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NATIONAL PROGRAM ON REFRIGERATION LEAK PREVENTION AND CONTROL IN VENEZUELA

Sustainable and climate-friendly phase-out of ozone-depleting substances (SPODS)

Implemented by:

VENACOR
CAMARA VENEZOLANA DE LA REFRIGERACIÓN, VENTILACIÓN, AIRE ACONDICIONADO Y AFINES

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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UNIDO Contract N°: 3000075362

FINAL REPORT

LEAK PREVENTION PROGRAM

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The project *Sustainable and climate-friendly Phase out of Ozone Depleting Substances (SPODS)* assists selected Latin American and Caribbean countries with their transformation processes in fulfilling their obligations under the Montreal Protocol related to the phase-out of ozone depleting substances and current HFC mitigation.

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The Board of Directors of **VENACOR,** the Venezuelan association of ventilation, air conditioning, and refrigeration industries, expresses its gratitude to the German agency **GIZ** for the trust placed in us to carry out sustainability projects for the refrigeration and air conditioning (RAC) sector in Venezuela within the framework of the program "Sustainable and climate-friendly phase-out of ozone-depleting substances" (SPODS).

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1. REFRIGERANT LEAK PREVENTION PROGRAM

1.1 PROGRAM BACKGROUND

The Kigali Amendment to the Montreal Protocol in October 2016 added hydrofluorocarbons (HFCs) to the reduction process. Therefore, countries are encouraged to undertake early action and develop long-term strategies to implement sustainable solutions. Many countries in Latin America and the Caribbean intend to ratify and implement the Kigali Amendment but require better access to technologies and technical and financial support to adopt and master them.

Europe is a world leader in strict regulations to reduce HFCs and has the know-how on alternative technologies and skilled maintenance technicians. The European Union (EU) wants effectively to demonstrate its willingness to support Latin American and Caribbean countries financially and technically in fulfilling their future obligations under the Montreal Protocol. In 2016 the EU adopted the financing decision for the project "Sustainable and climate-friendly phase-out of ozone-depleting substances" to demonstrate the feasibility of technical alternatives. The project activities intend to build alliances among Latin American and Caribbean countries on global HFCs mitigation actions. They aim to assist seven countries in enhancing their capacity to fulfill their obligations under the Montreal Protocol and promote climate-friendly solutions for phasing out ozone-depleting substances.

UNIDO will play a significant role in achieving the SPODS objectives through capacity building, training, and know-how transfer and will promote an inclusive and sustainable industrial development (ISID) in Grenada, México, and Venezuela (Bolivarian Republic).

The main goal of the UNIDO project is to find the compromise between local capacities and cost-efficient technology options with the least negative environmental impact. The activities are designed to support national strategies on ozone and climate protection in three countries based on cooling solutions which have proven effective. The program will help the participant countries transition to energy-efficient climate-friendly systems with natural refrigerants or refrigerants with low global warming potential (GWP). UNIDO will also provide assistance to develop relevant standards and good practices.

Furthermore, the project seeks to address some of the current barriers to the uptake of green technologies, such as the lack of trained maintenance technicians, issues associated with refrigerant availability and the end-of-life (EoL) phase, and unfamiliarity with alternative technologies.

Venezuela (Bolivarian Republic) adopted the five lines of actions in the SPODS and UNIDO projects:

1) Developing national strategies to mitigate the impact of HFCs
2) Developing a strategy for infrastructure to provide low-GWP refrigerants
3) Developing a strategy for adequate handling at the EoL phase
4) Training component
5) Identification and promotion of large-scale pilot projects in the RAC sector

The first line of action involves the following activities:

1.1. Extension of the existing program on refrigerant leak prevention and control (Zero-Leak) targeting large end users to include HFC

1.2. Extension of the ongoing training program on good practices in refrigeration to include HFC

1.2 PROGRAM OBJECTIVE

The project is based on the existing national refrigerant leak prevention program (Zero-Leak). It focuses on supermarkets and convenience stores since food retailers' refrigeration systems are characterized by large refrigerant charge volume and potentially high leak rates.

The project will:

a) Promote fluorinated refrigerants leak prevention in RAC systems through national regulations (COVENIN standards) on refrigerants.

b) In collaboration with the participant companies, develop a refrigerant leak monitoring system based on quantitative operating indicators.

c) Establish relationships between the refrigerant leak prevention program, the energy efficiency of the refrigeration, equivalent carbon emissions reduction, refrigerant emissions, and energy consumption reduction.

d) Extend the ongoing training program on good practices in refrigeration to include HFCs.

1.3 PRELIMINARY PHASE

The national program on refrigeration leak prevention and control was developed based on the Zero-Leak program's methods and lessons learned. The idea was to expand the project scope to cover more stores belonging to the food distribution and retail chains that participated in the Zero-Leak program and were willing to participate further.

The Zero-Leak pilot projects explored the capabilities and weaknesses of refrigeration end users and technicians responsible for maintaining the refrigeration systems. It analyzed their structure and work dynamics to develop and implement good practices.

The expected outcome is to achieve a balance between refrigeration end user and maintenance technicians to optimize the refrigeration system management by improving the communication efficiency to strengthen the human resources. The synergy created by refrigeration end users aware of the quality requirements and maintenance technicians trained to put their knowledge into practice will ensure well-functioning refrigeration systems.

The final product is a management plan for each participating facility developed by the end user team and better maintenance practices with clear goals associated with quality requirements.

The objective of the Zero-Leak program was to reduce refrigerant consumption. In this new phase, the national program on refrigeration leak prevention and control seeks to replicate the model on a larger scale. Besides, it intends to eliminate ODS. The components cover refrigerant consumption, energy consumption, energy efficiency, and CO2 emissions.

The program execution dynamics tried to raise participants' awareness of their responsibility when handling refrigerants by strengthening their knowledge and skills and helping them understand their impact on the climate and the mitigation options.

The evolution of the HCFC phase-out plan and the implementation of the Zero-Leak program resulted in the development of a national standard for detection and control of refrigerant leaks in RAC systems, that was the guide for the execution of the national program on refrigeration leak prevention and control. This report describes the actions associated with the methodology of the leak prevention program.

1.4 PROGRAM METHODOLOGY

The leak prevention program methodology is mainly based on the COVENIN draft standard "Detection and Control of Refrigerant Leaks in RAC Systems" (see annex I). COVENIN is a national system of voluntary quality standards for many applications and sectors, like manufacturing and maintenance. In annex II, you will find the checklist based on the standard used to gather information and assess the companies according to the standard requirements.

The methodology to calculate the coefficient of performance (COP) of a refrigerant system is a complex task when working with high-cooling capacity systems with multiple compression and expansion devices under highly variable and demanding operating conditions. Section 2 describes the methodology used in the leak prevention program in Venezuela.

Power consumption and other variables to calculate the COP of the refrigeration systems were measured twice during the project, at the beginning and the end of the monitoring period. We took measurements manually at the points where we could not obtain the information through the rack control system. On each occasion, records were collected for several hours in a single day.

PROGRAM IMPLEMENTATION

Program participants (refrigeration end users and maintenance service providers) were evaluated to verify that they meet the minimum requirements to ensure leak control in the refrigeration systems.

Each participant facility has a company representative and maintenance technicians responsible for maintaining the refrigeration system, either as in-house staff or external contractors. Each part has some degree of responsibility in leak control. A successful leak control depends on everyone doing their part and an effective communication between them. The leak prevention program intends to establish a balance between the refrigeration end user and the maintenance technicians. The projects in each facility start with an assessment of the project actors using the checklist in annex II.

The aspects assessed are described below:

a) ***Environmental awareness when using halogenated refrigerants***

Participants must understand the environmental risks associated with refrigeration systems based on halogenated refrigerants and the consequences of refrigerant release due to leaks or maintenance errors. Participants need to be aware of their role in the chain of hazardous substances and their responsibility to minimize the potential adverse effects.

b) ***Training of maintenance technicians***

Establish the technicians' training level on refrigeration and develop recommendations to update their knowledge and skills. Carry out workshops on good practices in refrigeration in the participant facilities.

c) ***Basic tools for maintenance and leak control***

Check tools, instruments, and devices used to service and maintained the refrigeration systems. Verify if they are suitable for ensuring good practices in refrigeration and leak control under the COVENIN draft standard for detection and control of refrigerant leaks in RAC systems.

d) ***Recommendations for leak control***

Refrigeration experts assessed the participant facilities according to the COVENIN draft standard for detection and control of refrigerant leaks in RAC systems and issued recommendations to end users and maintenance technicians for improving leak control.

e) ***Development of a maintenance management plan***

End users must be able to prepare a management plan to provide guidance to technicians on maintenance tasks and help monitor the facilities and improve leak control.

f) ***Refrigerant recovery and recycling***

Experts provided guidance to the participants on implementing on-site refrigerant recovery systems. Besides, they learned how to access the nearest available refrigerant reclaim facilities introduced by the National HCFC Phase-out Plan.

1.5 END USERS SELECTION

End users were selected based on the procedures established in the methodology design section in the inception report. Candidates were identified with the support of refrigeration maintenance contractors of VENACOR, which provided a list of food retailers with the required profile interested in the program. Candidates were supermarket and food retailers with refrigeration systems with at least 30 kg refrigerant capacity (because this is the sector with the highest refrigerant leak rate).

In the final selection stage, we contacted representatives of the selected companies' maintenance and infrastructure management departments. We explained the program objectives and benefits and asked for their participation. Afterward, candidates willing to join the program and begin a pilot project received the application form.

TABLE 1: *End users' selection and approval*

COMPANY / END USER	SECTOR	DESCRIPTION
JAMONES CURADOS JACUSA	Industrial refrigeration	Company dedicated to the elaboration of cured meat products
CENTRAL MADEIRENSE	Commercial refrigeration	Supermarket chain with 53 locations countrywide
MAKRO COMERCIALIZADORA	Commercial refrigeration	Dutch supermarket chain and wholesale food distributor with 37 locations country-wide
EXCELSIOR GAMA	Commercial refrigeration	Supermarket chain with 24 locations in the states of Caracas and Miranda

The goals of the awareness-raising meetings were successfully met. The managers of all the contacted companies agreed to apply. That was an essential step to start the project and move forward. We were ready to prepare the startup workshops.

TABLE 2: *End users' characteristics*

END USER	STORE IDENTIFICATION	System cooling capacity (TR)	Refrigerant charge (kg)
Sector Industrial Refrigeration			
JAMONES CURADOS JACUSA	N/A	3 × 15 1 × 4	3 × 120 kg 1 × 14 kg
Sector Commercial Refrigeration			
CENTRAL MADEIRENSE	Montalban supermarket	180	270
	Plaza las Americas supermarket	160	504

END USER	STORE IDENTIFICATION	System cooling capacity (TR)	Refrigerant charge (kg)
	Mariches distribution center	180	280
MAKRO COMERCIALIZADORA	Vargas supermarket	100	125
	Altos Mirandinos supermarket	102	153
EXCELSIOR GAMA	Santa Eduvigis supermarket	209	308
	La California supermarket	120	180

1.6 INDUCTION WORKSHOP

The program included several projects with specific characteristics and some shared aspects. The outcomes of the projects depend on the activities completed during each project. We also tried to identify shared aspects and establish patterns to compare results. Before the induction workshop, the first step was to develop the assessment criteria and procedures with the program team.

On Thursday, November 14, 2019, the Induction Workshop was held at the VENACOR headquarters. The workshop was hosted by the program experts and organized by VENACOR and FONDOIN.

Induction workshop content:

- Introduction
- Initial induction
- General aspects and applicable legal framework
- Background of the national program on refrigeration leak prevention and control
- Learned lessons
- Projects profile
- Expert/pilot project leader methodology
- Planning
- Inspections, measurements, recording, reporting
- Implementation of the COVENIN draft standard for detection and control of refrigerant leaks in RAC systems
- Expected outcome
- Q&A

The workshop was highly productive. It included VENACOR and FONDOIN representatives' presentations. The experts outlined their concerns and proposals and described technical aspects and criteria to optimize the project workflow and the systems' monitoring.

1.7 WORKSHOPS ON LEAK PREVENTION FOR END USERS

Once the end users were selected and the participant facilities confirmed, we scheduled the workshops. They were designed to provide guidance to supervisors and technicians (in companies using refrigeration and refrigeration maintenance service providers) responsible for the refrigeration system (management, operation, and maintenance). The content included the following aspects:

- Program objectives and methodology
- Good practices in refrigeration
- Legal framework: Decree 4.335: Regulatory standard for the control, consumption, production, import, export, and use of ozone-depleting substances
- COVENIN standard for refrigerant safe handling
- Pilot project development
- Inspection visits
- End users and maintenance providers functions and responsibilities
- Reporting requirements
- Follow-up visits
- Q&A

The workshops were led by the program Technical Coordinator. FONDOIN representatives and pilot project leaders were included as guest lecturers.

TABLE 3: *Dates and participants in the end users' start up workshops*

END USERS	DATE	PARTICIPANTS	MALE / FEMALE
JACUSA	11-11-2019	Plant manager. Maintenance manager. Refrigeration technicians. Refrigeration maintenance service provider.	5 / 3
CENTRAL MADEIRENSE	28-11-2019	National maintenance coordinator. Supermarket manager. Technical staff.	13 / 1
MAKRO DE VENEZUELA	03-12-2019	National maintenance manager. Expansion manager. Supermarket maintenance managers. Technical staff. Refrigeration maintenance Service provider.	9 / 2
EXCELSIOR GAMA	12-12-2019	Maintenance manager. Technical staff. Refrigeration maintenance service provider.	5 / 0

The program's technical coordinator opened the workshops describing the objectives in each pilot project stage. Then, the participants examined the COVENIN draft standard for detection and control of refrigerant leaks in RAC systems, which is the baseline to assess pilot projects in all stages (See annex I).

The workshops allowed for productive interactions between the experts and the maintenance technicians in each facility. Besides, we scheduled inspection visits and meetings to exchange information. At the end of the workshops, the participants could walk through the facility and see the refrigeration systems included in the project.

1.8 MONITORING PROGRESS

The monitoring phase of each pilot project was supposed to start with the acceptance of the end user's start up report. However, the lockdown measures to contain the COVID-19 pandemic coincided with the scheduled activities, and the initial monitoring had to be postponed.

After September 2020, the lockdown was eased. Meanwhile, monitoring activities were carried out with the assistance of the project leaders via email.

This situation was very complex, and some end users had difficulties proceeding with the project.

Makro Comercializadora dropped the project after the first contact and information gathering phase. They stopped responding to the requests. They received recommendations to control leaks, but they did not answer to the proposal. Given the lack of reply and since no agreement to start the activities was signed, the two pilot projects associated with Makro Comercializadora were canceled.

In March 2020, Central Madeirense decided to turn off the refrigeration rack in the Mariches distribution center and cancel the pilot project due to the demand reduction triggered by the COVID-19 pandemic. Besides, the refrigeration systems in the selected supermarkets (Montalban and Plaza las Americas) had problems that jeopardized the project. Incidents in the refrigeration systems led to catastrophic leaks in both supermarkets. The first one was detected in Montalban at the beginning of the project, and the second one in Plaza las Americas immediately after the data was collected. The company repaired the systems, and the monitoring was restarted.

Excelsior Gama also had significant leaks during the project execution. Both supermarkets had valve failures that lead to leaks. The first one was repaired with no consequences. In the second accident, all the refrigerant was released. Both cases are described in section 3.

TABLE 4: *Project activities completed*

END USER	FACILITY	Inspection	Information gathering	Startup report	Monitoring	COP estimate
Sector Industrial Refrigeration						
JAMONES CURADOS JACUSA	N/A	✓	✓	✓	✓	✓
Sector Commercial Refrigeration						
CENTRAL MADEIRENSE	Montalban supermarket	✓	✓	✓	✓	✗
	Supermarket Plaza las Americas	✓	✓	✓	✓	✓
	Mariches distribution center	✓	✓	✓	✗	✗
MAKRO COMERCIALIZADORA	Vargas supermarket	✓	90%	✓	✗	✗
	Altos Mirandinos supermarket	✓	90%	✓	✗	✗
EXCELSIOR GAMA	Santa Eduvigis supermarket	✓	✓	✓	✓	✓
	La California supermarket	✓	✓	✓	✓	✗

1.9 OUTCOMES

The project was faced with challenges and obstacles along the way due to the COVID-19 restrictions. Planned activities designed to help maintenance technicians with the leak prevention and control activities were canceled or put on hold. The COVID-19 lockdown severely affected the projects' activities, particularly the implementation of the recommendations and the follow-up visits.

LEAK PREVENTION

The outcomes were varied, from overall leakage reduction in some cases to unexpected high leaks. This pattern is typical during transition periods while the participants adopt measures to comply with the relevant standards.

The refrigeration systems under the program's scope are large systems with high cooling capacity. It takes time to amend the maintenance plans and acquire the infrastructure to improve leak control. Besides, the selected leak prevention and detection methods need to be implemented. Very often, the companies need new control devices and appropriate training.

The projects included in this report have mostly passed through the first phase and made some progress towards implementation, but no investment in control devices has been made for the time being. The unstable economic situation in Venezuela and the pandemic's impact have probably acted as barriers to the projects' implementation. However, we know that companies and organizations need time until ideas mature.

In all the projects, protocols, and procedures followed by the companies to prevent leaks before the program were ineffective and did not comply with the requirements of the standard for detection and control of refrigerant leaks in RAC systems:

- Daily visual inspections of the systems to verify new features and correct operation were considered sufficient to identify possible leaks without the support of a detection system, reducing the possibility of leak early detection.
- Leak detectors were not used regularly, even when available. They were merely used to confirm leaks detected during visual inspections or to discard porosity in welds and leaks in threaded connections after a repair service—but soapy water was the preferred method.
- Most refrigeration systems had significant leakage problems. It was impossible to fix them without affecting refrigeration production. The leaks kept getting bigger until the companies decided to shut down the systems and fix the leaks. Only Excelsior Gama repaired the leaks without shutting down the refrigeration system.

During the project execution stage, the maintenance departments analyzed the benefits of complying with the regulations and recommendations. They implemented the experts' proposals to the extent of their possibilities.

Leak rates in all systems at the beginning of the project were high. Some systems had problems even during the project implementation. Maintenance managers had no other choice than implement definitive solutions to go back to normal operation. All participant companies managed to control the leaks and reduce them substantially. The companies that decided to shut down the refrigeration systems and check every component to make the necessary repairs achieved the best results. Such a radical solution did not go without controversy. However, with refrigerators that are over 15 years old and have a high leak rate and recurrent failures, this approach turned out to be the most appropriate.

Jacusa found a significant number of leaks in the cold rooms and decided to shut them one at a time, inspect the circuit and detect and repair leaks. It was a long process, but the positive impact became visible at the end of the monitoring period.

Central Madeirense took the refrigerators out of service after the incidents and fully repaired them. The tasks were completed with sufficient time to follow the good practices in refrigeration and achieve positive results.

Table 5 shows the percentage of reduction in each facility. We can observe that the outcomes differ. The Central Madeirense supermarkets obtained the most significant reductions. The supermarket in Montalban achieved the zero-leak goal. Jacusa achieved different results, but refrigerant consumption in 2020 dropped on average by 42%. Finally, refrigerant consumption in the Excelsior Gama chain raised.

TABLE 5: *Refrigerant leaks in the monitored refrigeration systems*

END USER	FACILITY	2019 LEAKS	2020 LEAKS	LEAK VARIATION
Industrial Refrigeration				
JAMONES CURADOS JACUSA	NA	585	338	⇩ **– 42,2%**
Commercial Refrigeration				
CENTRAL MADEIRENSE	Montalban supermarket	1120	0	⇩ **– 100%**
	Plaza las Americas supermarket	392	12	⇩ **– 97%**
EXCELSIOR GAMA	Santa Eduvigis supermarket	194	522	⇧ **169%**
	La California supermarket	131	439	⇧ **235%**

In general, all participants reduced leaks by the end of the monitoring period. The reduction percentages can be used to quantify the participants' performance, i.e., as effectivity indicators to assess the participants' results and determine if they have met the program objectives and implement the leak control procedures. Regardless of the particular outcome, every participant deserves recognition for their willingness to accept the challenge, put their skills into practice, and make efforts to implement the recommendations.

LEGISLATIVE FRAMEWORK

All persons handling halogenated refrigerants in Venezuela must hold the authorization to handle hazardous substances, materials, and waste and be enrolled in the *Register of environmental damaging activities* (RACDA in Spanish). This is a compliance certificate that proves that an individual has the technical competence and basic tools to handle hazardous substances safely.

First, we determined the situation in the participant facilities:

JACUSA: Maintenance activities are carried out with the support of a maintenance contractor, without certified personnel. They are not enrolled in the RACDA. Both Jacusa and the maintenance service provider were unaware of the requirements. They will remedy the situation and comply with the legal requirements.

CENTRAL MADEIRENSE: In-house certified technicians carry out the maintenance activities. They are not enrolled in the RACDA, although they were aware of the requirement.

EXCELSIOR GAMA: A maintenance contractor carries out the maintenance activities. Therefore, the company does not need to be enrolled in the RACDA. Excelsior Gama only needs to verify that the maintenance contractor complies with the requirement.

In general, most participants were unaware of the environmental regulatory requirements. Only the refrigeration maintenance contractor Tecnonorte fully complies with the requirements.

TRAINING

Sufficiently trained staff improves the operational performance of any organization. Refrigeration technicians are no exception to this rule. The project assessed the expertise of the technicians in all participant companies. Having a certification is a good practice, and it is required by the environmental regulations in Venezuela. The project obviously sees it as a requirement, but also beyond that. It is a tool that the companies can use for their own benefit since certified technicians ensure adequate maintenance. Besides, certification is also a demonstration of social responsibility.

Companies need training today more than ever. In Venezuela, technical training needs are increasing due to the high staff turnover rate and talent drain. Training level in the participant companies was varied:

Jacusa needs to reinforce its training program for in-house and external maintenance technicians considering the number of refrigeration systems. Besides, the company must comply with the relevant regulations.

Central Madeirense has trained and certified technicians. They need training to maintain their skills and keep up-to-date to be able to face all maintenance challenges in the company.

Excelsior Gama works already with a qualified maintenance service provider. Still, in-house supervision staff would benefit from a certification.

In general, the training level is similar in all the participant companies. Central Madeirense is much better than the others when we compare the number of certified technicians.

TOOLS

Most participant companies already have the necessary basic tools and are adequately equipped. Some of them own the required tools, while others use the maintenance contractor's tools, equipment, and instruments. The most significant deficiency was related to refrigerant recovery and transfer according to the system charge capacity.

All participant companies received recommendations to improve the tools and equipment, but there were no significant improvements. Jacusa was the least equipped company, but also the one that improved the most. The main issue identified was that, for several reasons, some companies do not use some tools such as leak detectors or digital vacuum gauges, although they do have them.

IMPLEMENTATION OF THE RECOMMENDATIONS

End users received a report with recommendations to reduce refrigerant leaks reduction and implement the standard for detection and control of refrigerant leaks in RAC systems. The refrigeration systems of the companies were monitored during the project development to help them achieve their goals and record progress.

End users had the goal to improve the performance of the refrigerant systems and implement good leak prevention practices. Completing the necessary actions and making adjustments to achieve the goals required a high level of commitment and effort.

Project outcomes were mixed. Most companies managed to implement the recommendations related to maintenance management and leak repair. All issues were immediately addressed and resolved. Recommendations regarding permanent refrigerant leak detection were not implemented due to the investment costs involved. One company decided to migrate to a CO_2-based system and discarded the recommendation. The maintenance managers in the other companies will further consider the recommendation.

TABLE 6: *Summary of the implementation of the recommendations*

END USER	FACILITY	LEVEL OF IMPLEMEN-TATION	COP ESTIMATE
Industrial Refrigeration			
JAMONES CURADOS JACUSA	NA	70%	2,71
Commercial Refrigeration			
CENTRAL MADEIRENSE	Montalban supermarket	50%	×
	Plaza las Americas supermarket	50%	3,92
EXCELSIOR GAMA	Santa Eduvigis supermarket	55%	2,88
	La California supermarket	43%	×

The progress in the execution of the activities related to the implementation of the recommendation outlines the level of accomplishment in each company.

COEFFICIENT OF PERFORMANCE

The COP can be used to analyze performance variations as a result of refrigerant leaks. Section 2 describes the variables associated with the COP, the method used to calculate it, and how it can help to evaluate refrigeration systems.

Measurements should be taken during periods long enough to take into account variations due to operating conditions and thermal load. The measurement period should be as long as possible. It was not possible to install measurement tools in each facility. The best possible approach was to take measurements on specific days to monitor the parameters needed for the calculations.

Data was captured automatically and manually, depending on the options available for each refrigeration system. Electronic devices capable of capturing analog signals, transforming them into digital records, and transmitting them over the internet to a server for analysis were used to capture data automatically. We used two electronic devices. One temperature gauge with sensors located at six positions (compressor discharge, liquid line, low-temperature-suction, medium-temperature suction, high-temperature suction, and room temperature). The second device can measure voltage and current simultaneously. It has three sensors, one for each phase with clamps for the power cables.

The monitoring device was provided by the Venezuelan company and VENACOR member **Z&Z Ingenieros *(www.zzingenieros.com).*** Among other things, the company specializes in technology for the refrigeration sector. They agreed to support the program and were eager to demonstrate their products. The devices were specifically designed to meet the program's needs since Z&Z Ingenieros does not produce devices with multiple sensors or devices for measuring currents higher than 100A. They also provided training on using the device in one refrigeration system and gave support during the project implementation. VENACOR appreciates the valuable collaboration of Z&Z Ingenieros and its contribution to the program.

Manual measurements complemented the automated measurements. For example, condensers were measured manually because there were located farther away from the machine rooms. The pressure was also measured manually because all systems were already equipped with pressure control devices or had fixed pressure gauges to obtain the information easily.

The measurements were taken at each facility twice to confirm the information and fill the gaps. Afterward, we calculated the COP of the refrigeration systems and used it to confirm the measurements taken on the same day. It was impossible to find a correlation between COP and refrigerant leaks due to the impracticability to coordinate contractors and measurements teams with different response times and the unpredictable occurrence of leaks. Additionally, driving restrictions related to the pandemic added further complications.

We examined methodologies to use data to correlate the COP with the detected leaks. Since there are no permanent monitoring devices, the best solution is to take measurements after fixing the leaks. After the repair, the refrigeration system should be restarted, and measurements should be taken before charging the refrigerant. Then, after charging the refrigerant, measurements should be taken again until the system reaches a stable operating condition. The differences between one state and the other can be used to correlate the COP variation with the refrigerant amount in the system.

We were not able to put the methodology into practice, but we calculated theoretical estimates to correlate the refrigerant in the system and the COP of the refrigeration system. A refrigeration system works at maximum efficiency under specific conditions. Maintenance technicians should replicate this condition after charging the refrigerant as far as possible. Any deviation from this condition will reduce the COP.

One of the most sensitive variables that affects the COP is the refrigerant charge. The incidence is directly proportional to the amount of refrigerant within the refrigeration system. If we maintain stable operating conditions without changes in thermal load, any refrigerant leak will negatively affect the COP, reducing the expected efficiency of the refrigeration system and increasing the associated electrical consumption because the components must do more work to reach the selected temperature. Table 6 shows the COP obtained in each system.

FEEDBACK QUESTIONS FOR END USERS

In the final stage of the project, we developed feedback questions to incorporate the end users' perspective and gather direct information about their insights. The questions included three areas:

- project methodology and scope
- project implementation
- level of understanding and acceptance of the standard for detection and control of refrigerant leaks in RAC systems and training in good practices in refrigeration

Responses to the ***project methodology and scope*** reveal a positive reaction. Participants understand the project's activities and acknowledge that the project allowed them to learn aspects of maintenance management they did not know before.

66.7% of the participants agreed in the section ***benefits obtained*** that the leak prevention program implementation helped improve maintenance activities based on prevention. 33.3% stated that the project fulfilled their expectations. We can deduce that the expectations for improvement were not disappointed.

Maintenance managers and in-house technicians responsible for the refrigeration systems said the ***leak prevention project's impact*** was high. In contrast, company managers said it was null, and external maintenance technicians said it was low. In this regard, we can conclude that the program significantly impacted the target audience within the participant companies.

Questions about the ***interpretation of the standard for detection and control of refrigerant leaks*** indicate that a high percentage of the project participants read the standard. Two participants felt unsure about some aspects of the standard. When we asked them about the standard implementation, two participants commented that the standard is rigorous but viable and necessary. One participant qualified the standard as "appropriate" to prevent leaks. 100% of the participants accepted the standard. In general, the standard has gained widespread acceptance among the project participants.

Another analytical point in the feedback questions was ***the project execution***. All participants read and examined the technical recommendations, but 50% considered that the tasks proposed are not viable.

One participant company answered that the ***standard implementation helped reduce maintenance costs*** significantly. Another said that the costs reduction was not significant, while a third was not sure.

Participant companies commented that they ***improved the inspections to detect leaks and evaluated the status and operation of the refrigeration system key components as required in the standard*** for detection and control of refrigerant leaks in RAC systems.

Training and development of technical staff is a key aspect of the program. All participants are willing to make the necessary effort to have certified staff.

1.10 CONCLUSIONS

a) The program on refrigeration leak prevention and control in Venezuela included monitoring and coaching tasks in the participant companies (large refrigeration systems end users). The program acceptance was high among participants, particularly thanks to the program added value to the refrigeration systems maintenance quality and the cold chain management in the participant companies. The project helped complement and synchronize the needs and approaches of refrigeration end users and maintenance technicians.

b) The results reveal that the emissions estimates from the participating companies were placed too low. The data gathered during the projects confirmed that the actual emissions were higher than in the estimates.

c) The results confirm very high refrigerant emissions due to leaks in the refrigeration systems within food processing, distribution, and retail companies.

d) The use of a standard for detection and control of refrigerant leaks as a baseline proved very useful in achieving the program goals. Standard requirements provide a valuable basis for assessing maintenance quality. Therefore, the standard can be a valuable tool to promote and evaluate good practices in refrigeration and provide an objective ground to assess the performance of the technical teams.

e) Technicians' training level played a crucial role in achieving the project's objectives. Maintenance technical teams with a higher level of specific training on refrigeration systems achieved a positive outcome easier than others. This was particularly the case for maintenance teams with a certification for handling hazardous substances.

f) The COP is a good performance indicator for refrigeration systems. It can also help detect leaks since the COP is directly proportional to the refrigerant amount in the refrigeration circuit. When the system has a leak and the refrigeration amount decreases, the COP drops.

g) Refrigerant leaks are the main source of carbon emissions associated with refrigeration systems. In systems with high leak rates, such as the refrigeration systems included in the projects, leaks can represent more than 90% of the total emissions. Therefore, leak prevention and control are the most critical factors in reducing global warming.

2. COEFFICIENT OF PERFORMANCE

Energy efficiency has always been an essential factor in the design of thermal machines. Good designs make the most of the energy used in the system. In the past, little attention was paid to energy efficiency in heating, cooling, ventilation, and air conditioning systems due to the relatively low cost of fuel. Sudden price increases, concerns about fuel shortages, and environmental considerations have changed this situation. Designers, in-house operators, and contractors must consider energy efficiency as essential.

The COP of a heat pump, refrigerator, or air conditioner is a ratio of the useful heating or cooling provided by the appliance to the work that the appliance has to do. Higher COPs equate to lower operating costs. The COP usually exceeds 1, especially in heat pumps, because, instead of just converting work to heat (which, if 100% efficient, would be a COP of 1), it pumps additional heat from a heat source to where the heat is required. For systems with several components, COP calculations should consider the energy consumption of all the power-consuming components. The COP is highly dependent on operating conditions, especially absolute temperature and relative temperature between sink and system and is often graphed or averaged against the expected conditions.

2.1 COP AND COEFFICIENT OF SYSTEM PERFORMANCE

The energy efficiency of a refrigeration system is expressed as the coefficient of system performance (COSP).

$$\text{COSP} = \frac{\text{Capacity (kW)}}{\text{Power (kW)}}$$

The power is the net energy supplied from external sources to the compressor and all motors associated with the system (e.g., fan motors, pumps, and controls).

Efficiency can also be expressed as COP—This is just the efficiency of the compressor; it does not take into account the power input of other electrical components such as fan motors and pumps.

The COP is highly dependent on the system temperature lift–The temperature lift is the difference between the evaporating and condensing temperatures.

- The compressor capacity increases when the temperature lift is reduced
- The compressor power input decreases when the condensing temperature is lowered
- The compressor power input increases when the evaporating temperature increases, but the increase in power input is not as high as the increase in capacity (hence the COP still goes up)

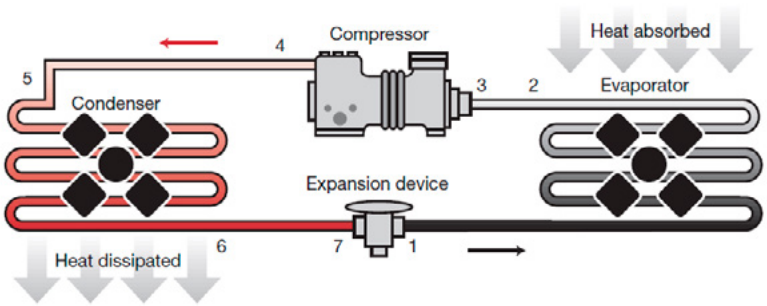
Supermarkets are energy-intensive buildings with a large potential for efficiency improvements. As refrigeration makes up approximately half of a supermarket's energy use, considerable efforts have been made to improve the refrigeration systems.

2.2 EFFICIENCY MEASUREMENT

COP and COSP can be used to measure refrigeration efficiency. COSP is used more frequently because it takes into account all ancillary loads (e.g., fan motors and pumps) and the controls associated with the refrigeration systems. The COP does not take these loads into consideration and considers only the core refrigeration system performance.

The COSP is the cooling capacity (kW) divided by the operating input power (kW).

Theoretical efficiency for the refrigeration cycle is defined as the heat extracted divided by the work input, or COP.



When dealing with old systems that have been in use for many years and with operating conditions that differ from the original design conditions, taking measurements can be a complex task. The "Technical Guide on procedures for determining the energy performance of water chiller plants and autonomous air treatment equipment", IDEA, Institute for Diversification and Energy Saving, 2007 describes it as follows:

"The variability of the external factors that affect the operating conditions, and consequently, the performance of the refrigeration machines considered as part of a refrigeration system make it difficult to determine performance values different from the instantaneous ones that may occur.

The information about performance in the manufacturers' technical documents refers in almost all cases to theoretical or practical data obtained in a test bench under conditions of maximum machine capacity. In this technical-commercial information, data on operating conditions and performance in partial load situations are rarely provided.

The information on operating conditions and performances at partial load is of great value for those who have to evaluate the energy efficiency of machines in real operating situations (different from those under test bench conditions), such as conditions usually found in refrigeration systems operating in buildings. These refrigeration systems are under the effects of external factors that can hardly be modified with the precision and speed required to operate "in nominal conditions" as in the manufacturer technical document.

In real life, refrigeration systems are inspected when they are operating under partial load conditions, without considering the actual conditions, even when the inspection is performed during times of peak refrigeration demand. It is very unlikely that all the factors that affect the refrigeration system operation match the design operating conditions.

Consequently, the operating data gathered in most inspections will correspond to "non-nominal" operating conditions and cannot be compared with data in the user manual because the conditions are not the same. In any case, the inspection technicians can contact the manufacturers and request the performance data obtained from test bench measurements under conditions similar to the inspection conditions. This solution is recommended when no other information is available. Then, they can compare the manufacturer information with the values resulting from the calculation method in this guide.

The calculation method is based on direct measurement, recording, and consumption calculation during a period to identify the actual power. Then, the corresponding power demand curve for the period can be estimated. Measurements are taken using fixed tools and recording instruments and devices.

The power demand during a specific period will result in the energy used in that period, divided by the total energy consumption required to operate the refrigeration system during the same period, resulting in the seasonal COP of the system. The power demand curve can be estimated through a mathematical model, such as a heat loss and gain calculation method, or by measuring the powers supplied by using an energy meter.

In summary, using any of the indicated data collection procedures, the refrigeration system seasonal COP would be determined by the following expression:

$$COP = \int Q \times dt$$

That is, by the relationship between the energy used by the appliance, system, or facility in the period considered and the sum of the energy consumption required for the operation during the same period.

The annual or seasonal consumption of electrical and thermal energy must be compared with the annual consumption calculated in the project to detect and analyze the deviations during the operating period. When the consumption exceeds by 20% the calculated consumption, the causes of the gap must be found, and the corresponding corrective measures must be taken."

2.3 PROJECT COOLING SYSTEMS

CONDENSERS

Cooling systems have condensers (with fans) that carry the heat away. Condensers have an inlet and an outlet manifold (with ports and safety valves) to measure pressure.

EVAPORATORS

Copper pipes connect evaporators, compressors, and condensers. The compressors supply refrigerant to evaporators with different temperature sensors (low, medium, and high).

Evaporation systems usually include freezing chambers, storage chambers, freezing cabinets, storage cabinets, storage coolers, and other refrigeration units. All evaporators in the participant supermarkets are dynamic, while Jacusa evaporators are static.

TABLE 7: *Chillers in the leak control projects*

END USER	Compressors (Brand/Model) Power supply	Cooling capacity (TR) approximate refrigerant charge R-22 (kg)	OBSERVATIONS
EXCELSIOR GAMA			
Santa Eduvigis	HUSSMANN COPELAND CS0209VDM 460 VAC-3 F-60 Hz	209 (308)	The systems have a low-temperature sensor (MBT) and a medium-temperature sensor (MMT) Three pressure levels: two suction levels and a discharge level.
La California	HILPHOENIX COPELAND PS815VLRAC4S15 208 VAC- 3 F- 60 Hz	120 (180)	
CENTRAL MADEIRENSE			
Montalban	HILPHOENIX TYLER P180-323	80 (300)	The systems have a low-temperature sensor and two pressure levels
Plaza las Americas	HILLPHOENIX TYLER VRP 160-430	130 (500)	
Mariches	HILLPHOENIX TYLER VRP- 180- 515	186 (280)	

END USER	Compressors (Brand/Model) Power supply	Cooling capacity (TR) approximate refrigerant charge R-22 (kg)	OBSERVATIONS
MAKRO			
Makro Los Teques	HILLPHOENIX PS1027VLRAP3525 208-3F-60Hz	84 (1100)	The systems have three temperature sensors (low, medium, and high) and two pressure levels
Makro Vargas	HILLPHOENIX PS715VLRAP4S15 480-3F-60Hz	53 (670)	
JACUSA			
Jamones Curados Jacusa	3 independent chillers Sabroe, SM 016 and 1 Bitzer, open York Condenser 220-3F-60Hz	49 (374)	The systems control low, medium, and high-temperature environments. Cold rooms with static evaporators and one dynamic

The cooling systems in the Excelsior Gama and Central Madeirense supermarkets have a low-temperature sensor (MBT) and a medium-temperature sensor (MMT) with three pressure levels: low suction pressure, medium suction pressure, and discharge pressure.

The cooling system in the Makro supermarkets has a low-temperature sensor (MBT), a medium-temperature sensor (MMT), and a high-temperature sensor (MAT) with four pressure levels: low pressure, medium pressure, high pressure, and discharge pressure.

Jacusa's cooling system is independent, with open compressors, air-cooled condensers, and static evaporators.

Each circuit consists of any compressor installed in parallel, a one-way valve, a solenoid valve, and an expansion valve (placed on each evaporator).

To simplify the leak monitoring and the energy efficiency calculations, instead of working with systems including several evaporators, we considered an evaporator with a mass flow equivalent to the mass flow of every single evaporator.

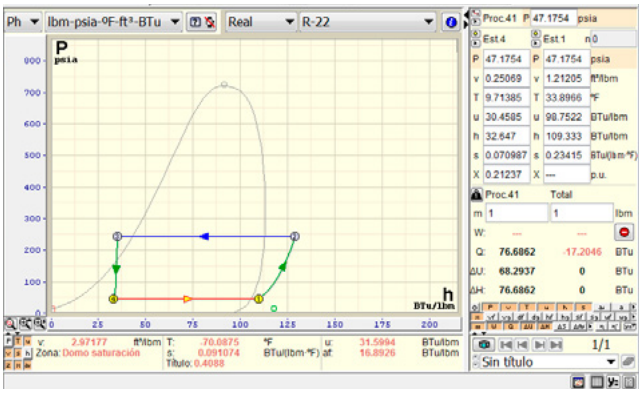
2.4 COSP CALCULATION METHOD

a) We used TermoGraf, a thermodynamic simulation software, to simulate the cooling circulation according to the MB and MMT operating conditions (evaporation and condensation pressure and temperatures) and the conditions in the MBT, MMT, and MAT collectors and the discharge collector. The data was gathered either by direct measurements or from PLC control units.

b) Measure the condenser inlet and outlet temperature.

c) Measure airflow to the condenser.

d) Calculate the condenser enthalpy. Then determine the cooling load and the heat gained in the evaporator.



Simulation using the TermoGraf software

e) Calculate the mass of refrigerant

$$m = 1{,}05 \times PCM \times \Delta T / \Delta h_{Cond}$$

f) Calculate the heat entering the evaporator

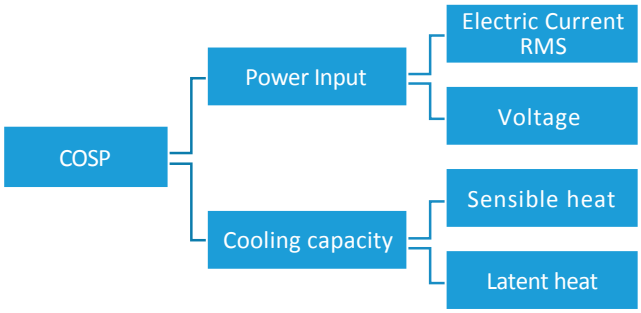
$$Q_{Evp} = Q_{MBT} + Q_{MMT} = m_{ref}\,(\Delta h_{MBT} + \Delta h_{MMT})$$

g) To calculate the cooling capacity, measure the voltage and amperage in the cooling system main feeder

h) Calculate COSP = Cooling power / Electrical power of the system

$$COSP = \frac{Q_{Evp}}{\text{Electric Power (Evp + comp. + cond.)}}$$

100% working load.



2.5 ELECTRICAL POWER

In autonomous equipment, the measurement of supply voltages and current consumption should be taken on the main conductors of the general connection to the machine (main switch of the refrigeration system) to get the instant consumption of all the elements necessary for its operation. The data obtained in this way will make it possible to directly determine the instantaneous total power absorbed by the machine under the conditions in which the measurements are actually taken. Consequently, the actual performance can be determined more accurately.

2.6 PERFORMANCE ANALYSIS

The COP is used to determine the performance of the refrigeration systems. It can also be used to analyze operating costs and plan maintenance activities. COP monitoring is a great tool that can help maintenance technicians do a better job, and refrigeration end users save money.

COP variations are associated with changes in the refrigeration system under normal operating conditions. The changes must be reversed over time and restored within the operating range. A marked and sustained deviation implies that something in the system is causing unusual behavior.

This approach will help end users understand and anticipate potential problems and detect improper operating conditions.

A COP value outside the operating range may be associated with:

1. Refrigerant level variations. Refrigerant leaks cause an imbalance in the refrigerant mass, affecting the performance.
2. Components with operating pressures and temperatures outside the recommended range affect the COP significantly. Besides, they might be warning us of mechanical or electrical failures and leaks in the refrigeration system.
3. Permanent high-power consumption in the system or its components is a warning of a malfunction requiring attention. This issue may be associated with the problems mentioned above.

3. PROJECTS SUMMARY

The program was implemented in times of great economic difficulty in Venezuela, affecting all population sectors. In the industrial and commercial sector, most companies cut the maintenance and equipment replacement budget. Besides, many technicians left the country, weakening the workforce.

The crisis impact can be seen in every participant company. All of them reduced or even interrupted the preventive maintenance plans. Technicians only applied corrective maintenance. Disinvestment resulted in high refrigerant consumption, even higher than expected due to the high leak rate. Leaks remained undetected in many cases.

The first phase in implementing the projects, right after the selected companies agreed to be part of the program, included inspections of the refrigeration systems. We assessed the operating conditions and analyzed the maintenance plan, particularly the leak control plan. The companies received the inspection results in a diagnostic report for each system, with recommendations based on the standard for detection and control of refrigerant leaks in RAC systems. This section presents a summary of the reports.

The diagnostic reports with the recommendations for reducing refrigerant emissions and implementing a leak detection and repair program were the starting point for each participant end user. The recommendations included tasks and monthly follow-up visits to verify the progress. The goal was to complete all the recommended tasks before the end of the project.

The energy efficiency of the refrigeration systems was estimated after examining the measurement options conditions in each case.

At the beginning of March 2020, the COVID-19 pandemic interrupted the projects implementation. Quarantine measures in Venezuela suspended all projects activities. The lockdown restrictions were in place until the end of the year but were eased after September. Meanwhile, the follow-up activities were carried out with the project leaders' assistance via email. The situation was very complex, and some end users had difficulties proceeding with the project.

Three projects were canceled due to the effects of the pandemic on the economy. The two Makro Comercializadora supermarkets and the Central Madeirense distribution center did not complete their projects. This report includes the progress up to the first stage (information gathering and recommendations).

3.1 JAMONES CURADOS JACUSA

JAMONES CURADOS JACUSA S.A. is a private cured meat producer. The company produces and sells a wide variety of sausages, cooked and cured hams, pepperoni, and mortadella, among other products.

Jacusa needs cooling for curing hams and preserving the production. The refrigeration system includes cellars or cold rooms to store raw meat, other raw materials, and finished products. The cold rooms are also used as curing rooms. Jacusa has 68 cold rooms that operate with independent direct expansion condensing units. The project did not include all the systems due to the diversity and extension. Only four refrigeration systems were under the project scope.

Refrigeration systems

The four selected refrigeration systems are independent single-stage chillers with open compressors (Sabroe chillers, three with York condensers, and one with a Bitzer condenser). The first condensing units are special systems designed for curing meat. Each one feeds two or three cold rooms in parallel. They generate natural convection cooling through numerous batteries of evaporators in each one. The other unit feeds a conventional freezing cellar with two forced ventilation evaporators.

The systems are direct expansion systems with R-22 refrigerant cooled by air condensers. The refrigerant charge information shows the high annual leak in the systems, as can be seen in the following table:

Chiller	MODEL	Cooling capacity (TR / Btu)	R-22 Charge (kg)	Annual Leak, 2019 (kg)
#1	**Sabroe CM016**	15 / 180.000	120	251
#2	**Sabroe CM016**	15 / 180.000	120	NA
#3	**Bitzer 5**	4 /	14	153
#4	**Sabroe CM016**	15 / 180.000	120	201

The plant managers are responsible for the maintenance management. They supervise and coordinate the preventive and corrective maintenance activities in the production plant. An external contractor is in charge of the maintenance activities. The company has the equipment, tools, and consumables required to give support to the in-house and external technicians.

Leak control

Leaks reported during 2019 were extremely high in relation to the systems' total load. This condition requires immediate attention to detect the causes of the high refrigerant leak rate.

Jacusa hopes to correct the anomalies through the project implementation and reduce refrigerant consumption. After assessing the systems and examining the maintenance plan, we identified several aspects that must be fixed to improve the systems' management and reduce the refrigerant leak rate.

Project components

The project included the following aspects:

a) ***Compliance with environmental regulations:***

The company needs to comply with the regulations and adopt an approach to manage the refrigeration systems maintenance according to the company's needs and interests. Currently, the systems are in a non-compliance situation, and both Jacusa and the maintenance contractor must initiate actions to comply with the relevant regulations.

b) ***Technical training:***

Only certified technicians are authorized to handled halogenated refrigerants. Technicians in Jacusa and the maintenance contractor are not certified.

c) ***Tools:***

Jacusa provides to the maintenance contractor all the necessary tools to perform the maintenance activities. However, more tools are required, such as suitable tools for leak detection. The maintenance contractor does not have the basic tools needed for the task.

d) ***Recovery and recycling:***

The maintenance contractor has the skills to recover refrigerant from the condensing unit. They do not recover refrigerant from the evaporation circuit.

e) ***Compliance with the standard for detection and control of refrigerant leaks in RAC systems:***

The checklist shows a rather negative situation. Several aspects need to be addressed to achieve compliance. The recommendations include these issues.

Recommendations

1. Examine the environmental regulations and adjust the maintenance procedures to achieve compliance.
2. Strengthen the maintenance team according to the actual needs and considering the refrigeration systems conditions (e.g., based on the year of manufacture).
3. Build a training program for the maintenance technicians and get them certified.
4. Acquire tools to ensure leak detection, refrigerant extraction, and leak repair.
5. Improve the leak detection using adequate leak detection methods. Repair the leaks detected, including the leaks identified in the report. Implement the recommendations to achieve compliance with the standard for detection and control of refrigerant leaks and ensure proper leak detection and repair.
6. Amend the existing maintenance plan to incorporate the measures included in the standard for detection and control of refrigerant leaks.

The report includes general and technical recommendations. The implementation was verified during follow-up visits. The recommendations were expected to be fully implemented by the end of the project.

Results

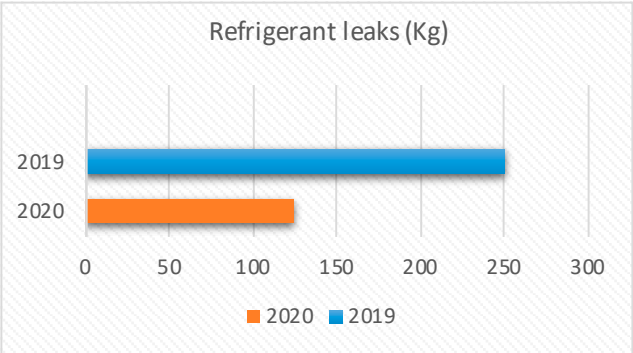
a) Leak control

i REFRIGERATION UNIT 1 (cold rooms 1C1-2-6)

YEAR	LEAK (KG)
2019	251
2020	124

The refrigeration system consists of a condensing unit with a compressor and three cold rooms. The leak rate was high.

The refrigeration unit was inspected to locate all existing leaks. Most leaks were in the cold rooms, at the expansion valves joints. We found many expansion valves that had to be repaired. It took a while until the leak rate was reduced. During the monitoring period, 124 kg of refrigerant were added to the system, against 251 kg during the previous year (50% less). The figure is still high in absolute terms, but during the last five months of the monitoring period, it was not necessary to add more refrigerant. If the trend continues over time, the result is very satisfactory.



ii REFRIGERATION UNIT 2 (cold rooms 2C22 and 23)

The refrigeration system consists of a condensing unit with a compressor and two cold rooms. The leak rate was high, but lower than in 2019.

The refrigeration unit was inspected to locate all existing leaks. During the monitoring period, 119 kg of refrigerant were added to the system, precisely the total system charge. At the end of the monitoring period, we observed a leak rate drop. If the trend continues over time, the leak rate reduction will be significant and acceptable.

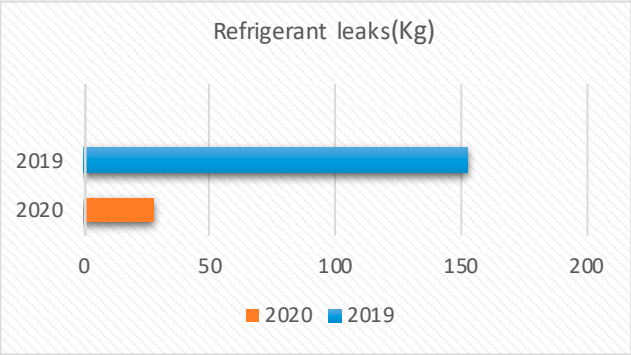
iii REFRIGERATION UNIT 3 (cold rooms 2C2)

YEAR	LEAK (KG)
2019	152.5
2020	27.5

The refrigeration system consists of a condensing unit and two evaporators. It was thoroughly examined because the refrigerant emission was too high compared with the system refrigerant capacity. The maintenance technicians replaced defective pipes and fittings, reconditioned the compressor, and replaced the filter drier and control devices. Then, they pressurized the unit. Some spare parts were still missing, but the pressure records did not reveal pressure drops, i.e., the leaks were successfully repaired by the end of the monitoring period.

The refrigeration unit has been idle for a long time. However, the results reflect an 82.2% annual leak reduction. If the refrigeration unit's hermeticity is maintained, the emissions reduction could be higher. This result is satisfactory.

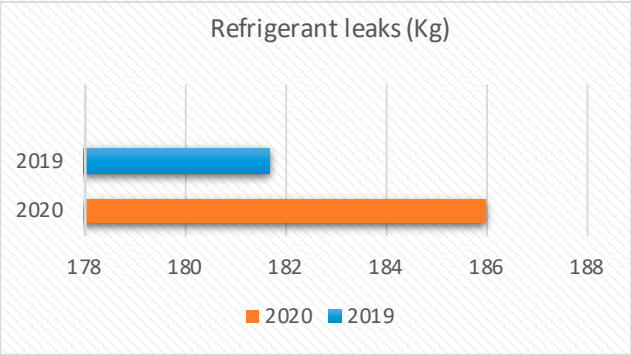
YEAR	LEAK (KG)
2019	181.7
2020	186.0



iv ***REFRIGERATION UNIT 4 (cold rooms 2C17 y 18)***

The refrigeration system consists of a condensing unit with a compressor and two cold rooms. The leak rate was high. Most leaks were located at the expansion valves joints and were associated with broken nuts. The maintenance technicians replaced all the flare nuts (48 valves in each cold room). The compressor had a leak in the mechanical seal, which was replaced.

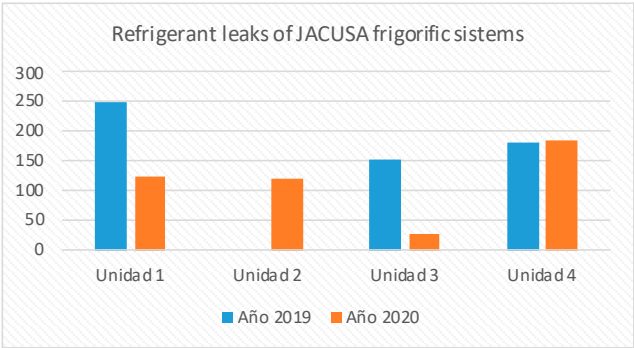
YEAR	LEAK (KG)
2019	181.7
2020	186.0



After an intensive year of work, the results are satisfactory in a certain way. The overall figures for the monitoring period do not reflect a refrigerant consumption reduction because 186 kg of refrigerant had to be charged during the monitoring period, while the refrigerant added during the previous year amounted only to 182 kg. (2% leak increase and equivalent to 155% of the system's nominal load). The goal of eliminating the leaks was achieved (no leak incidents have been recorded up to date). However, the process took too long, and undesirable emissions that could have been avoided through more effective actions occurred.

Overall refrigerant consumption considering the four refrigeration units shows a reduction. Since we do not know the consumption for the unit 2 in 2019, we cannot compare. However, if we exclude unit 2, we achieve a 42.3% reduction compared to the previous year. This result is positive, but it is still far from the expected reduction. Jacusa must continue the efforts to achieve higher reductions.

REFRIGERANT CONSUMPTION (KG)		
	Year 2019	**Year 2020**
System 1	251	124
System 2	ND	119
System 3	152,5	27,5
System 4	181,7	186
Total (1 to 4)	585,2	465,5
Total (1+3+4)		337,5



b) Project components evaluation

AREAS	DESCRIPTION OF RESULTS
LEAK PREVENTION AND CONTROL	The project helped improve many leak prevention and control measures and incorporate aspects that the company had not considered so far. The company improved the event log with a more detailed logging system. The company should further monitor the system's cooling capacity to improve leak prevention and detection, particularly in the system's connections, as required in the standard for detection and control of refrigerant leaks in RAC systems. The company must acquire the required tools. The company must improve the technical staff training.
ENVIRONMENTAL REGULATIONS	The end user must comply with the environmental regulations in Decree No. 4335 when handling halogenated substances in the refrigeration system.
TECHNICAL TRAINING	In-house and external technicians need more training to acquire the skills required to control leaks. They need to get certified as required in the standard for detection and control of refrigerant leaks in RAC systems The end user must ensure that all maintenance contractors are duly certified as required in the standard for detection and control of refrigerant leaks in RAC systems.
TOOLS	The end user needs to acquire the tools, equipment, and instruments required to perform the maintenance activities. They should use electronic leak detectors to detect leaks as soon as possible. They should use digital vacuum gauges to verify the system tightness before charging refrigerant.
COMPLIANCE WITH THE COVENIN DRAFT STANDARD FOR DETECTION AND CONTROL OF REFRIGERANT LEAKS IN RAC SYSTEMS	The end user complies with most of the standard requirements. Other aspects need improvement. The company does not comply with 5.2.5 about the one-line diagram of the refrigeration system. 7.1 requires weekly supervision of all points where leaks may develop using recommended methods to prevent leaks.
MAINTENANCE SERVICE PROVIDER	The maintenance contractor must provide training to the technicians and adequate tools in accordance with the standard to improve the service quality. By the end of the monitoring period, the maintenance contractor had already acquired some of the recommended tools.
COP ESTIMATION	System thermodynamic data were obtained by field measurements. The system COP is 2.71, which is within an acceptable range considering that the system is more than 20 years old.

c) Achievements

We assessed the achievements based on the implementation of the recommendations. The implementation was partial. The end user should make efforts to implement all of them in order to achieve the expected results.

1. ***Improvement and adaptation of the leak log according to the standard:*** The company keeps track of the maintenance activities using an electronic management system that records and plans scheduled activities. The recommendation was to update the leak detection plan and log the data according to the standard requirements. The company fully implemented the recommendation.
2. ***Develop a system flow diagram:*** The company could not achieve this objective. The task is still pending.
3. ***Install service valve caps and hose clamps:*** Maintenance technicians installed valve caps and hose clamps. The company fully implemented the recommendation.
4. ***Check the refrigeration system for leaks:*** The four units were thoroughly inspected for leaks. The task was successfully completed.
5. ***Repair leaks:*** The company was committed to this task. The task is still under way, but significant progress was made. According to the records of the last two months within the monitoring period, the leakage was reduced compared with the previous months. The maintenance technicians implemented the detection, repair, and recharging procedures correctly, but they need to acquire better tools to ensure tightness. The recommendation was to improve leak detection as required in the standard for detection and control of refrigerant leaks in RAC systems. The company fully implemented the recommendation.
6. ***Acquire recommended tools and equipment:*** The COVID-19 pandemic made it difficult to implement the recommendation. However, the maintenance contractor acquired a vacuum pump and an electronic leak detector. The task is still in progress.

The end user achieved some improvement and made progress in implementing good practices in refrigeration. They implemented several recommendations to reduce refrigerant leaks. However, they need to help the maintenance contractor improve the technicians' abilities.

Maintenance managers must complete the pending tasks as soon as possible and reduce the refrigerant leak rate.

3.2 EXCELSIOR GAMA Santa Eduvigis supermarket

EXCELSIOR GAMA is a private supermarket chain with a centralized distribution center and 24 locations in Caracas. The Santa Eduvigis supermarket is the chain's largest supermarket. Refrigeration is used to freeze and preserve food.

Refrigeration system

Single-stage compressors control the supermarket refrigeration system, an R-22 air condensation system that feeds by direct expansion the cold rooms and the refrigeration racks in the supermarket. The system cooling capacity is 208 tons of refrigeration (TR).

The compressors are located in a machine room. They include a low-temperature sensor with four compressors connected in parallel, a medium-temperature sensor with five compressors connected in parallel (nine compressors in total). The system includes 12 air-cooled condensers located on the supermarket roof. The evaporation section consists of five freezing cellars and four frozen self-service units (nine low-temperature circuits in total), as well as 33 refrigerated units (33

EXCELSIOR GAMA SANTA EDUVIGIS	
Cooling capacity	208 TR
R-22 charge	308 kg.
Leak % in 2019	63%

medium-temperature circuits in total). Besides, there are eight independent units and one air conditioning system outside the project scope.

The project goal is to assess and monitor the refrigeration system and implement the methodology and recommendations in the standard for detection and control of refrigerant leaks in RAC systems.

The company's technical department supervises the maintenance activities executed by TECNONORTE, a maintenance service provider with extensive experience in the industry. The system maintenance program has been affected by the economic situation in Venezuela and was reduced to corrective maintenance with some basic preventive measures. However, the refrigeration system was in good condition, and components were adequately maintained. That was a promising starting point for implementing the recommendations on building technical capacity and strengthening the professional and technical teams.

Leak control

The refrigerant leak rate in 2019 was high: 194 kg of R-22 were added to the system in six months (63% of the system's nominal refrigerant load). This is well above any acceptable level. The company hopes to correct the anomalies through the project and reduce the refrigerant consumption.

Project components

a) ***Compliance with environmental regulations:***

The company complies with the regulations. Excelsior Gama works with a maintenance contractor with skilled technicians certified to handle halogenated refrigerants.

b) ***Technical training:***

The maintenance contractor technicians are already duly certified.

c) ***Tools:***

The maintenance contractor tools comply with the standard and are adequate to control leaks in the system.

d) ***Recovery and recycling:***

The maintenance contractor has the skills and the required tools to recover refrigerants.

e) ***Compliance with the standard for detection and control of refrigerant leaks in RAC systems:***

The checklist shows a favorable situation. Some aspects need to be addressed to achieve compliance. The recommendations include these issues.

Recommendations

The Excelsior Gama Santa Eduvigis supermarket meets most of the maintenance requirements included in the standard for detection and control of refrigerant leaks in RAC systems. However, they could improve the overall performance and reduce refrigerant leak through the following recommendations:

1. Strengthen the maintenance team by implementing the recommendations in the standard for detection and control of refrigerant leaks in RAC systems.
2. Install a leak detection system in compliance with the standard.
3. Search for leaks in the system's circuit using appropriate detection methods and repair the leaks as soon as possible.
4. Amend the maintenance plan to incorporate the measures suggested in the standard for detection and control of refrigerant leaks in RAC systems.

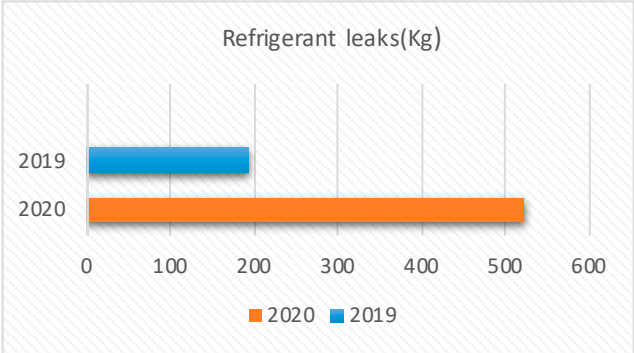
The diagnostic report was well received. The maintenance manager accepted the recommendations and acknowledged the work done to identify practices needing improvement. The company is willing to comply with the relevant regulations to reduce leaks and contribute to the environment.

The recommendations included maintenance activities that were rapidly completed. Activities outcomes were assessed during new inspections.

Results

a) Leak control

YEAR	LEAK (KG)
2019	193,6
2020	521,8



Refrigerant leaks recorded during the project were higher than expected and, unfortunately, higher than in 2019. The amount of refrigerant charged during the monitoring period in 2020 was 521.8 kg, 170% more than in 2019. This amount is very high, considering that the system has a nominal load of 312 kg and, therefore, the leaks recorded amounted to 167% of the nominal load.

Unexpected leaks were found in the middle of the project. Several liquid control valves in the rack connected with the evaporator batteries were leaking. According to the technicians, the valve seals had never been replaced and had reached the end of the useful life. In order to avoid further problems, the company decided to replace all the 35 valves. Additionally, the technicians detected some minor leaks in the medium and low-temperature cool rooms.

The standard recommends leak early detection using adequate tools as a regular preventive measure, particularly in systems with a refrigerant capacity similar to this one. If this recommendation had been followed, a large part of the incidents could have been prevented.

Excelsior Gama has everything they need to implement a successful leak prevention program. However, they need to improve some aspects. The maintenance contractor has skilled technicians and adequate tools in compliance with the standard.

Operating conditions monitoring and leak detection could help reduce refrigerant consumption and avoid unexpected problems.

The results cannot be considered satisfactory considering the high amount of refrigerant released due to leaks. According to the maintenance reports, since the leaks were detected, it took too long to replace the defective valves. More than two months went by before the new valves were installed. Meanwhile, 80% of the refrigerant was released. The company should act more resolutely to tackle these problems rapidly and avoid unnecessary discharges.

b) Project components evaluation

AREAS	RESULTS DESCRIPTION
LEAK PREVENTION AND CONTROL	The project helped improve many leak prevention and control measures and incorporate aspects that the company had not considered so far. The company improved the event log with a more detailed logging system and hired additional staff to improve the monitoring of the system. The standard for detection and control of refrigerant leaks in RAC systems states that systems with a refrigerant capacity similar to the one in the supermarket should be inspected on a weekly basis. The company should install a fixed leak detection system to warn of the refrigerant's presence in the environment. The combination of both recommendations would probably have prevented the incidents during the monitoring period.
ENVIRONMENTAL REGULATIONS	The maintenance contractor complies with the environmental regulations in Decree No. 4335 when handling halogenated substances. Technicians are trained and duly certified. They have the required tools.
TECHNICAL TRAINING	The maintenance contractor has demonstrated technical ability and experience in leak control. The technicians are duly certified. In-house technicians do not need a certification because the contractor is in charge of the maintenance activities. However, in-house certified staff would improve leak control and prevention. The end user must ensure that all maintenance technicians are duly certified as required in the standard for detection and control of refrigerant leaks in RAC systems.
TOOLS	The maintenance contractor has adequate tools, equipment, and instruments to perform the maintenance activities. They should use electronic leak detectors to detect leaks as soon as possible. They should use digital vacuum gauges to verify the system tightness before charging refrigerant.

AREAS	RESULTS DESCRIPTION
COMPLIANCE WITH THE DRAFT STANDARD FOR DETECTION AND CONTROL OF REFRIGERANT LEAKS IN RAC SYSTEMS	The company complies with most of the standard requirements. Some aspects need improvement. The company does not comply with 5.2.5 about the one-line diagram because they do not have the facility plans. Besides, the maintenance managers will replace the refrigeration system in the short term. 7.1 requires weekly monitoring of all points where leaks may develop using recommended methods to prevent leaks. The company inspects the system on a daily basis, but the task is not included in the maintenance plan.
MAINTENANCE SERVICE PROVIDER	Tecnonorte, the maintenance contractor, has trained technicians and adequate tools to complete the maintenance activities as required in the standard for detection and control of refrigerant leaks in RAC systems.
COP ESTIMATION	System thermodynamic data were obtained by field measurements. The COP is 2.88, which is within an acceptable range considering that the system is 15 years old.

c) Achievements

We assessed the achievements based on the implementation of the recommendations. The implementation was partial due to the difficulties encountered. The company must make efforts to put them into practice and achieve the expected results.

1. ***Improvement and adaptation of the leak log as required in the standard for detection and control of refrigerant leaks in RAC systems:*** The project helped improve many maintenance aspects, but the technicians must make further efforts. Tidiness and cleanliness were improved, as well as data collection. The recommendation is to log all the data as recommended in the standard. The company implemented the recommendation partially (60%).
2. ***Develop a system flow diagram:*** This objective could not be achieved because the company does not have the facility plans. Besides, they want to replace the refrigeration system in the short term. They are not willing to pay for this task right now.
3. ***Adjust couplings on the pressure switch and install service valve caps:*** Maintenance technicians adjusted the couplings to eliminate potential leaks and installed valve caps. The company fully implemented the recommendation.
4. ***Tighten hose clamps and loose pipes:*** The company fully implemented the recommendation.
5. ***Check the refrigeration system for leaks:*** The objective was partially met. The system is not inspected as often as recommended by the standard. The company should make efforts to check the system on a regular basis, particularly in the absence of a leak detection system. The visual inspection procedure in place is not enough. Besides, the refrigeration system is not checked on weekends.
6. Technicians searched for leaks in the machine room (100%) and at some points in the cellars, preparation area, and sales floor, covering a total of 70% of the system.
7. ***Repair leaks:*** The task is still under way. Leaks were repaired as soon as detected. However, when a valve needs to be replaced, the Tecnonorte must wait until Excelsior Gama buys the valve. Valuable time gets wasted. Nevertheless, the maintenance technicians implement the detection, repair, and recharging procedures correctly. The recommendation is to improve leak early detection as required in the standard for detection and control of refrigerant leaks in RAC systems.
8. ***Installation of a leak detection system:*** The recommendation was discarded for now because the company wants to replace the refrigeration system. It will be reevaluated in due course.

Excelsior Gama achieved some improvement and made progress in implementing good practices in refrigeration. They implemented several recommendations in the supermarket Santa Eduvigis to reduce refrigerant leak. Recommendations on corrective maintenance tasks were successfully implemented, while preventive activities were not carried out, although they have a stronger beneficial impact.

Maintenance managers must complete the pending tasks as soon as possible and reduce the refrigerant leak rate.

3.3 EXCELSIOR GAMA La California supermarket

La California is an EXCELSIOR GAMA supermarket located in the Lider mall in east Caracas. Refrigeration is used to freeze and preserve food.

Refrigeration system

Single-stage compressors control the supermarket refrigeration system, an R-22 air condensation system with a cooling capacity of 120 TR.

EXCELSIOR GAMA LA CALIFORNIA	
Cooling capacity	120 TR
R-22 charge	180 kg.
Leak % in 2019	73%

The compressors are located in a machine room. They include a low-temperature sensor with four compressors connected in parallel and a medium-temperature sensor with four compressors also installed in parallel (eight compressors in total). The system includes air-cooled condensers located on the supermarket roof. The evaporation consists of six freezing cellars and four refrigerated rooms (low-temperature sensor) with three circuits and refrigeration racks (medium-temperature sensor). Besides, there are some independent units and one air conditioning system outside the project scope.

The project goal is to assess and monitor the refrigeration system and implement the methodology and recommendations in the standard for detection and control of refrigerant leaks in RAC systems.

The company's technical department supervises the maintenance activities executed by TECNONORTE, a maintenance service provider with extensive experience in the industry. The maintenance program has been affected by the economic situation in Venezuela and was reduced to corrective maintenance with some basic preventive measures. However, the refrigeration system was in good condition, and all components were adequately maintained. That was a promising starting point for implementing the recommendation on building technical capacity and strengthening the professional and technical teams.

Leak control

Refrigerant leak rate 2019 was high: 131 kg of R-22 were added to the system in six months (73% of the system's nominal load). This is well above any acceptable level. The company hopes to correct the anomalies through the project and reduce refrigerant consumption.

Project components

a) ***Compliance with environmental regulations:***

The company complies with the regulations. Excelsior Gama works with a maintenance contractor with skilled technicians certified to handle halogenated refrigerants.

b) ***Technical training:***

The maintenance contractor technicians are already duly certified.

c) ***Tools:***

The maintenance contractor tools comply with the standard and are adequate to control leaks in the system.

d) ***Recovery and recycling:***

The maintenance contractor has the skills and the required tools to recover refrigerants.

e) ***Compliance with the standard for detection and control of refrigerant leaks in RAC systems:***

The checklist shows a quite positive situation. Some aspects still need to be addressed to achieve compliance. The recommendations include these issues.

Recommendations

The Excelsior Gama La California Supermarket meets most of the maintenance requirements in the standard for detection and control of refrigerant leaks in RAC systems. However, they could improve the overall performance and reduce refrigerant emissions through the following recommendations:

1. Strengthen the maintenance team by the implementation of the standard requirements.
2. Improve leak detection in all the circuits using appropriate leak detection methods and implement a leak prevention plan, including leak repair.
3. Amend the maintenance management plan to incorporate the measures suggested by the standard.

The diagnostic report was well received. The maintenance manager accepted the recommendations and acknowledged the work done.

Technicians responsible for the system maintenance agreed that the recommendations and observations were beneficial and helped identify and correct bad practices to improve the system performance and maintenance. The company is willing to comply with the relevant regulations to reduce leaks and contribute to the environment.

The recommendations include maintenance activities that were rapidly completed. Activities outcomes were assessed during new inspections.

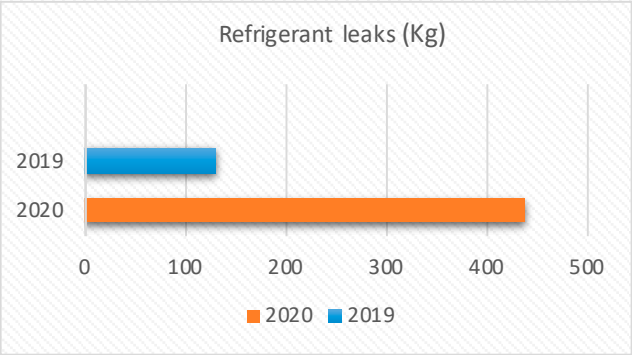
Results

a) Leak control

LEAK RECORD (YEAR)	KG
2019	131,2
2020	439,0

The refrigerant leak during the 2019 was high. The situation did not improve during the project. On the contrary, refrigerant emissions increased excessively.

The amount of refrigerant charged to the system during the monitoring period was 439 kg, representing 235% more than in 2019. This amount is very high, considering that the system has a nominal load of 180 kg, and therefore the leak is equivalent to 244% of the nominal load.



Some leaks were detected in the middle of the monitoring period in a service valve and in liquid stop valves and then repaired. The most relevant leaks were two incidents with high discharge pressure (137 kg of refrigerant released) and a catastrophic leak while the system was unsupervised (100% refrigerant released). The standard recommends leak early detection using appropriate tools as a regular

preventive measure. This recommendation can help avoid similar incidents in the absence of automatic detection systems. During the monitored period, the technician in charge of the refrigeration system went to the supermarket only once a week due to the COVID-19 restrictions. The maintenance contractor did not have a fixed contract. Both factors led to insufficient supervision and, to some extent, played a role in the incidents.

The results show that there is room for improvement. Excelsior Gama has everything they need to implement a successful leak prevention program. However, the incidents that took place during the monitoring period affected the supermarket operation and led to refrigerant release. The company needs to improve the system supervision and control.

The maintenance technicians should improve the monitoring of the operating parameters and the leak detection method to reduce refrigerant consumption and avoid unexpected operational problems.

The results cannot be considered satisfactory given the incidents described and considering the high amount of refrigerant released. The company should take measures to improve the refrigeration system supervision and monitoring. The maintenance company should develop strategies to minimize the risk of leakage.

b) Project *component* evaluation

AREAS	RESULTS DESCRIPTION
LEAK PREVENTION AND CONTROL	The project helped improve many leak prevention and control measures and incorporate aspects that the company had not considered so far. The company improved the event log with a more detailed logging system and hired additional staff to improve the monitoring of the system. The standard for detection and control of refrigerant leaks in RAC systems states that systems with a refrigerant capacity similar to the one in the supermarket should be inspected on weekly basis. The company should install a fixed leak detection system to warn of refrigerant presence in the environment. The combination of both recommendations would probably have prevented the incidents during the monitoring period.
ENVIRONMENTAL REGULATIONS	The maintenance contractor complies with the environmental regulations in Decree No. 4335 when handling halogenated substances. Technicians are trained personnel and duly certified. They have the required tools.
TECHNICAL TRAINING	The maintenance contractor has demonstrated technical ability and experience in leak control. The technicians are duly certified. Excelsior Gama maintenance technicians do not need a certification because the contractor is in charge of the maintenance activities. However, in-house certified staff would improve leak control and system supervision. The end user must ensure that all maintenance technicians are duly certified as required in the standard for detection and control of refrigerant leaks in RAC systems.
TOOLS	The maintenance contractor has adequate tools, equipment, and instruments to perform maintenance activities. They should use electronic leak detectors to detect leaks as soon as possible. They should use digital vacuum gauges to verify the system tightness before charging refrigerant.

AREAS	RESULTS DESCRIPTION
COMPLIANCE WITH DRAFT STANDARD FOR DETECTION AND CONTROL OF REFRIGERANT LEAKS IN RAC SYSTEMS	The company complies with most of the standard requirements. Some aspects need improvement. The company does not comply with 5.2.5 about the one-line diagram because they do not have the facility plans. Besides, the maintenance managers will replace the refrigeration system in the short term. 7.1 requires monthly supervision of all points where leaks may develop using recommended methods to prevent leaks. The company inspects the system on a daily basis, but the task is not included in the maintenance plan.
MAINTENANCE SERVICE PROVIDER	Tecnonorte, the maintenance contractor, has trained technicians and adequate tools to complete the maintenance activities in accordance with the standard.
COP ESTIMATION	This activity was not carried out because it was not possible to take measurements due to technical difficulties.

c) Achievements

We assessed the achievements based on recommendations implementation. The implementation was partial due to the difficulties encountered. The end user must make efforts to implement all of them in order to achieve the expected results.

1. ***Improvement and adaptation of the leak log as required in the standard for detection and control of refrigerant leaks in RAC systems:*** The project helped improve many maintenance aspects, but further efforts are needed. The company should improve the data acquisition through a log system to ensure that the data is recorded according to the standard requirements. The company implemented the recommendation partially (60%).
2. ***Develop a system flow diagram:*** The company could not achieve this objective. The task is pending.
3. ***Install service valve caps and hose clamp:*** Maintenance technicians installed valve caps and hose clamps. The company fully implemented the recommendation.
4. ***Check the refrigeration system for leaks:*** The objective was not met. The in-house technician in charge of the task was working reduced hours. The maintenance contractor was not asked to complete the task. The company should make an effort and thoroughly check the system on a regular basis, particularly in the absence of a leak detection system.
5. ***Repair leaks:*** The task is still under way. The technicians implemented the detection, repair, and recharging procedures correctly. The company should improve the leak early detection as required in the standard for detection and control of refrigerant leaks in RAC systems. This company fully implemented the recommendation.

The end user achieved some improvement and made progress in implementing good practices in refrigeration. Excelsior Gama implemented several recommendations to reduce refrigerant leak. However, the implementation of the recommendations remained below the expectations. Most corrective maintenance activities were successfully completed, while preventive activities were not carried out.

Maintenance managers must complete the pending tasks as soon as possible and reduce the refrigerant leak rate.

3.4 CENTRAL MADEIRENSE Montalban supermarket

Founded in 1949, CENTRAL MADEIRENSE is the largest supermarket chain in Venezuela, with 53 locations and a centralized distribution center which supplies the supermarkets. The selected Central Madeirense supermarket is located in a mall in Montalban, a city west of Caracas. The project technical team selected the supermarket based on the large number of significant leaks over the years. Refrigeration is used to freeze and preserve food.

Refrigeration system

CENTRAL MADEIRENSE MONTALBAN	
Cooling capacity	80 TR
R-22 charge	300 kg.
Leak % in 2019	280%

Single-stage direct expansion compressors control the supermarket refrigeration system, an R-22 system with a cooling capacity of 80 TR.

The compressors are located in a machine room. They include eight compressors independently connected controlled by a central control panel.

There is an air-cooled condenser with eight fans in the upper part of the machine room. The evaporation section includes five cold rooms and 10 refrigerated cabinets connected to the system. Besides, there are independent units and an air conditioning system outside the project scope.

Maintenance activities are centrally managed through the company maintenance in coordination with the supermarket maintenance manager. They supervise and coordinate all preventive and corrective maintenance activities. The technical staff carries out most maintenance activities. The company outsources the maintenance activities that the in-house technicians cannot complete. All of them should hold the mandatory authorization to handle hazardous substances, materials, and waste and be enrolled in the RACDA.

Leak control

Maintenance technicians reported 840 kg of R-22 refrigerant charged in 2019. The refrigeration system was recharged many times, but the causes and sources of refrigerant leak were not recorded, and therefore we cannot analyze them.

A catastrophic leak was detected in November 2019, at the beginning of the project and before the first technical inspection. All the R-22 was released.

The first technical inspection found a high number of refrigerant leaks in pipes and fittings. The company decided to disconnect all the problematic circuits to verify them using a high-impact corrective approach that required two months' work (until January 2020). The project had a difficult start due to this unexpected incident.

The company repaired the leaks, recharged the system with 280 kg of refrigerant, and resumed service in January 2020.

The system has a very high leak rate due to a modified configuration and multiple defective elements. The data analysis shows a charge of 840 kg of R-22, 280% of the system's nominal load. If we only consider the single refrigerant charge of 280 kg of R-22 (93% of the system's nominal load) and ignore the previous leaks before the incident in 2019, the leak rate is well above any acceptable level. The company hopes to correct the anomalies through the project and reduce refrigerant consumption.

Project components

a) ***Compliance with environmental regulations:***

In-house technicians are responsible for the maintenance, but they are not enrolled in the RACDA. Therefore, they do not comply with the environmental regulations.

b) ***Technical training:***

The company maintenance department has certified maintenance technicians, and the staff assigned to the supermarket are duly certified.

c) ***Tools:***

The company maintenance department should acquire the following tools to prevent and control leaks as required in the standard for detection and control of refrigerant leaks in RAC systems :

i. Electronic vacuum gauge
ii. Electronic scale
iii. Cylinders for refrigerant recovery
iv. Schrader valve core removal tool

d) ***Recovery and recycling:***

The company maintenance department has the skills to recover refrigerants, but they should acquire the required tools.

e) ***Compliance with the standard for detection and control of refrigerant leaks in RAC systems***

The checklist shows a favorable situation. Some aspects need to be addressed to achieve compliance. The recommendations include these issues.

Recommendations

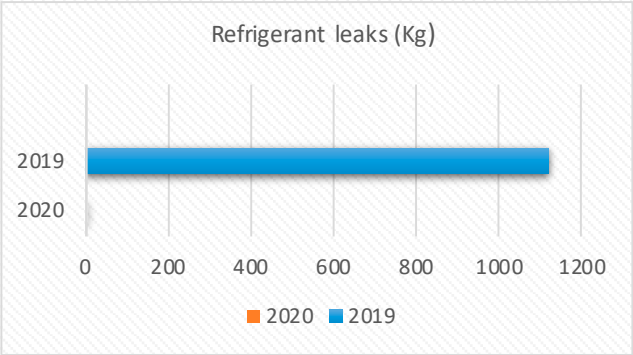
The Central Madeirense Montalban supermarket meets most of the maintenance requirements of the standard for detection and control of refrigerant leaks in RAC systems. However, they could improve the overall performance and reduce refrigerant emission through the following recommendations:

1. Enroll in the RACDA.
2. Strengthen the maintenance team by the implementation of the leak control standard requirements.
3. Log all incidents and interventions adequately.
4. Install a leak detection system as required by the standard according to the system's refrigerant capacity.
5. Develop the one-line diagram of the refrigeration system and place copies on visible locations near each system component.
6. Search for leaks in the system circuits using appropriate detection methods and repair the leaks as soon as possible.
7. Amend the maintenance plan to incorporate the measures suggested in the standard.
8. The system operates under a particular condition as a result of the post-incident corrective measure implemented. The company should replace the damaged control valve and balance the system as indicated in the project report.

Results

a) Leak control

LEAK RECORD (YEAR)	KG
2019	1.120
2020	0



The refrigerant leak during 2019 was alarming. The last incident served as a turning point, after which the company checked the whole system and completed the necessary corrective measures. The maintenance managers decided to shut down the system, identified all the existing leaks, and repaired them instead of fixing one leak at a time as a reactive maintenance strategy to avoid the system shutdown. The outcome was very satisfactory and exceeded the expectations. No new leaks were detected during the monitoring period.

Although the methodology was successful, it is important to note that a constant monitoring strategy such as the one proposed in the leak control program would have worked in a similar way and even better. If the company had implemented the recommendations in the standard before the incident, all issues would have been identified and resolved early enough without significant refrigerant emission.

Early leak detection with proper tools is part of the recommended weekly leak prevention routine to avoid incidents such as the one that affected the system, particularly when automatic detection systems are not available. The Montalban supermarket has a leak detection device in the machine room, but it is out of order. The company should repair it to recover the automated leak detection functionality.

The results were totally satisfactory. The company reached a 100% leak reduction during the project. The company should implement the recommendations on monitoring to prevent leaks in the future.

The Central Madeirense Montalban supermarket has everything they need to implement a successful leak prevention program. The corrective maintenance activities completed before the monitoring period were crucial to success.

The results exceeded all expectations. No refrigerant was added during the monitoring period. Thus, the maintenance team achieved the zero-leak goal and reduced leakage to 100% compared with 2019.

The company should reinforce the preventive maintenance strategy.

b) Project components evaluation

AREAS	DESCRIPTION OF RESULTS
LEAK PREVENTION AND CONTROL	The project helped to improve many leak prevention and control aspects and incorporate others that the company had not considered so far. The end user improved the event log with a more detailed logging system. The standard for detection and control of refrigerant leaks in RAC systems states that systems with a refrigerant capacity similar to the one in the supermarket should be inspected on weekly basis. The company should install a fixed leak detection system to warn of the presence of refrigerants in the environment.

AREAS	DESCRIPTION OF RESULTS
ENVIRONMENTAL REGULATIONS	The end user must comply with the environmental regulations in Decree No. 4335 and enroll in the RACDA. In-house technicians take care of the refrigeration system maintenance. They are certified and have adequate tools to perform maintenance activities. They only need to enroll in the RACDA to comply with the mandatory regulation.
TECHNICAL TRAINING	In-house technicians have demonstrated technical ability and experience in leak control. They are duly certified. In case of outsourcing maintenance activities, the maintenance manager must ensure that the external technicians are duly certified as required in the standard for detection and control of refrigerant leaks in RAC systems.
TOOLS	The end user has adequate tools, equipment, and instruments to perform maintenance activities. Since the refrigerant volume in the system is high, the company should acquire high-capacity refrigerant recovery cylinders. They should use electronic leak detectors to detect leaks as soon as possible. They should use digital vacuum gauges to verify the system tightness before charging refrigerant.
COMPLIANCE WITH THE DRAFT THE STANDARD FOR DETECTION AND CONTROL OF REFRIGERANT LEAKS IN RAC SYSTEMS	The end user complies with most of the standard requirements. Some aspects need improvement. The company does not comply with 5.2.5 about the one-line diagram of the refrigeration system. 7.1 requires weekly monitoring of all points where leaks may develop using recommended methods to prevent leaks and recommends installing a fixed leak detection system. The company inspects the system on a quarterly basis. They should inspect it as often as indicated to reduce the leak rate.
MAINTENANCE SERVICE PROVIDER	In-house technicians take care of the refrigeration system maintenance. They are duly trained and have the tools as required by the standard.
COP ESTIMATION	This activity was not carried out because it was impossible to take measurements due to technical difficulties.

c) Achievements

We assessed the achievements based on the implementation of the recommendations. The implementation was partial due to the difficulties encountered. The company must make efforts to put them into practice to achieve the expected results.

1. ***Improvement and adaptation of the leak log as required in the standard for detection and control of refrigerant leaks in RAC systems:*** The project helped improve many maintenance aspects, but the technicians must make further efforts. The recommendation is to log all the operating data as suggested in the standard. The company implemented the recommendation partially (70%).
2. ***Develop a system flow chart:*** The company could not achieve this objective. The task is still pending.

3. ***Improve the leak detection methods to ensure system tightness:*** The technicians used electronic detectors, but they stopped using them after a while because they did not trust the devices.
4. ***Check the refrigeration system for leaks:*** This objective was met after the catastrophic leak mentioned above. The company shut down the system and checked the circuits separately. After that, the refrigerant system is inspected on a quarterly basis. The company should schedule weekly inspections as the standard recommends, particularly in the absence of an automated leak detection system. A daily visual inspection is not enough.
5. ***Install a leak detection system:*** There is a leak detection device in the machine room, but it is out of order (either not operational or damaged). The company should repair it to recover the automated leak detection functionality. The task was not completed. The company managers should consider it.
6. ***Install service valve caps and hose clamps:*** Maintenance technicians installed caps and hose clamps. The task was successfully completed.
7. ***Inspect valves with Teflon seals:*** The task was completed.
8. Repair or replace the valve adjustment screw in the main control: This valve was the source of the catastrophic leak. It was temporarily repaired.
9. ***Repair leaks:*** The company should repair all leaks. The in-house maintenance technicians implemented the detection, repair, and recharging procedures correctly. The recommendation was to improve leak detection as required in the standard for detection and control of refrigerant leaks in RAC systems. The company fully implemented the recommendation.
10. ***Acquire recommended tools and equipment:*** The COVID-19 pandemic made it difficult to implement the recommendation. The task is still in progress and will be completed in the short term.

The company achieved some improvements in the implementation of good practices in refrigeration. Central Madeirense implemented several recommendations to reduce refrigerant leak. Some suggestions are still pending.

3.5 CENTRAL MADEIRENSE Plaza las Americas supermarket

The CENTRAL MADEIRENSE Plaza las Americas supermarket is located in a mall east of Caracas. The project technical team selected the supermarket based on the large number of significant leaks over the years. Refrigeration is used to freeze and preserve food.

Refrigeration system

Singe stage direct expansion compressors control the supermarket refrigeration system, an R-22 system with a cooling capacity of 130 TR.

The compressors are located in a machine room. They include seven compressors independently connected compressors controlled by a central control panel. It has 15 cooling circuits and a 10 axial fan air-cooled condenser located at the top of the engine room. The evaporation section includes four cold rooms and eight refrigerated cabinets connected to the system. Besides, the supermarket has independent units and an air conditioning system outside the project scope.

CENTRAL MADEIRENSE PLAZA LAS AMERICAS	
Cooling capacity	130 TR
R-22 charge	500 *kg.*
Leak % in 2019	78%

Maintenance activities are managed through the company maintenance department in coordination with the supermarket maintenance manager. The company's in-house technicians carry out preventive and corrective maintenance activities in the supermarket.

The maintenance log is a valuable tool for assessing the system's performance and predicting potential failures. The log analysis revealed the system weaknesses and helped identify the aspects that needed particular attention to improve the operation and prevent failures.

Leak control

In 2019, the maintenance technicians added 392 kg of R-22 refrigerant. The total was added in several interventions.

Several leak points were identified and repaired before the diagnostic report. Unfortunately, an incident occurred after that. In the first week of January 2020 the refrigerant charge was released entirely as a result of a catastrophic leak. Apparently, the leak was caused by a broken pipe. After repairing it, the system was recharged with 504 kg of refrigerant.

The reported leakage for 2019 is high in relation to the system's total load. The data analysis shows a charge of 392 kg of R-22, 78% of the system's nominal load. This is well above any acceptable level.

After the catastrophic rupture at the beginning of the project, the technicians added 504 kg of refrigerant to the system to restore the operating conditions. Since the incident happened during the monitoring period, the amount was included within the leak control project. The incident is unfortunate in every way.

The company hopes to minimize the effects through the project implementation and is willing to take all the necessary corrective measures. Comparative analyzes with equivalent systems indicate that annual leak rates of 30% are high and unacceptable, even if operating in adverse conditions.

Project components

a) ***Compliance with environmental regulations:***

In-house technicians are responsible for the maintenance. They are not enrolled in the RACDA. Therefore, they do not comply with the regulations.

b) ***Technical training:***

The company maintenance department has certified maintenance technicians, and the staff assigned to the supermarket are duly certified.

c) ***Tools:***

The company maintenance department should acquire the following tools to prevent and control leaks as required in the standard for detection and control of refrigerant leaks in RAC systems:

a. Electronic vacuum gauge
b. Electronic scale
c. Cylinders for refrigerant recovery
d. Schrader valve core removal tool

d) ***Recovery and recycling:***

The company maintenance department has the skills to recover refrigerants, but they should acquire the required tools.

e) ***Compliance with the standard for detection and control of refrigerant leaks in RAC systems:***

The standard checklist shows a favorable situation. Some aspects need to be addressed to achieve compliance. The recommendations include these issues.

Recommendations

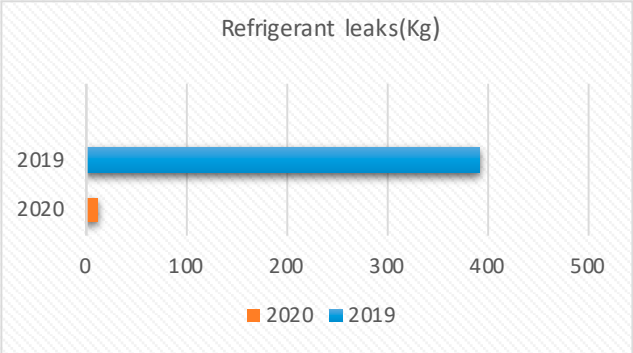
The Central Madeirense Plaza las America supermarket meets most of the maintenance requirements of the standard for detection and control of refrigerant leaks in RAC systems. However, they could improve the overall performance and reduce refrigerant emission through the following recommendations:

1. Enroll in the RACDA.
2. Strengthen the maintenance team by the implementation of standard requirements.
3. Log all incidents and interventions adequately.
4. Develop the one-line diagram of the refrigeration system and place copies on visible locations near each system component.
5. Install a leak detection system as required by the standard due to the refrigerant charge in the system.
6. Search for leaks in the system's circuits using appropriate detection methods and repair the leaks as soon as possible.

Results

a) Refrigerant leaks

LEAK RECORD (YEAR)	KG
2019	392
2020	12



At the beginning of the project, a catastrophic leak affected the system. After intensive work, a broken liquid pipe was repaired. The technicians charged 504 kg of refrigerant in the system. Later on, during the rest of the monitoring period, 12 kg had to be added after a leak in the oil receiver. 100 kg were charged to expand the system capabilities with a new cheese and charcuterie display.

After the incident, we decided to restart the project. The monitoring was resumed in February when the system was already repaired. The record of the catastrophic leak was kept out of the project. As a result, the scenario changed completely, with only 12 kg of refrigerant charge against 392 kg in 2019. This allows us to assess the impact of the corrective measures and the appropriate procedures to verify the system.

Under this new scenario, the results were satisfactory, with a leak reduction of 96.9% in one year. The system went from a leak rate of 78% of the system's nominal load to only 4%. The actual refrigerant consumption during 2020 cannot simply dismiss 504 kg lost in the catastrophic incident. However, its omission for the purposes of the project helps visualize how maintenance improvement contributes to leak reduction.

The standard requires a weekly leak detection routine using the appropriate tools. This recommendation is crucial in the absence of an automatic detection system.

b) Project components evaluation

AREAS	DESCRIPTION OF RESULTS
LEAK PREVENTION AND CONTROL	The project helped to improve many leak prevention and control aspects and incorporate others that the company had not considered so far. The company improved the event log with a more detailed logging system. The standard for detection and control of refrigerant leaks in RAC systems states that systems with a refrigerant capacity similar to the one in the supermarket should be inspected on weekly basis. The company should have a fixed leak detection system to warn of the presence of refrigerants in the environment.
ENVIRONMENTAL REGULATIONS	The company must comply with the environmental regulations in Decree No. 4335 when handling halogenated substances. In-house technicians take care of the refrigeration system maintenance. They are certified and have adequate tools to perform maintenance activities. They only need to enroll in the RACDA to comply with the mandatory regulation.
TECHNICAL TRAINING	The company maintenance department has demonstrated technical capacity and expertise for leak control. In-house technicians are duly certified. In case of outsourcing maintenance activities, the maintenance manager must ensure that the external technicians are duly certified as required in the standard for detection and control of refrigerant leaks in RAC systems.
TOOLS	The company has adequate tools, equipment, and instruments to perform the task. Since the refrigerant volume in the system is high, the company should acquire high-capacity refrigerant recovery cylinders. They should use electronic leak detectors to detect leaks as soon as possible. They should use digital vacuum gauges to verify the system tightness before charging refrigerant.
COMPLIANCE WITH THE DRAFT STANDARD FOR DETECTION AND CONTROL OF REFRIGERANT LEAKS IN RAC SYSTEMS	The company complies with most of the standard requirements. Some aspects need improvement. The company does not comply with 5.2.5 about the one-line diagram of the refrigeration system. 7.1 requires weekly supervision of all points where leaks may develop using recommended methods to prevent leaks and recommends installing a fixed leak detection system. The company inspects the system on a quarterly basis. They should inspect it as often as indicated to reduce the leak rate.
MAINTENANCE SERVICE PROVIDER	In-house technicians take care of the refrigerant system maintenance. They are duly trained and have the tools as required by the standard.
COP ESTIMATION	System thermodynamic data were obtained by field measurements. The COP is 3.92, which is within an acceptable range considering that the system is 15 years old.

c) Achievements

We assessed the achievement based on the implementation of the recommendations. The implementation was partial due to the difficulties encountered. The company must make efforts to put them into practice to achieve the expected results.

1. ***Improvement and adaptation of the leak log as required in the standard for detection and control of refrigerant leaks in the RAC system:*** The project helped improve many maintenance aspects, but the technicians must make further efforts to log data in a more detailed way. The recommendation is to log all the data suggested in the standard. The company implemented the recommendation partially (80%).
2. ***Develop a system flow diagram***: This objective could not be completed. The task is still pending.
3. ***Install service valve caps and tighten clamps:*** Maintenance technicians install valve caps and tighten the clamps. The task was successfully completed.
4. ***Check the refrigeration system for leaks:*** The objective was met after the catastrophic leak mentioned above. The company shut down the system and checked the circuits separately. After that, the refrigerant system is inspected on a quarterly basis. The company should schedule weekly inspections as the standard recommends, particularly in the absence of an automated leak detection system. A daily visual inspection is not enough.
5. ***Repair leaks:*** The company should repair all leaks. The in-house maintenance technicians implemented the detection, repair, and recharging procedures correctly. The recommendation was to improve leak detection in accordance with the standard. This company fully implemented the recommendation.
6. ***Install a leak detection system:*** The task was not completed. The company managers will consider it.
7. ***Acquire the recommended tools and equipment:*** The COVID-19 pandemic made it challenging to implement the recommendation. The task is pending and will be completed in the short term.

The company achieved some improvements in the implementation of good practices in refrigeration. Central Madeirense implemented several recommendations to reduce refrigerant leak.

Recommendations on corrective maintenance tasks were successfully implemented, while preventive activities were not carried out, although they have a stronger beneficial impact.

Maintenance managers must complete the pending tasks as soon as possible and reduce the refrigerant leak rate.