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An Experimental Study Towards Decreasing the Energy Efficiency Index Value in Industrial Refrigerators

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Abstract

Energy labeling is performed according to the energy efficiency index (EEI) value in industrial refrigerators. In order to reduce the EEI value calculated according to the amount of energy consumed and the characteristics of the cooler, two systems were designed in this study and the energy label class of the coolers was determined according to the results obtained. Two systems were designed in this study and the energy label class of the refrigerators was determined according to the obtained results. In this study, two different refrigerators (Type 1 and Type 2) were designed, manufactured and tested. The systems are designed using R290 (propane). It is a new generation natural and environmentally friendly refrigerant with two inlet-outlet evaporators, double condensers and double compressors that provide a homogeneous refrigeration. During the experiments, temperature-pressure measurements of the cooled products and refrigeration system equipment were taken from certain points every minute and test data were recorded. In the experiments, the average air temperature and relative humidity values of the test chamber of the experiment with resistance glass in the Type 1refrigerator were measured as 25 °C and 59,09%, respectively, the average air temperature and relative humidity values of the test room of the Type 2 system experiment with antifogging film were measured as 25,231 °C and 57,207%, respectively. In the experiments, defrosting process was carried out twice a day in the refrigerators. During the experiment, the highest and lowest average temperatures of the cooled products were measured as -16,18 °C and -19,40 °C. Increasing product temperatures during defrosting and stopping cooling increased the power consumption in the system. As a result of the calculations, the energy efficiency index value of the Type 1 resistance model was calculated to be 60,53 and it was seen that the energy label was class “E”. In the Type 2 model in which anti-fog coating film is used, the energy efficiency index value is 49,25 and it has been observed that the energy label is class "D".

1. INTRODUCTION

Industrial refrigerators can be defined in two main groups as display cabinets and storage cabinets. Industrial type display cabinets have many features such as horizontal, vertical, combined, open, closed, positive and negative set temperatures. Dairy products, packaged meat display refrigerator cabinets, fruit-vegetables etc. display refrigerator cabinets can be grouped as service sections (meat, appetizers, delicatessen products display section), deep freezers, cake cabinets, seafood display cabinets, frozen food display sections and promotional type refrigerator cabinets. In this study, vertical type door deep freezer industrial refrigerators are used and it includes the experimental results of the design that provides energy efficiency in industrial refrigerators. The performance of propane, which is one of the environmentally friendly refrigerants, and the performance of glass with anti-fog film were investigated experimentally, and it was aimed to contribute the results to the literature.

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Since the vertical-door deep-freezer industrial type refrigerators operate at low evaporation (-35°C), there is a temperature difference between the freezer indoor temperature and the outdoor temperature. Due to this temperature difference and when doors are constantly opened and closed in a busy retail environment, condensation occurs on the windows of the doors. For this reason, customers cannot see the displayed products and as a result, a significant problem may arise that will affect sales. For this problem, the use of resistances in glasses creates high costs and increases energy consumption. Thanks to the anti-fog film that will be applied to the inner surface of the doors instead of the resistances used, it prevents fogging and maintains the glass transparency, allowing customers to see the products offered clearly. Thus, doors with anti-fog film provide the opportunity to save high levels of energy with "zero energy consumption".

Anti-fog coatings are films that have recently started to be studied. These films lose their effectiveness over time and need to be reapplied to that area. Anti-fog films are resistant to oil and grease as well as being water resistant [1].

Anti-fog films do not form moisture on them when they have hydrophilic properties. The water particles that will form on the film cannot hold on to the film and slide.

These films are used in some sports and safety equipment (diving masks, safety glasses, visors…), delicatessen cabinets, car windows, glass doors of freezer cabinets, shower cabin windows and many more.

Thanks to the adhesion of anti-fog films to the windows of freezer cabinets in supermarkets, customers can easily see the products inside the cabinet. Since the freezer cabinet operates at low evaporation temperature, the temperature difference between inside and outside is large. Therefore, if the film is not attached, water condenses on the glass and condensation occurs due to the customer opening the cabinet door [2]. As a result, the visibility of the materials inside the cabinet is reduced. The installation of anti-fog films on the windows of freezer cabinets has been examined in the literature and it has been seen that not many studies have been done. Therefore, in the study, the effect of anti-fog film on the freezer cabinet windows on energy consumption was investigated and the energy efficiency index (EEI) value was calculated. The energy efficiency index "(EEI)" means an index value calculated in percent (%) for the relative energy efficiency of an industrial refrigerator with a direct sales function [22] and based on this value, an energy label is applied to industrial refrigerators.

Dixel tested for 2 conditions in his study. In the 1st test condition, freezing temperature of -20ºC, ambient temperature of 26.2ºC and relative humidity of 48% were used. In the 2nd test conditions, the values when the freezing temperature is -20ºC, the ambient temperature is 26.4ºC and the relative humidity is 48%, the cabinet heater is off and the anti-fog film were used. The average daily energy use was found to be 3.89 kWh before using the anti-fog film, and 2.54 kWh after using the anti-fog film. After using the anti-fog film, the average power consumption decreased by 0.056 kW, the average energy used daily was 1.36 kWh, and the energy consumption was reduced by 35% [1].

In another study, Dixel stated that using an anti-fog film saves between 20% and 60% energy and has a simple payback period of 10 months [3].

The study of Rauss et al. was based on 4 different scenarios. In the 1st scenario, it was studied on the refrigerator cabinet where the cabinet door materials are old, there is no anti-fog film, the lath heater between the glass had low capacity, there was a glass heater, and there was no frame heater. In the second scenario, a refrigerator cabinet was_studied where the cabinet door materials were old, there was an anti-fog film, the lath heater between the glass had low capacity, there was no glass heater, and there was no frame heater. In the 3rd scenario, a refrigerator cabinet was studied, in which the cabinet door materials were developed, there was no anti-fog film, the lath heater between the glass was high capacity, there was no glass heater, and there was no frame heater. In the 4th scenario, a refrigerator cabinet was studied where the cabinet door materials were developed, there was an anti-fog film, the lath heater between the glass had high capacity, there was no glass heater, and there was no frame heater. In the room conditions at 23,8ºC and 55% relative humidity, the cleaning time of the fog was 1.35 minutes for the 1st scenario and 2.40 minutes for the 3rd scenario, according to the scenarios. Since excessive sweating occurred outside the cabinet door in the 2nd scenario, it could not be calculated and no condensation was observed for the 4th scenario [4].

Madico window film company has done tests on hot water, refrigerator and freezer. They examined the effect of using the anti-fog film in these three places on the disappearance of the fog on the glass. In the hot water fog test, when the film is not used, the fog is cleared after 2.5 minutes, while no condensation occurs when the film is used. In the coolant fog test, when the film is not used, the fog is cleared after 13 minutes, while no condensation occurs when the film is used. In the freezer fog test, the fog was cleared after 19 minutes when the film was not used, and after 1 minute when the film was used [5].

Sabic Global company tested the anti-fog film on a five-door freezer cabinet. After the film was attached, the cabinet glass heaters were turned off. Experimental data were monitored for 2 years and it was seen that the power of the freezer was reduced by 400 W. It is estimated that the investment would be amortized in 10 months, depending on the store [6].

As a result of the work of the FSI coating technologies company, the anti-fog film remained clean for a longer time under 60% relative humidity, -25ºC temperature conditions. In these weather conditions, the glass of the freezer whose door was left open can remain without fogging for 180 seconds. The cost of the film was calculated at $40 per cabinet door. Using film ensures that the compressor life was extended since it does not require heating the glass of the freezer [7].

Sunray Film company examined the energy and economic savings of installing anti-fog film on the doors of 3 different cabinet types in the Grocery Market. The ice cream cabinet had 20 doors, the low temperature cabinet had 60 doors, and the medium temperature cabinet had 20 doors. As a result of the calculations, it is found that the ice cream refrigerator saves 16819 kWh, the low temperature refrigerator 50456 kWh and the medium temperature refrigerator 6307 kWh after the anti-fog film was installed. The annual cost savings were calculated as $1867 for the ice cream refrigerator, $5601 for the low temperature refrigerator and $700 for the medium temperature refrigerator [8].

In another study by Sunray Film company, anti-fog film was attached to 52188 cabinet doors in Tesco markets and examined. As a result of the study, it is seen that 41004000 kWh energy savings were achieved and 31680 tons of CO_2 emissions per year are prevented [8].

According to ANSI/AHRI 1321 Standard, the coefficient of performance (COP) values of the reciprocating compressor-operated cooling system in medium temperature commercial refrigerator cabinets vary according to the dew point. COP values according to temperature; It was calculated as 2.86 at -18ºC, 3.53 at -10ºC, 4.61 at -1ºC, 4.74 at 0ºC, and 5 at 2ºC [9].

According to ANSI/AHRI 1201 Standard, COP values vary according to the dew point of the reciprocating compressor-operated cooling system in medium temperature commercial refrigerator cabinets. COP values according to temperature; It was calculated as 2.69 at -18ºC, 3.34 at -10ºC, 4.41 at -1ºC, 4.56 at 0ºC, 4.86 at 2ºC. The COP values in low temperature and freezer cabinets were calculated as 1.55 at -39ºC, 1.96 at -30ºC, 2.52 at -20ºC, and 2.58 at -19ºC [10].

In the study of Radha et al., the effect of R12 and R134a refrigerants in freezer cabinets used to prevent food from spoiling was investigated. According to the R12 refrigerant, ozone depletion potential is 0.86, global warming potential was 3.2, daily energy consumption was 6 kWh, mass flow rate was 0.0017 kg/h and COP value was 8.076. According to R134a refrigerant, ozone depletion potential was 0, global warming potential was 0.27, daily energy consumption was 4.25 kWh, mass flow rate was 0.0012 kg/h and COP value was 8.42. As a result of the calculations, it was seen that R134a provided more performance than R12 refrigerant [11].

Erten et al. conducted tests on the cooling cabinet using R290 refrigerant and air defrosting method. They observed the positive effects of defrosting on cooling performance. During the experiments in the cooling cabinet, 8 defrosting events occurred. According to the values measured before these 8 conditions occurred, COP values were found to be 2.13, 2.31, 2.30, 2.29, 2.6, 3.36, 3.29, 3.30 and 3.49, respectively [12].

Koşan et al., using R449a refrigerant, made calculations by selecting the condenser in the cooling system with classical and micro channels. In the cooling system with micro-channel condenser, the volume flow rate is 600 m3/h, the total energy consumption is 14.409 kWh, the average COP value is 2.351, the total CO_2 emission value is 346.524 kg/day. In the cooling system with a classical condenser, the volume flow rate is 780 m3/h, the total energy consumption is 16.202 kWh, the average COP value is 2.086, and the total CO_2 emission value is 392.575 kg/day. As a result of the calculations, the average energy efficiency value was found to be 25.564% for the micro-channel system and 23.950% for the classical system. As a result of the study, it was concluded that the use of the micro-channel system was better than the classical system in terms of energy consumption, COP, energy efficiency and CO_2 emission [13].

According to the study of Waide et al., the classification of the energy efficiency index of refrigerators according to 5 types of energy efficiency classes according to China was examined. EEI≤ 55% in 1st grade, 55% <65% in 2nd grade, 65% <80% in 3rd grade, 80% <90% in 4th grade, and 90% <100% in 5th grade. There were no energy efficiency labels in Brazil, India, Australia, Japan and South Africa [14].

According to the study of Tait et al., the EEI value of 80 in vertical refrigerator cabinets, the EEI value of 50 in horizontal freezer cabinets, the EEI value of 70 in beverage coolers and the EEI value of 75 in vending machine cabinets were considered according to the minimum energy performance standard. In addition, the COP value of the cooling system conforming to ISO 23953 and ARI standards and the COP values of the CO_2 and R404a refrigerant cooling systems made by Girotto et al. [15] were compared. COP values were taken as 2 according to the ISO 23953 standard, 3.25 according to the ARI standard, 3 according to the CO_2 refrigeration cycle made by Girotto and 3.75 according to the R404a fluid refrigeration cycle [16].

According to the study of Geilinger et al., the annual energy consumption for glass door vertical cabinets was 2168 kWh for beverage cooled, 1606 kWh for ice cream cabinets, 1348 kWh for storage refrigerators, and 3690 kWh for storage freezers. Energy efficiency classes were determined based on the energy efficiency index value calculated from these consumption values [17]. EEI values differed according to classes. In the best energy efficiency classes, the EEI value was <10 in class A, 10-20 in class B, and 20-35 in C. In the worst energy efficiency classes, it was 50-65 in the E class, 65-80 in the F class, and >80 in the G class.

Propane (R290), one of the refrigerants, is a natural refrigerant with excellent environmental and thermophysical properties. It is a natural hydrocarbon used in many refrigeration and air conditioning applications. Compared to standard HCFC and HFC refrigerants, it does not contain fluorine and therefore has lower environmental impacts. Compared with R22 and R134a refrigerants, R290 appears to have very good thermodynamic properties. The molecular weight of R290 is 49% lower than R22 and 56.7% lower than R134a. Its lower molecular weight indicates that the refrigerant has a high latent heat of vaporization. The latent heat of vaporization of R290 is 82% higher than R22. When compared for the same cooling capacity, it is sufficient to use less mass of R290, which has a high latent heat of evaporation, compared to R22 and R134a. R290 has an ozone depletion potential (ODP) of 0 and a global warming potential (GWP) of 3 [18].

Yan et al. simulated the use of a mixture of R290 and R600a refrigerants in a cascade refrigeration system and compared them with a classical refrigeration cycle. As a result of the comparison, in the system using R290 and R600a, the COP value improved by 7.8-13.3%, the volumetric cooling capacity improved by 10.2-17.1%, and the compressor pressure ratio decreased by 7.4-12.3% [19].

Ataer et al. conducted their study on a cooling system with 500 W cooling load using R134a, R404a, R407a, R410a, R507 and R290 fluids. As a result of the study, it was observed that the COP values of R404a, R407a, R410a and R507 refrigerants were low, while R134a, R290 were higher [20].

In Afshari's study, the COP values of Peltier thermoelectric refrigerators were calculated according to the operation in heating and cooling modes, and the air-to-water Peltier thermoelectric performance was experimentally investigated. It has been shown that when operating in cooling mode, the air-to-water Peltier thermoelectric device can reduce the refrigerator temperature below the freezing temperature of water. According to the experimental results obtained in the study, the COP or coefficient of performance value in the heating mode was found to be approximately 200% higher than the cooling mode [21].

Afshari et al., in their study, compared the COP values of heat pumps and chillers with similar working principles and using different refrigerants in heating and cooling conditions. They used R134a, R407c, R22 and R404a refrigerants as refrigerants. In the study, the suction and discharge lines of the compressor were closely examined considering the temperature, pressure, enthalpy, entropy and compression ratio. It has been determined that the optimum charge amount of the freezer is 15-25% lower than the system when operating in the heat pump mode. Finally, the effect of condenser flow rate on performance is examined to compare another difference between heat pump and cooling devices. As a result of the experiments, it is found that the COP value of the heat pump is 100 times higher than the COP value of the cooling device in some cases [22].

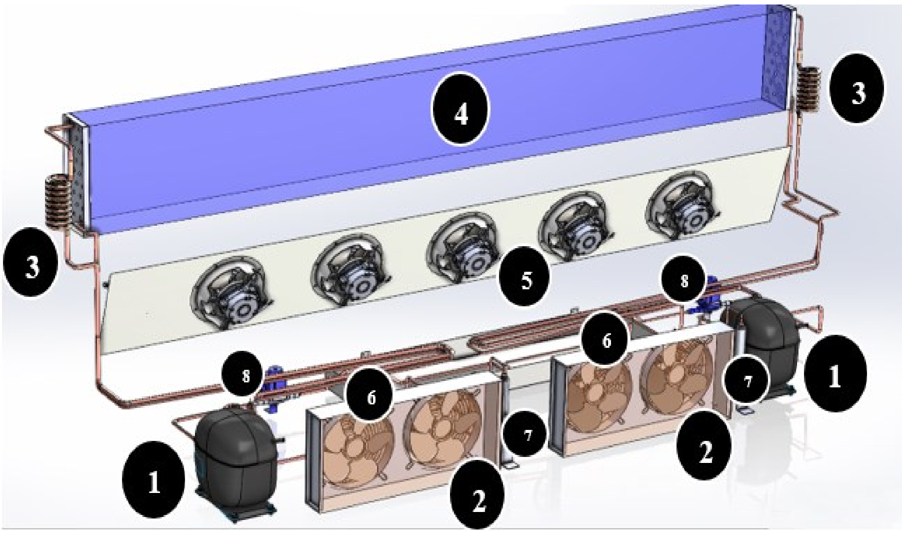
In this study, it was aimed to present the results to the researchers by making analyzes to compare the compressor power consumption, total power consumption and energy efficiency indexes by attaching a resistance (Type 1) and anti-fog film (Type 2) to the door windows of the 3-door vertical industrial freezer cabinet.

2.MATERIALS AND METHODS

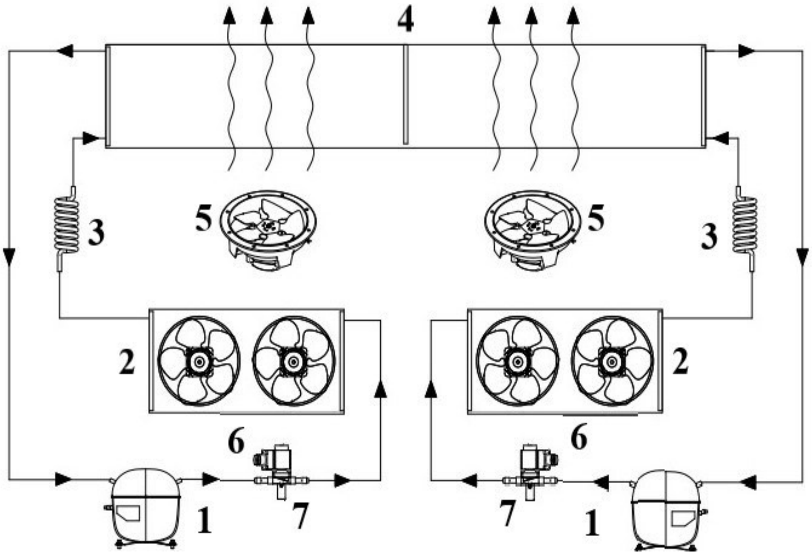
The aim of the study is to analyze the performance of a deep freezer with R290 refrigerant and to investigate the effect of without resistance anti-fog glass on the EEI value.

In the study, the refrigeration cycle for the designed and tested industrial freezer is shown in Figure 1a. In the refrigeration system, in Type 1 and Type 2, grooved pipe hydrophilic coated air-cooled evaporator with 5 fans at 1800 rpm, air-cooled microchannel condenser (2 pcs), hermetic piston compressor (2 pcs), capillary tube (4 pcs), high and low pressure measuring devices (4 units) and R290 refrigerant is used in the cycle. Type 1 uses resistant glass, while Type 2 uses non-heated glass with an anti-fog film attached. The reason for using R290 refrigerant in the cycle is that it is a new generation natural refrigerant, has low ODP and GWP values, and has a high latent heat of evaporation.

By using propane fluid in the system, it was desired to reduce the EEI value of the system to a lower level and to observe its effect on its performance. In addition, it was aimed to see the effect of using both propane fluid and glass with anti-fog film on the EEI value and to improve this value further. Tests were carried out in accordance with the TS EN ISO 23953-2 standard, and the EEI value of the deep freezer was determined to comply with the standard.



(a)



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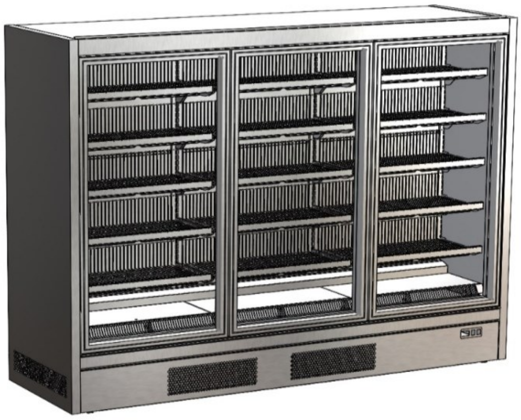

(c)

Figure 1. *Schematic view and flow chart of the refrigeration system(a-b) 1. Compressor 2. Condenser 3. Capillary Tube 4. Evaporator 5. Evaporator Fans 6. Condenser Fans 7. Dryer 8. Pressure Gauge*

Figure 2 shows an example of a freezer cabinet.

Figure 2. *Vertical door freezer cabinet*

Experiments were carried out in the test room with test equipment calibrated within the scope of TS EN ISO 23953-2 standard. The refrigeration performance of the system, energy consumption measurement, temperature measurements, pressure measurements and energy efficiency tests were carried out. While performing these tests, temperature measurements were taken from certain points of the refrigeration system equipment (compressor, condenser and evaporator inlet-outlet temperature values) by means of thermocouples every minute. Information on measuring equipment used in prototype production and testing is given in Table 1.

Table 1. *Measurement tools used in prototype production and tests and their technical specifications*

Device Name	*Brand*	*Model*	*Measuring Range*	*Unit*	*Accuracy*
Thermocouple	*Omega*	*Cl-23a*	*-40 / +150*	*°C*	*±0.1*
High Pressure Gauge	*Eliwell*	*Hp*	*0-30*	*bar*	*±0.1*
Low Pressure Gauge	*Eliwell*	*Lp*	*0,5-8*	*bar*	*±0.01*
Thermohygrometer	*Rotronic*	*M23w2ht-1x*	*0 / +50* *0-100*	*°C* *%RH*	*±0.03* *±1.5%*
Anemometer	*E+E Elektronik*	*Ee660-V7*	*0-2*	*m/s*	*±0.01*
Digital Gas Meter	*Value*	*Ves-100b*	*0-100*	*kg*	*±0.05%*
Digital Manifold	*Testo*	*550*	*-50 / +150* *-1 / +60*	*bar*	*±0.1* *± 0.01*
Energy Analyzer	*Janitza*	*Umg 508*	*-*	*amper* *volt*	*Current ±0.2%* *Voltage ±0.1%*
Flow Meter	*Siemens*	*Sıtrans Fc Mass 6000*	*0-1000*	*kg/h*	*±0.1%*

The equipment used in the refrigeration system and their values are shown in Table 2.

Table 2. *Type 1 and Type 2 values of the equipment used in the* refrigeration *system*

Equipment	*Type 1*	*Type 2*
Evaporator	*1400 W*	*1400 W*
Evaporator Fan	*5x18 W*	*5x18 W*
Evaporator Fan Flow Rate	*5x350 m^3/h*	*5x350 m^3/h*
Condenser	*2x1300 W*	*2x1300 W*
Condenser Fan	*4x13 W*	*4x13 W*
Condenser Fan Flow	*4x200 m^3/h*	*4x200 m^3/h*
Compressor	*2x600 W*	*2x600 W*
Door Resistance	*375 W*	*0*
Frame Resistor	*400 W*	*400 W*
Drainage Resistance	*600 W*	*600 W*

For Type 1, the cost of the 3-door glass with resistance is 5500 TL, for Type 2 the cost of the glass with anti-fog film is 6500 TL, the electricity price is 1.07 TL/kWh [23] according to the TEDAŞ 2021 electricity sales price, and the payback period is calculated.

3.THEORETICAL ANALYSIS

The performance analyzes of the refrigeration system given in Figure 1 were made according to the 1st and 2nd Laws of thermodynamics. The evaporator capacity (Q_e) used in the refrigeration system is determined by the following equation [28].

$$\dot{Q}_e = \dot{m}.(h_1 - h_4) \quad 1$$

Here, $\dot{m}$ is the mass flow rate of the refrigerant, h_1 is the enthalpy of the fluid at the evaporator outlet, and h_4 is the enthalpy of the fluid at the evaporator inlet. The compressor power in the system is found by equation 2 [28].

$$\dot{W}_{comp} = \dot{m}.(h_2 - h_1) \quad 2$$

Here, h_2 represents the enthalpy of the fluid leaving the compressor, and h_1 the enthalpy of the fluid entering the compressor. The coefficient of performance (COP) of the refrigeration system can be calculated by equation 3 [28].

$$COP = \frac{Q_e}{W_{comp}} \quad 3$$

The energy efficiency index (EEI) value can be calculated with the 4th equation. The AE value in the equation represents the annual energy consumption (kWh/year), and the SAE value represents the reference value of the annual energy consumption amount [28].

$$EEI = \frac{AE}{SAE} \quad 4$$

Type 1 Class E boundary conditions are $50 \leq EEI < 65$ and TYPE 2 Class D boundary conditions are $35 \leq EEI < 50$ [24]. Energy efficiency classes are determined according to Table 3.

Table 3. *Energy efficiency classes [24]*

Energy efficiency class	***EEI***
A	*EEI <10*
B	*10≤ EEI <20*
C	*20≤ EEI <35*
D	*35≤ EEI <50*
E	*50≤ EEI <65*
F	*65≤ EEI <80*
G	*EEI ≥100*

To find the AE value in equation 4, it is necessary to know the daily energy consumption (Equation 5) [24].

$$AE = 365.E_{day} \quad 5$$

It is necessary to know some coefficients to find the SAE value in equation 4. These coefficients can be found in the "Regulation of the European Parliament and the Council" [24, 25]. According to the regulation, M coefficient is 7.5, N coefficient is 19.300, C temperature coefficient value is 0.9, P coefficient is 1.10 for vertical supermarket freezer cabinets. The Y value should be taken as the sum of the total display areas in m^2 of all the compartments of the refrigerationdevice in the same temperature class.

$$SAE = 365.P.(M + N.Y).C \quad 6$$

When the electrical energy (kWh) consumed by the compressor used in the refrigeration system is evaluated, Sovacool in his published study [26] stated the average CO_2 equivalent density for electricity generation from coal as fuel as approximately 0.96 kg CO_2/kWh. This value can be corrected as 2.08 kg CO_2/kWh when calculated with 40% transmission and distribution losses and 20% losses due to inefficient electrical appliances used [27].

CO_2 reduction can be done with equation 7 [27].

$$\Phi_{CO_2} = \Psi_{CO_2} . \dot{Q}_u \tag{7}$$

4.RESULT

In this study, resistance and anti-fog film energy consumption, energy efficiency index, pressure calculations, evaporator temperature change analyzes were made on the 3 door vertical industrial freezer cabinet door glasses used in the industrial refrigeration system. R290a is used as refrigerant in both systems. The values obtained as a result of the 24 hour analysis are presented in the graphics. Figure 3 and Figure 4 show the operating pressure ranges of resistance and anti-fog film coating models, respectively. In the resistance model, it works in the range of high pressure 9-12.5, low pressure 0.6-1.3 bar, and in the anti-fog film-coated model, it works in the range of high pressure 9-12, low pressure 0.6-1.4 bar. Average low and high pressure values were found to be 1.06 and 9.67 bar for the resistance model, and 1.08 and 9.73 bar for the anti-fog film coated model. In this case, it was observed that the high pressure value was 0.06 bar lower in the resistance model.

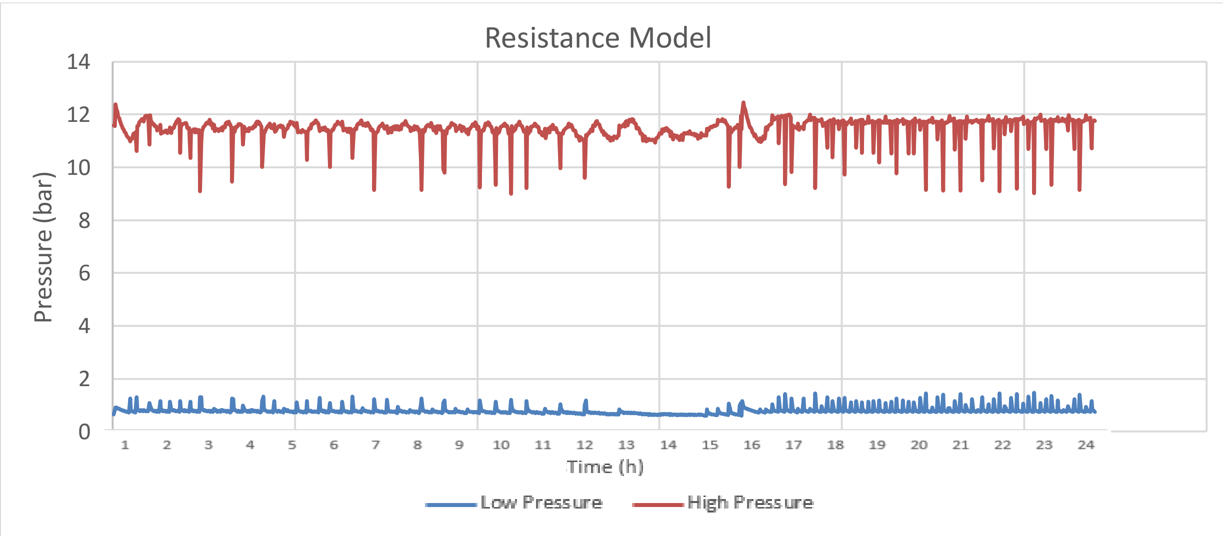

Figure 3. *Time dependent high and low pressure values of the resistance model*

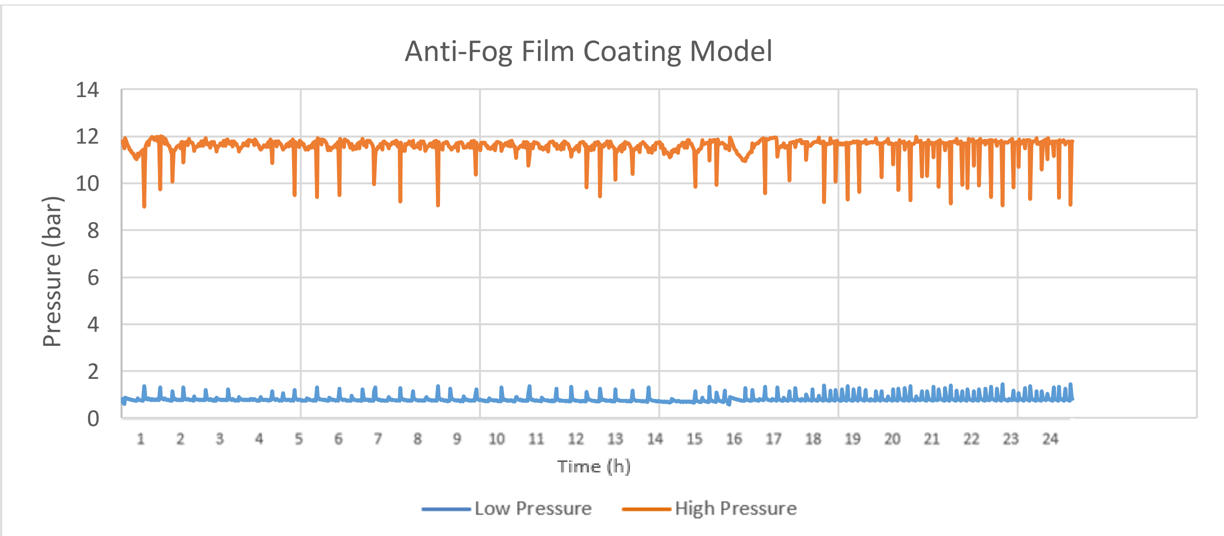

Figure 4. *Time-dependent high and low pressure values of the anti-fog film coating model*

The time-dependent energy consumed by the compressors and fans in the modelrefrigeration systems with resistance and anti-fog film coating is given in Figure 5. The compressor in the resistance model consumed more energy over time. The highest energy consumption was seen as 2.605 kWh in the 7th hour in the resistance model and 1.977 kWh in the 7th hour in the anti-fog film coated model. The average hourly energy consumption value of the resistance model was 2.014 kWh, and the model with anti-fog film coating was 1.638 kWh.

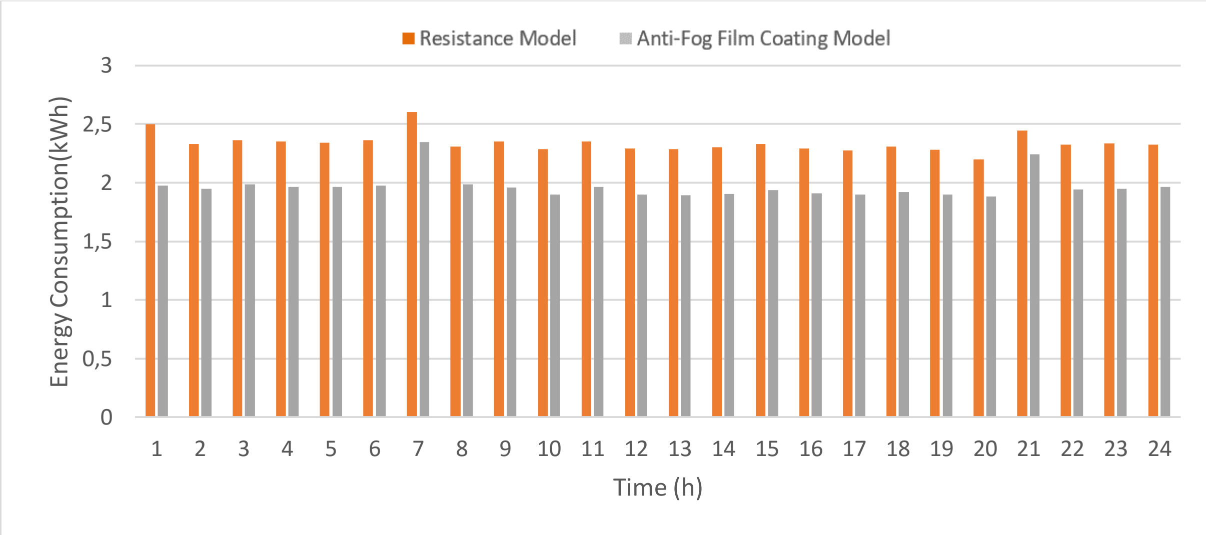

Figure 5. *Energy consumption of the refrigeration system*

Figure 6 shows the model refrigeration systems with time-dependent refrigeration COP resistance and anti-fog film coating. Refrigeration COP of the resistance and anti-fog film coated models was seen as the highest COP value of 1.873 for the resistance model at the 19th hour, while the highest COP value was seen as 1.837 for the anti-fog film-coated model at the 8th hour. The average refrigeration COP of the resistance and anti-fog film coated model is 1.696 and 1.686, respectively.

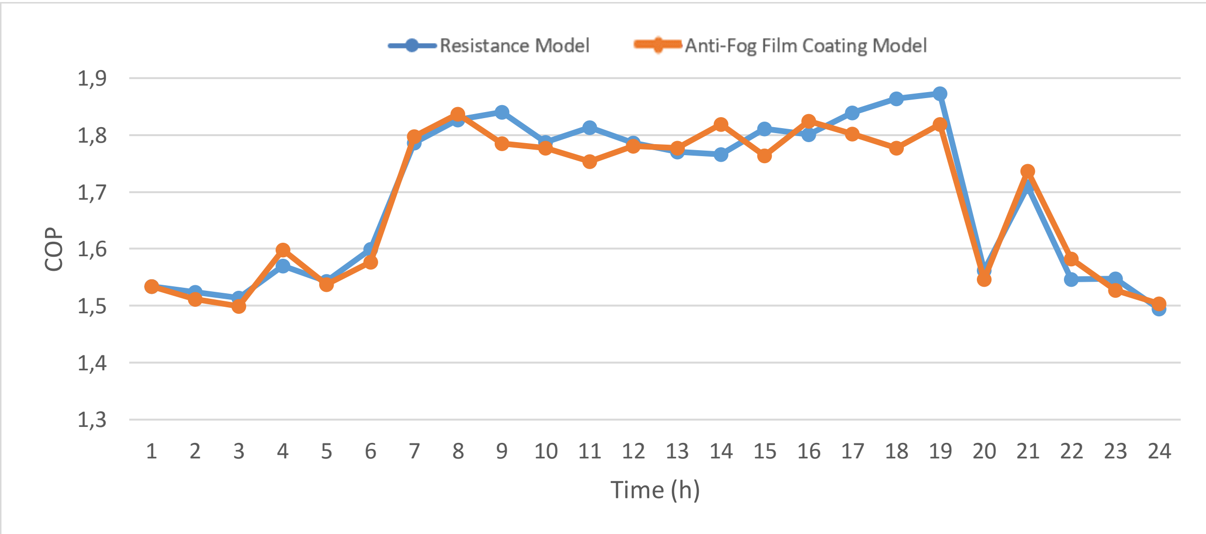

Figure 6. *COP value of the* refrigeration *system*

In the experimental setup shown in Figure 2, within the scope of TS EN ISO 23953-2 standard, defrosting twice a day, at 7:00 and 21:00, is a total of 31 minutes. During the experiment, the average air temperature and relative humidity values of the test room with resistance glass were measured as 25°C and 59.09%, respectively, and the average air temperature and relative humidity values of the test room of the anti-fog film-coated glass experiment were measured as 25.231°C and 57.207%, respectively, and reached the values specified in the standard found to be suitable. According to this measured temperature and relative humidity, the dew point thermometer temperature was found to be an average of 16.7ºC from the psychrometric diagram.

The variation of the evaporator inlet and outlet air temperature over time is shown in Figure 7. The average inlet and outlet temperatures of the evaporators in the resistance model were calculated as -23.08ºC, -19.11ºC and -21.92ºC, -19.68ºC, respectively. The average inlet and outlet temperatures of the evaporators in the anti-fog film coated model were calculated as -22.82ºC, -18.98ºC and -21.60ºC, -19.49ºC, respectively.

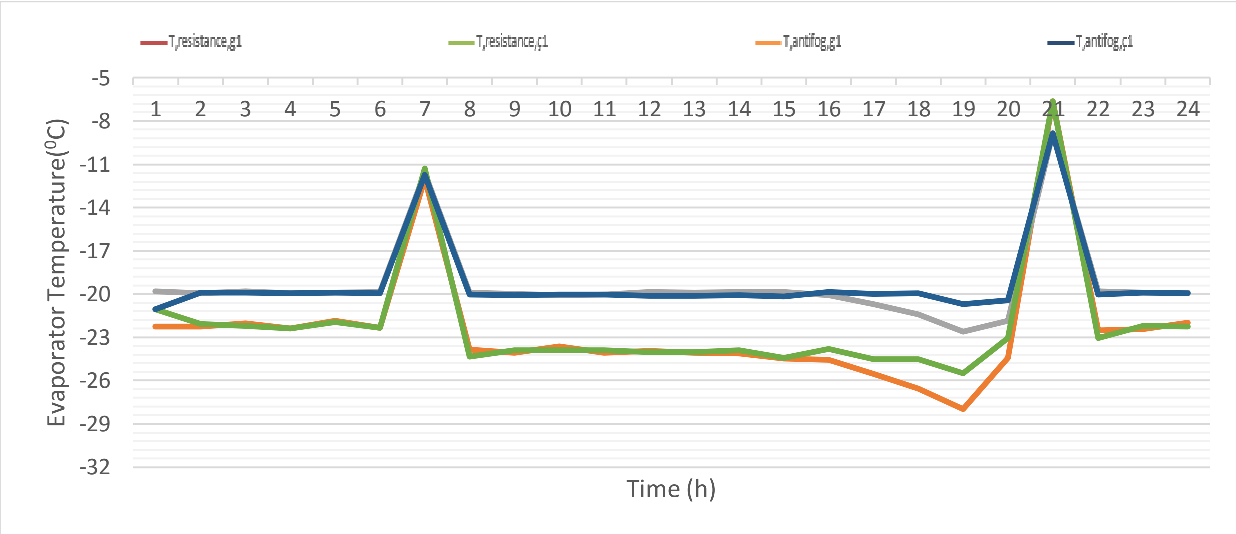

Figure 7. *Variation of evaporator inlet and outlet air temperature over time*

As seen in Figure 7, moisture begins to condense on the glass surface because the evaporator temperatures are below the dew point. Despite the condensation of moisture, after a while in the experiment, ice formation was observed after the evaporator surface temperature dropped below the freezing temperature of the water. The effect of increased thermal resistance caused by ice formation in the experiment is understood by increasing the temperature of the evaporator outlet air at the end of each refrigeration period. However, the increased ice thickness on the evaporator surface can reduce the cross-sectional area through which the air passes, thus increasing the differential pressure in the air flow. During defrost (7th and 21st hours), it requires more cooling power due to the increasing temperatures of the products. Hotgas defrost method is used in this industrial refrigerator. As hot gas is sent to the evaporator while the system is in the defrosting process, the increase in evaporator inlet-outlet air temperatures is seen in the graph. With the hot gas defrost method, icing and snowing events on the evaporator surface are eliminated by performing an effective defrosting process in a short time without further temperature increases in the products. The water grains dissolved in the hydrophilic coated evaporators are drained quickly and a clean defrost process is made.

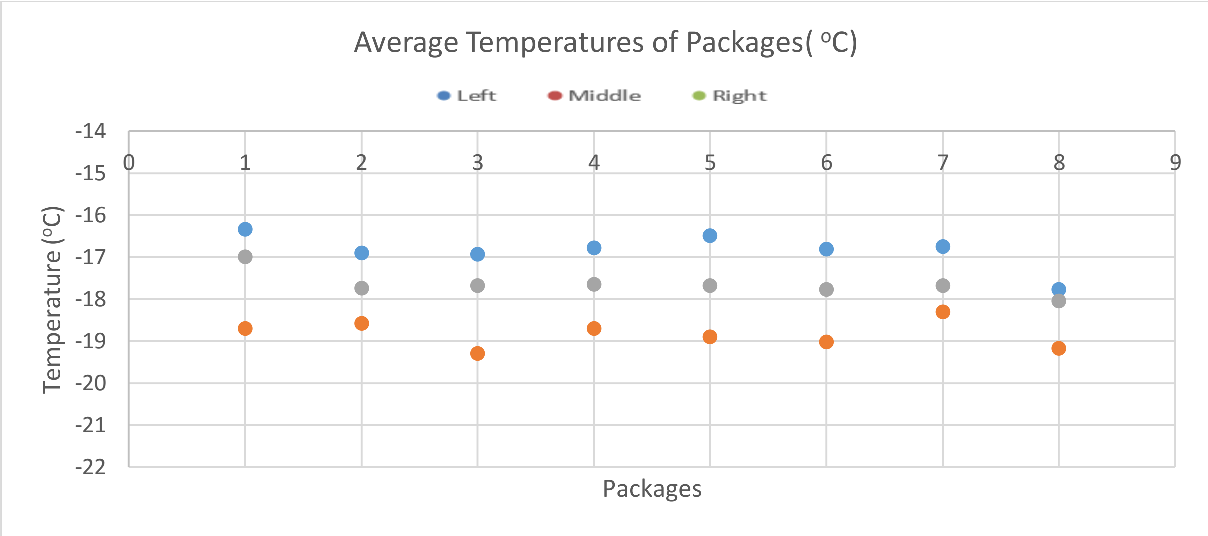

Figure 8. *Average temperature values of packages inside the cabinet*

As seen in Figure 8, the average temperature values of 8 packages on the left, middle and right sides of the cabinet are shown. The maximum temperature average value of the packages in the cabinet is -16,335^{0}C, and the minimum temperature average value is -19,292^{0}C.

5.CONCLUSION

In this study, the changes in the door glasses of the 3-door vertical deep freezer with industrial type R290 refrigerant type 1 with resistance and Type 2 with anti-fog film were compared.

Labeling of industrial display cabinets placed on the market in the EU after March 1, 2021 has become mandatory. Classification from A to G on the label is determined according to the energy efficiency index value. In addition, according to the eco-design requirement, as of March 1, 2021, the energy efficiency index value for vertical and combined supermarket cabinets must be less than 100, and as of September 1, 2023, it must be less than 80 [24]. These obligations, which will affect direct sales, in order for manufacturers to maintain their market shares and not lose their power in the competitive environment, in order to produce energy efficient high quality devices, as in this study, anti-fog film door, grooved-hydrophilic coated and microchannel heat exchanger, environmentally friendly efficient refrigerant, etc. systems should be studied and continuous improvement should be made.

In the resistance model, the daily total energy consumption in the compressor is 22.68 kWh, the daily energy consumption in the door heater is 9 kWh, and the total daily energy consumption is 48.34 kWh. As a result of the calculations, the energy efficiency index value was 60.53 and it was seen that the energy efficiency class was “E”. In the case of installing an anti-fog coating film, the daily energy consumption in the compressor is 22.46 kWh, and the total daily energy consumption is 39.33 kWh. As a result of the calculations, the energy efficiency index value was 49.25 and it was seen that the energy efficiency class was “D”. In the environmental approach, it has been calculated that there will be 18.72 kg CO_2/day savings with the use of Type 2.

The cooling COP determines how effectively the refrigeration system is used. The average COP value of the resistance model was calculated as 1.696 and the average COP value of the anti-fog coating model was calculated as 1.686.

As a result, the anti-fog coating model was better determined in terms of energy consumption and energy efficiency index than the resistance model. As a result of the calculations, the payback period of Type 2 was found to be 3.46 months. In this sense, the low energy consumption of Type 2 and the use of anti-fog coating film will provide significant energy savings.

With the energy efficiency studies to be carried out, more work should be done to reduce the EEI value by reducing the operating time of the compressor and energy costs should be reduced. In addition, the negative effects of refrigerators on the environment will be reduced.

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