis per capita income went up to $848 in the current fiscal year from $816 last year. 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. 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. House hold refrigerator energy consumption

depends on user awareness. As Bangladeshi user has low awareness, sometimes they unnecessarily open the refrigerator-freezer door many times as a result dramatically increase the energy consumption. If a user unnecessarily open and closed the door more and more times, energy consumption may be increased. So performance of household refrigerator fully depends on how to use a refrigerator-freezer by a user. The number of door opening greatly affected the energy consumption of household refrigerator. Very few experimental and theoretical studies have been carried out on the analysis of effect of door opening on energy consumption of refrigerator. 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. Gage (1995) investigated the daily energy consumption of the nine units of refrigerator that is ranged from 1.7-5.3 kW h day^{-1}. It is consumed 1.4 kW h day^{-1} (12% increases) more energy in 26 door opening compare to no door opening. It is increased about 1.6 kW h day^{-1} by 1°C increasing the ambient temperature. 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. They also found that energy consumption increases around 53 W h day^{-1} for 1°C increase in temperature. Hasanuzzaman *et al.* (2008) experimentally investigated the effect of different variable on energy consumption of household refrigerator. Their result shows that there is a great influence of different variable on energy consumption and average consumption is about 3.3 kW h 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. 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 number of door opening on energy consumption of household refrigerator-freezer.

EXPERIMENTAL METHODOLOGY

A conventional one door one chamber household refrigerator with internal cabin volume 51 L has been used for this experiment. The experimental set-up comprised with a refrigerator, thermocouple, digital energy meter and data acquisition system. Figure 1 shows the schematic

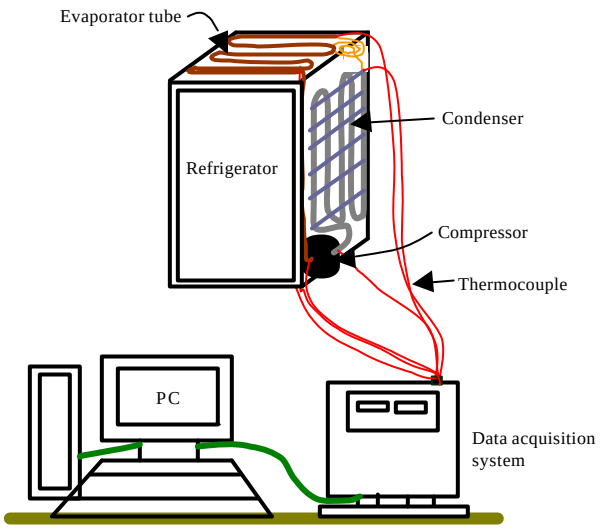

Fig. 1: Schematic diagram of the experimental set-up

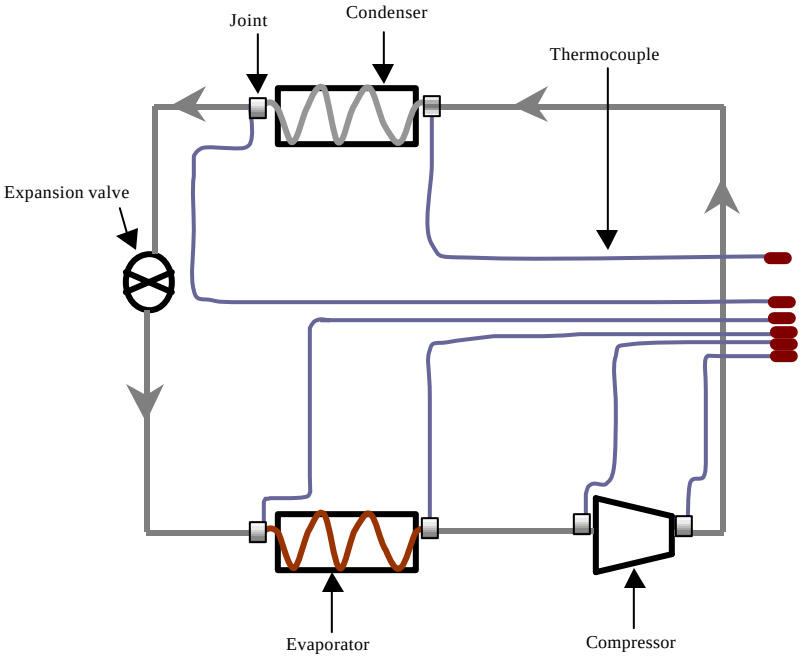

Fig. 2: Location of thermocouple

Table 1: Experimental conditions

Experiment No.	No. of door opening time (h)	Total experimental time (h)	Ambient temperature (°C)	Thermal load (m^3)
1	2	6	32	0.003
2	4	6	32	0.003
3	6	6	32	0.003
4	8	6	32	0.003

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 ±0.1°C. For measuring the average air temperature inside the cabinet, total six K-type thermocouple has been used and which is located at the top, middle and bottom 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. The time of door remains open per experiment was 20 sec. The thermostat setting temperature inside the cabin was maintained as 3-5°C.

Experimental conditions: Experiments were conducted at different conditions. Table 1 shows the details experimental conditions.

EXPERIMENTAL RESULTS AND DISCUSSION

The effect of number door opening on performance of a household refrigerator-freezer has been investigated and followings are the significant findings.

Effect of number of door opening on energy consumption: Figure 3 and 4 show the effect of number of door opening on energy consumption and percentage of energy consumption of a household refrigerator respectively. It is clearly shown from that figure a considerable amount of energy consumption is increased due to number of door opening increased. Depending on the number of door opening for 12-48 times per 6 h about 6.67-30% higher energy consumption has been observed as compared to closed door condition. Based on the experiment, it is found that it increases by 1.43 kW 6 h^{-1} when the number of door opening increases from 12-48. It increases by 39 W h per door opening.

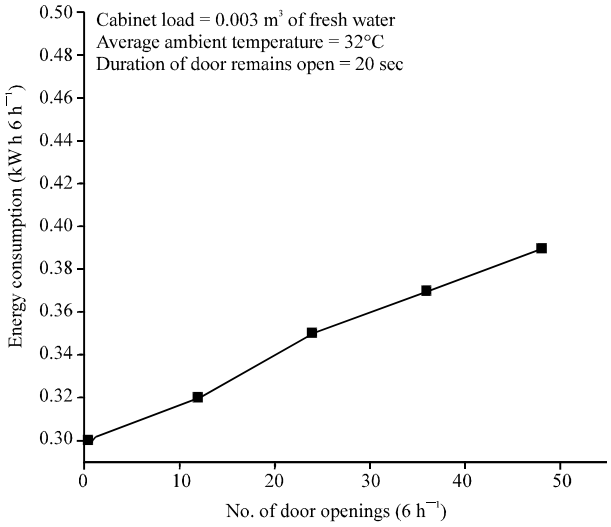

Fig. 3: Variation of energy consumption with number of door openings

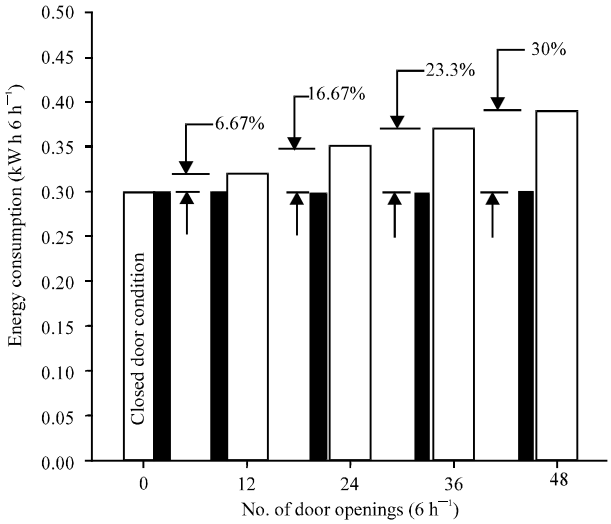

Fig. 4: Percentage of energy consumption at different door opening condition

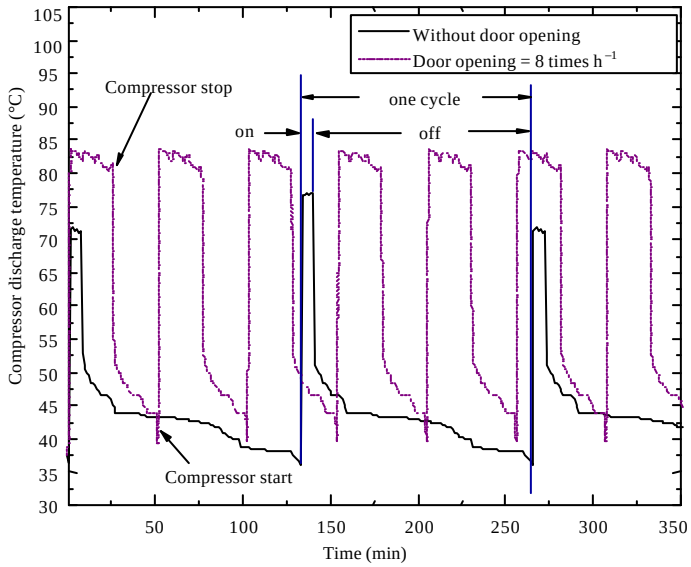

Fig. 5: Time vs compressor discharge temperature

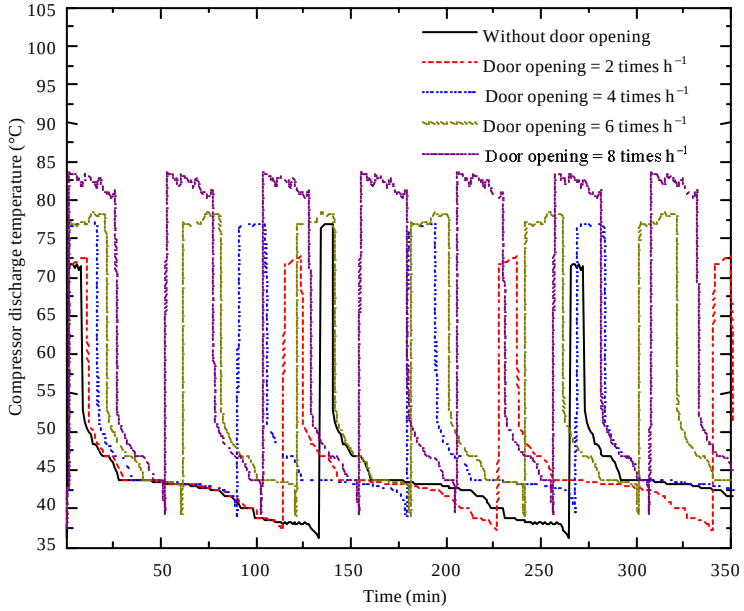

Fig. 6: Time vs compressor discharge temperature at different door openings

The number of door opening has great effects on energy consumption. When it' 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. 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. That's why, if the number of door opening increases, energy consumption increased obviously.

Effect of number of door opening on compressor on-off cycling of household refrigerator: Figure 5 and 6 show the effect of number of door opening on compressor on-off

cycling of a household refrigerator, from which the number of compressor on-off cycle within a certain period of time can be pointed up. From Fig. 5 the point where the compressor outlet temperature just start to decrease from its peak is identified as the moment of compressor just off and the point where the compressor outlet temperature just start to increase from its lower value is recognized as the moment of compressor just on. It is clearly observed from these Figs. that if number of door opening are increased which increase the number of on-off cycling of compressor. Depending on number of door opening, number of compressor on-off cycling 2-4 times higher as compared to closed door condition. Figure 6 shows the maximum number of on-off cycling is occurred for number of door opening 8 times h^{-1} while it is decreases with decreasing the number of door opening.

The compressor on-off mode is triggered by the thermostat at a specific desired temperature which is located in the evaporator compartment. When door is opened surrounding warm and moist air mixes with the cabinet cool air which increases the cabinet temperature above the desired temperature rapidly. As a result the thermostat triggers the compressor in on mode quickly which ultimately increase the compressor on-off cycling. It is well established from the previous research work that the compressor on-off cycle causes significant amount of efficiency and capacity loss. Erik and palm (Bjork and Palm, 2006) experimentally found that efficiency loss of the system is 9% and the capacity loss is 11% due to compressor on-off cycling of house hold refrigerator. Moreover, the compressor lost huge amount of lubrication to the bearings which ultimately reduce compressor life time due to higher on-off cycling.

From the above discussions it is clear that the number of compressor on-off cycle is a predominant factor for the performance of a house hold refrigerator. So, if user be serious, who can maintain the minimum number of door opening and ultimately reduce these types of losses of a household refrigerator.

Effect of number of door opening on Temperature fluctuation inside the cabin of a household refrigerator: Figure 7 shows the average air temperature inside the cabinet of the experimental refrigerator at closed door condition. This is done only for determining the appropriate

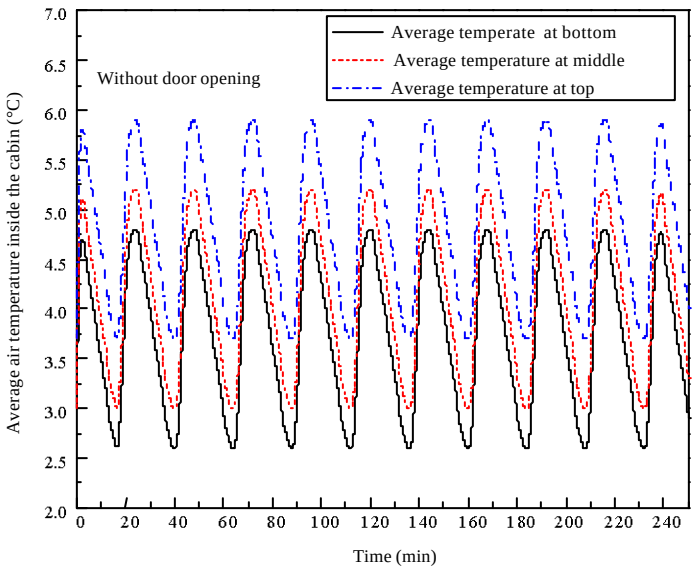

Fig. 7: Average air temperature inside the cabin of the experimental set-up

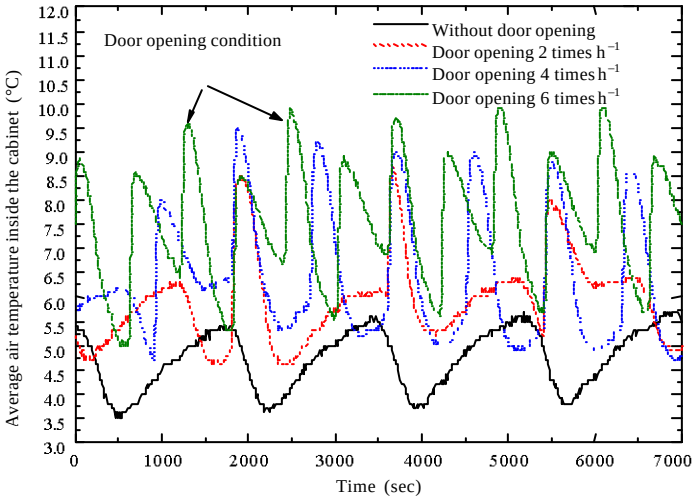

Fig. 8: Average air temperature inside the cabinet at different door openings with respect to time

average temperature which has been used for making a comparison of temperature fluctuation with and without door opening. During the closed door condition the temperature at the top position of the chamber is higher than set point temperature whereas at the bottom position it is so lower. So the temperature that has been got from the top position and the bottom position did no select for appropriate temperature. Therefore, the temperature that has been found from the middle position which is almost similar to the set point temperature and this temperature is selected as an appropriate temperature.

Figure 8 shows the effect of door opening on temperature fluctuation inside the cabin of a household refrigerator with respect to time. The test result shows the temperature fluctuation inside the cabin is significantly higher as compared to closed door condition. Figure 9 shows the maximum am and minimum temperature inside the cabinet which is raised and dropped during the on-off cycling. Depending on the number of door opening about 3°C more temperature has been raised due to door opening as compared to closed door condition. The test result also shows that the temperature difference between the maximum and minimum about 2°C has been observed for closed door condition whereas for door opening it was varied from 4 to 5°C which is so higher as compared to closed door condition. This higher temperature difference makes more temperature fluctuation. This higher temperatures and/or fluctuations damage the food quality inside cabinet which has been reported in many literatures. Blond and Le Meste (2004) investigated the effect of temperature fluctuation on food quality and they found that the higher temperatures and/or fluctuations of storage temperature produce cumulative adverse effects on the quality of stored foods which is the primary cause of damage to food. So if user be serious, it is possible to reduce this type of problem.

Temperature fluctuation means rapidly rise and drop the temperature for a specific time inside the cabin. When door is opened ambient hot and moist air mixes with the cold air inside the cabin which rise the air temperature inside the cabin. When inside air temperature is rising above the setting temperature (3-5°C) the compressor is started until the temperature drops down the set point temperature. If again door is opened the same phenomenon has been occurred. Before

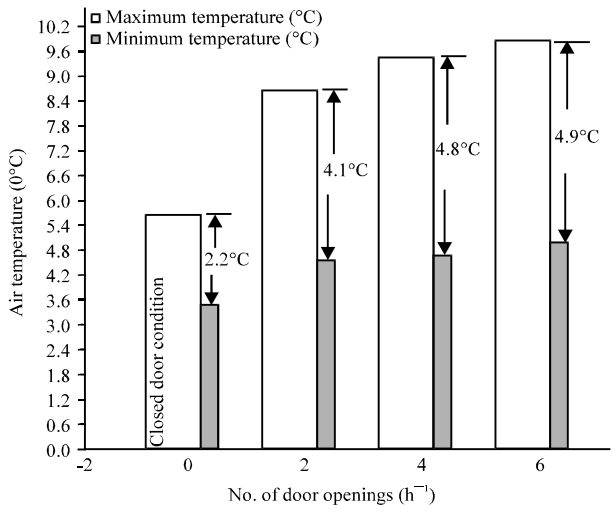

Fig. 9: Maximum and minimum air temperature inside the cabinet at different door openings

maintaining the desired temperature if door is again opened which rise the temperature again and that's why does not maintained the constant or steady temperature inside the cabin.

CONCLUSION

Considering the Bangladeshi user, effects of number of door opening on a house hold refrigerator has been investigated experimentally. From the test results, it is clearly concluded that energy consumption of refrigerator with door opening is increased as compared to the same product without door opening. Depending on the number of door opening about 7-30% more energy consumption has been observed as compared to closed door condition. It is also clear that the compressor on-off cycling is increased about 2-5 times due to the number of door opening increase which ultimately increases the system loss of the refrigeration system. The test result also proved that the temperature fluctuation inside the cabin is increased with increasing the number of door opening which ultimately damage the quality of the food. If the users in Bangladesh be serious, a significant amount of energy could be saved and reduce the system losses with proper utilizing of the refrigerator-freezer.

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