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Investigating the Effect of an Ambient Temperature on the Performance of domestic coolers (Case Study: Household Refrigerator type Beko)

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دراسة تأثير درجة الحرارة المحيط على أداء الثلاجة المنزلية
(دراسة حالة: ثلاجة منزلية من نوع *Beko*)

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الملخص:
التبريد من أهم متطلبات الحياة، فلا يخلو أي منزل حديث من أجهزة التبريد، سواء ثلاجات لتخزين الطعام، أو مكيفات هواء منزلية. الثلاجة المنزلية هي جهاز تبريد يستخدم الطاقة الكهربائية للقيام بعمل لإنتاج التبريد. وللحفاظ على أداء الثلاجة، هناك حاجة لفهم معامل أداء الثلاجة إذا كانت درجة الحرارة الخارجية متغيرة.
في هذا البحث، استخدم العمل التجريبي ثلاجة منزلية من إنتاج شركة BECO كنموذج لدراسة تأثير درجة الحرارة المحيطة على معامل الأداء، وغاز التبريد العامل لهذه الوحدة هو مبرد .R-134a وشمل الإعداد أجهزة استشعار في مواقع محددة لقياس المعلومات الرئيسية مثل درجات الحرارة وضغوط المبرد (المنخفضة والعالية). ومن النتائج العملية التي تم الحصول عليها، حساب معلمات أداء الثلاجة داخل الغرفه عند درجات حراره متفاوتة (20°C - 38°C) وفي أوقات مختلفة من اليوم.
وأظهرت النتائج المتحصل عليها من هذه الدراسة أن متوسط معاملات الأداء المحسوبة تقل مع زيادة درجة حرارة الغرفة، وأن معامل الأداء يصل إلى أعلى قيمة له عند أدنى درجة حرارة للغرفة.

الكلمات الدالة: ثلاجة منزلية، معامل الأداء، درجة حرارة الغرفة.

Abstract:
Refrigeration is one of the most important requirements of life, as no modern home is without cooling instruments, whether refrigerators for storing food, or domestic air conditioners. A home refrigerator is a refrigeration device that uses electrical energy to do work to produce cooling. To maintain the performance of a refrigerator, there is a need to understand the performance coefficient of the refrigerator if the outdoor temperature is varied.
In this research, the experiment work utilized a BECO house hold refrigerator as a model to study the effect of ambient temperature on the performance coefficient, the working refrigerant gas for this unit is an R-134a refrigerant. The setup included sensors in specific locations to measure the main parameters

such temperatures, refrigerant pressures (low and high). From the practical results obtained, the parameters of the refrigerator’s performance inside the room were calculated at varying degrees (20^{o}C to 38^{o}C) and at different times of the day.
The results obtained from this study showed that the average calculated performance coefficients decreased with increasing room temperature, and that the performance coefficient reaches its highest value at lower room temperature.

Keywords: home refrigerator, performance coefficient, room temperature.

Introduction

Refrigeration serves a fundamental function in augmenting human comfort and enabling the conduct of daily activities, as it proficiently maintains the integrity of various food items over prolonged durations throughout diverse seasonal contexts. Moreover, refrigeration has catalyzed novel avenues for economic advancement, establishing itself as one of the most pivotal and indispensable sectors in contemporary industry. In addition to its primary function of conserving substantial quantities of food and critical nutrients, refrigeration also promotes efficient transportation while significantly reducing spoilage during transit to isolated regions. Furthermore, it assumes a crucial role in the safeguarding of medical supplies and pharmaceutical products. [1]

Various categories of foodstuffs are conserved through either refrigeration at slightly above zero degrees Celsius or freezing at sub-zero temperatures, utilizing devices commonly designated as refrigerators.

Thermal energy inherently transfers from regions of elevated temperature to those of diminished temperature, a phenomenon that transpires autonomously without the necessity for mechanical apparatus. Nevertheless, the rectification of this phenomenon mandates external intervention. The movement of thermal energy from a cooler medium to a warmer counterpart is referred to as refrigeration. This concept is delineated as the process of extracting thermal energy from a substance or environment, thereby decreasing its thermal state and maintaining it below the ambient conditions. Fundamentally, refrigeration constitutes the incessant extraction of heat from an object or space that possesses a temperature lower than that of its surroundings. This mechanism is executed within domestic refrigerators, which operate on the principles of a closed thermodynamic cycle. Within this cycle, a refrigerant fluid circulates, assimilating and expelling heat throughout its journey. [2]

The efficiency of a refrigeration unit is quantitatively assessed through the coefficient of performance (COP), which serves as an indicator of the appliance's efficacy in extracting thermal energy from a designated refrigerated space. In order to facilitate this thermal energy extraction, it is imperative that energy is supplied to the compressor. The COP can be defined as the ratio of thermal energy removed from the refrigerated environment to the energy input necessary for compressor operation. Fundamentally, this energy input corresponds to the disparity between the thermal energy released into the ambient environment (via the condenser) and the thermal energy extracted from the refrigerated space. Consequently, the COP is affected by the quantity of thermal energy expelled to the environment by the condenser, which in turn is contingent upon the temperature differential between the refrigerant within the condenser and the ambient temperature of the surrounding environment. [3]

Human has known refrigeration since ancient times due to his need for it, and they benefited from it for the purpose of preserving food when available in several ways, including: Cooling by evaporation, pottery and made many vessels from it, exchange by radiation between the surface of the water and the sky at night and store snow in caves for long periods. [4]

Then the development began with the inventions of refrigeration, and Jacob Perkins obtained a patent in 1834 for a closed-power compressor refrigeration machine, using ethyl alcohol as a refrigerant. Then the physicist John Gorrie developed in 1844, a refrigeration machine that used compressed air cooling, to produce ice and cold air for hospitals. In 1850, the French developed refrigeration machines when Ferdinand Carré invented the super-refrigeration machine, then a machine was invented that cooled in the white fire of steam in 1890. [5]

In 1910, the Kelvinator Company produced the home refrigerator and put it on the market for sale. In 1945, a major development occurred when sub-controls were used in refrigeration devices, providing refrigerators specifically for home use through the companies Cliff and Fertwegdeer. [2]

Home Refrigerator

A refrigerator is a machine invented by the Frenchman Ferdinand Carré in 1859 that uses electrical energy to create work to produce cooling. Refrigerators are used to preserve different types of foods. Food is preserved either by cooling at temperatures slightly above zero degrees Celsius, or by freezing at temperatures below zero degrees Celsius.[2] There are two main types of refrigerators, depending on the number of rooms for storing food. The first type is a regular refrigerator with one door, but it is divided internally into two parts, where the freezer is installed in the upper part of the room, while the lower part is the cooling room that contains shelves and drawers for storing foods. The second type is a double-door refrigerator, which contains two separate rooms, each with an independent door. The upper room is the freezer and the lower room is the cooling room.

The shapes of refrigerators vary in size and type, but the components of their parts do not differ much, as the home refrigerator consists of four main parts: the compressor, the evaporator, the expansion valve, and the evaporator as shown in Figure (1). R134 gas is considered one of the most widely used refrigerants at the present time in home refrigerators. Among its specifications are: its general name. Tetrafluoroethane, scientific formula CF_3CH_2F, symbol R134-a, boiling point -26.1°C [6]

R. Saidur , H.H. Masjuki, I.A. Choudhury. [7] They Investigated the ambient temperature, thermostat setting positions, and the effect of door opening on the energy consumption of a refrigerator. They used two frost-free household refrigerators of the same capacity to determine the sensitivity of their energy consumption to different usage conditions. The room temperature was changed from 14 °C to 32 °C. Their investigation revealed that about 60-70% of the energy consumed by the refrigerator is energy to cover the heat flow due to temperature differences. They concluded that room temperature has the greatest effect on energy consumption, followed by door opening.

M.Y. Taib, M.M. Sani, M. M. Noor and K. Kadirgama,[8] studied the Performance Analysis of a Domestic Refrigerator in Malaysia using Experimental Method. Their study presents the development process of refrigerator test rig and performance evaluation of a domestic refrigerator that has been used in Malaysia. The experiment platform which called test rig was developed from refrigerator model NRB33TA National brand. The result shows that the average COP of the refrigeration system using the refrigerator test rig was about 2.7

Refrigerator is one of the home appliances that use mechanical vapor compression cycle in its operation. The performance of the system becomes the main issue and many researches are still underway to evaluate and improve the efficiency of the system. Therefore, this paper presents the performance evaluation of a home refrigerator that was used in Libya. The main objective of this study was to obtain the performance of the refrigeration system in terms of the coefficient of performance (COP) by determining one of the important parameters during the operating mode which is the ambient temperature

Basic Refrigeration Circuit in a household Refrigerator

Evaporation and condensation of a liquid is the change between a liquid and a gaseous state. When evaporating, the liquid must obtain sufficient latent heat to evaporate, and this occurs on the side of the space to be cooled. While when condensing, the latent heat in the vapor of the intermediate liquid is expelled to the outside. [6]

The refrigeration circuit of a home refrigerator consists of four main parts: Compressor, Condenser, Expansion Valve or capillary tube and Evaporator as shown in Figure 1. [9]

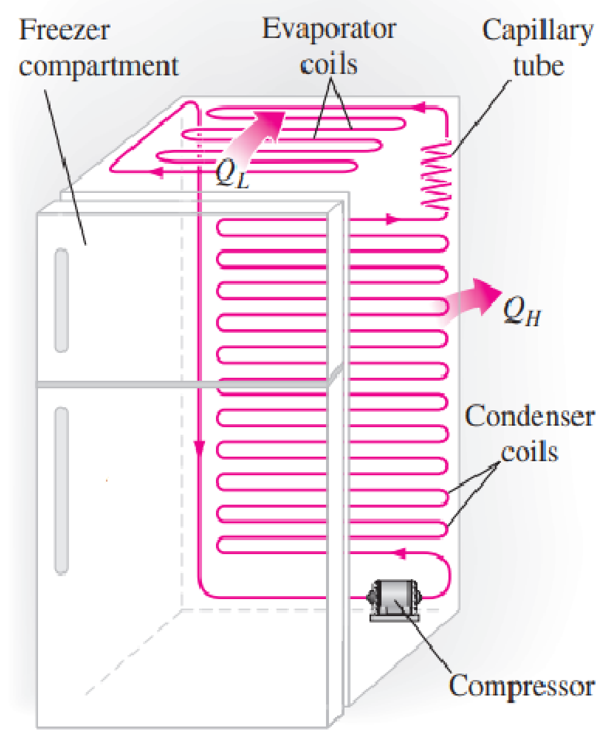

Figure (1) the main parts of a household refrigerator.

Methodology

In this work, a domestic refrigerator of the type BECO L58CZ with a capacity of 1PH, operating voltage 50 Hz - 240 V - 220 V, refrigerant R134a, was equipped and pressure gauges and temperature gauges were installed, as shown in figure 2, and fixed on the refrigerator pipes starting from the compressor outlet pipes, passing through the condenser, at the refrigerator door, and at the return point from the evaporator.

To calculate the performance rate of the refrigerator, the amount of heat lost from the condenser, the amount of heat gained from the evaporator, and the specific work of the compressor must be calculated. This requires calculating both the pressure and temperature at several different points, from which the specific enthalpy of the medium (h) can be found from the diagrams, tables, and programs. Places were identified in the refrigerator to install pressure and temperature measuring devices, and these points were illustrated on the cycle flow diagram, Figure 3, and were implemented as follows:

1. Discharging the gas charge in the refrigerator.

2. Installing a device to measure the high pressure of the refrigerant when it exits the compressor at point 1 (P_H). Figure 4 shows High pressure gauge.

3. Installing a device to measure the low pressure of the refrigerant when it inlet the compressor at point 5 (P_L). Figure 5 shows High pressure gauge.
4. Installing devices to measure temperature and placing them in different places (points: 1-2-4-5).
5. Check the deposition in the system and perform an air emptying operation.
6. Charge the system with refrigerant (R134a).
7. Ensure that there are no leaks in the places where the pressure gauge is installed.
8. Ensure that each part is fully functional and not affected by increases and modifications.

Figure (2) Installation of pressure and temperature measuring devices for a home refrigerator

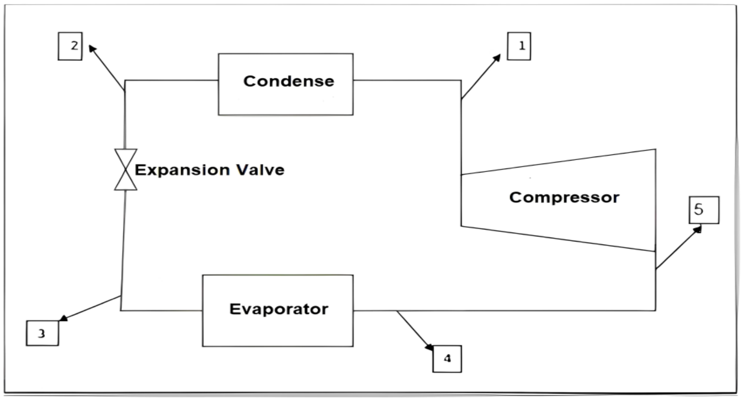

Figure (3) Pressure and temperature gauge installation points on the refrigeration cycle diagram for refrigerator

Figure (5) shows low pressure gauge.

Figure (4) shows High pressure gauge.

Measurement points

The temperature gauges and pressure gauges were placed at the points shown in Figure 2, so that the high pressure (P_h) represented P_1 and the low pressure (P_L) represented P5. The properties of each point can be determined using the following points:

1. (T_1,P_1) The exit point from the compressor (entry to the condenser).
2. ((T_2,P_1) The exit point from the condenser (entry to the capillary tube).
3. (T_4,P_5) The exit point from the evaporator.
4. (T_5,P_5) The entry point to the compressor.

Thermodynamic Analysis of Compression Refrigeration Cycle

The vapor compression refrigeration cycle consists of four main parts, and four operations are performed in it. Each part of the cooling system is considered an open system and the first law of open system thermodynamics can be applied: [9]

$$\dot{Q} - \dot{W} \quad = \dot{m}\left[(h_e - h_i) + \frac{V_e^2 - V_i^2}{2} + g(Z_e - Z_i)\right] \qquad (1)$$

Where:

$\dot{Q}$: heat transfer rate to or from the system (kW).

$\dot{W}$: compressor work (kW).

$\dot{m}$: refrigerant mass flow rate (kg/s).

h_i, he: refrigerant inlet and outlet specific enthalpy (kJ/kg).

V_i, V_e: refrigerant inlet and outlet velocity (m/s).

Z_i , Z_e: enter and exit point height (m).

Compression process by compressor

This process is done by the compressor where the compressor draws the vapor from inside the evaporator and raises its pressure and thus its temperature because the mechanical energy expended by the compressor is converted into thermal energy stored in the vapor, which is the reason for the increase in pressure and temperature of the vapor.

From equation 1 and neglecting the kinetic and potential energies and considering that the compressor is thermally insulated, the equation becomes as follows:

$$-w_c = [(h_1 - h_5)] \qquad (2)$$

Where:

w_c: specific work of the compressor (kJ/kg).

h_5, h_1: specific enthalpy of entering and exiting the compressor (kJ/kg).

Heat loss process in the condenser

The heat loss process in the condenser takes place at constant pressure, where the heat of the refrigerant is lost to the external environment whose temperature is lower than the condenser. From equation 1 and neglecting the kinetic and potential energies with no work in the condenser, the equation becomes as follows: [10]

$$q_c = (h_2 - h_1) \qquad (3)$$

Where: q_c: the amount of specific heat lost from the condenser (kJ/kg), h_2: the specific enthalpy of exiting the condenser (kJ/kg).

The process of strangulation through the capillary tube

Adiabatic throttling occurs through the capillary tube, reducing the high condenser pressure to the lower evaporator pressure. From equation 1 and neglecting the kinetic and potential energies with no work and considering that the process is adiabatic, the equation becomes as follows:

$$h_2 = h_3 \qquad (4)$$

Where: h_3: the specific enthalpy of exiting the capillary tube (kJ/kg)

Heat gain process in the evaporator

This process is carried out with constant pressure, where the refrigerant acquires an amount of heat from the space to be cooled (the refrigerator cabin), where the refrigerant is evaporated. From equation 1 and neglecting the kinetic and potential energies with no work in the evaporator, the equation becomes as follows: [9]

$$q_e = h_4 - h_3 \qquad (5)$$

Where: q_e: the amount of specific heat gained from the evaporator. (kJ/kg) ، h_4: the specific enthalpy of exiting the evaporator (kJ/kg).

Calculating the refrigerator's performance coefficient

The efficiency of the refrigerator is expressed in terms of a coefficient called the coefficient of performance (Coefficient of performance) and is symbolized by the symbol COP, and its value is the amount of heat removed from the cooling space by the evaporator divided by the work of the compressor.

$$\mathrm{COP} = \frac{q_e}{w_c} \qquad (6)$$

By substituting the value of q_e from equation 5 and the value of w_c from equation 2, we obtain an equation to express the refrigerator's performance coefficient in terms of specific enthalpy. [10]

$$\mathrm{COP} = \frac{h_4 - h_3}{h_1 - h_5} \qquad (7)$$

Calculations and Results

After installing the pressure and temperature gauges, the refrigerator was turned on after ensuring its safety and that it was working safety and without malfunctions. Then data was taken and the parameters were read at a the range of room temperatures to study them, (20-22-25-27-28-30-32-

35-38 degrees Celsius), and the refrigerator's performance coefficient (COP) was calculated at different room temperature conditions using equation 7. The readings were taken on days when the air temperature was according to one of the previous degrees and with the help of a heater to raise the temperature to high temperatures.

Calculating the Performance Coefficient for the Refrigerator's Cooling Cycle

The refrigerator performance coefficient was calculated using equation 6 at several times of the day and at different temperatures for the room, in which the refrigerator under study is located. A set of readings were taken during each hour, and the average of these readings was taken after recording the temperatures and pressures. Through these readings, the specific heat content (enthalpy) was found at the entry and exit points of the refrigerant fluid from parts of the refrigerator cooling circuit, and the Computer Aided Thermodynamic tables3 software was used to find the specific heat content values for R134-a.

Sample of variable calculations at room temperature 22 ^{o}C

The readings were taken at several hours on a day when the average room temperature during that day was 22 °C. A set of readings were taken during the hours shown in the table. The average of these readings was taken at the beginning of the hour and tabulated as shown in the table (1).

Table (1) Temperature and pressure readings at room temperature 22 °C

No	Time	P_H (MPa)	P_L (MPa)	T_1 (°C)	T_2 (°C)	T_4 (°C)	T_5 (°C)
1	9:00	0.9085	0.00728	52	26.9	-6.5	21.4
2	10:00	0.9078	0.00734	53.8	27.4	-7.2	22.9
3	11:00	0.9098	0.00741	55.1	28.3	-6.9	23.4
4	12:00	0.9088	0.00738	55	27.2	-6.8	21.8
5	13:00	0.9103	0.00755	54.6	27.8	-7	22.3
6	14:00	0.9108	0.00759	54.8	27.9	-7.3	22.5
7	15:00	0.9106	0.0076	55.2	28.1	-7.4	22.7
8	16:00	0.911	0.00763	56.1	27.6	-7.1	22.9
9	17:00	0.9109	0.00761	55.7	27.8	-6.8	23.3
10	18:00	0.91103	0.00764	55.9	27.3	-6.5	22.7

To calculate the coefficient of performance, the specific enthalpy values of the identified points were calculated using the IRC program to calculate the coefficient of performance. Table 2 shows specific enthalpy at 9:00 for room temperature 22 °C. And the calculations were performed for each of the compressive work (W_c), the heat lost at the condenser (q_C) and the heat gained in the evaporator (q_e) using the above-mentioned equations. From Table 1, the average sum of performance coefficients for each temperature can be calculated. Figure 6 Shows the performance coefficient curve of the refrigerator during the day from 9:00 am to 6:00 Pm at room temperature 22^{o} C. In this case the coefficient of performance of the refrigerator at a temperature of 22°C is 12.062.

Table (2): Readings and specific enthalpy at 9:00 for room temperature 22 °C

Reading	P_H Mpa	P_L Mpa	T_1 °c	T_2 °c	T_4 °c	T_5 ° c	h_1 (kJ/kg)	h_2 (kJ/kg)	h_3 (kJ/kg)	h_4 (kJ/kg)	h_5 (kJ/kg)
Value	0.9085	0.0073	52	26.9	-6.5	21.4	434.8	237.3	237.3	400.8	423.2

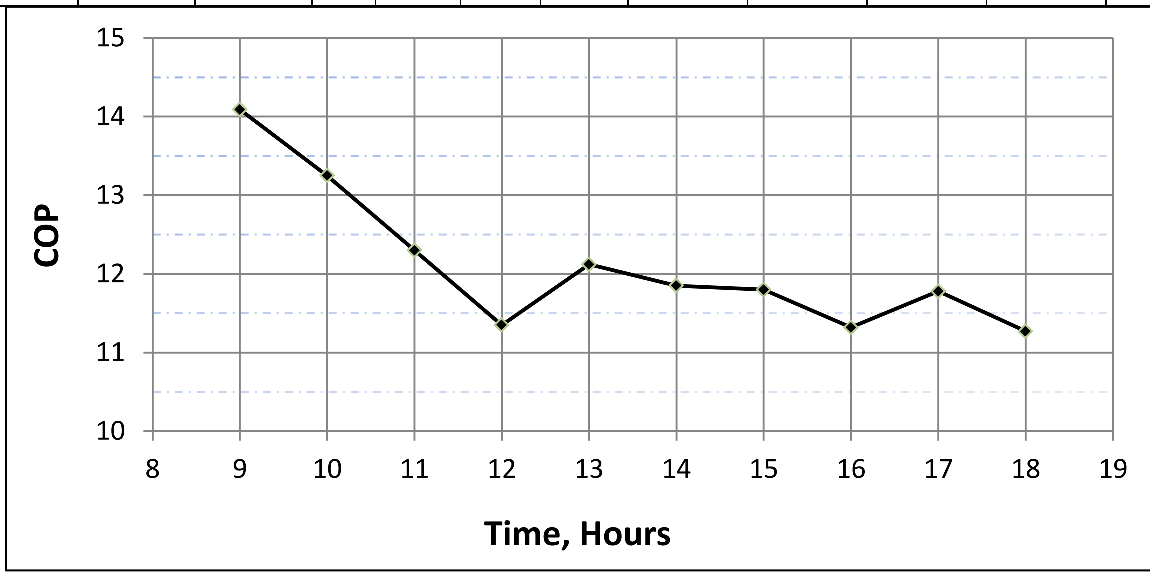

Figure (6) Performance coefficient of the refrigerator during day at room temperature 22° C

In the same way, the performance coefficients were calculated at the temperatures recorded in the room as shown in Table 3 to facilitate its study. Using the Excel program, we obtain the comparison curve as shown in Figure 7.

Table (3) Average sum of performance coefficients for each temperature.

Temperatures C°	20	22	25	27	28	30	32	35	38
Average COP	12.941	12.062	9.911	9.517	8.764	8.028	7.500	7.026	6.252

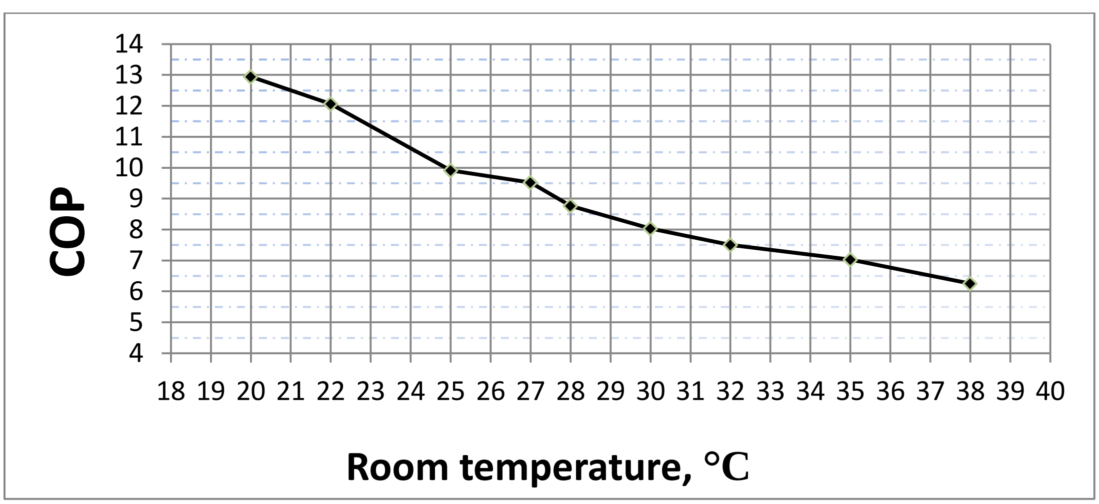

Figure (7). The relationship between performance coefficient and room temperature

Referring to the figure 7 we notice that the room temperature has a clear effect on the performance coefficient (COP) of the refrigerator, the change in the performance coefficient is clear when the temperature changes from 20 °C to 38 °C. The performance coefficient of the refrigerator is the highest value when the room temperature is 20°C and gradually decreases with increasing room temperature. The performance coefficient of the refrigerator is the lowest value when the room temperature is 38°C.

The result of relationship between the amount of heat removed by the evaporator and the room temperature is shown in Figure 8.

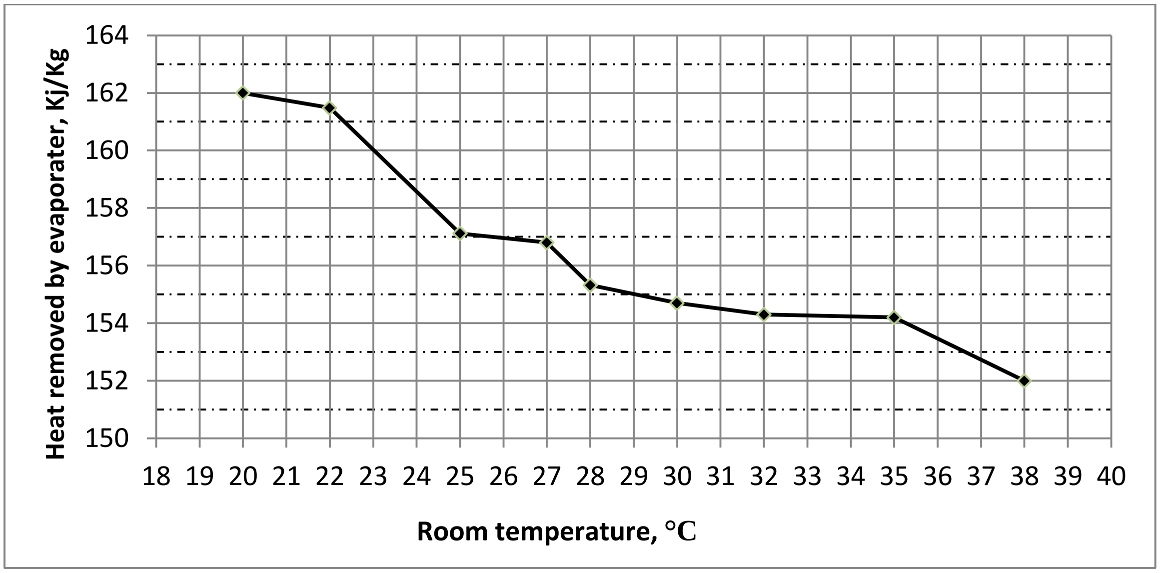

Figure (8) the amount of heat removed by the evaporator at different room temperature

From the result it is clear that the amount of heat removed by the evaporator decreases with increasing room temperature.

Conclusion

The current work focuses on determining the performance of a home refrigerator over varying ambient temperatures. The experiment was conducted conventionally by taking all of data manually. Since the experimental work was not done to standard parameters, the results cannot be compared directly with the manufacturer's data and the researchers' previous work. However, it provides information about how the system performs and reacts to ambient temperatures. From the results obtained in this study, which were expressed graphically, we conclude that the room temperature has a clear effect on the refrigerator’s performance coefficient, and the change in the performance coefficient becomes clear when the temperature changes from 20 °C to 38°C. The performance coefficient of the refrigerator has the highest value at a room temperature of 20°C and the lowest value at a room temperature of 38°C. We can also conclude that the compressor work increases with increasing room temperature, and the amount of heat removed by the evaporator decreases with increasing room temperature.

So, the performance coefficients (COP) are a measure of how efficiently a refrigerator converts electrical energy into cooling energy. When the temperature of the room in which the refrigerator is located rises, two main effects occurs that influence the COP; Temperature differences: The refrigerator transfers heat from inside to outside. The higher the room temperature, the more heat the refrigerator must remove to transfer heat to the surrounding environment. This requires more energy, which reduces the efficiency of the system. Second. Increased heat load: At higher temperatures, the refrigerator needs to work harder to maintain a low internal temperature. This extra effort leads to increased energy consumption, thereby reducing the coefficient of performance. In general, when a refrigerator is placed in a warmer environment, it becomes less efficient in its performance, leading to higher electricity bills and the need for more frequent maintenance.

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