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An Example of Remote Monitoring for A Refrigerated Display Cabinet: Effects on Energy Performance

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Highlights

- An approach is presented to study the impact of remote monitoring on energy efficiency in RDCs.
- An algorithm was developed to control the parameters that lead to increased energy consumption.
- This method will lead to a reduction in carbon emissions, energy consumption, and energy costs.

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Abstract

Refrigerated display cabinets, which are widely used in supermarkets, are one of the parts of the cold chain. These refrigerators are used for both cold storage and frozen storage of products at specific temperature ranges by standards. In refrigerated display cabinets, the air refrigerated by the heat drawn by the evaporator is blown to the food products. Due to negative interactions with hot ambient air, open-type refrigerated display cabinets consume large amounts of electrical energy. Therefore, the refrigerated display cabinet must have high energy efficiency. Energy labeling was made mandatory for refrigerated display cabinets launched in 2021 and energy labeling was classified from A to G. With this application, refrigerators are classified according to their efficiency. The energy consumption values of the compressor, evaporator fan, condenser fan, PTC resistor, and lighting units that cause energy consumption in the refrigerator were determined, and an algorithm was developed to keep these parameters under control. With this algorithm, energy consumption data is presented and, possible problems are detected, and warnings are given for these problems. With this algorithm that warns the refrigerator when necessary, malfunctions that may occur in the refrigerating system will be prevented. With this remote monitoring method, which aims to check whether the refrigerated display cabinets' meet the energy consumption values specified by the manufacturer under actual operating conditions, the impact of the remote monitoring method on energy efficiency has been revealed, and it was concluded that it can contribute to operational efficiency by reducing energy costs and carbon emissions.

1. INTRODUCTION

Refrigerating plants are units designed to refrigerate an area or control the temperature of a process, often used in industrial, commercial, or building applications. These refrigerating plants usually include specialized equipment used to refrigerate air or water. Refrigerating plants can be used in many different sectors. These are systems designed to suit a specific application or industry need, such as industrial refrigerating systems, food production facilities, cold room applications, air conditioning systems, and ice production facilities.

Remote monitoring systems and energy performance monitoring are technological solutions developed to increase the efficiency of refrigerating systems and optimize energy consumption. These systems are used to improve energy efficiency, reduce costs by facilitating service and maintenance operations, enable remote detection by monitoring the status of equipment, provide security control by providing instant

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warnings/alarms with the data received, plan maintenance processes, ensure system security by providing limited access to authorized personnel and minimize environmental impact.
Main features of these systems:

- **Sensor and Data Acquisition:** In refrigerating systems, sensors continuously measure temperature, pressure, flow rate, and other vital parameters. The data obtained by these sensors is the basis for analyzing system performance.
- **Data Transmission and Internet Connection:** Data acquired for monitoring refrigerating systems is usually transmitted remotely via an internet connection. This allows real-time monitoring of system performance.
- **Data Analysis and Reporting:** The collected data is analyzed through specialized software or platforms. These analyses are used to assess energy consumption, efficiency level, and potential problems. It also provides regular information to users through reports.
- **Remote Control and Automation:** Remote monitoring systems often also offer the possibility to control refrigerating systems remotely. This makes it possible to make the necessary adjustments remotely to save energy and optimize system performance.
- **Alarm and Warning Systems:** Remote monitoring systems notify the user with alarms and warnings of problems that may occur or have occurred due to the processing of measured data and the control algorithm. This way, problems can be detected quickly, and serious failures can be prevented by intervening.
- **Energy Efficiency:** Based on the results of the analysis, remote monitoring systems can recommend increasing system performance and improving energy efficiency. These recommendations include optimizing refrigerating system parameters or using more efficient equipment.
- **Energy Analysis and Performance Monitoring:** Remote monitoring systems analyze essential parameters such as energy consumption, system efficiency, and uptime. These analyses help determine the facility's energy use, identify potential efficiency gains, evaluate savings opportunities, and monitor them when necessary.

Literature studies were reviewed to show the importance of remote monitoring systems in refrigerating systems regarding energy efficiency, service, maintenance, and total costs.

Katırcıoğlu et al. [1] proposed a novel approach to monitor surface temperature changes in refrigerating systems using infrared imaging for early detection of potential failures. The study focused on four key regions: maximum surface temperature, minimum surface temperature, average surface temperature, and peak surface temperature within each selected area. The researchers analyzed the surface temperature data using graphs and correlated it with various failure types. Examining failure modes based on surface change characteristics proved effective in comprehensively evaluating all considered failure modes. Notably, the proposed system distinguishes itself from traditional fault detection methods relying on pressure, temperature, and electrical measurements due to its user-friendly nature, capability for remote measurements, and simultaneous recording features. Janecke et al. [2] emphasized the economic and environmental benefits of addressing faults in heating, ventilation, air conditioning, and refrigerating systems to enhance energy efficiency. Their investigation delved into static and dynamic fault detection and diagnosis (FDD) methods applicable to subcritical and transcritical refrigerating cycles. The researchers utilized virtual sensors generated from low-cost sensors to identify faulty behavior. They observed that existing low-cost static FDD methods could detect multiple transient faults even in the presence of secondary system faults. The study highlighted the versatility of this approach for both subcritical and transcritical refrigerating systems. Evaluation of the potential advantages of dynamic FDD over static methods, through simulation and experimentation, revealed minimal benefits. The findings indicated that dynamic FDD algorithms offered limited advantages, the increase in the number of sensors was constrained, and associated costs would rise.

Taheri-Garavand et al. [3] introduced an innovative, intelligent system for fault diagnosis and condition monitoring, employing infrared thermal images to categorize various states of the evaporator. The system addresses six distinct evaporator faults, including clogging of evaporator tubes, clogging of evaporator fins, loose connections between fins and tubes, evaporator cover failure, refrigerant leakage, and normal conditions. The proposed methodology involves thermal image acquisition, image preprocessing, image processing, two-dimensional discrete wavelet transform (2D-DWT) application, feature extraction, feature selection using genetic algorithms, and classification. Utilizing 2D-DWT, thermal images were decomposed, and statistical texture features were extracted from the original photos, enhancing the performance of a neural network classifier. Based on the feature selection process, the optimized neural network topology was determined to be 16-6-6. Test results indicated the system's efficacy for intelligent condition monitoring and fault diagnosis of evaporators. Wang et al. [4] explored fault detection techniques to enhance energy efficiency in refrigerators. Their method aimed to develop a fault detection approach with higher accuracies using a Bayesian network and principal component analysis. Principal component analysis decomposed average data into central component and residual subspaces, providing an efficient model for the Bayesian network. Evaluation of ASHRAE RP-1043 experimental data demonstrated significant accuracy improvement, particularly at mild failure levels (up to 43%), such as condenser fouling. Bogdanovská et al. [5] analyzed failures in condensing refrigerator units using R134a and R404A refrigerants. They found that 30% of system failures were attributed to the condensing unit valve. Quality management tools and risk assessment methods were employed to address these issues. Pareto analysis and Lorenz curve identified crucial minor causes. Implementing technological process changes, informed by fault tree analysis related to valve mounting and the pipe-valve assembly procedure, led to a 40% reduction in defects in condensation and increased unit efficiency. Notably, valve problems in refrigerator condensing units were nearly halved.

Erdoğmuş et al. [6] highlighted the challenges of maintaining refrigerating systems and the consequential issues of delayed fault detection leading to increased time and costs. The study emphasized that such circumstances contribute to elevated energy consumption and operational expenses. To address these concerns, the authors advocated for a method of fault detection involving monitoring changes in pressure, temperature, and electricity consumption values and comparing them with standard operating conditions. Common failures in refrigerating systems, as outlined in the study, encompass compressor, condenser, evaporator, expansion valve, and fan failures, along with thermal issues, phase protection relay malfunctions, refrigerant charge discrepancies, connection problems, electric motor failure, and surface contamination in condenser-evaporator units. The study underscored that faults and failures within the refrigerating cycle directly impact the refrigerating performance coefficient. A crucial aspect emphasized was the necessity for traceable energy management models to identify and prevent failures. The design and implementation of such models were reported to reduce energy, maintenance, and repair costs while preventing long-term damage to the system. The study underscored the critical role of algorithm design for energy efficiency, incorporating factors like system management, alarm notification, and precise temperature control in creating traceable energy management models and control systems for refrigerating systems. Nasiri et al. [7] delved into intelligent troubleshooting processes for faults and equipment operations, which are vital for modern industries. The impact of refrigerating temperature on engine components was emphasized. The authors proposed a novel method for monitoring state changes and identifying potential failures, employing a deep convolutional neural network model with a specialized configuration. This model integrated a feature extraction method based on thermal images and growth steps. The model successfully detected gasket expansion, tube swelling, refrigerant leakage, and cap failures by processing direct heating thermal images. Evaluation results demonstrated superior performance to traditional programmatic intelligence methods, with a fault detection accuracy of 96.67%. This underscores the effectiveness of the proposed convolutional neural network model in monitoring enclosure conditions and intelligently troubleshooting faults across various operational scenarios.

Aktaş et al. [8] developed an intelligent fan management algorithm to mitigate pollution in the condenser. The algorithm dynamically adjusts fan speed based on the refrigerant temperature at the condenser outlet, concurrently determining the differential pressure on the air side of the condenser and the reverse running time of the fan. According to the researchers, this advanced algorithm effectively controls condenser surface contamination and fan energy consumption. Through the variable speed management of fans, the algorithm maintained the subcooling temperature of the refrigerating system at 5°C, resulting in an increased refrigerating capacity of 2075 W. This approach led to a noteworthy 3.55% enhancement in the system Coefficient of Performance (COP) value. The outcomes underscore the efficacy of the intelligent fan management algorithm in conserving energy and elevating the overall performance of the system. Cavazzini et al. [9] highlighted the significance of optimized control and maintenance strategies to facilitate the energy transition in buildings relying on renewable energy sources. Real-time analysis of monitoring systems within the heating and refrigerating hydraulic circuit enabled prompt detection of faults, issues, and performance degradations. The authors aimed to contribute to developing control strategies aligned with building and user needs. They proposed that such strategies could assist in prioritizing planned or unplanned maintenance activities based on economic factors and provide valuable evidence for building owners. In a 57-housing building implementation, the monitoring system demonstrated its ability to promptly detect heat pump and boiler failures through real-time data analysis. The system also effectively identified performance degradation in the heat pump, issuing a timely warning signal to prevent a complete failure. These findings highlight the advantages of incorporating monitoring systems into heating and refrigerating hydraulic circuits to guide diagnosis, maintenance, and management strategies, ultimately enhancing system performance.

Movahed et al. [10] highlighted the prevalent application of Fault Detection and Diagnosis (FDD) for averting potential failures arising from prolonged operation of heating, ventilation, and air conditioning (HVAC) systems. Recently, a growing interest has been in leveraging machine learning methods for FDD analysis in HVAC systems. The authors underscored the rarity of HVAC failures, making average operation data more abundant than faulty condition data, resulting in biased classification algorithms in existing literature. The study proposes a machine-learning approach for diagnosing faults in air-handling and rooftop units within HVAC systems to address this challenge. This methodology integrates principal component analysis (PCA), time series problem detection, and the random forest method. PCA effectively captures 95% of data variance with a single principal component, reducing the dataset size. The reported results indicate that the proposed model achieves an 89% classification accuracy for air handling units, 85% for PCA, and 79% for multi-zone air handling units. The primary goals of this model are to minimize false positives, address data imbalance, and monitor the normal state of equipment. By doing so, the study aims to enhance the accuracy and reliability of HVAC fault detection procedures.

Remote monitoring systems can improve operational efficiency by reducing energy costs, lowering maintenance costs, and supporting environmental sustainability. For this reason, they are widely used in various application areas, from industrial plants to commercial buildings, and investments are being made in these technologies to improve the performance of facilities.

In this study, it is aimed to,

- Determining whether a refrigerated display cabinet is operating at its energy label value by remote monitoring,
- Evaluation of remote monitoring in terms of carbon emissions,
- Revealing the effect of remote monitoring on energy efficiency,
- Presenting a new feasible energy labeling algorithm.

2. REFRIGERATING SYSTEM

Compressors, evaporator-condenser fans, lighting fixtures, and heaters are the leading electrical energy-consuming equipment in refrigerated display cabinets (RDC). The refrigerators are managed using the information received from temperature and pressure sensors with the help of a digital controller. The set temperature value is the target temperature value for cold food storage. The differential temperature value indicates the temperature value at which the compressor will restart when the compressor is stopped after reaching the set temperature. Defrost eliminates icing/snow formation on the evaporator side of the refrigerators. In RDCs, the refrigerating function active state (compressor, evaporator-condenser fans running), the refrigerating function inactive state, and the defrosting state (compressor not running-condenser fans not running-evaporator fans running) are repeated continuously in a cyclic manner. To monitor the energy performance of energy-consuming equipment in refrigerators in remote monitoring systems, current, voltage, frequency, and power information can be obtained, and data can be recorded every minute with the help of an energy analyzer. The compressor, one of the critical equipment of the refrigerating system, is the most energy-consuming. Energy consumption can be reduced with improvements in the efficiency of the compressor [11].

On March 1, 2021, energy labeling became mandatory for refrigerated display cabinets placed on the market in the European Union, and energy labeling was classified from A to G. With this application, refrigerators are classified according to their efficiency. Figure 1 shows a sample energy label of an E-class refrigerator.

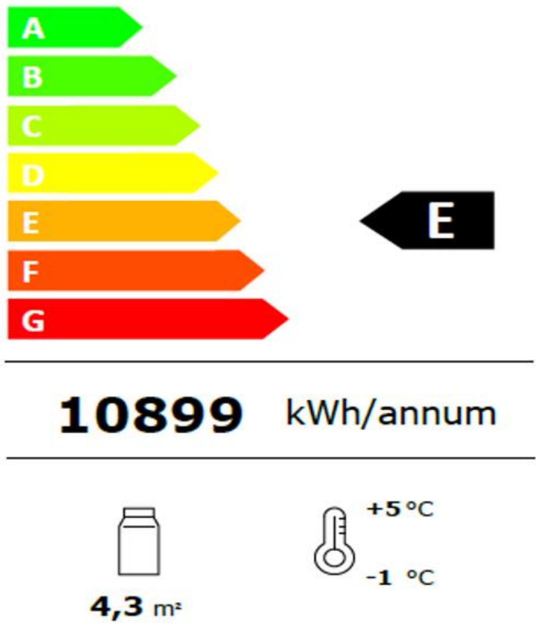

Figure 1. *Energy label for 2500 module plug/play open type vertical refrigerator with R290 refrigerant*

2.1. Experimental Test Procedure

Refrigerated display cabinets are tested in test rooms according to TS EN ISO 23953-2:2017 standard. Testing activities are done by automating the test room under standard climate class-3 conditions at 25°C temperature and 60% relative humidity. The test chamber's ceiling and two side walls must be thermally insulated and covered with a metal layer. The lighting in the room is provided using fluorescent lights with a standard illumination level of 600±100 lux at a height of one meter from the floor. An air conditioning unit and automation system arrange the desired temperature, relative humidity, and air speed in the test room according to these standards. The air speed in the test chambers where the refrigerators are tested is 0.1-0.2 m /s, and the airflow is directed from the blowing wall of the test room towards the direction of the suction wall. While testing activities are carried out in the test rooms, data is collected and recorded every minute during the 24-hour test period. Energy consumption of energy-consuming equipment in the refrigerator (compressor, heater, fan, lighting, etc.) is measured with the help of an energy analyzer. The flow rate of the refrigerator circulating in the circuit is determined using a flowmeter. Test packages (M-packs) with equivalent properties are used in the test room and placed in the refrigerator instead of the product. Each temperature channel measures its temperature from the center core point on the M-packages. Refrigerating air curtain supply and suction air speed values are measured with the help of an anemometer placed at these points. During the test activities, the standard carries out energy performance tests, with the refrigerator's lighting on and 12 hours off, and 12 hours' curtain open and 12 hours' curtain closed for open type refrigerators. Measurements should be made with an accuracy of ±0.5°C for temperature, ±1.5% for relative humidity, and ±0.5% for power consumption. The amount of radiation and the temperature change occurring through radiation caused by the walls and ceiling of the test room should not exceed ±2°C, which is the air temperature value recorded at the same level. Temperature and relative humidity tolerances should be ±1°C and ± 3% respectively [12]. Figure 2 shows the schematic representation of the refrigerated display cabinet, and Figure 3 shows the photograph of the tested refrigerator.

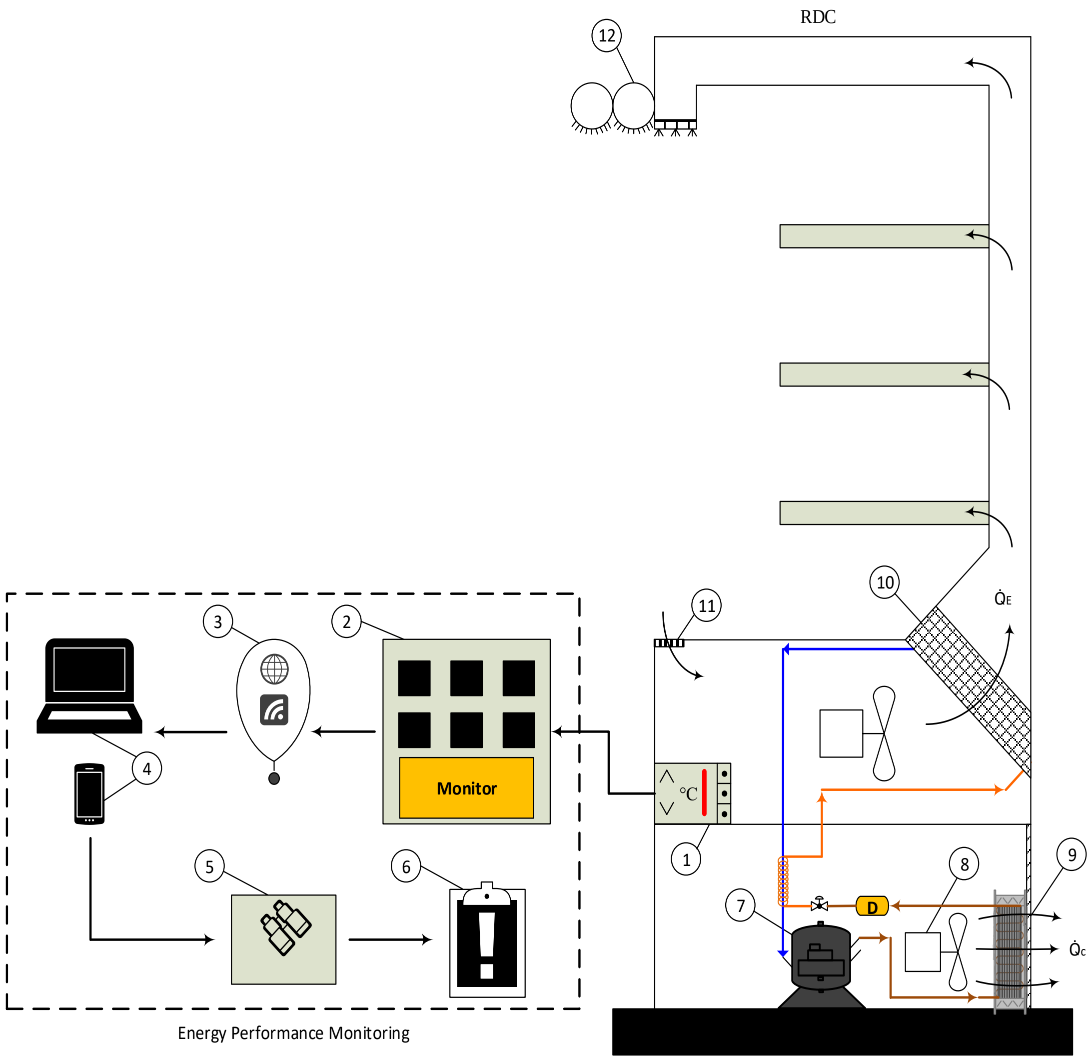

Figure 2. *Schematic representation of a refrigerated display cabinet. 1: temperature meter, 2: monitor, 3: Wi-Fi, 4: electronic devices, 5: performance monitoring, 6: warning, 7: compressor, 8: fan, 9: condenser, 10: evaporator, 11: return air vent, 12: night curtain*

Figure 3. *Photograph of the tested refrigerated display cabinet*

3. DETERMINATION OF ENERGY LABEL

It is the ratio of annual energy (*AE*) consumption of refrigerators to standard annual energy (*SAE*) consumption and energy efficiency index (*EEI*) value, and it is calculated as in Equation (1). This computed value determines the energy class in RDCs. The *EEI* value found is classified according to the letters corresponding to specific values within the scope of the Commission Delegated Regulation (EU) 2019/2018 standard. The *EEI* value may vary depending on the refrigerator's energy consumption. The *EEI* of a refrigerator with low energy consumption is also low in value. A low *EEI* value means the energy label class is high. For this reason, commercial business owners demand refrigerators with low energy consumption *EEI* value and high energy label class

$$EEI=\frac{AE}{SAE} \tag{1}$$

where, *AE*, the daily energy consumption amount, is calculated as in Equation (2) [13]:

$$AE=365\cdot E_{daily} \tag{2}$$

$$E_{daily}=\begin{bmatrix}\left(\dot{W}_{compressor}\cdot t_{compressor}\right)+\left(\dot{W}_{evaporator\,fan}\cdot t_{evaporator\,fan}\right)+\left(\dot{W}_{condenser\,fan}\cdot t_{condenser\,fan}\right)+\\ \left(\dot{W}_{heater}\cdot t_{heater}\right)+\left(\dot{W}_{led}\cdot t_{led}\right)\end{bmatrix}. \tag{3}$$

The *SAE* is calculated with the Equation (4) [13]:

$$SAE=365\cdot P\cdot(M+NY)\cdot C \quad (4)$$

To find *the SAE* value in Equation (4), the coefficients in the Regulation of the European Parliament and of Council were determined. According to regulation, M =9.1, N =9.1, C =1.15 and P =1.1 for RDCs [14]. The Y value should be calculated as the sum of the exposed areas in m^2 of all compartments of the refrigerating device in the same temperature class.

Table 1 contains the label data of the tested refrigerated display cabinet, and Table 2 includes information on the equipment in the refrigerator. The daily energy consumption of the tested refrigerator was calculated in line with the given equations. According to the calculations based on the total input power, the daily energy consumption of the refrigerator is calculated as 29.86 kWh.

Table 1. *Label data for the tested refrigerated display cabinet*

Parameters	**Values**
Refrigerant	R290
Thermostat	0°C / 2°C
Defrost time	6 x 15 minutes / 1 day
Compressor	0.6 kW x 2 pcs
Condenser	2 kW x 2 pcs
Evaporator	2.8 kW
Condenser fan	1400 rpm, 13 W x 6 pcs
Evaporator fan	1400 rpm, 13 W x 4 pcs
Evaporator fans' operating time	24 hours/day
Condenser fans' operating time	14 hours/day
Working time of the resistance in the defrost container	14.63 hours/day
PTC resistance input power in the defrost container	350 W x 2 pcs

Table 2. *Information about the equipment in the tested refrigerated display cabinet*

Equipment	**Piece**	**Working time (hour/day)**	**Total input power (W)**	**Total consumption (kWh/day)**
Compressor	2	14	1200	16.8
Evaporator fans	4	24	52	1.248
Condenser fans	6	14	78	1.092
Internal lighting	2	12	40	0.48
PTC resistance	1	14.63	700	10.241
Total	**15**	**78.63**	**2070**	**29.86**

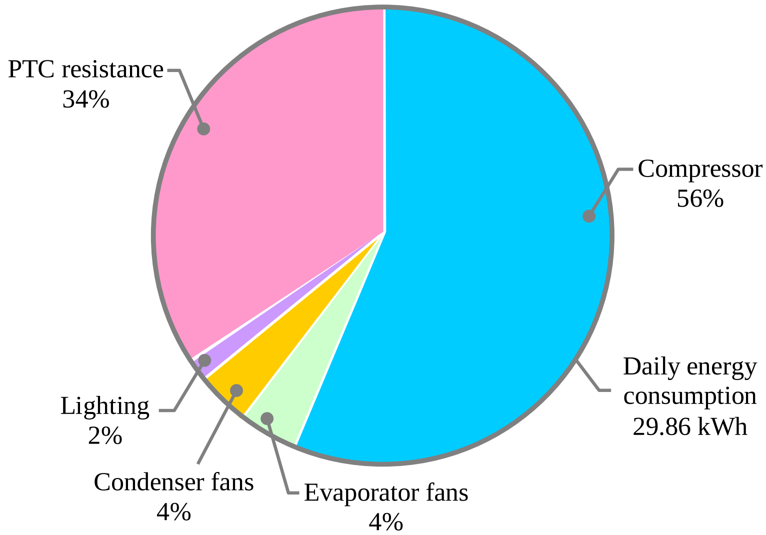

Figure 4. *Energy consumption graph of equipment of tested refrigerator*

The energy consumption rates of the equipment in this refrigerator, whose daily energy consumption is 29.86 kWh, are given in Figure 4. According to this graph, the compressor is the equipment that consumes the most energy at 56%, and the compressor is PTC resistance at 34% (Positive Temperature Coefficient). The evaporator and condenser fans follow resistance at 8% and lighting at 2%. Situations that cause the compressor and PTC resistance, which are the most energy-consuming equipment, to consume too much energy, and preventing these situations are essential issues.

3.1. Situations That Cause the Compressor to Work Hard

- Irregular air flow due to the breakage of the honeycomb, thus increasing the refrigerating load,
- Since the refrigerator is placed too close to the wall, the condenser is challenging to remove waste heat,
- Fouling of the condenser and evaporator,
- Placing the products hot in the refrigerator so that the compressor works more than necessary to meet the desired refrigerating load,
- Placing the products in the suction vent of the refrigerator so that the air to be refrigerated is insufficient,
- Lack of sufficient level of refrigerator in the refrigerating system due to refrigerator leaks,
- High indoor temperature and relative humidity in working environment conditions,
- Situations such as deterioration of the air curtain cause the compressor to work excessively.

3.2. Situations That Cause PTC Resistances to Work Hard

- Disruption of airflow (non-homogeneous airflow) during the drying process of antibacterial fabrics with condenser airflow,
- Antibacterial fabrics wear out,
- Deterioration of the airflow structure in the air curtain, that is, the thermal protection provided,
- Situations such as operating the refrigerator with high temperature and relative humidity conditions cause the PTC resistance to work excessively.

The CO_2 emissions caused by the energy consumption are a large part of the total CO_2 emissions [15]. Therefore, the measurement of carbon emissions is an important issue. With the proposed remote monitoring system, energy consumption can be monitored, and the amount of carbon emission caused using the refrigerator can be calculated depending on the consumption. Türkiye's Electricity Production and Electricity Consumption Point Emission Factors, which represent the amounts of greenhouse gas emissions released per unit of net electricity production and unit electricity consumption, have been calculated by the

Republic of Türkiye Ministry of Energy and Natural Resources. As a result of these calculations, it was found that an average of 0.440 tons of CO_2 equivalent greenhouse gas emissions were released per 1 MWh (unit) of net electricity production in Türkiye. This factor can be used in various areas, such as carbon footprint calculations and calculation of greenhouse gas reduction amounts [16]. With this study, carbon emissions will be kept under control thanks to the remote monitoring system in the refrigerator, whose daily energy consumption is calculated as 29.86 kWh, and greenhouse gas emissions equivalent to 13.13 $kgCO_2$ per day and 4795.5 $kgCO_2$ per year will be prevented.

4. ENERGY PERFORMANCE LABEL DETERMINATION ALGORITHM

In this study, an energy performance label determination algorithm was developed to determine the energy label according to the energy consumption data of a refrigerator used for display purposes, and the algorithm flow diagram is given in Figure 5. This algorithm records the compressor power, evaporator fan power, condenser fan power, PTC resistance power, and lighting power of the refrigerator, depending on time. The refrigerator data was measured according to the "TS EN ISO 23953-2:2017 Refrigerated Display Cabinets - Part 2: Classification, Rules and Test Conditions" standard, and the data were recorded at one-minute intervals. There are two-time counters in the energy performance label class determination algorithm. $Counter_1$ is used to evaluate daily data, and $Counter_2$ is used to assess annual data. At the end of 24 hours, the daily energy consumption of the refrigerator, E_g, is calculated with Equation (3). Then, a one-year time evaluation is performed with $Counter_2$.

At the end of 24 hours, the daily energy consumption of the refrigerator AE_d is calculated for a day. In this case, E_d and AE_d are equal for one day. For refrigerated display cabinets *AE*, *SAE*, and *EEI* values used in energy label classification are calculated with the "Commission Delegated Regulation (EU) 2019/2018 Additional Regulation (EU) No. 2017/1369 of the European Parliament and Council on about Energy Labelling of Refrigerating Appliances with A Direct Sales Function". Standard daily energy consumption SAE_d can be found by dividing the normal annual energy consumption value by 365. After this data is obtained, the daily energy efficiency index EEI_d is calculated. Then, EEI_{label_d} is the daily ratio of the daily energy efficiency index and the label value. It is questioned whether the ratio is higher than this value. If the daily energy efficiency index EEI_d is low, it informs the user by giving a typical power consumption warning. If the EEI_d value is higher than the calculated label value, the PTC resistance's daily energy consumption E_{PTC_d} data is first analyzed. Suppose this value is more than the daily $E_{PTC\_nom\_d}$ value of the refrigerator. In that case, the algorithm warns the user that PTC is working too much, antibacterial fabrics, if any, should be checked, airflow in the condenser and refrigerator should be checked, and air leaks (infiltration) should be checked, respectively. These types of warnings require the user to take action by considering them. After these warnings, the algorithm returns to the measurement block to process the following data. If the daily energy consumption of the PTC resistance is less than the nominal value E_{PTC_d}, the algorithm evaluates the daily energy consumption of compressor E_{com_d}. If the daily energy consumption value of the refrigerator compressor E_{com_g} is less than the nominal daily consumption value $E_{com\_nom\_d}$, the algorithm informs the user with a standard compressor power consumption warning. If the E_{com_d} value is greater than the daily consumption value, the compressor is working more than necessary; the airflow should be checked, condenser and evaporator pollution should be checked, it should be checked whether the outdoor temperature is above 25°C and 60% of the relative humidity, the connection of the refrigerating cabinet to the wall. It warns that the distance should be checked. The energy performance label class determination algorithm also performs daily label evaluation operations in annual control blocks. Thus, thanks to the algorithm, it can query the correct operating conditions when using the refrigerator. This energy performance label class determination algorithm aims to protect the energy label values of refrigerators. In this way, the energy consumption of refrigerators is reduced, and energy efficiency is brought closer to the targeted data. The controlled refrigerated display cabinet can control energy costs and carbon emissions.

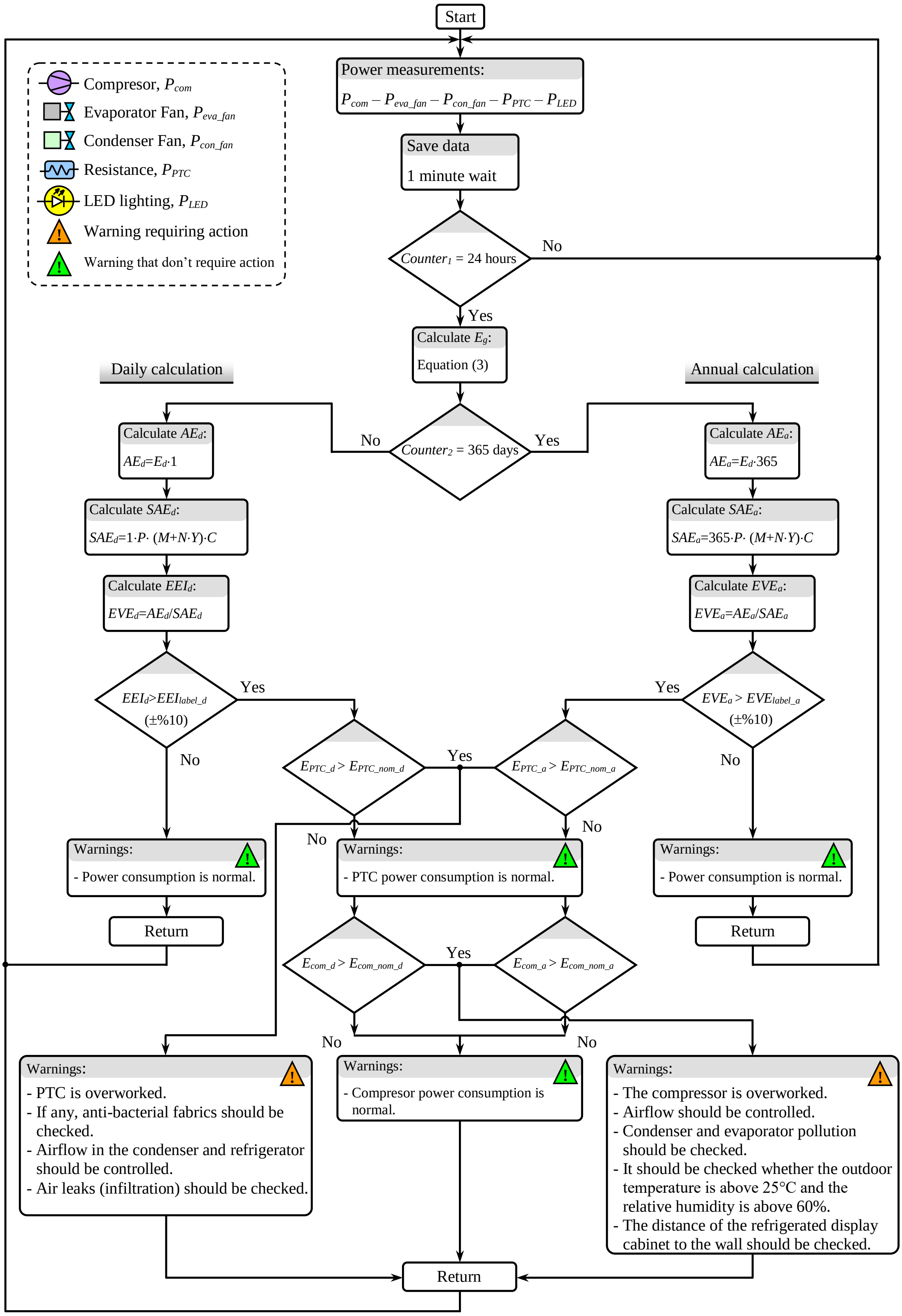

Figure 5. *Energy performance label determination algorithm of the refrigerated display cabinet*

In case the refrigerator exceeds the energy label value, the criteria that increase the energy consumption given in the warnings headings in Figure 5 should be checked one by one. After the controls, maintenance, and repair, the energy consumption will be monitored and the refrigerator will operate at the label value.

4.1. Previous Works

Lin et al. [17] developed a low-cost and rapid-installation data monitoring and analysis system for refrigerating system. Energy consumption, coefficient of performance, operating conditions, failure information of refrigerating equipment were calculated and determined. This system was helped staff to remotely monitor the refrigerating system and identify problems in the plant to improve the energy efficiency of the system. Momeni et al. [18] implemented a real-time data monitoring system based on IoT technology in a vapor compression refrigerating cycle. As a result of the energy analysis, the total refrigerating capacity and power consumption during the day were found to be 489.5 kWh and 250.9 kWh, respectively. From midnight to peak hours, refrigerating capacity increased by 63% and power consumption by 98%. Erten et al. [19] designed a new condensation pan that improves drying efficiency and energy efficiency by directing the air from the condenser to the fabrics. The operating time of the electrical resistance in the new design was reduced by 44.8% compared to the operating time of the electrical resistance in the existing design, and the condensation pan in the new design was found to have 5.9% less CO_2 emissions than the existing design condensation pan.

5. CONCLUSIONS AND DISCUSSION

Open-type refrigerated display cabinets are widely used in supermarkets to display products in an impressive way and, at the same time, to preserve them optimally. Open-type refrigerated display cabinets, which are widely used because they provide easy access to products, consume a lot of energy because they come into contact with hot ambient air. The energy labels of these cabinets include energy consumption data provided by the manufacturers, but these data are generally obtained under standard test conditions. Determining how much of the performance stated on the energy label is achieved in real application environments and long-term use.

This study examines the impact of remote monitoring and control on energy efficiency in refrigerating systems and presents an innovative approach to determining the energy performance label for refrigerated display cabinets. The basic components of the cabin; compressor, evaporator fan, condenser fan, PTC resistance, and lighting units are analyzed based on daily energy consumption data, and a special algorithm is used. The algorithm, which was developed to keep these parameters under control because of examining the parameters that cause the refrigerator to consume too much energy, presents daily and annual energy consumption data to the user while determining the energy performance label class and, at the same time detects potential problems and notifies them with warning messages. This system, which offers monitoring and control via an internet connection, will prevent unwanted product losses by giving the necessary warnings. With this algorithm, which alerts the refrigerator, when necessary, malfunctions that may occur in the refrigerating system will be prevented, and these situations will be monitored. This method will lead to a reduction in carbon emissions, energy consumption, and energy costs.

This method aims to check whether the refrigerating cabinets meet the energy consumption values specified by the manufacturer under actual operating conditions. This is a crucial step to optimize energy consumption and increase environmental sustainability. This system, which will enable remote monitoring of refrigerators, can be applied to all refrigerators. The ultimate aim of this system is to monitor possible excess energy consumption and to notify the increased consumption with a warning. This method can be applied to all refrigerators with known energy labels to monitor energy consumption and provide efficiency. With this method, carbon emissions can be monitored indirectly by monitoring energy consumption. This monitoring system will also limit the increase in carbon emissions with the warnings it will give.

Additionally, this study supports the use of low-carbon energy by contributing to the energy efficiency targets set in the 28th Conference of the Parties (COP 28) agreement. Reducing energy consumption can be part of global efforts towards a sustainable future.

ABBREVIATIONS

FDD	Fault detection and diagnosis
COP	Coefficient of performance
HVAC	Heating, ventilation, and air conditioning
IoT	Internet-of-Things
PCA	Principal component analysis
RDC	Refrigerated display cabinet
PTC	Positive temperature coefficient

NOMENCLATURE

E_{daily}	Daily energy consumption, kWh
$\dot{W}_{evaporator\ fan}$	Evaporator fan power, kW
$\dot{W}_{heater}$	Heater power, kW
$\dot{W}_{compresor}$	Compressor power, kW
$\dot{W}_{condenser\ fan}$	Condenser fan power, kW
$\dot{W}_{led}$	LED lighting power, kW
$t_{evaporator\ fan}$	Evaporator fan operating time, hours
t_{heater}	Heater operating time, hours
$t_{compresor}$	Compressor operating time, hours
$t_{condenser\ fan}$	Condenser fan operating time, hours
t_{led}	LED lighting operating time, hours
EEI	Energy efficiency index
AE	Annual energy consumption, kWh/year
SAE	Standard annual energy consumption, kWh/year

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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