Journal of Scientific & Industrial Research
Vol. 76, September 2017, pp. 575-580

Experimental Studies and Test Results on the Energy Efficiency of Household Refrigerating Appliances

Ilhan Kosalay* and H Gokhan ILK

Ankara University, Engineering Faculty Electrical and Electronics Engineering Depetment Golbası Campus, L blok 06830 Golbası/Ankara/Turkey

Received 08 June 2016; revised 19 January 2017; accepted 20 May 2017

Refrigerators are a must for every household around the world. They are important in terms of energy efficiency as they exist almost in every home and many of the offices. In addition their consumption counts a considerable percentage of the overall electricity bill. In this study we describe the details of a test cell for household refrigerating appliances' energy efficiency measurement, including equipment and provide the experimental and test results obtained. The test cell, which is inside the test and measurement laboratory is named "Ankara Energy Efficiency in Household Appliances Technologies Research Centre" and it was financially supported by UNDP (United Nations Development Programme). Measurements were recorded according to IEC 62552, Household refrigerating appliances - Characteristics and test methods - Part 3: Energy consumption standard. Test results which confirmed the manufacturer's claimed energy efficiency index of A+++ were recorded and assessed using MATLAB®

Keywords: Measurement, Energy Efficiency Index, Energy Consumption, Household Refrigerators

Introduction

In the simplest form, improving energy efficiency is defined as "to consume less energy for same amount of work". Energy efficiency applications can be applied in many fields, such as: buildings, vehicles, transportation systems, heating and lighting systems, various instruments, industry, power plants, power generation, transmission and distribution systems. It is well known in the literature that energy efficiency at homes results in considerable power savings[1]. It is necessary to invest in energy efficient technologies in order benefit from these savings. Governments in developed economies are making considerable investments in energy efficiency technologies and encouraging residential households to conserve energy[2]. Another study[3] specifically focuses on refrigerators, since their energy consumption is predicted to constitute over 30% of the total average domestic electricity bill in Brazilian households, which is also consistent with other publications in the literature for Turkey. It is argued in the study[3] that if all new Brazilian refrigerators had an energy efficiency at the level consistent with the least life cycle cost of ownership, it would result in an annual savings of 2.8 billion dollars (US$) in electricity bills, 45 TWh of electricity demand, and 18 Mt of CO2 emissions, with a respective payback period of 7 years which is less than half the average estimated lifetime of a refrigerator. It is also very important to discuss energy efficiency labelling. Labeling programs currently operated by the South Korean government are considered in an empirical study[4], and the effects of such labels on appliance choice. This study found that households showed a positive preference for labeled appliances, and an intention to pay more to purchase appliances with energy efficiency, and/or other environmental labels, with more value placed on energy efficiency labels than other environmental labels. The efforts are similar all around the world; Turkish government[5] and EU[6] have issued legislations on the energy efficiency labels in official registers, which prove the importance given on energy efficiency and belief in the market penetration of energy efficient products in recent years. Some researchers have proved that the consumption of energy in refrigerators is dominantly affected from real operational circumstances. Daily energy consumption can differ for the same equipment[7,8]. In some researches, "Demand Side Management" subject was analyzed in terms of controlling of the refrigerators, also economical influence on end users

*Author for Correspondence
E-mail: ikosalay@ankara.edu.tr

was analyzed[9,10] to increase global performance of the household refrigerators, novel multi-objective optimization methods were used in some theoretical studies as genetic algorithm[11,12,13].On the other side, some studies are focused on improving the energy efficiency of the refrigerators using hydrocarbon mixture refrigerants[14,15,16]. Designing energy efficient systems presents a challenge as a factor affecting the electricity price and economic growth in the market. In order to increase energy efficiency in technical problems, various artificial intelligence algorithms such as artificial bee column have been utilized. Optimal energy calculation in combined networks of many sources is an important factor that increases energy efficiency[17,18,19]. With the participation of renewable energy power plants in power systems, the concept of efficient energy management has become even more important[20].

In this study, we also would like to stress the potential savings and energy efficiency in household equipment and especially in refrigerators. Energy consumption rate of the refrigerator is 31 % amongst household equipment[21]. The question of interest for this study is how to measure the energy efficiency of a household refrigerator according to standards and what are the important parameters for energy labelling. In the study, the infrastructure, environment, equipment and measurement set up related to the test system are explained first time in scientific journal literature.

Infrastructure

All energy efficiency measurements were taken at Ankara Energy Efficiency in Household Appliances Technologies Research Centre, which had been designed and built according to specifications described in IEC 62552-1 Ed.1, Household refrigerating appliances - Characteristics and test methods - Part 1: General requirements[22]. The test cell has been designed and built to handle the measurements of up to two refrigerators simultaneously. The test cell provides a unique environment where temperature, air flow and humidity parameters are under control. In addition to IEC 62552 standard, the test cell has been designed and built light and sound proof in order to make noise and vibration tests beyond the standard's requirements.

Test cell, the chamber

The test cell could be considered as a chamber where temperature, air flow and humidity are under control. In addition our test cell had been designed and built light and sound proof for additional noise and vibration tests. The cell is under the basement of the Electrical and Electronics Engineering Department in order not to be afftected from the environment. The cell is only connected to the measurement laboratory through a cable canal as illustrated in Figure 1. Test and measurement equipment is in the measurement laboratory and connected to the refrigerator in the test cell through cable canal in order not to perturbate the parameters such as temperature, humidity and air flow during measurements, as described in the standard.

The device under test (DUT)

The refrigerator used in our energy efficiency measurements is a major brand in Turkey and is also exported to many countries in Europe. It is a refrigerator with a 3-star compartment under category 6. The refrigerator is called DUT (device under test) from now on as the producer claims the device as A+++.

Test equipment used while taking measurements

The loads which mimic food are standard M type[8] packages as defined in IEC 62552, (500 grams weight and 50 mm x 100 mm x 100 mm dimensions). Thermocuples used for temperature measurements are standard T type. While some thermocoples are immersed into the loads, some of them are left open in air in the DUT in order to measure the homogenity within the volume. Thermocouples were connected to a data logger device, Chroma 51101-64. Although the data logger has a capacity of 64 slots maximum, only 8 slots have been used[23]. True power had been measured by using the digital power meter, Chroma 66202. The power meter had been connected to the DUT via a test fixture to enable easy cable connection

Fig. 1 — Measurement laboratory next to the test cell seperated by a cable canal only

for voltage measurement in parallel and current measurement in series. The measurement set up is illustrated in Figure 2.

Calculating the EEI (Energy Efficiency Index)

The EEI is calculated according to Equation 1; which is basically a normalisation of the DUT's energy consumption to the standard energy consumption of an example device for one year, given in percentage.

$$EEI = \frac{AE_c}{SAE_c} x100 \quad \text{... (1)}$$

AE_c: DUT's annual energy consumption (kWh/year)

SAE_c: Standard energy consumption of an example refrigerator per year (kWh/year)

While AE_C is calculated according to Equation 2. The standard defines the consumption to be measured after the DUT's steady state and of course multiplies by 365 as one year has 365 days and each day has 24 hours.

$$AE_c = E_{24h} x365 \quad \text{... (2)}$$

E_{24h}:DUT's energy consumption in 24 hours (kWh)

The tricky bit is the calculation of the SAE_c, Standard energy consumption of a similar refrigerator per year as standard consumption should depend on many parameters including its size, purposes for cooling and the climate it is intended to operate. SAE_c is calculated according to Equation 3,

$$SAE_c = V_{eq} x\, M + N + CH \quad \text{... (3)}$$

where, V_{eq}: is the equivalent volume of refrigeragor M, N: coefficients determined from the category of the refrigerator and the climate conditions it has been designed for respectively. The DUT has been designed and manufactured for ST (subtropical) conditions and values of M=0.777 and N=303 have been copied directly from the standard IEC 62552 CH=50 kWH/year is a correction factor for refrigerators with a cellar compartment larger than 15 liters (DUT has a cellar compartment of 20 liters).

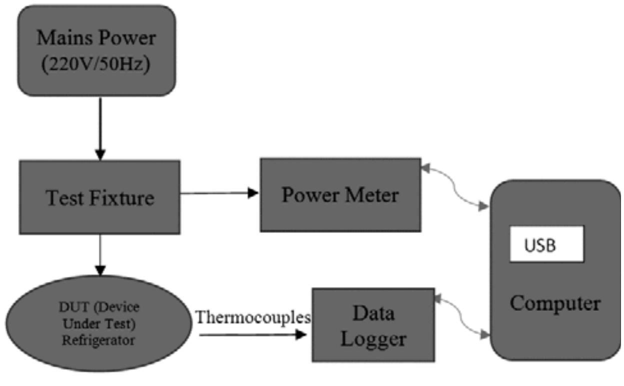

Fig. 2— Measurement setup

Energy efficiency labels for refrigerators

The important figures on the energy efficiency label are the annual energy consumption (E) and the energy efficiency class (C), which is basically a normalisation to the energy consumption of the refrigerator in this category (similar temperatures of cooling and/or freezing for similar volumes, under similar climate conditions) for one year, given in percentage. The label also gives figures of emitted noise (H) in decibels during operation. Equipment available in our lab also enables us to measure the noise and vibration levels of the DUT but these performance values are beyond the scope of this study. Table 1 gives the corresponding EEI classes for the EEI intervals. EEI (the energy consumption of DUT normalised to its "expected" consumption). A+++ is the most efficient, while G is the least efficient product.

Measurement results

The standard IEC 62552-1, Household refrigerating appliances - Characteristics and test methods - Part 1: General requirements define strict rules for the measurement environment. The test cell should be at 25 °C ± 1 K, humidity under 75% and air flow less than 0.25 m/s during the entire measurement process. The measurements should be taken for more than 24 hours and after the temperature is settled. Figure 3 (a) illustrates the typical operation cycle for a refrigerator for 24 hours (in this case the operating cycle of our DUT) starting at "Start of the refrigeration process" around room temperatures and it takes around 4 hours

Table 1 — EEI classes

Energy efficiency class	EEI
A+++	$EEI<22$
A++	$22\leq EEI<33$
A+	$33\leq EEI<44$
A	$44\leq EEI<55$
B	$55\leq EEI<75$
C	$75\leq EEI<95$
D	$95\leq EEI<110$
E	$110\leq EEI<125$
F	$125\leq EEI<150$
G	$EEI\geq 150$

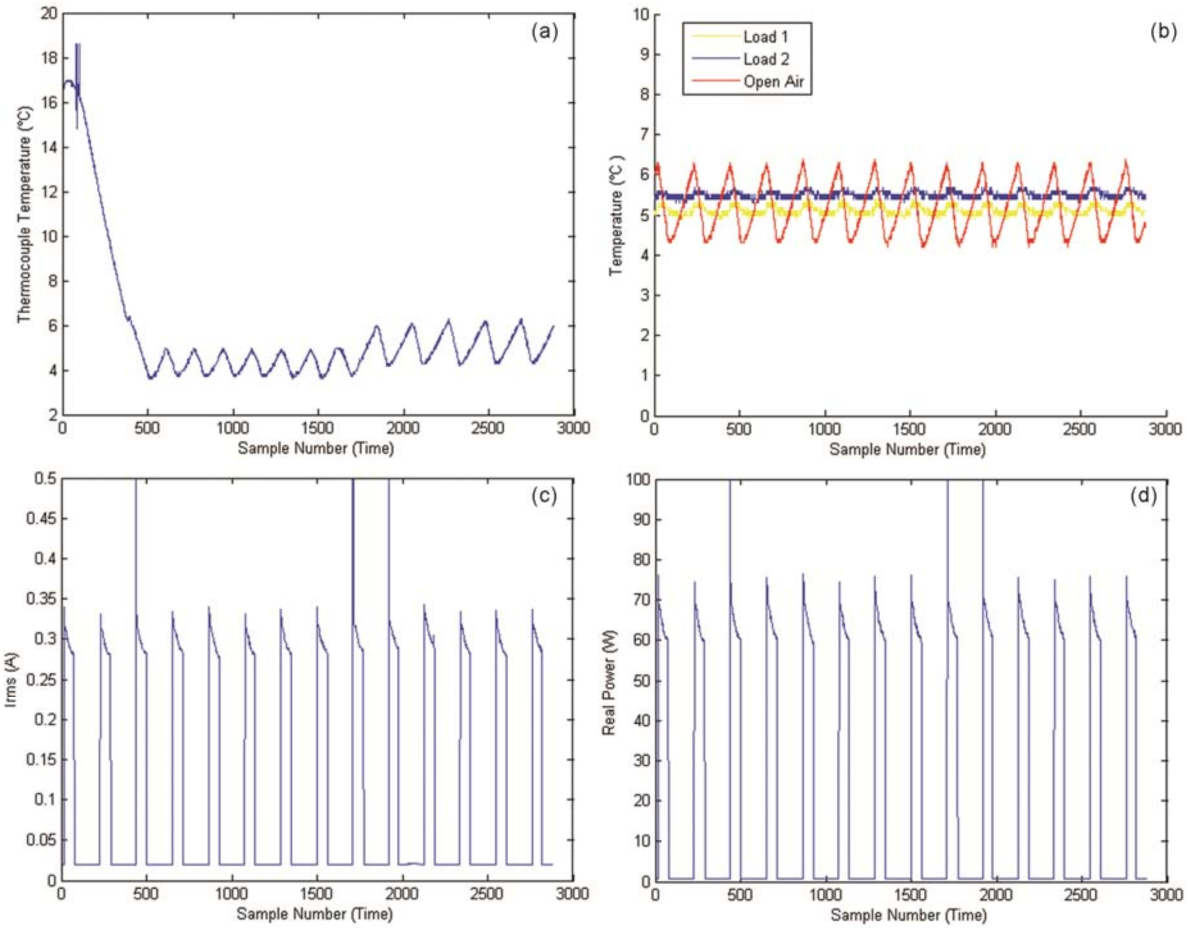

Fig. 3 — Measurement values

to reach the required cooling temperatures (4 °C), the compressor cycle can be easily observed between 4 -5 °C. Figure 3 (a) is also exceptional in the sense that when the "required" cooling temperature is raised to 5 °C, the compressor cycles are raised by 1 °C (between 5-6 °C). The measurements for the EEI are recorded after the initial 24 hours, i.e. between 24 -48 hours after initial operation for a duration of 24 hours.

Recording of the measurements

All power and temperature measurement data have been recorded with a sampling period of 30 seconds, which means a total of 2,880 samples are obtained for the duration of 24 hours. Figure 3 (b) illustrates the outputs of three different thermocouples recorded for 24 hours of operation. The yellow and blue recordings are obtained from the thermocuples which are immersed in standard M type loads while the red oscillating data is obtained from thermocouple which is open in air. The oscillating range for the loads are narrower compared to the open air thermocouple, simply because temperature change in open air inside the refrigerator cannot penetrate into the loads. This data is also exceptional in the sense that when the refrigerator is unattended (doors closed) and the room temperature is fixed, the DUT can keep the desired temperature (5 °C) with extremely narrow margins. In addition the refrigerator starts cooling when the ambient temperature inside the volume touches 6 °C and cools inside the refrigerator until right below 5 °C. Figures 3 (c) and (d) display the RMS current and real power recorded synchoronuous to thermocouple recordings. The DUT uses 350 mA current (around 80 Watts) when cooling starts and drops less than 1 Watt in the stand by mode.

Calculation of the EEI

It is now possible to calculate the EEI figure since thermocuple outputs present proper cooling characteristics for the DUT. Energy consumption have been measured twice in order to observe the effects of room temperature at 20 °C and 25 °C on the

Table 2 — EEI for the DUT

Cell temp. (°C)	(AE_c) (kWH/year) Obtained from the measurements (24 hours of operation)	(SAE_c) (kWH/year) Calculated according to the standard IEC 62552	(EEI)	EEI class
20	0.4728*365=172.57	921.00	18.74	A+++
25	0.4733*365=172.75	876.18	19.72	A+++

cooling performance of the DUT. The DUT had been operated for 48 hours but only the data in between 24-48 hours of operation (once after the DUT has been settled) have been used. This comparison is fair as the DUT is designed to operate for ST (sub tropic) climates, that is between +16 - +38 °C but the energy efficiency tests should be carried out at 25 °C, according to the standard IEC 62552. Table 1 shows EEI range and Table 2 gives the EEI values and EEI class for the DUT at 20 °C and at 25 °C.

Conclusions

In this paper; we examine the potential savings and energy efficiency in refrigerators. Our motivation stems from the fact that refrigerators play a major role in consumption and unfortunately they cannot be planned or arranged to operate at certain time slots of the day. To this purpose we examine how to measure the energy efficiency of a household refrigerator according to standards and important parameters for energy labelling. Before taking any energy measurements, temperature distribution within the refrigerator has been examined and thermocouples immersed in different standard loads on different shelves show homogeneous temperature distribution. In addition, it is observed that they are within the described intervals. Then energy measurements for the EEI (Energy Efficiency Index) are recorded using a power meter, after an initial operation, in order to allow the DUT (Device Under Test) settle. Power measurements between 24-48 hours after switching of the appliance for a duration of 24 hours had been used. Test and measurements, carried according to IEC 62552, Household refrigerating appliances - Characteristics and test methods - Part 3: Energy consumption standards confirmed the manufacturer's claimed energy efficiency index of A+++.

Acknowledgements

Ankara Energy Efficiency in Household Appliances Technologies Research Centre is established with the support of the Grant Programme under Market Transformation of Energy Efficient Appliances in Turkey Project (EVÜDP) implemented by the General Directorate for Renewable Energy (GDRE) of the Ministry of Energy and Natural Resources and United Nations Development Programme (UNDP) with the financial assistance of Global Environment Facility (GEF)

References

1 Adan H &Fuerst F, Do energy efficiency measures really reduce household energy consumption? A difference-in-difference analysis, *Energ Effic*, **4** (2015) 1-13.

2 HavasL, Ballweg J, Penna C &Race D, Energizing households: a financial analysis of incentivized energy efficiency measures in remote Australia, *Energ Effic*, **8** (2015) 951–962.

3 VendrusculoE A, Queiroz G C, Jannuzzi G M, Júnior H X S & Pomilio J A, Life cycle cost analysis of energy efficiency design options for refrigerators in Brazil, *Energ Effic*, **2** (2009) 271–286.

4 Jeong G & Kim Y, The effects of energy efficiency and environmental labels on appliance choice in South Korea, *Energ Effic*, **8** (2015) 559–576.

5 Energy Labeling legislation of household appliances: Energy labelling of household refrigerating appliances, Turkish *Official Register*, Date: 24.03.2002, Issue: 24705

6 Commission Delegated Regulation (EU) No 1060/2010 of 28 September 2010 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labeling of household refrigerating appliances

7 Geppert J & Stamminger R, Analysis of effecting factors on domestic refrigerators' energy consumption in use, *Energ Convers Manage*,**76**(2013)794-800.

8 Geppert J, *Modelling of domestic refrigerators' energy consumption under real life conditions in Europe*, PhD Dissertation, University of Bonn, Shaker Verlag, Aachen Germany, (2011).

9 Zehir M A &Bagriyanik M, Demand Side Management by controlling refrigerators and its effects on consumers,*Energ Convers Manage*, **64** (2012)238-244.

10 Ortega MA, Escrivà GE & Heras I S, Methodology for validating technical tools to assess customer demand response: application to a commercial customer, *Energ ConversManage*, **52** (2011)1507–1511.

11 Yuan X D &Cheng W L, Multi-objective optimization of household refrigerator with novel heat-storage condensers by Genetic Algorithm, *Energ Convers Manage*, **84**(2014)550-561.

12 Zhou ML & Wang X, Yu J L, Theoretical study on a novel dual-nozzle ejector enhanced refrigeration cycle for household refrigerator-freezers, *Energ ConversManage*,**73** (2013)278–84.

13 Yao Y & Chen J, Global optimization of a central air-conditioning system using decomposition–coordination method, *Energ Buildings*, **42** (2010)570–583.

14 RastiM, Hatamipour M S, Aghamiri S F & Tavakoli M, Enhancement of domestic refrigerator's energy efficiency

index using a hydrocarbon mixture refrigerant, *Measurement*, **45** (2012)1807-1813.

15 Jwo C S, Ting C C &Wang W R, Efficiency analysis of home refrigerators by replacing hydrocarbon refrigerants, *Measurement*, **42** (2009) 697-701.

16 Xu B, Wang Y, Chen J, Li F, Li D &Pan X, Investigation of domestic air conditioner with a novel low charge microchannel condenser suitable for hydrocarbon refrigerant, *Measurement*, In Press, Accepted Manuscript, Available online 16 April 2016.

17 Weida He, Chuan Zhang & Rong Hao, Analysis of electricity price and economic growth, *J Sci Ind Re, India,* **74** (2015) 11-18.

18 Roselin J & Latha P, Energy efficient coverage using artificial bee colony optimization in wireless sensor networks, *J Sci Ind Res India,* **75** (2016) 19-27.

19 DeviB R, RaniM A & RaoK K, Optimal energy calculation for cooperative grid networks, *J Sci Ind Res, India,* **74** (2015) 651-654.

20 Sekar K & Duraisamy V, Efficient Energy Management System for Integrated Renewable Power Generation Systems, *J Sci Ind Res India*,**74** (2015) 325-329.

21 White *Goods Suppliers' Association e-magazine*, (www.beysad.org.tr), 84(2011).

22 IEC 62552-1 Ed.1, Household refrigerating appliances - Characteristics and test methods - Part 1: General requirements, Standard IEC 62552-2 Ed.1, Household refrigerating appliances - Characteristics and test methods - Part 2: Performance requirements 59M/46/CD: IEC 62552-3 Ed.1, Household refrigerating appliances - Characteristics and test methods - Part 3: Energy consumption.

23 *Chroma Thermal/Multi-Function Data Logger 51101-64/ 51101C-64 User's Manual.*