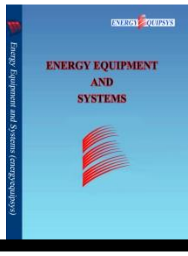
Energy Equip. Sys. / Vol. 10/No. 1/March. 2022/ 13-26

ENERGY EQUIPSYS

Energy Equipment and Systems

http://energyequipsys.ut.ac.ir
www.energyequipsys.com



Experimental comparison of internal and external condensers effect on the energy consumption of household refrigerators

Authors

Nader Alihosseini[a]
Babak Mohammadi[a]
Mohammad Eftekhari Yazdi[a]
Gholamreza Salehi[a*]

[a] Department of Mechanical Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran

Article history:

Received : 10 May 2021
Accepted : 4 July 2021

ABSTRACT

The purpose of this study is to evaluate the impact of moving the condenser of a household refrigerator within the body on the refrigerator's performance and energy consumption. The effects of the internal and external condensers on energy consumption and cooling capacity in a household refrigerator are next explored. This study was conducted experimentally and in a laboratory setting, and all terms and conditions were in accordance with the international electrotechnical commission 62552-2015 for cooling system testing. The studies were conducted in a 5-foot refrigerator. On this refrigerator, both internal and external condenser models were installed. In the first situation, the internal condenser was inserted into the cooling cycle and the associated tests and calculations were performed. In the other situation, the internal condenser was removed from the cooling cycle and the external condenser was replaced by changing the valve status. In this case, the relevant diagrams and calculations were obtained and analyzed. Based on the findings of this study, it can be stated that using the internal condenser reduces energy consumption and, as a result, has a higher energy grade than using the external condenser. The internal condenser in the heat transfer process work better than the external condenser, based on the temperatures obtained. An internal condenser is also a preferable solution for a household refrigerator in terms of installation and cost.

Keywords: Refrigerator, Cooling Cycle, Internal Condenser, External Condenser, Energy Grade.

1. Introduction

One of the main problems that arise over time and the use of refrigerators and freezers for the condenser is that it becomes unclean. In this situation, it will be difficult to transmit the heat of the hot gas to the environment, and the conversion of hot gas to cold liquid will be difficult. As a result, the evaporator will be cooled a little, and the cooling process will be difficult. One of the current needs of the household appliance sector is the introduction of innovative designs, particularly in household refrigerators, which account for the majority of the industry's production. On the other hand, one of the most essential concerns of any country is the energy supply of power and its optimal consumption. According to the statistics of the Energy Efficiency Organization, 34% of Iran's electricity consumption is related to household consumption, of which 28% is related to refrigerators and freezers. One of the most important competitive factors among manufacturers is the amount of electricity used

* Corresponding author: Gholamreza Salehi
Department of Mechanical Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran
Email: gh.salehi@iauctb.ac.ir

in household appliances. Refrigerators and freezers are the most energy-intensive residential appliances, accounting for 34% of total electricity use. According to the preceding, it is critical to develop and manufacture household appliances that consume less energy. The high electrical energy consumption of refrigerators and freezers necessitates extra attention to the refrigeration cycle and its components. The goal of this research is to find the best way to optimize electrical energy in a 5-foot refrigerator. Only the type of condenser will be altered and its influence on energy consumption and product grade will be explored in order to attain this goal, which will be accomplished by constantly considering all elements affecting the refrigeration cycle.

The following is a summary of the study on household refrigerators and freezers that has been conducted thus far.

Bansal and Chin [1] designed and modelled internal condensers in household refrigerators. They used modelling and numerical calculations to calculate the capacity of the condenser, the pressure drop, and the quantity of heat transfer for the internal condenser in household refrigerators. The purpose of this study was to calculate the error rate in the laboratory and numerical modes. It was also reported that 90% of the heat transfer in condensers is done with the outside environment and 10% with the inside of the refrigerator. Bansal and Chin [2] in another study, compared the results of modelling and experimental and laboratory research with conventional condensers in household refrigerators. They used a two-door refrigerator with a capacity of 27 and 133 liters as a laboratory sample. The experiments performed on this refrigerator in a laboratory environment were performed at an ambient temperature of 25 °C and humidity below 25% and a wind speed of less than 1 m/s. They came to the conclusion that the values acquired in the laboratory and the calculations done differed by 10%. Tosun et al. [3] combined two mini-condenser models to increase system performance in a household refrigerator. They then made changes to the capillary balance and the amount of gas in order to find the best combination for better performance. By merging the mini-condensers, the capillary length was 3.25 m and the amount of refrigerant was 50 gr. Dmitriyev et al. [4] examined the refrigerant charge for a refrigerator-freezer. The experiments were performed with different capacities of condenser and evaporator. The authors proposed a method for calculating the desired amount of development refrigerant. Saji and Joseph [5] measured the performance of a water-cooled condenser in the tropics to reduce energy consumption. The proposed system for energy saving and environmental benefits was analyzed. Experimental work was performed in the tropics, and experimental findings showed that tubular plate condensers in small-scale refrigeration systems could reduce daily energy consumption by 21 to 27%. Cho et al. [6] reduced the refrigerant charge by optimizing the condenser geometry. This study aimed to investigate the effect of condenser geometry on household refrigerators and freezers in terms of reducing refrigerant load. An internal hot wall condenser in the freezer was designed to store additional refrigerant load. The coefficient of performance (COP) decreased with the reducing length and diameter of the hot wall condenser. The reduction in performance was offset by a reduction in energy consumption. Zhang et al. [7] looked at how adjusting the airflow field around the wire helix condenser affected the refrigerator's performance without freezing. Forced convection condenser, fan, and compressor were used in one line and inside the bottom of the refrigerator. The refrigerator's energy usage was lowered by 2.37% as a result of the findings. Yuan and Cheng [8] performed a multi-objective optimization of a household refrigerator-freezer with new heat storage condensers by a genetic algorithm. After optimization, the optimized curves in the new and conventional refrigerators were compared with each other. The overall performance of both the new and conventional refrigerators was enhanced. Bassiouny [9] examined the effect of the space around the condenser of the refrigerator. The effect of the space around the refrigerator condenser on the rejected heat was studied using an analytical and computational model. The driving force for the heat dissipated by the refrigerant from the inside of the refrigerator was the temperature difference between the outer surface of the condenser and the surrounding air. The results showed that having an enough surrounding space width ($s > 200$ mm) leads to a decrease in the temperature of the air flowing vertically around the condenser coil. Cheng et al. [10] evaluated the heat transfer performance of evaporators and condensers, which significantly affects the efficiency of household refrigerators. Acording to obtain results to increase the heat transfer of condensers and evaporators, a new dual energy storage refrigerator with heat storage capacitor and cold storage evaporator was used. Hajabdolahi and Hosseini [10] dynamically modeled a cool room cooled by a steam-compression refrigeration cycle. Coefficient of performance and total annual cost is selected as two objective functions. Three refrigerants of R134a, R22, and R407c were used as working refrigerants within the cycle to study and select the most suitable one. The results showed that refrigerant R407c was the most suitable refrigerant. Hyuk et al. [11] checked air-side heat transfer and pressure drop characteristics of flat-type, U-and V-shaped microchannel condensers for refrigerator applications. They reviewed and compared two models of condensers. According to the results, U-shaped with a longer tube length was recommended to obtain a high absolute heat transfer rate and V-shaped was recommended to realize high compactness and heat transfer efficiency. Boeng and Melo [12] investigated the thermodynamic behavior of a household refrigerator with wire on tube condenser for different refrigerant charge and expansion conditions. A minimum energy consumption region was determined and it was found that the improper combinations of refrigerant charge and expansion restriction increase the energy consumption by up to 30%. Aprea et al. [13] substituted the HFC134a by HFO1234yf for a household refrigerator with a roll-welded condenser. The refrigerant amounts of 85, 95, 100, 105, and 110 g were used and it was found that 3% energy saving was obtained if 110 g of HFO1234yf was used. Agrawal et al. [14] performed a series of experiments to find the optimum charge amount of R290/R600a mixture (50/50%) instead of the R134a household refrigerator which has a wire mesh air-cooled condenser. The optimum charge amount is found as 60 gr. Vaitkus and Dagilis [15] analyzed the plate evaporator of a transport refrigerant system to reduce the amount of refrigerant. Two different systems were analyzed and it was reported that the use of microchannel condenser instead of traditional copper tube/aluminum fin condensers descends the charge by 40-70%. Few studies address the substitution of the mini-channel condenser by the wire-on-tube condenser. Pottker and Hrnjak [16] examined the effect of condenser subcooling on the performance of vapor compression systems. They presents a theoretical study about the effect of condenser subcooling on the performance of vapor compression systems. It was shown that, as condenser subcooling increases, the COP reaches a maximum as a result of a trade-off between increasing refrigerating effect and specific compression work. Jeon et al. [17] evaluated comparative performance evaluation of conventional and condenser outlet split ejector-based household refrigerator-freezers using R-600a. For entire cycle operation at similar cooling capacity condition, the overall COP improvement of the test bench adopting COS ejector cycle over the baseline cycle is 11.4% at the ER of 0.18. Sonnenrein et al. [18] investigated the reduction of refrigerator energy consumption through the integration of latent heat storage elements in wire-and-tube condensers. The results indicate that particularly the application of phase change materials lowers the condenser temperature, which leads to a significantly reduced power consumption. Salem et al. [19] studied the performance of a vapor compression refrigeration system using a conically coiled tube-in-tube evaporator and condenser. This study experimentally investigated the effect of the geometrical parameters of a vertical conically coiled tube-in-tube evaporator/condenser and their operating conditions on their effectiveness and the coefficient of performance (COP) of a vapor compression refrigeration system (VCRS). The results showed that increasing the evaporator/condenser taper angles and torsions in addition to decreasing their water Dean numbers augment the evaporator/condenser effectiveness and the COP of the VCRS. Xu et al. [20] investigated the domestic air conditioner with a novel low charge microchannel condenser suitable for hydrocarbon refrigerant. A novel low charge microchannel condenser was proposed and investigated experimentally and numerically in domestic air conditioner system. Experimental results showed that in comparison with normal microchannel condenser, cooling capacity of the novel condenser system increased by 1.6%, system refrigerant charge decreased by 28.3%. Ge et al. [21] designed optimisation of CO2 gas cooler/condenser in a refrigeration system. They investigated the performance of the CO2 gas coolers/condensers with different structure designs, controls and system integration at different operating conditions through experimentation. Qureshi and Zubair [22] checked the impact of fouling on the condenser of a vapor compression refrigeration system. They presented an experimental study on the nature of the effects of condenser fouling on some performance characteristics and properties of a simple vapor compression system. The results of the experiments indicated a logarithmic behavioral change when the ambient and room temperatures were kept constant. Azzouzi et al. [23] done a parametric study of the wire-on-tube condenser subcooling effect on the performance of vapor compression refrigeration system. According to the results, the increase in subcooling temperature plays a significant role in the rise of refrigeration cycle efficiency. Yilmaz et al. [24] done a thermodynamic evaluation on high pressure condenser of double effect absorption refrigeration system. A simulation was developed to investigate the energy transfer between the high pressure condenser and low pressure generator. The results showed that the proper designation of the high pressure condenser temperature improves the COP and ECOP due its significant impact, and its value necessarily has to be higher than the outlet temperature of the LPG based on the operating scheme. Wang et al. [25] investigated experimental of air conditioning system using evaporative cooling condenser. Using an evaporative cooling condenser, the coefficient of performance of an air conditioning system was increased. Wang et al. [26] done performance assessment for three kind of condenser in refrigerating System. Use water cooling condenser, air cooling condenser and evaporation condenser respectively with the same vapor compression refrigeration system to get performance assessment. The refrigerating capacity of evaporative condenser system was 31.0% higher than that of air cooling condenser system, the COP of evaporative condenser system was 14.3% higher than that of air cooling condenser system. Vali and Reddy [27] done an experimental about performance evaluation of vapor compression refrigeration system with helical type condenser by using R134a and R410A refrigerants. The performance of the condenser also helped to increase COP of the system. R410A refrigerant in all conditions showed better performance than R134a refrigerant. Bhatkar [28] checked experimental performance of R134a and R152a using microchannel condenser. The results showed that, refrigerant charge of R152a was reduced by 40% over R134a with the microchannel condenser. Yin et al. [29] evaluated the microchannel condenser characteristics by numerical simulation. Several simulations were conducted to determine the impact of return air temperature, tube wall temperature, and non-uniform refrigerant flow rate. The model results matched well with laboratory test results for one-slab and two-slab microchannel heat exchangers on heat transfer and pressure drop. Zhong et al. [30] studied experimentally thermodynamic performance of double-row liquid–vapor separation microchannel condenser. A double-row liquid–vapor separation microchannel condenser was presented. The findings showed that, the tube wall temperature of the back row decreased faster than that of the front row, which indicated that the back row had a larger pressure drop.

Much research has been conducted due to the importance of condensers. In this study, a internal condenser inside the body of the refrigerator is used to eliminate basic problems and optimize energy consumption. This type of condenser is attached to both sides of the refrigerator body and is situated between the sheet and the foam of the refrigerator body. Because the exterior body of the refrigerator transfers the condenser's heat and the body of the refrigerator has a wide surface area, dust rarely stops heat transfer in this form of the condenser. The key to the survival of refrigerator and freezer factories in Iran (in the current situation where there is a strong competitive environment between them and foreign manufacturers) is to achieve higher quality. One of the primary quality indicators in refrigerators and freezers is energy consumption reduction, which is addressed in this study. The main purpose of this project is to investigate the effect of condenser type on the power consumption of the refrigerator experimentally and in the laboratory. The condenser is one of the most important factors that affect power consumption and can be used effectively to improve product output. It should be mentioned that this research was conducted in a laboratory environment.

Nomenclatures

EEI	Energy Efficiency Index
AE_C	Annual Energy Consumption

V_{eq}	Is the equivalent volume
n	Is the number of compartments
CC	Are volume correction factors
BI	Are volume correction factors
SAE_C	Standard Annual Energy Consumption
M, N	M and N values by household refrigerating appliance category
FF_C	Is the volume correction factor for frost-free compartments
CH	Is equal to 50 (kWh/year) for household refrigerating appliances with a chill compartment with the storage volume of at least 15 (L)
V_c	Is the storage volume of the compartment(s)
T_c	Is the nominal temperature of the compartment(s)

2. Product specifications

As illustrated in Fig.1, the product in this test is a 5-foot refrigerator. A 220-240 (V) ~ 50 (Hz) ~ 1 (PH) compressor is used.

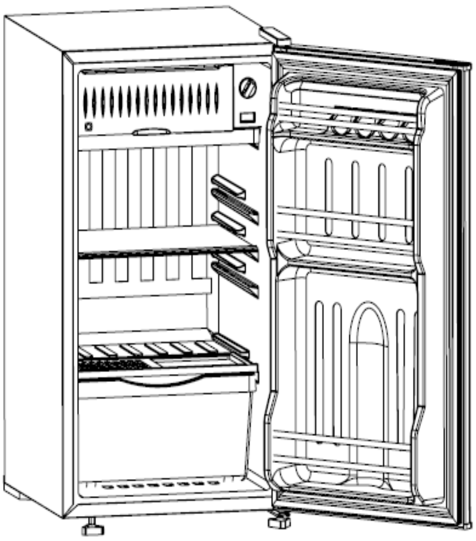


Fig. 1. Schematic of the product being tested.

R-600a refrigerant is used in the compression refrigeration cycle of the home refrigerator, the specifications of which are presented in Table 1. Because the goal of this study is to find out how the condenser affects the cooling cycle of this product, a map of both condenser models is provided. The external condenser used for the refrigerator is shown in Fig. 2 and the internal condenser is shown in Fig. 3.

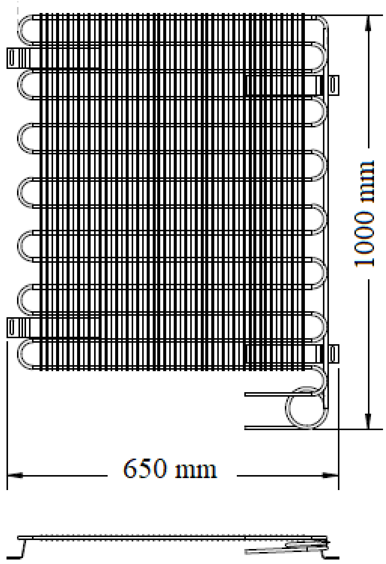


Fig. 2. External condenser map.

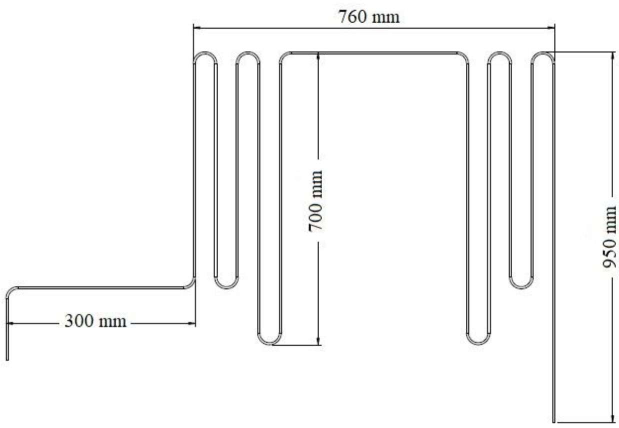


Fig. 3. Internal condenser map.

Table 1. R-600a refrigerant specifications [31].

Refrigerant	Chemical formula	Chemical name	Molecular Weight (gr/mol)	Specific heat capacity (J/Kmol)	Melting point (˚C)	Boiling point (˚C)	Global warming potential
R-600a	C_4H_{10}	Isobutane	58.12	96.65	-159.42	-11.7	1

In this experiment, the effect of both modes on increasing or decreasing the efficiency of the cooling cycle performed according to Fig. 4 is investigated.

3.General test and laboratory conditions

The household refrigerator is tested in a test room that meets the IEC 62552-2015 [32]. The refrigerator door remains closed for a period of time during the test and does not open at all. During the refrigerator test, the laboratory ambient temperature is 25 °C. The refrigeration device is placed on a platform whose upper part is made of solid wood and is matte black and its lower part is left open for free air circulation. The refrigeration device under test is protected from the effects of air currents at speeds of more than 0.25 m/s. Also, the refrigeration device is tested at nominal voltage with relative tolerance ± 1% and nominal frequency with relative tolerance ± 1%. Inside the refrigerator cabin and different parts of the cycle, there are sensors with a mass of 25 gr ± 5% and general measurement uncertainty of up to ± 0.5%. Temperatures are recorded with a measurement interval of 30 s. An energy measuring instrument with readability of up to 0.001 kWh was used to measure energy use. Temperature readings are performed after the arrival of the refrigerator under stable operating conditions. Stable working conditions for fresh food compartment floors are between 0 °C and 8 °C, while the temperature of the floors in the freezer section should be maximum -18 °C.

4.Method of determining energy efficiency index [33]

The energy efficiency index is calculated based on Eq. (1) and rounded to one decimal place:

$$EEI = (AE_c/SAE_c) \times 100 \tag{1}$$

AE_c: Annual energy consumption of household refrigeration equipment.
SAE_c: Standard annual energy consumption of household refrigeration equipment.
The energy consumption of a refrigeration device is measured for 24 hours to determine the annual energy consumption of a refrigeration device. And then its annual energy consumption is calculated from Eq. (2) and rounded to 2 decimal places.

$$AE_c = E_{24h} \times 365 \tag{2}$$

$E_{24\,h}$: A household refrigeration device's energy consumption is measured in kWh/day and is rounded to three decimal places. To determine the standard annual energy consumption, it is calculated by Eq. (3) in terms of kW/year and rounded to 2 decimal places.

$$SAE_c = V_{eq} \times M + N + CH \tag{3}$$

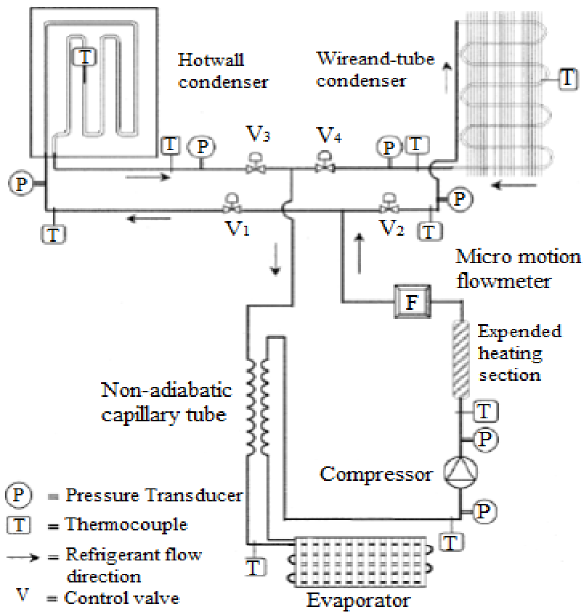


Fig. 4. The cooling cycle performed in this experiment.

V_{eq}: Is the equivalent volume.
CH: is 50 kWh/year for a household refrigerating device with a useable volume of at least 15 L in the low-temperature compartment, and is zero in all other circumstances. The M and N values are different for each group of household refrigerators.
The equivalent volume of a household refrigeration appliance, according to Eq. (4), is a set of 4 equivalent volumes of all containers, calculated in L and rounded to the nearest integer.

$$V_{eq} = [\sum_{c=1}^{c=n} V_c \times \left(\frac{25 - T_c}{20}\right) \times FF_c] \times CC \times BI \quad (4)$$

n: Number of compartments.
V_c: Useful volume of each compartment/ compartments.
T_c: Nominal temperature of each chamber.
$(25 - T_c)/20$: Thermodynamic coefficient.
FF_c: Correction factor of the volume of each compartment/ compartments.
CC and BI: Volume correction factors.
The volume correction factors for CC and BI are considered to be 1.2 and 1, respectively.

5.Results and discussions

The test room's settings were adjusted based on the type of test, which meant that the temperature was set at 25°C and the humidity was kept below 75%. The refrigerator was placed on the platform after the temperature and humidity were stabilized, in accordance with IEC 62552-2015. The sensors were placed on and around the refrigerator in various locations. The refrigerator was turned on, and the thermostat was set to 5 degrees for the refrigerator and below zero for the other compartment, and it worked for 48 hours at the desired temperature. This period is allotted to the refrigerator in order to guarantee that the temperature inside and the thermostat settings are both steady. After 48 hours, the refrigerator was put to the test for another 24 hours, yielding graphs that are analyzed below.

5.1.Refrigerator diagrams with internal condenser

According to the purpose of this study, which is to investigate the effect of condenser type on the cooling cycle, the inlet and outlet temperatures of the condenser are of considerable importance. The condenser inlet temperature is 42 °C at the highest and 27.6 °C at the lowest, as indicated in Fig. 5.
Fig. 6 depicts the temperature of the condenser output as measured by a sensor at the end of the condenser passage. The highest temperature at the condenser outlet is 40.7 °C, and the minimum is 25.5 °C, as shown in Fig. 6. Considering the function of the condenser, whose task is to reduce the temperature of the refrigerant, it can be seen that this operation took place in the condenser and the temperature of the refrigerant gas at the condenser outlet is lower than its inlet.

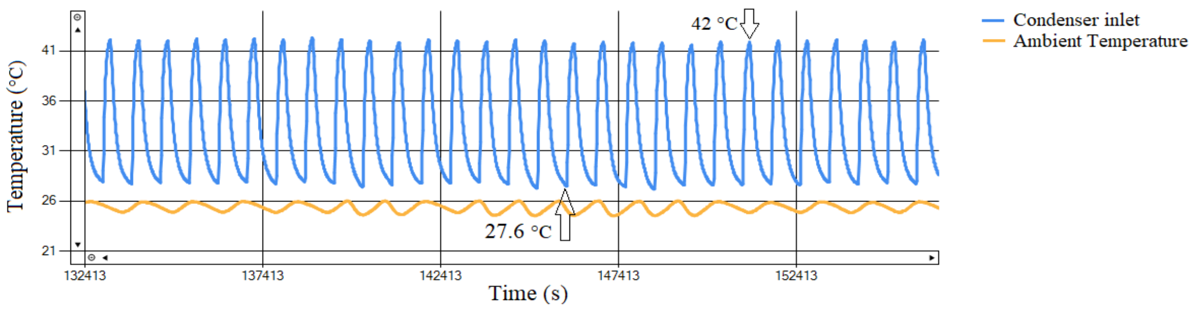


Fig. 5. Internal condenser inlet temperature.

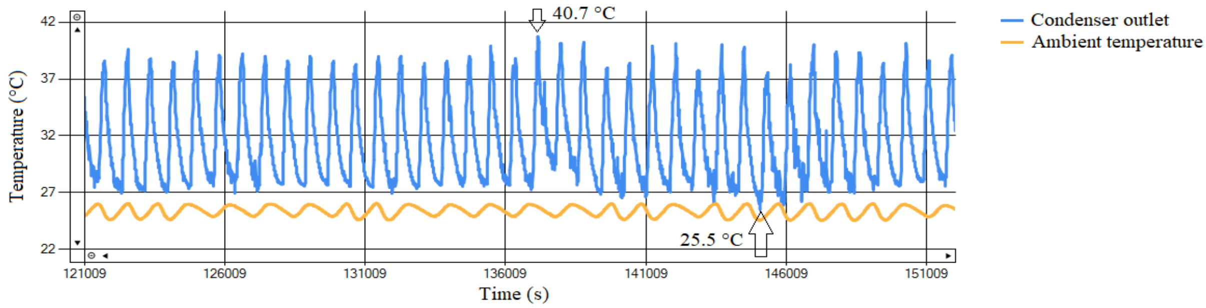


Fig. 6. Internal condenser outlet temperature.

Figure 7 shows the evaporator inlet temperature. The lowest and maximum temperatures observed at the evaporator inlet are -25.4 °C and -5 °C, respectively.

Figure 8 illustrates the evaporator outlet temperature, which ranges from -22.5 to -4.8 °C. When the temperature at the outlet and inlet of the evaporator is compared, it can be seen that the inlet of the evaporator has a lower temperature than the outflow, which is a fully natural phenomenon. Because the closer the refrigerant comes to the outlet, the more heat it collects from the environment inside the chamber, and the higher its temperature, it signals proper evaporator operation during the cooling cycle.

The temperature of the suction tube was monitored using a sensor. The suction pipe connects the evaporator to the compressor and transports refrigerant. This transfer is done by the compressor and by creating suction. For this reason, this tube is known as a suction tube. The temperature of the suction tube is 27.4 °C at its peak point and 18.3 °C at its lowest point, as shown in Fig. 9. It's also worth noting that the sensor was placed 50 mm away from the compressor.

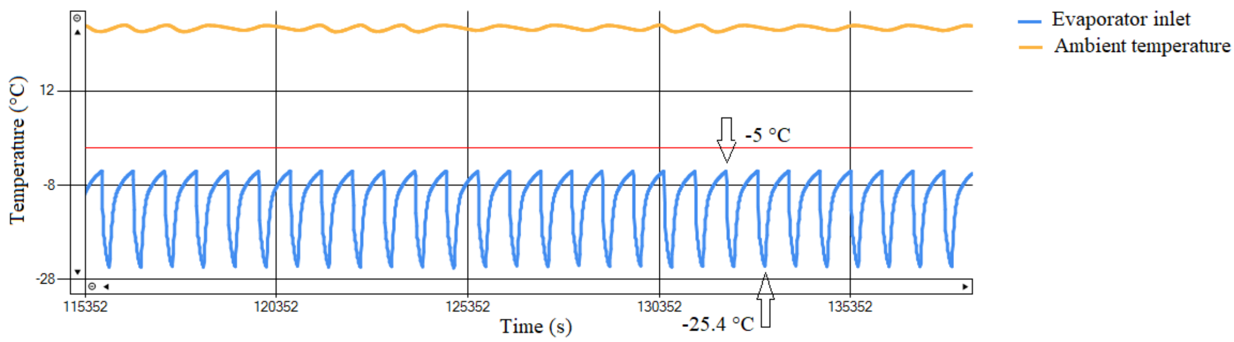


Fig. 7. Internal condense evaporator inlet temperature.

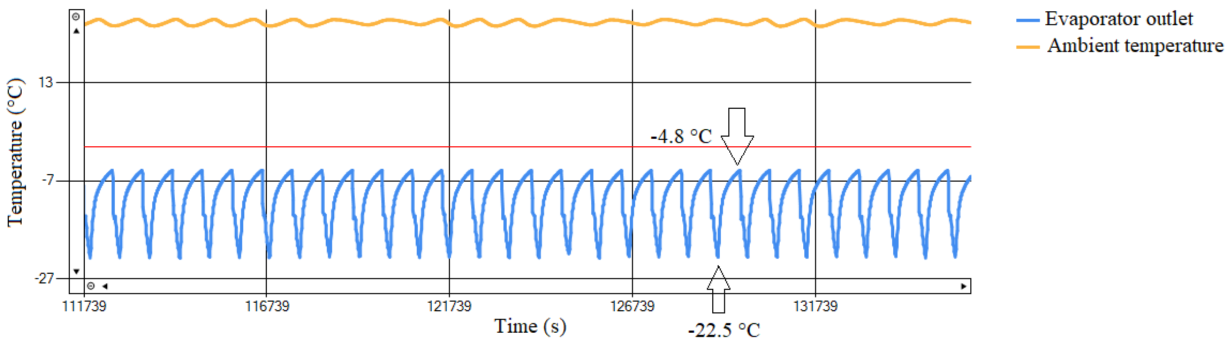


Fig. 8. Internal condenser evaporator outlet temperature.

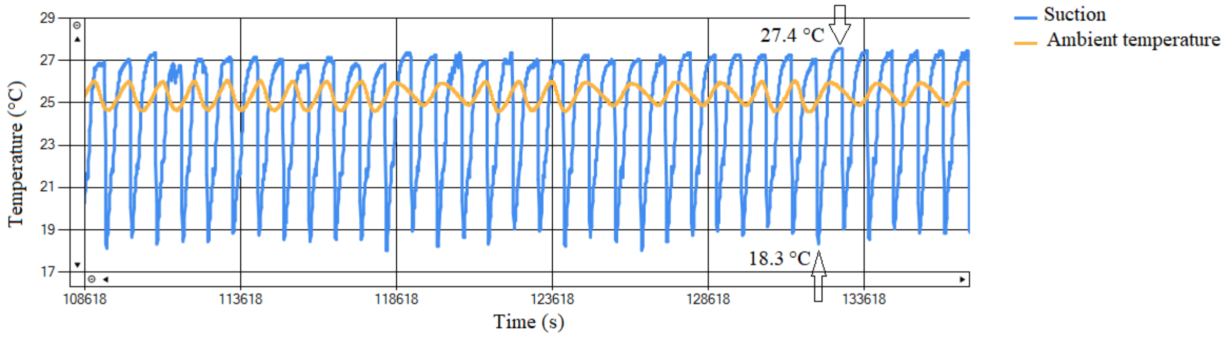


Fig. 9. Internal condenser suction tube temperature.

The compartment had three sensors: one in the top third, one in the middle, and a third in the bottom third. The temperature of the middle sensor, which shows the temperature within the refrigerator and in the middle, can be seen in the schematic in Fig. 10. The maximum temperature is 5.6 °C, and the minimum is 5.4 °C, as can be observed.

5.2.Refrigerator diagrams with external condenser

The temperature at the condenser intake is 41.8 °C at the highest and 27.8 °C at the lowest, as shown in Fig. 11.

The sensor put on the outlet pipe in the condenser, according to Fig. 12, indicates the lowest temperature at 27.2 °C and the highest temperature at 41.5 °C. The course of the diagram is regular, as with prior diagrams, confirming the refrigerator's stability during testing. When comparing this diagram to the previous one showing the condenser inlet, it can be noted that the refrigerant temperature has reduced when compared to the first case, the condenser inlet, indicating that the condenser has performed correctly.

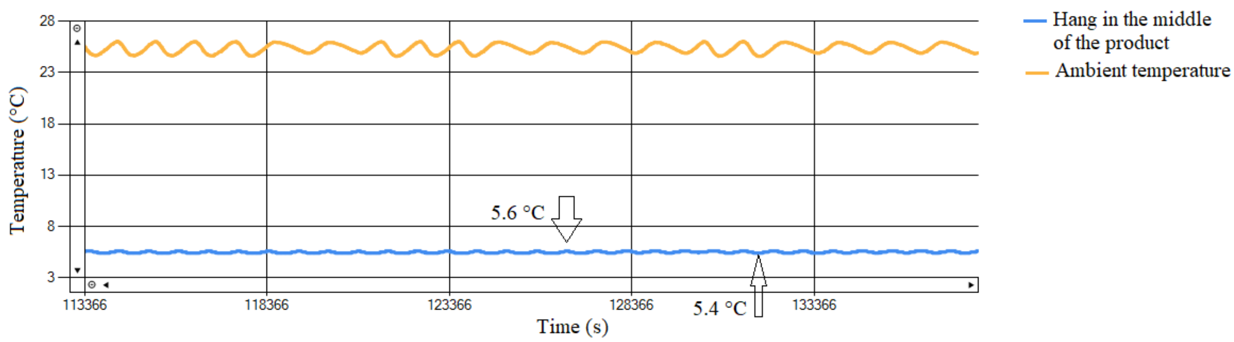


Fig. 10. Internal condenser refrigerator inside temperature.

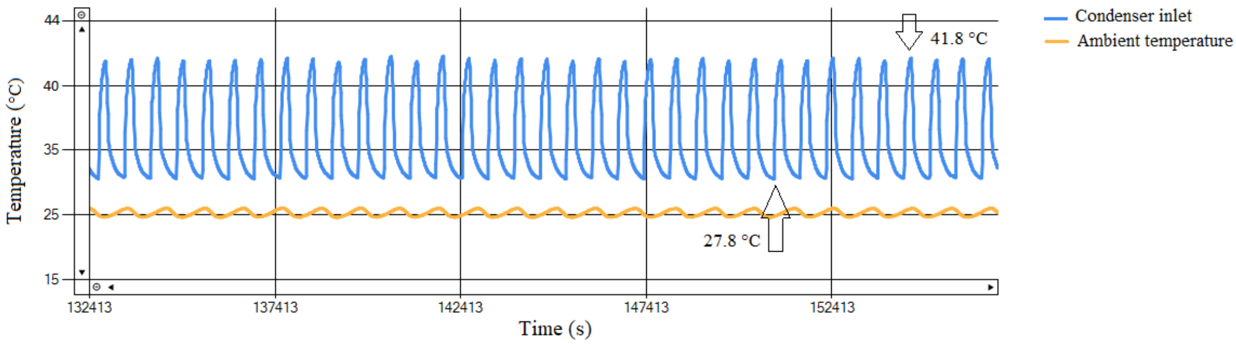


Fig. 11. External condenser inlet temperature.

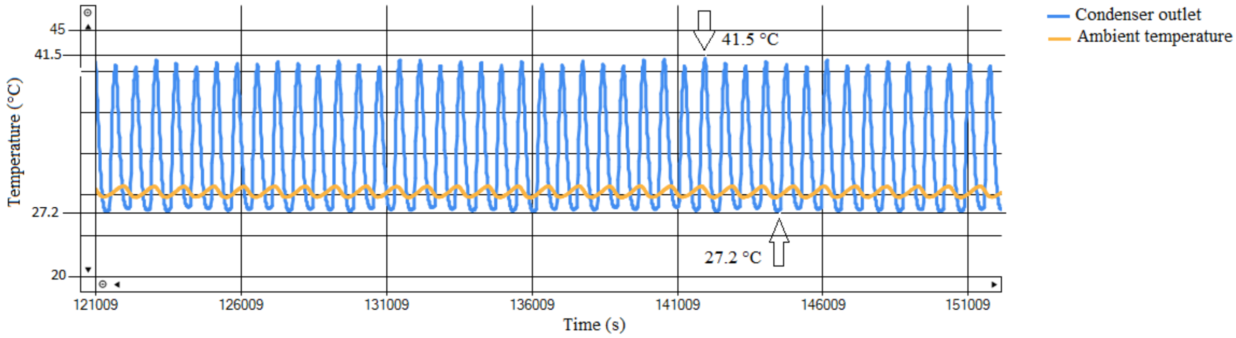


Fig. 12. External condenser outlet temperature.

The relative temperature of the refrigerant at the beginning of the evaporator intake was determined using a sensor installed at the evaporator inlet. The minimum temperature measured during the process is -24.2 °C, and the maximum temperature is -5.9 °C, as shown in Fig. 13.

The sensor positioned at the evaporator outlet is recorded at the lowest temperature of -23.4 °C and the highest temperature recorded with this sensor is -5.8 °C, according to Fig. 14. Comparing this diagram with the previous diagram showing the evaporator inlet temperature, it can be seen that the evaporator outlet temperature has increased. This rise in evaporator temperature is normal because the refrigerant absorbs heat from the compartment as it goes in the evaporator path, raising the refrigerant temperature.

A number of sensors were put 5 mm apart from the compressor on the suction pipe. Fig. 15 shows that the temperature of the suction tube is between 19.1 °C and 29.8 °C.

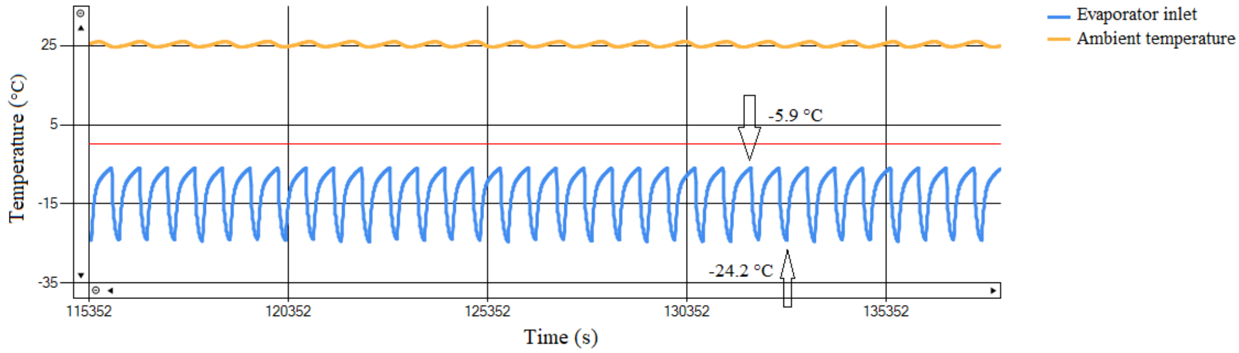


Fig. 13. External condenser evaporator inlet temperature.

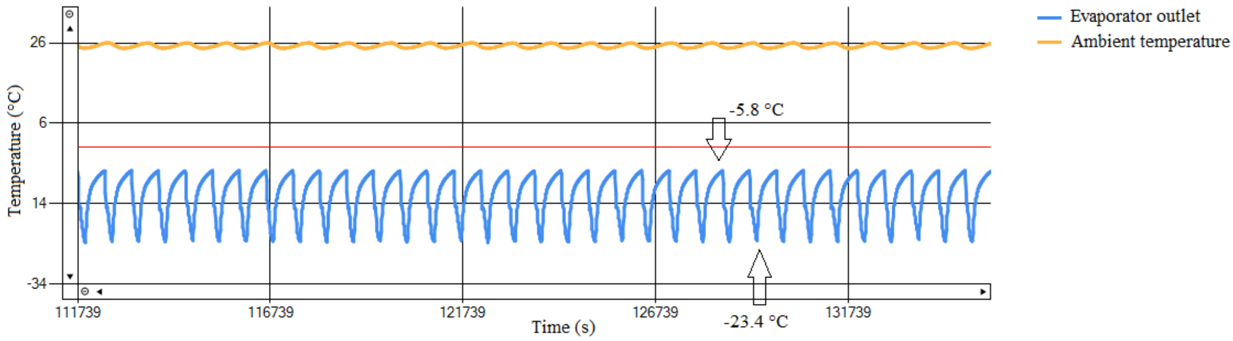


Fig. 14. External condenser evaporator outlet temperature.

The refrigerator temperature was set at 5 °C to create consistent conditions for product testing, as previously stated. As illustrated in Fig.16, the sensor hung in the middle of the refrigerator displays a temperature of 5.2 °C at the maximum and 5.1 °C at the lowest.

5.3. Energy consumption index calculations for the refrigerator with internal condenser

To compute a refrigeration device's yearly energy consumption, the device's energy consumption is measured for 24 h and then the annual energy consumption is calculated using the following equation and rounded to two decimal places, i.e.

$E_{24h} = 0.3369$

$AE_C = E_{24h} \times 365$

$AE_C = 0.3369 \times 365$

$AE_C = 122.9685 \cong 123\ kWh/year$

The standard annual energy (SAE) consumption is calculated by the following relation in kWh/year and is rounded to 2 decimal places:

$SAE_C = V_{eq} \times M + N + CH$

Where V_{eq} is the volume equivalent of a household refrigeration device.

Depending on the type of refrigerator, the value of N is equal to 245, the value of M is equal to 0.233 and the value of CH is equal to 0.

$SAE_C = 80 \times 0.233 + 245 + 0$

$SAE_C = 263.64\ KWH/Year$

Now, according to the obtained values, the result is:

$EEI = (AE_C/SAE_C) \times 100$

$EEI = (123/263.64) \times 100$

$EEI = 46.65$

5.4. Energy consumption index calculations for the refrigerator with external condenser

$E_{24h} = 0.4$

$AE_C = E_{24h} \times 365$

$AE_C = 0.4 \times 365$

$AE_C = 146kWh/year$

$SAE_C = 263.64$

Now, according to the obtained values, the result is:

$EEI = (AE_C/SAE_C) \times 100$

$EEI = (146/263.64) \times 100$

$EEI = 55.37$

When the grades for both items are compared, it can be observed that the refrigerator with the internal condenser has a superior performance and has been able to demonstrate greater efficiency by receiving grade A. This means that the use of condensers in this model of the refrigerator can save energy. According to Table 2, it can be seen that the lower the EEI, the better the grade of the refrigerator, which means less energy consumption in that product.

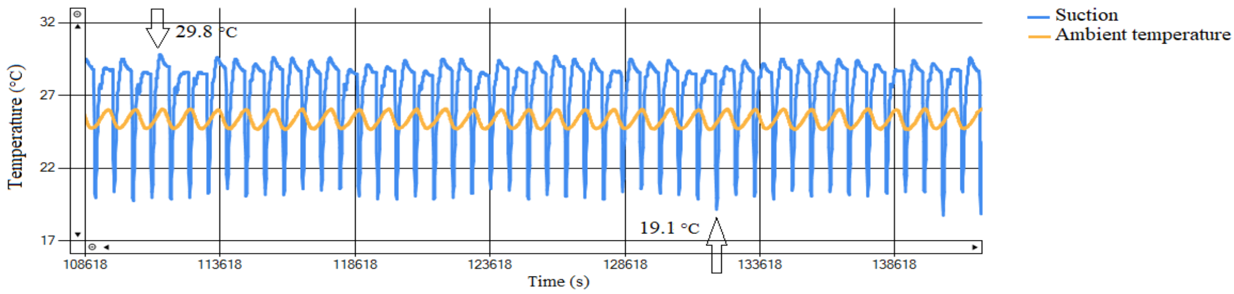


Fig. 15. External condenser suction tube temperature.

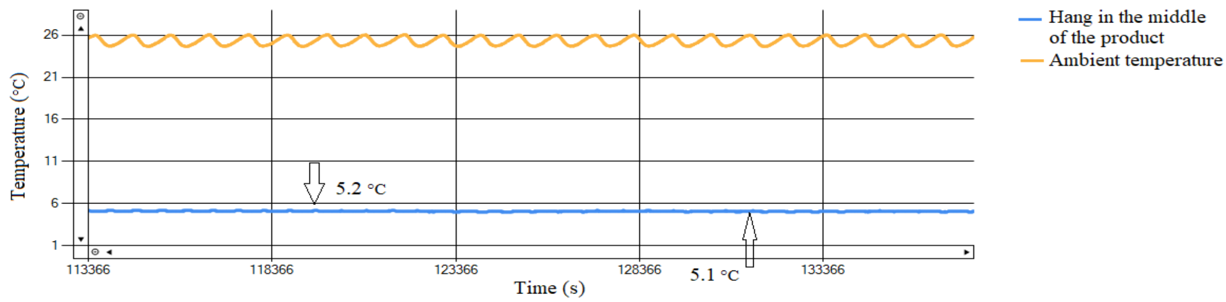


Fig. 16. External condenser refrigerator inside temperature.

Table 2. Energy efficiency group [33].

Energy efficiency	EEI
A^+	$33 \leq EEI < 42$
A	$42 \leq EEI < 55$
B	$55 \leq EEI < 75$

6.Conclusion

In this study, a 5-foot refrigerator was selected for testing and two types of external and internal condensers were used for comparison. The refrigerator was tested in a laboratory according to the 62552-2015 international standard. According to experiments, the use of an internal condenser reduces energy consumption. With both types of condensers, the temperature of different points in the refrigeration cycle was tested, and the energy consumption was computed.

The following results were achieved as a consequence of laboratory experiments:

- By performing calculations to determine the energy consumption grade, it was observed that the refrigerator with an internal condenser has energy consumption grade A. Grade B was obtained by replacing the external condenser on the product.
- The energy consumption of a refrigerator with an internal condenser during 24 h is less than a refrigerator with an external condenser.
- Therefore, according to the above, it can be concluded that the use of a condenser is generally more suitable for the cooling cycle. So that leads to reduced energy consumption and better product grading.
- The temperature recorded at the outlet of the internal condenser is equal to 40.7 °C and at the external condenser, this temperature is equal to 41.5 °C. By comparing these two cases, it can be seen that the process of heat transfers and reduction of refrigerant temperature in the internal condenser is better and at the exit point, a lower temperature is obtained. Considering the performance of the condensers in the cooling cycle, which is responsible for reducing the temperature of the refrigerant, it can be concluded that the internal condenser has provided better performance. At the evaporator inlet, it was observed that the temperature drops in the refrigerator with the internal condenser worked better than the refrigerator with the outside condenser. This means that a lower temperature was recorded in the refrigerator with a condenser.

Acknowledgment

The esteemed officials of TAKRAN MOBARED INDUSTRIAL COMPANY, who cooperated and provided financial assistance in conducting this research, are thanked and appreciated.

References

[1] P. K. Bansal and T. C. Chin, “Design and modelling of hot-wall condensers in domestic refrigerators,” Appl. Therm. Eng., vol. 22, no. 14, Oct. 2002, doi: 10.1016/S1359-4311(02)00081-9.

[2] P. K. Bansal and T. C. Chin, “Modelling and optimisation of wire-and-tube condenser,” Int. J. Refrig., vol. 26, no. 5, Aug. 2003, doi: 10.1016/S0140-7007(02)00044-0.

[3] M. Tosun, B. Doğan, M. M. Öztürk, and L. B. Erbay, “Integration of a mini-channel condenser into a household refrigerator with regard to accurate capillary tube length and refrigerant amount,” Int. J. Refrig., vol. 98, Feb. 2019, doi: 10.1016/j.ijrefrig.2018.11.012.

[4] V. Dmitriyev and V. Pisarenko, “Determination of optimum refrigerant charge for domestic refrigerator units,” Int. J. Refrig., vol. 7, no. 3, May 1984, doi: 10.1016/0140-7007(84)90097-5.

[5] P. Saji Raveendran and S. Joseph Sekhar, “Experimental studies on the performance improvement of household refrigerator connected to domestic water system with a

water-cooled condenser in tropical regions," Appl. Therm. Eng., vol. 179, Oct. 2020, doi: 10.1016/j.applthermaleng.2020.115684.

[6] W. Cho, D. S. Jang, S. H. Lee, S. Yun, and Y. Kim, "Refrigerant charge reduction in R600a domestic refrigerator-freezer by optimizing hot-wall condenser geometry," Int. J. Refrig., vol. 117, Sep. 2020, doi: 10.1016/j.ijrefrig.2020.05.012.

[7] Z. Zhang, D. Huang, R. Zhao, and Y. Leng, "Effect of airflow field optimization around spiral wire-on-tube condenser on a frost-free refrigerator performance," Appl. Therm. Eng., vol. 114, Mar. 2017, doi: 10.1016/j.applthermaleng.2016.12.024.

[8] X.-D. Yuan and W.-L. Cheng, "Multi-objective optimization of household refrigerator with novel heat-storage condensers by Genetic algorithm," Energy Convers. Manag. vol. 84, Aug. 2014, doi: 10.1016/j.enconman.2014.04.086.

[9] R. Bassiouny, "Evaluating the effect of the space surrounding the condenser of a household refrigerator," Int. J. Refrig., vol. 32, no. 7, Nov. 2009, doi: 10.1016/j.ijrefrig.2009.03.011.

[10] H. Hajabdollahi and Z. Hosseini, "Energy Equipment and Systems Dynamical modeling and thermo-economic optimization of a cold room assisted vapor-compression refrigeration cycle," 2020. [Online]. Available: http://energyequipsys.ut.ac.irwww.energyequipsys.com.

[11] S. H. Oh, S. H. Lee, D. Lee, S. H. Moon, and Y. Kim, "Air-side heat transfer and pressure drop characteristics of flat-type, U- and V-shaped microchannel condensers for refrigerator applications," Int. J. Heat Mass Transf., vol. 176, Sep. 2021, doi: 10.1016/j.ijheatmasstransfer.2021.121460.

[12] J. Boeng and C. Melo, "Mapping the energy consumption of household refrigerators by varying the refrigerant charge and the expansion restriction," Int. J. Refrig., vol. 41, May 2014, doi: 10.1016/j.ijrefrig.2013.06.005.

[13] C. Aprea, A. Greco, and A. Maiorino, "An experimental investigation on the substitution of HFC134a with HFO1234YF in a domestic refrigerator," Appl. Therm. Eng., vol. 106, Aug. 2016, doi: 10.1016/j.applthermaleng.2016.06.098.

[14] N. Agrawal, S. Patil, and P. Nanda, "Experimental Studies of a Domestic Refrigerator Using R290/R600a Zeotropic Blends," Energy Procedia, vol. 109, Mar. 2017, doi: 10.1016/j.egypro.2017.03.051.

[15] L. Vaitkus and V. Dagilis, "Refrigerant charge reduction in low-temperature transport refrigerator with the eutectic plate evaporator," Int. J. Refrig., vol. 47, Nov. 2014, doi: 10.1016/j.ijrefrig.2014.07.011.

[16] G. Pottker and P. Hrnjak, "Effect of the condenser subcooling on the performance of vapor compression systems," Int. J. Refrig., vol. 50, Feb. 2015, doi: 10.1016/j.ijrefrig.2014.11.003.

[17] Y. Jeon, D. Kim, J. Jung, D. S. Jang, and Y. Kim, "Comparative performance evaluation of conventional and condenser outlet split ejector-based domestic refrigerator-freezers using R600a," Energy, vol. 161, Oct. 2018, doi: 10.1016/j.energy.2018.08.007.

[18] G. Sonnenrein, A. Elsner, E. Baumhögger, A. Morbach, K. Fieback, and J. Vrabec, "Reducing the power consumption of household refrigerators through the integration of latent heat storage elements in wire-and-tube condensers," Int. J. Refrig., vol. 51, Mar. 2015, doi: 10.1016/j.ijrefrig.2014.12.011.

[19] M. R. Salem, H. A. El-Gammal, A. A. Abd-Elaziz, and K. M. Elshazly, "Study of the performance of a vapor compression refrigeration system using conically coiled tube-in-tube evaporator and condenser," Int. J. Refrig., vol. 99, Mar. 2019, doi: 10.1016/j.ijrefrig.2018.12.006.

[20] B. Xu, Y. Wang, J. Chen, F. Li, D. Li, and X. Pan, "Investigation of domestic air conditioner with a novel low charge microchannel condenser suitable for hydrocarbon refrigerant," Measurement, vol. 90, Aug. 2016, doi: 10.1016/j.measurement.2016.04.034.

[21] Y. T. Ge, S. A. Tassou, I. D. Santosa, and K. Tsamos, "Design optimisation of CO2 gas cooler/condenser in a refrigeration system," Appl. Energy, vol. 160, Dec. 2015, doi: 10.1016/j.apenergy.2015.01.123.

[22] B. A. Qureshi and S. M. Zubair, “The impact of fouling on the condenser of a vapor compression refrigeration system: An experimental observation,” Int. J. Refrig., vol. 38, Feb. 2014, doi: 10.1016/j.ijrefrig.2013.08.012.

[23] D. Azzouzi, M. Kelkouli, and F. Amaryoucef, “Parametric study of the wire-on-tube condenser subcooling effect on the performance of vapor compression refrigeration system,” Appl. Therm. Eng., vol. 122, Jul. 2017, doi: 10.1016/j.applthermaleng.2017.05.003.

[24] İ. H. Yılmaz, K. Saka, and O. Kaynakli, “A thermodynamic evaluation on high pressure condenser of double effect absorption refrigeration system,” Energy, vol. 113, Oct. 2016, doi: 10.1016/j.energy.2016.07.133.

[25] T. Wang, C. Sheng, and A. G. A. Nnanna, “Experimental investigation of air conditioning system using evaporative cooling condenser,” Energy Build., vol. 81, Oct. 2014, doi: 10.1016/j.enbuild.2014.06.047.

[26] Z. Wang, L. Wang, W. Fu, and Y. Sun, “Performance assessment for three kind of condenser in refrigerating Syetem,” Sep. 2013, doi: 10.1109/ICAMechS.2013.6681763.

[27] R. Hussain Vali and M. Reddy, “AN EXPERIMENTAL INVESTIGATION AND PERFORMANCE EVALUATION OF VAPOR COMPRESSION REFRIGERATION SYSTEM WITH HELICAL TYPE CONDENSER BY USING R-134A AND R-410A REFRIGERANTS,” www.ijerst.com, vol. 4, no. 3, 2015, [Online]. Available: http://www.ijerst.com/currentissue.php.

[28] V. W. Bhatkar, “EXPERIMENTAL PERFORMANCE OF R134a AND R152a USING MICROCHANNEL CONDENSER,” J. Therm. Eng., vol. 1, no. 7, Jul. 2015, doi: 10.18186/jte.55930.

[29] X.-W. Yin, W. Wang, V. Patnaik, J.-S. Zhou, and X.-C. Huang, “Evaluation of microchannel condenser characteristics by numerical simulation,” Int. J. Refrig., vol. 54, Jun. 2015, doi: 10.1016/j.ijrefrig.2015.03.006.

[30] T. Zhong et al., “Experimental investigation on the thermodynamic performance of double-row liquid–vapor separation microchannel condenser,” Int. J. Refrig., vol. 67, Jul. 2016, doi: 10.1016/j.ijrefrig.2016.02.020.

[31] Specifications for Refrigerants, 2019.

[32] IEC 62552, “Household refrigerating appliances- characteristics and test methods,” 2015.

[33] 30/EU with regard to energy labelling of household refrigerating appliances of the European Parliament and of the Council setting a framework for energy labelling, and certain Delegated Regulations on energy-related products.