

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF CHANGE IN AMBIENT AIR TEMPERATURE ON POWER CONSUMPTION OF DOMESTIC REFRIGERATORS

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ABSTRACT

One of the manifestations of climate change is increase in ambient air temperature usually referred to as global warming. For sustainable development in a country, there is need to identify impacts of climate change and the necessary adaptation and mitigation strategies to adopt. To simulate the effect of global warming on the power consumption of refrigerators, a (model No. 150) THERMOCOOL refrigerator filled with twenty-five 750cl packaged water bottles was run in an air-conditioned room, in a room with the air-conditioner switched off and near an oven in a bakery. The electric power consumption of the refrigerator was measured using "Watts up?.net" Watt meter and the ambient temperature was measured using FLUKE temperature/humidity meter. The average hourly energy consumption of the refrigerator operating at mean ambient temperatures of 25.4°C, 30.7°C, 38.8°C were 93.844Wh, 100.32Wh, 105.08Wh, respectively. Some possible ways to reduce the increase in power consumption of refrigerators due to global warming include using compressors of higher efficiency and condensers of greater effectiveness.

Key words: Ambient temperature, Power consumption, Domestic refrigerators, Climate change

1. INTRODUCTION

The effects of climate change are interrelated but can be broadly classified into four categories, namely: hydrological effects, ecological effects, anthropological effects and effects on geographical landscape (Fagbenle, 2010). As was mentioned by Fagbenle (2010), climate change results in increase in river and sea water levels and a general distortion in the thermal structure of water. Other effects include destruction of water life habitat and loss of coastal landscape. The primary causes of global warming are human activities such as release of aerosols into the atmosphere which depletes stratosphere ozone layer, emission of green house gases as a result of combustion of fossil fuels and biomass (IPCC, 2007, Wilson and Law, 2007).

Olorunmaiye et al. (2012) from their statistical analysis of hourly dry-bulb temperature for Ikeja and Ilorin in Nigeria for the periods 1978-1992 and 1995-2008 found that the average hourly temperature for the two locations were higher during the period 1995-2008 than for the period 1978-1992. It was also reported in the same work that both the mean temperature and the 2½% outside design air temperature for the four warmest months in the year (for air conditioning cooling load calculation) increased from an earlier period to another for the periods 1951-1965, 1978-1992 and 1995-2008 for both Ikeja and Ilorin. These increases in temperature were presented as evidence of global warming in Nigeria (Olorunmaiye et al., 2012).

While most of the effects of climate change have been well investigated with documentation on trends, the adaptive nature of humans have made it difficult to measure trends in anthropological effects; for example the use of refrigerators and air-conditioners to combat high ambient temperature make it less likely to get accurate data on effects of climate change on human health due to environmental temperature increases. However, refrigerators and air-conditioners (powered with electricity) as a human adaptive mechanism has its own long-term negative effect on climate change by contributing to the production of greenhouse gases in the environment. Refrigerators are common household appliances in some rural and all urban areas in Nigeria like in other in other developing countries. It was reported by Saidur et al. (2005) that 75% of houses in Malaysia have refrigerator-freezers and that refrigerator-freezer was found to be the largest consumer of electricity in residential houses in the country.

Saidur et al. (2005) developed an empirical relationship between energy consumption of a refrigerator-freezer and three independent variables, namely: ambient temperature, load in freezer compartment and the number of times the refrigerator door is opened per hour. Among the three independent variables, the effect of change in ambient temperature was found to be the strongest on energy consumption of the refrigerator-freezer.

Considering the increase in ambient temperature as a manifestation of global warming, this study looks at the effect of ambient air temperature on power consumption during refrigeration. This investigation was carried out using three different ambient temperatures classified as low temperature, medium temperature and high temperature. The study was undertaken at the first two conditions for nine hours while the study under the third condition took place for nearly six hours. The extended period of experimental work in each case represents an improvement over the work of Saidur et al. (2005) who carried out their experiment for one hour in each case. Extended time was spent to measure energy consumption in each experiment done in this work to ensure that the refrigerator works longer than the period to cool down the loaded items in the refrigerator to the temperature set with the thermostat. Results of the experimental work carried out are herein presented and discussed.

2. EXPERIMENTAL WORK

The instruments used in the data gathering were:

FLUKE 971 Temperature – humidity meter made by FLUKE Corporation, Taiwan. It can measure dry bulb temperature and relative humidity RH at the same time. (Specifications: Temperature range: -20°C – 60°C; RH range: 5-95%; Accuracy: Temperature $\pm 0.5^\circ\text{C}$, RH $\pm 2.5\%$ at 25°C) (Fluke Corporation, 2005).

“Watts up? PRO” Power Analyser and Watt meter made by Electronic Educational Devices, Inc. Denver Colorado, USA. Model Wattsup?/PRO/ES/.Net/UO. It made use of a data logger software down loaded from www.wattsupmeters.com.

By high frequency sampling of voltages and current measurements as well as power factor, the true power consumption is indicated by the watt meter (Electronics Educational Devices, Incorporated, 2008).

Experimental data were gathered for a refrigerator (THERMOCOOL, Model T150) which was connected to a Watt meter to record data such as wattage, amperage, energy consumed, power factor and other parameters. Figure 1 shows a block diagram of the experimental setup.

Table 1 shows the technical specification of the refrigerator used for this work.

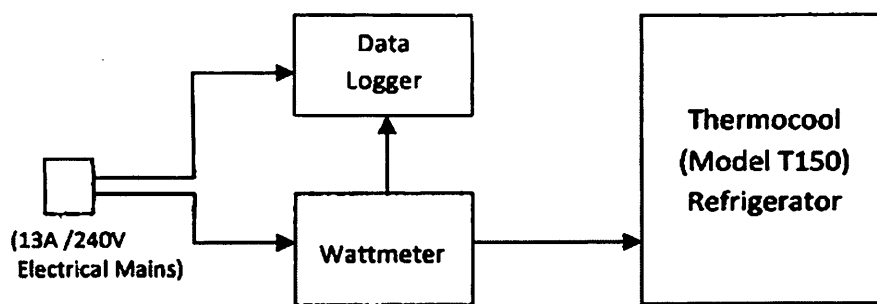


Figure 1: Block Diagram of the Experimental Setup

The Watt meter was connected to a 13A/230V socket while the electric load (Model T150 THERMOCOOL refrigerator) was connected to the watt meter so that energy consumed by the load could be measured over time. An ACER Travelmate 5720 Laptop Computer on which the data logging software of the watt meter had been installed was connected to the watt meter as data logger.

Table 1: Technical Specification of the Refrigerator

Freezer Capacity (litre)	8.30
Fresh Food Compartment Capacity (litre)	78
Power Rating (W)	110
Voltage (V)	220-240
Frequency (Hz)	60
Number of Doors	1 external & 1 internal for freezer compartment
Refrigerant Type	R12

The refrigerator was loaded with twenty-five 75cl bottles of VISLERI packaged water with the following distribution: 4 bottles in the freezer compartment, 12 bottles on the topmost shelf, 7 bottles on the middle shelf and 2 bottles on the fruit storage compartment.

The experiment was carried out in three ambient conditions:

Day 1 (10/3/2011): The experiment was done in an air – conditioned room. And this was maintained throughout the experiment. The initial room temperature was taken and the ambient temperature of the room was taken at intervals of one hour. The watt meter recorded the consumed electrical power and other parameters every fifteen seconds, and this was logged electronically. It was observed at the end of the nine hours of the experiment, that the water in two of the bottles in the freezer compartment were frozen.

Day 2 (11/3/2011): The experiment was carried out in the same room as on Day 1 with the air-conditioner switched off, doors and windows were opened to allow for good ventilation of the room with ambient air. Experimental data recorded were logged for 9 hours like on the first day. It was observed at the end of the nine-hour experiment that the water in only one of the bottles in the freezer compartment was frozen.

Day 3 (12/3/2011): The experiment was carried out at FORTUNATE BAKERY located at No. 9 Tijani Adejumo street, behind Lower River Basin Headquarters, Fate, Ilorin. The refrigerator was placed at about 75cm from the oven of the Bakery. The hourly ambient temperature of the place was taken during the experiment. Other parameters such as Watts, Volts, amps, Watt-hour were recorded using the Watt meter and its data logger. It was observed that none of the water bottles in the freezer compartment was frozen. See Figure 2 for a photograph of the experimental set up near the bakery oven.

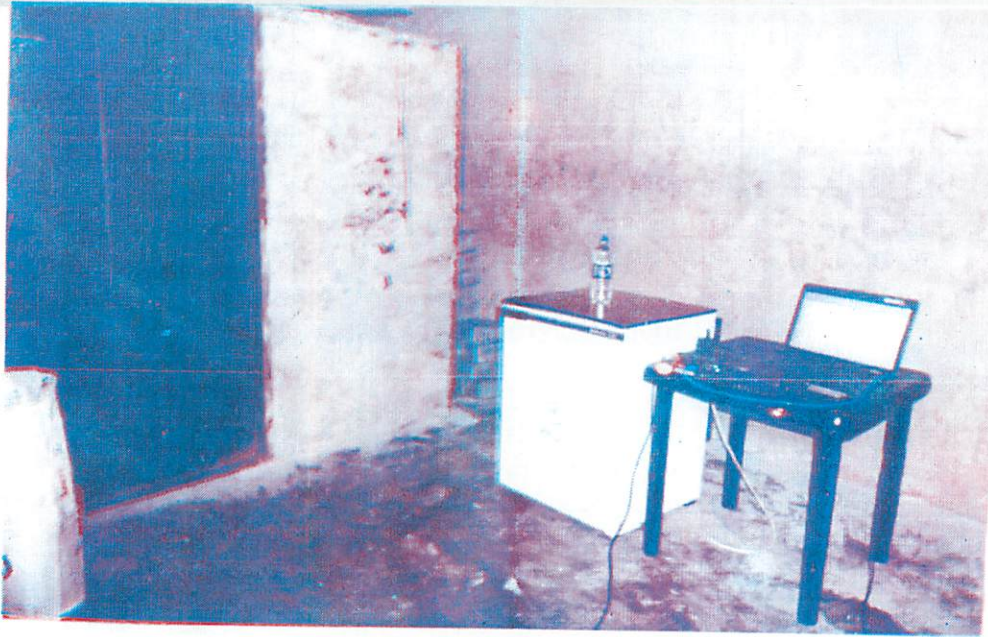


Figure 2: Experimental Set-Up near the Oven

3. RESULTS OBTAINED

The Power consumption for the periods of the experiments against time in segments of 3 hours are presented for the three days of the experiment in Figures 3(a), (b), (c), 4(a), (b), (c) and 5(a) and (b). The areas under the curves in Figures 3 to 5 give the energy consumed in Watt-hour during the three-hour segments and these results are shown in Tables 2-4.

Figure 6 shows the plot of results presented in Tables 2-4 using the same symbol to show the results for the first three-hour segments for the three days and another symbol for the second three-hour segment and a third symbol for the third three-hour segment. Note that for the third day the energy consumed for the second three-hour segment was obtained by simple proportion from the 277.7Wh obtained for 2.75 hours (4.02-6.47pm) in Table 4.

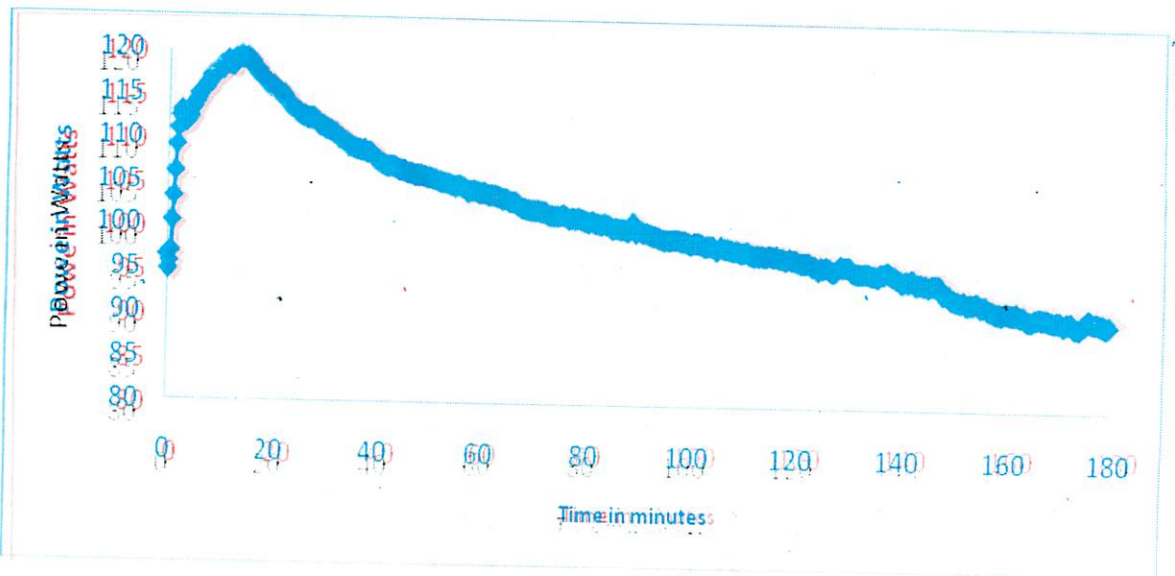


Figure 3a: Power against Time for the First 3 hours of Running the Refrigerator in an Air-Conditioned Room (10/03/11)

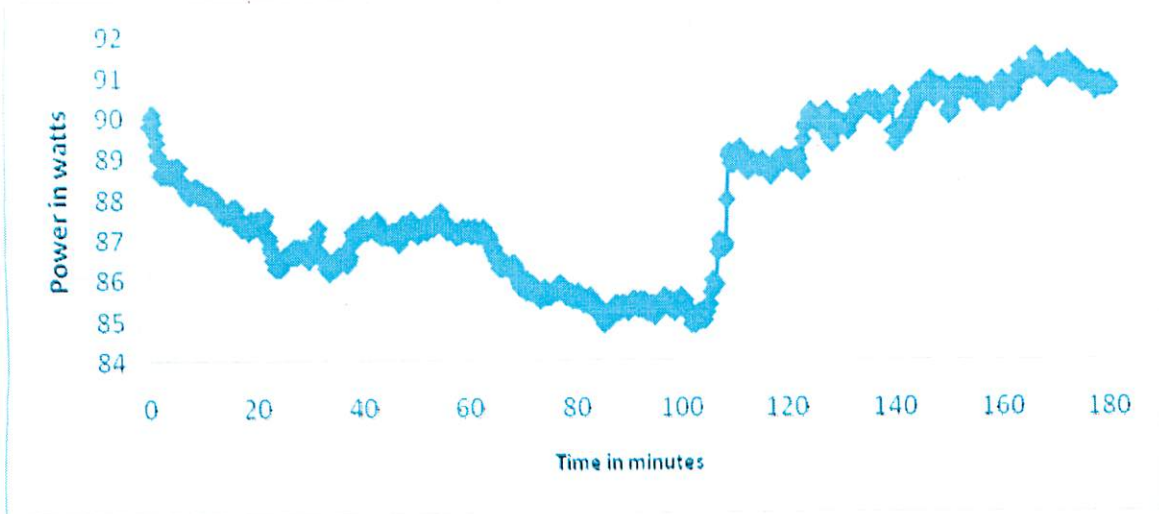


Figure 3b: Power against Time for the Second 3 hours of Running the Refrigerator in an Air-Conditioned Room (10/03/11)

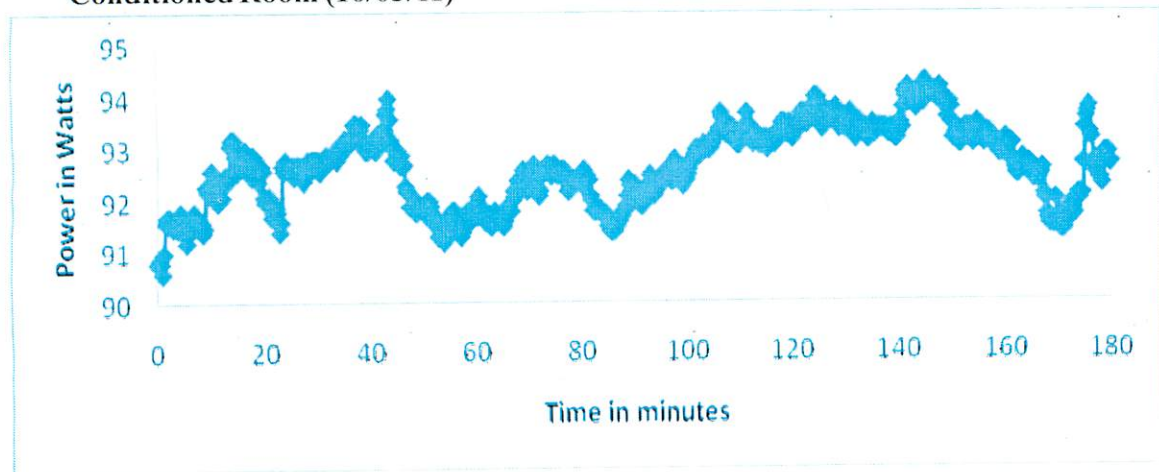


Figure 3c: Power against Time for the Third 3 hours of Running the Refrigerator in an Air-Conditioned Room (10/03/11)

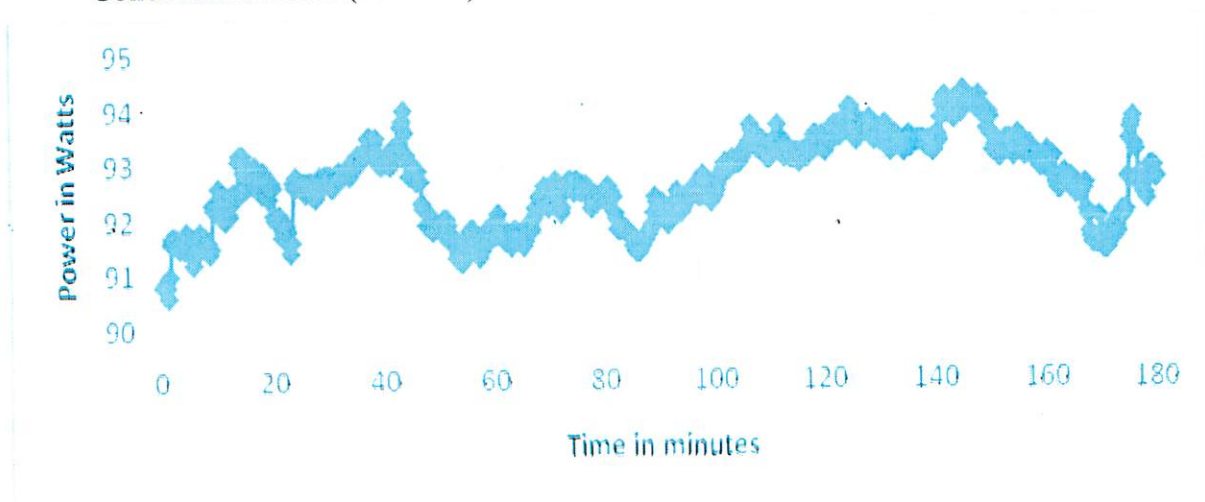


Figure 4a: Power against Time for the First 3 hours of Running the Refrigerator in Room with Air-Conditioner Switched Off (11/03/11)

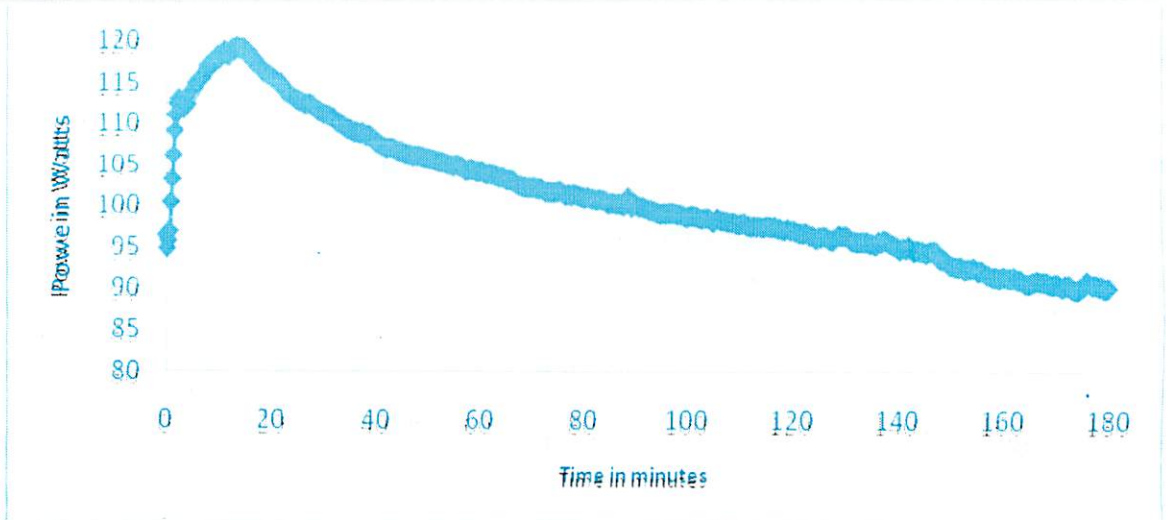


Figure 4b: Power against Time for the Second 3 hours of Running the Refrigerator in Room with Air-Conditioner Switched Off (11/03/11)

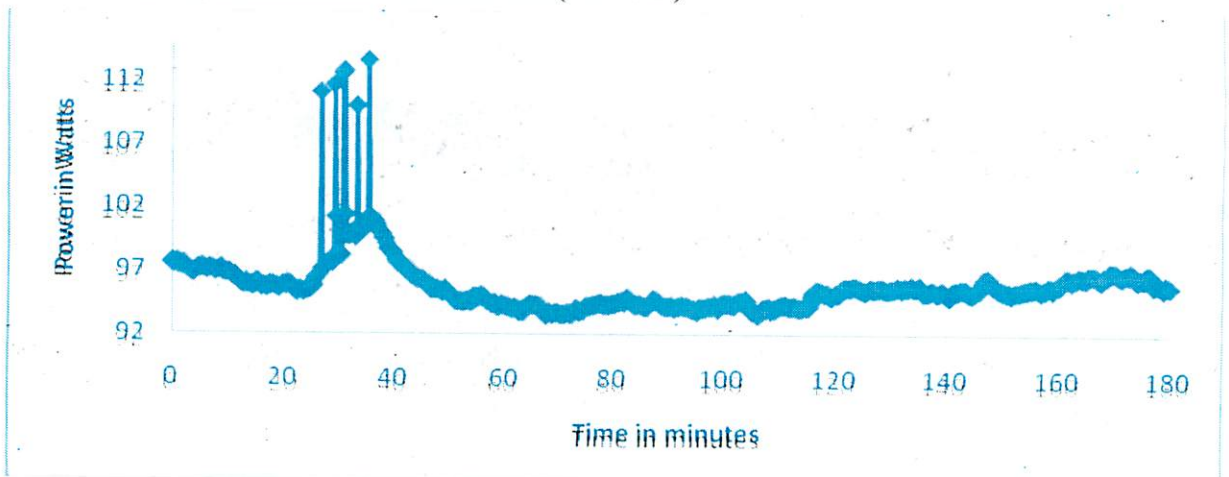


Figure 4c: Power against Time for the Third 3 hours of Running the Refrigerator in Room with Air-Conditioner Switched Off (11/03/11)

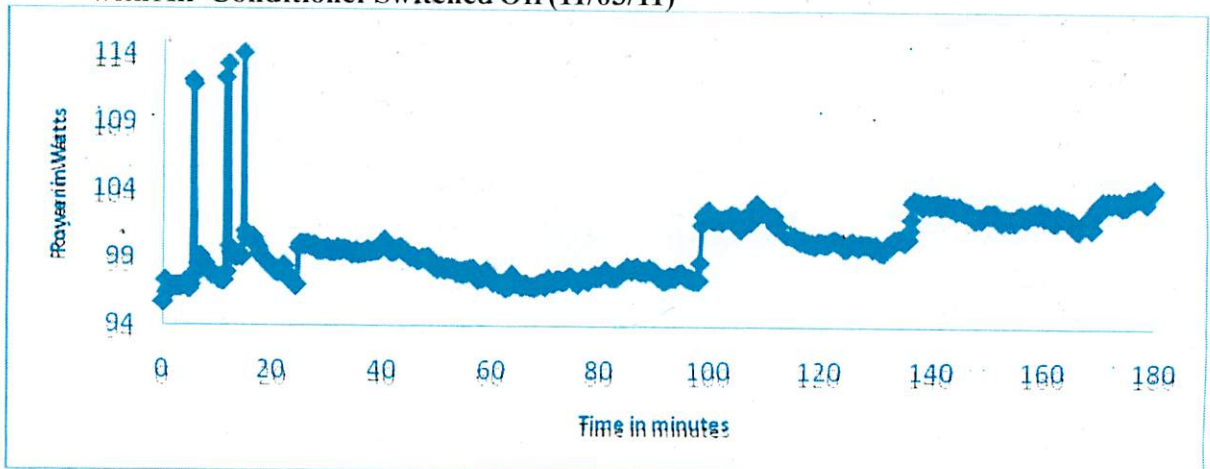


Figure 5a: Power against Time for the First 3 hours of Running the Refrigerator near the Oven of a Bakery (12/03/11)

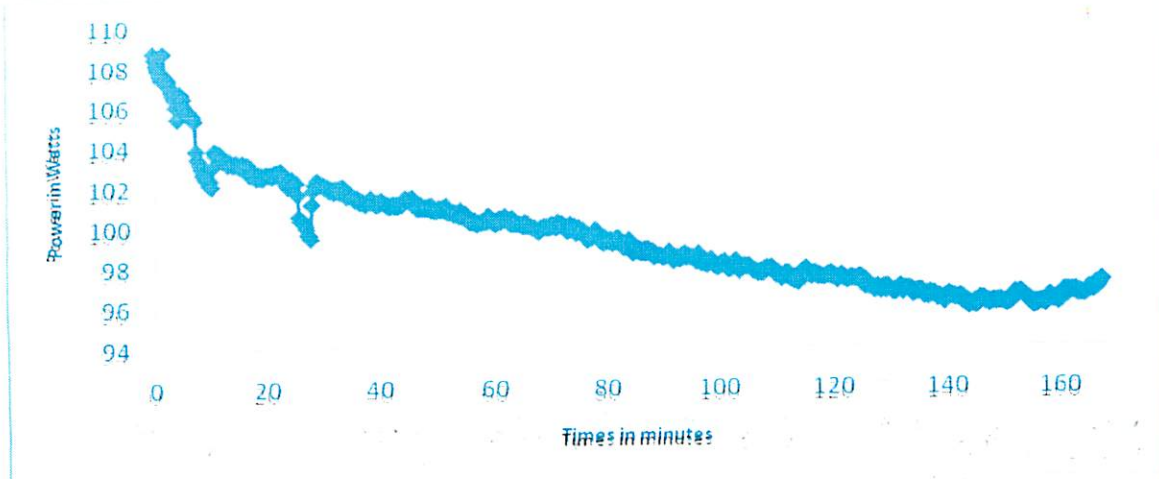


Figure 5b: Power against Time for the Second Period of Running the Refrigerator near the Oven of a Bakery (12/03/11)

Table 2: Energy Consumed during the Three Three-hour Periods of the Experiment in a Room with Air-Conditioner Switched On (10/3/2011)

	Energy Consumed (Wh)	Average Temperature (°C)	Ambient
First 3 hours (from 10.08am to 1.08pm)	302.8	26.0	
Second 3 hours (from 1.12pm to 4.12pm)	264.0	25.3	
Third 3 hours (from 4.13pm to 7.13pm)	277.8	25.03	

Table 3: Energy Consumed during the Three Three-hour Periods of the Experiment in a Room with Air-Conditioner Switched Off (11/3/2011)

	Energy Consumed (Wh)	Average Temperature (°C)	Ambient
First 3 hours (from 10.08am to 1.08pm)	316.3	29.7	
Second 3 hours (from 1.12pm to 4.12pm)	286.9	30.6	
Third 3 hours (from 4.13pm to 7.13pm)	299.7	31.8	

Table 4: Energy Consumed during the Time of the Experiment near the Oven of a Bakery (12/3/2011)

	Energy Consumed (Wh)	Average Temperature (°C)	Ambient
First 3 hour (from 1.00pm to 4.00pm)	326.5	37.1	
Second period (from 4.02pm to 6.47pm)	277.7	40.4	

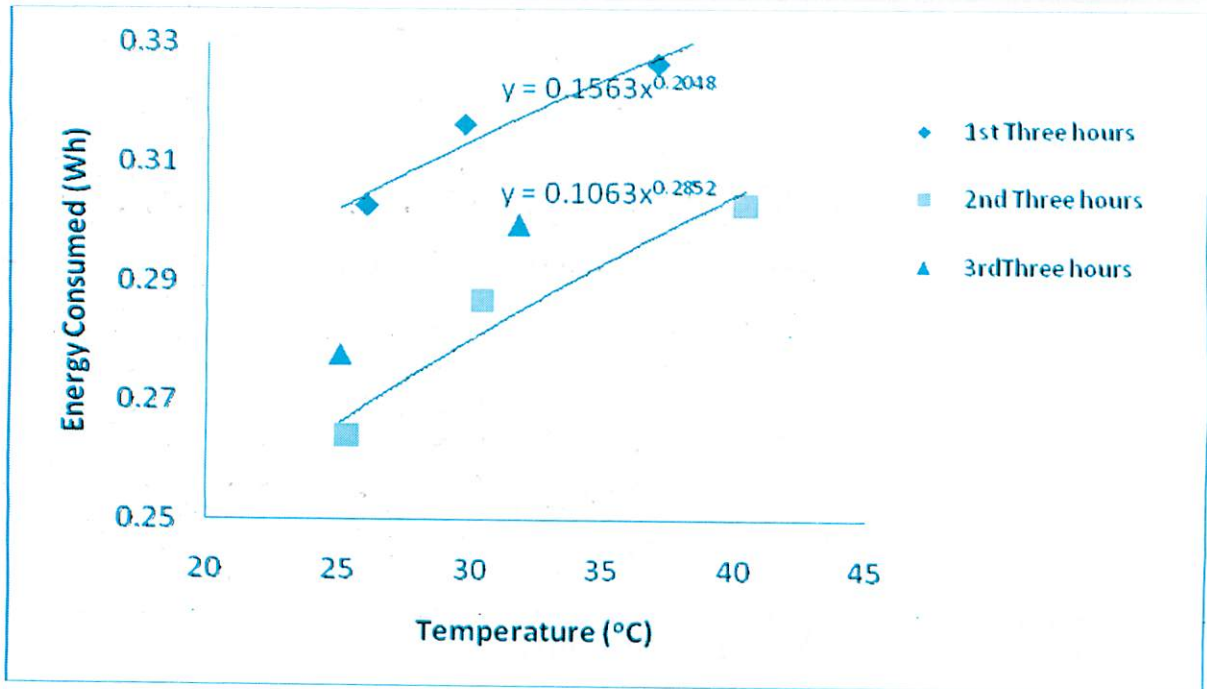


Figure 6: Energy Consumed by the Refrigerator at different Ambient Air Temperature

4. DISCUSSION OF RESULTS

The energy consumed during the first three hours of the experiment at different ambient conditions from Tables 2-4 are 302.8, 316.3 and 326.5 Wh at average ambient temperature of 26°C, 29.7°C and 37.1°C, respectively. The energy consumption at the three ambient conditions can be compared to establish the effect of ambient temperature on energy consumption of the refrigerator because in all the three cases, the 25 bottles of packaged water arrived in the refrigerator at approximately the same temperature and so the temperature reduction loads are approximately equal.

The sudden peaks in power consumption in Figures 4(b) and 4(c) were caused by the opening of refrigerator door at these points which allowed the relatively high temperature ambient air to rush in and this increased the cooling load and eventually the power consumed. From these results it can be seen that the higher the ambient temperatures in which the refrigerator operates, the higher the rate of energy consumption.

This is in agreement with the results of Saidur et al (2005) who found the empirical relationship of Energy Consumed (E in Wh) as a function of Temperature (T in °C), load (water) in the freezer compartment (W, kg) and frequency of door opening (D, cycles per hour) to be

$$E = 73.8965 T^{0.2214} W^{0.0406} D^{0.0096} \quad (1)$$

In this work only the dependence of E on T was investigated and the relationship between E and T for the first three-hour segments was found to be

$$E = 156.3T^{0.2048} \quad (2)$$

and for the second three-hour segments,

$$E = 106.3T^{0.2852} \quad (3)$$

One limitation of the work of saidur et al (2005) was the one hour duration of their experiment. This means that they recorded energy consumed by the refrigerator-freezer during the stage when product temperature reduction load was a significant part of the refrigeration cooling load. Whereas in this

work it can be seen that the equation (equation (2)) relating E with T during the first three-hour segments when product load is significant is different from the equation (equation (3)) relating E with T during the second three-hour segments when product reduction load is no longer significant and heat transmission through the refrigerator wall is the dominant refrigeration cooling load. It should also be noted that Saidur et al (2005) used a more modern refrigerator that is more energy efficient than the one used in this work.

Taking average values from Tables 2-4, the average hourly energy consumption of the refrigerator operating at mean ambient temperatures of 25.4°C, 30.7°C, 38.8°C were 93.844Wh, 100.32Wh, 105.08Wh respectively. The power rating of the refrigerator is 110W and for three hours of operation the energy consumed at that rate is 330Wh. The amount of energy consumed for three hours shown in Tables 2-4 are all less than 330Wh. Cottel and Olarewaju (1995) reported that refrigerators are designed to keep food fresh in the temperature range 0°C – 4°C in an ambient temperature of 43°C or 38°C if electricity voltages fall to 90% of the rated value. No magnitude of energy consumed for three hours was up to 330Wh in this work because the highest value of the ambient temperature in which the refrigerator worked was not up to 43°C. Moreover, the thermostat setting of the refrigerator was on No. 5 out of a maximum cooling of No. 7.

5. CONCLUSION AND RECOMMENDATIONS

The results of the experimental work show that different ambient temperature requires different amount of energy for the operation of a refrigerator. And from these results it can be concluded that global warming will lead to greater consumption of energy to run refrigeration and air-conditioning systems. Therefore a way of adaptation to this effect is generation of more power especially from renewable sources to meet the attendant increase in demand of power to run cooling systems such as refrigeration and air conditioning systems. It is also necessary to use more efficient compressors and heat exchangers of higher effectiveness in refrigerators. An adaptation measure that will make it possible to run refrigerators in cooler rooms is using “cool roofs” for buildings. Cool roof reduces heat transmission into a building either by using solar reflective roof coatings on top of the roofing material (U.S. Department of Energy 2011), or by using polyurethane lining as insulation under the roofing sheets (The Guardian, 2011). The actual rate of energy consumption by an appliance may not be up to the rated power indicated on the appliance most of the time. For accurate energy auditing some measurements such as was done in this work is necessary.

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