WEENTECH
Proceedings in
Energy
ISSN:2059-2353

Available online at www.weentechpublishers.com

WEENTECH Proceedings in Energy 6 (2020) 88-98

5th Virtual International Conference on Energy, Environment and Economics, ICEEE2020, 18-19 August 2020

IoT energy monitoring of a refrigeration installation

José Uslenghi, Angel Sapena-Bano*, Manuel Pineda-Sanchez, Jordi Burriel-Valencia, Ruben Puche-Panadero, Javier Martinez-Roman

Institute for Energy Engineering, Universitat Politècnica de València, 46022 València, Spain

Corresponding author's mail: asapena@die.upv.es

Abstract

This paper presents an application for the energy monitoring of commercial refrigeration facility, based on the concept and technology of the Internet of Things. The purpose of this application is to offer support to the activities of energy audits ant to the implementation of energy management systems, where the energy consumption of a facility must be characterized, or the saving measures applied must be supervised. Among the main features offered by this application are the possibility of remotely monitoring the operating conditions of a refrigeration cycle, as well as its energy consumption. Likewise, its Internet connectivity allows the monitoring system to be scaled up and to group the measurements of several refrigeration installations, which transforms this application into a powerful tool for benchmarking. Internet access also allows notifications via e-mail under particular conditions of the operation of any of the facilities. On the other hand, the application has the capacity to collect and to store in a database the measurements taken by the field devices, allowing the generation of historical reports showing the evolution of the operation of the installation. The main component of this application is the industrial gateway, SIMATIC IOT2040, which is used to read industrial communication buses and to connect to the Internet. Likewise, the open source software Node-RED has been the programming platform used for data reading and processing.

*Keywords: E*nergy monitoring; Energy consumption; Refrigeration installations

---

https://doi.org/10.32438/WPE.2620
Manuscript History
Receipt of completed manuscript: 26 July 2020
Receipt of Revised Manuscript: 10 August 2020
Date of Acceptance: 12 August 2020
Online available from: 18 August 2020

1. Introduction

The Internet of Things (IoT) is being increasingly used in the daily operation of many industries. It has been applied to the design of smart buildings in [1], to facilities management in [2], or to home automation in [3]. In particular, the use of IoT for monitoring the operation and energy consumption of refrigeration installations, as those in supermarkets, may lead to substantial energy savings via the improvement of its operating parameters, because of the analysis of its working performance [4], [5]. Additionally, the deployment of an IoT monitoring system in different installations may provide a simultaneous assessment of the impact of the improvements derived from this analysis. An added feature proposed in [6] is the use of the IoT system to detect failures of the refrigeration systems, so helping manage preventive and corrective maintenance programs.

For designing an IoT solution, such as the one proposed for monitoring a refrigeration system, two main architectures and business models have emerged in the technical literature, a vertical and a horizontal one [7]. The vertical approach is a monolithic one, where all the IoT elements are pre-selected, from hardware to the cloud. The IoT sensors and actuators are connected to the Internet directly, or using a local gateway, and linked to proprietary cloud-based services. This approach has the advantage of guarantying the compatibility among all the different elements of the system, it centralizes the support service to a single provider, and allows the developers to focus on the development of the application, avoiding interoperability issues. On the other hand, that implies a full dependence on a single vendor for any technical change or upgrade, and results in high acquisition and maintenance costs, due to this dependency. On the contrary, the horizontal approach leaves the freedom to select the single components, which guarantees a high level of modularity, customizability, and scalability, and allows the use of low- cost IoT components. Nevertheless, this approach requires a deep technical understanding of the communication capabilities of each component, and a considerable effort to achieve a smooth and error-free interoperability among the different components of the systems. In this work, the horizontal approach has been chosen, mainly due to its scalability and reduced cost.

Once selected the horizontal approach, a key constraint for the deployment of IoT based monitoring of refrigeration installations is the cost [8]. To reduce it, many authors propose the use of open-source hardware and software components. For example, in [9] a system is presented based on a low-cost, open-source hardware platform ESP8266, equipped with DS18B20 temperature sensors, and also on a free open-source LAMP (Linux + Apache + MySQL + PHP) server, hosted on a low-cost Raspberry Pi computer. Nevertheless, this approach has several shortcomings, which are addressed in the solution proposed in this work:

- open-source hardware lacks the reliability of industrial hardware platforms, which are designed to operate in harsh environments [10].
- the measurements are not correlated with the variables used by the main refrigeration, controller, such as the electrical power consumption, the state of the ventilators and condensers, the defrost cycles, etc.
- new temperature sensors must be installed, instead of reading the data coming from the existing sensors that are integrated in the control loop.

To overcome these drawbacks, the proposal presented in this work for monitoring the energy consumption of refrigeration installations takes an innovative IoT approach, whose main guidelines are the following ones:

- Collecting data from existing resources, so reducing the investment in new hardware. These types of installations are usually controlled by programmable logic controllers, which in many cases offer the possibility to access their internal working registers via standard protocols.

- Use of industrial hardware for new devices. Industrial-grade hardware, such as industrial gateways or three-phase power analysers, are designed to operate in harsh environments, which guarantees their reliability, much higher than in the case of non-industrial equipment. The use of industry 4.0 technologies [11] has result in a wide offer of industrial-grade IoT platforms, such as the one used in this project. Other authors propose instead the use of open-source hardware, as the ESP8266 platform in [9], but in this work a commercial, industrial hardware platform has been chosen, based on its greater reliability.
- Reduced footprint and non-invasive installation. All the new hardware must be packaged in a small footprint electrical cabinet, easy to install, with a minimum impact on the existing installation.
- Use of open-source software, which helps reduce the cost and facilitates the maintenance and possible upgrade of the IoT installation by trained personnel [12], [13].
- Possibility or local and secure remote access to the supervision panels of each individual installation [14], as well as a shared access to the data deployed on a cloud network for obtaining comparative analysis of all the installations connected to the application.

Based on these requirements, this paper presents the developed installation for IoT monitoring of q supermarket refrigerators installation. It is structured as follows: in Section 2, the installation is described, in Section 3, the IoT solution deployed is analysed, and in Section 4 the conclusions of this work are presented.

2. **Description of the installation**

The installation under supervision consists in the refrigeration system of three different supermarkets in Argentina. Each supermarket has various types of refrigerator cabinets, intended for different functions, and also operating at different temperatures, as in the case of fruit, meat or frozen cabinets. These refrigeration cabinets use a direct expansion system with an air-refrigerant evaporator and independent temperature control of compressors and condensers (see Fig. 1).

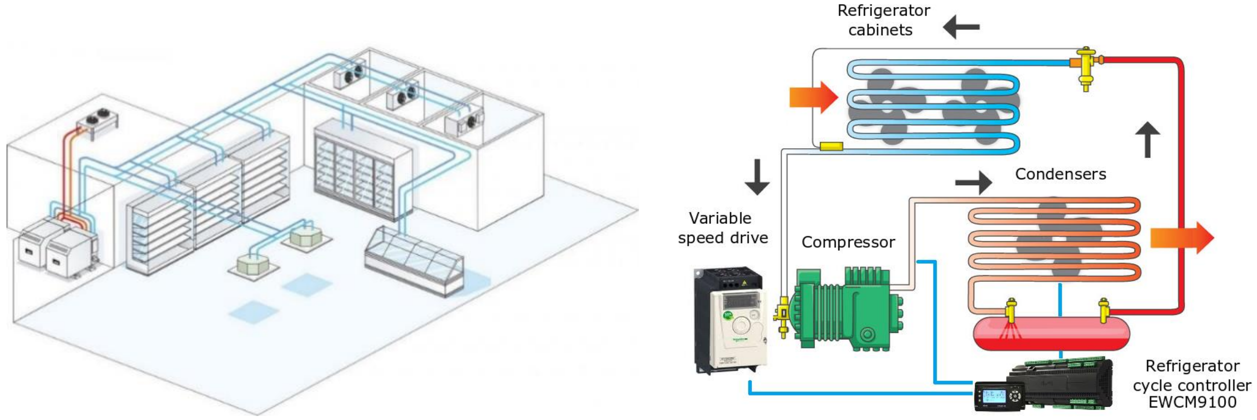


Fig. 1 Schematic of the supermarket refrigeration system under supervision (left) and of its control system (right).

An electronic controller, shown in Fig. 2, right, receives the information from the different sensors such as pressure, temperature or level of receiving tanks in the installation, and controls the actuation of the compressors, the condenser fans and the valves. This controller is the same for the three supermarkets, model EWCM9100, from Eliwell Ibérica, whose electrical schema is shown in Fig. 2, left.

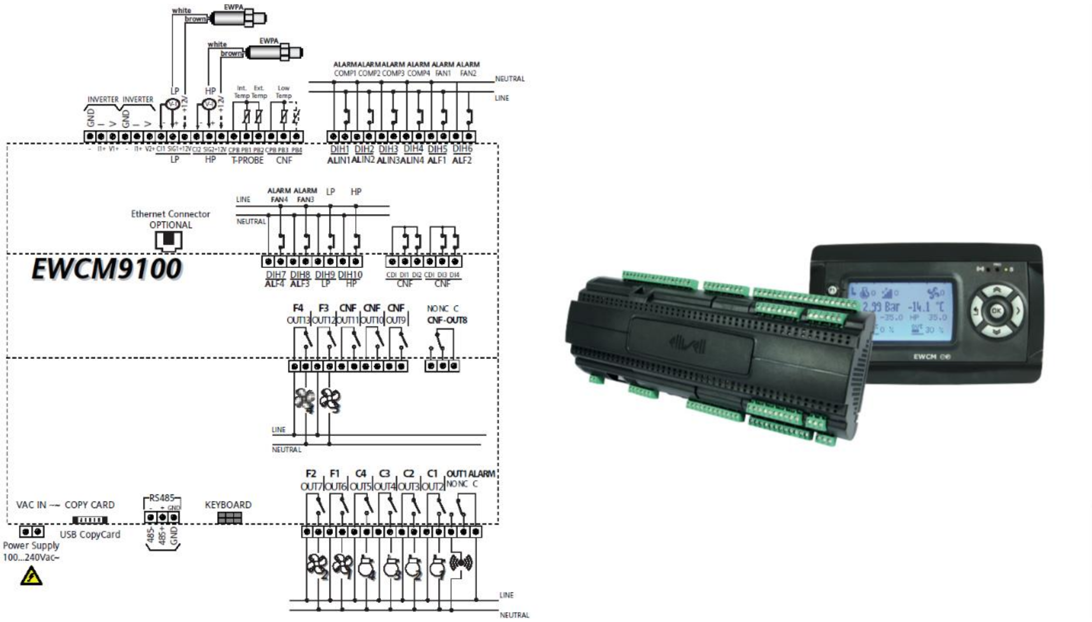


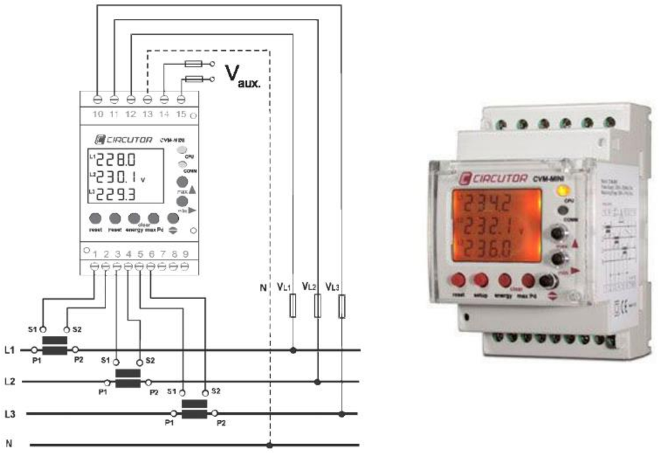
Fig. 2 Refrigerator cycle controller used in the installation, model ECM9110, from Eliwell Ibérica (right), and the electrical schema showing its connection to the installation (left).

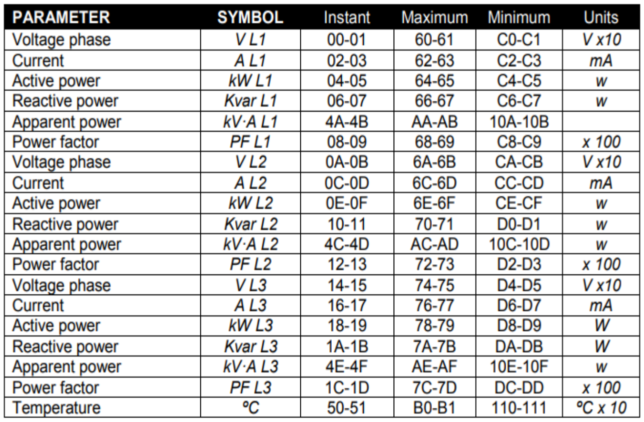
This controller has a built in Modbus interface. Modbus is a client/server communication protocol between devices connected on a network. It is simple and robust, openly published, royalty-free and easy to deploy and maintain. The Modbus standard used by Eliwell enables the use of the remote terminal unit (RTU) coding for data transmission. The EWCM9100 provides the access to every internal register through the Modbus interface, using the RS485 communications port. Fig. 3 shows some of the register corresponding to the ventilators control, among others.

INDEX	FOLDER	LABEL	ADDRESS	R/W	DESCRIPTION	DATA SIZE	CPL	RANGE	DEFAULT	EXP	M.U.	Notes
733	Ventilators	**336 - Cod2**	**4413**	RW	Delta 2 cut-off	WORD	Y	-1500 ... 9999	18	-1	°F	
734	Ventilators	**337 - dHAL**	**4414**	RW	HAL delta	WORD	Y	-1500 ... 9999	36	-1	°F	
735	Ventilators	**338 - HAL**	**4415**	RW	High alarm	WORD	Y	-1500 ... 9999	410	-1	°F	
736	Ventilators	**339 - dSFo**	**4416**	RW	Fixed offset dyn set	WORD	Y	-1500 ... 9999	36	-1	°F	
737	Ventilators	**340 - HPP1**	**4417**	RW	HP prev. limit 1	WORD	Y	-1500 ... 9999	374	-1	°F	
738	Ventilators	**341 - HPP2**	**4418**	RW	HP prev. limit 2	WORD	Y	-1500 ... 9999	392	-1	°F	
739	Ventilators	**342 - HPPb**	**4419**	RW	HP prev. alarm band	WORD	Y	-1500 ... 9999	18	-1	°F	
740	Ventilators	**343 - dLAL**	**4420**	RW	LAL delta	WORD	Y	-1500 ... 9999	36	-1	°F	
741	Ventilators	**344 - LAL**	**4421**	RW	Low alarm	WORD	Y	-1500 ... 9999	410	-1	°F	
742	Ventilators	**345 - InLPt**	**4422**	RW	INV min power limit	WORD	Y	-1500 ... 9999	932	-1	°F	
743	Ventilators	**346 - dSdo**	**4423**	RW	Dyn. Offset Dyn. Set	WORD	Y	-1500 ... 9999	90	-1	°F	
744	Ventilators	**347 - dSLdo**	**4424**	RW	Min Dyn.Offs.Dyn.Set	WORD	Y	-1500 ... 9999	54	-1	°F	
745	Ventilators	**348 - dSMEt**	**4425**	RW	MaxExtTemDynSet	WORD	Y	-1500 ... 9999	860	-1	°F	
746	Ventilators	**349 - LdSP**	**4426**	RW	Min. dynamic set	WORD	Y	-1500 ... 9999	860	-1	°F	
747	Ventilators	**350 - SCt1**	**4427**	RW	Minimum sub-cooling	WORD	Y	-1500 ... 9999	54	-1	°F	
748	Ventilators	**351 - SCt2**	**4428**	RW	Maximum sub-cooling	WORD	Y	-1500 ... 9999	108	-1	°F	
749	Ventilators	**352 - SCd1**	**4429**	RW	Sub-cooling delta1	WORD	Y	-1500 ... 9999	18	-1	°F	

Fig. 3 Ventilators related Modbus registers in the EWCM9100 controller.

To supervise the installation it is needed, in addition to the PLC that controls the refrigeration cycle, a three-phase power analyser that is able to measure the electrical power and energy absorbed by the installation. To achieve this goal, a Circutor CVM-MINI device, shown in Fig. 4, has been selected. As in the case of the EWCM9100 controller, this power analyser has a built-in Modbus RTU interface which provides a reading access to the registers where the electrical measures are stored. Fig. 4, right, shows some of these registers.





PARAMETER	SYMBOL	Instant	Maximum	Minimum	Units
Voltage phase	*V L1*	00-01	60-61	C0-C1	*V x10*
Current	*A L1*	02-03	62-63	C2-C3	*mA*
Active power	*kW L1*	04-05	64-65	C4-C5	*w*
Reactive power	*Kvar L1*	06-07	66-67	C6-C7	*w*
Apparent power	*kV·A L1*	4A-4B	AA-AB	10A-10B	
Power factor	*PF L1*	08-09	68-69	C8-C9	*x 100*
Voltage phase	*V L2*	0A-0B	6A-6B	CA-CB	*V x10*
Current	*A L2*	0C-0D	6C-6D	CC-CD	*mA*
Active power	*kW L2*	0E-0F	6E-6F	CE-CF	*w*
Reactive power	*Kvar L2*	10-11	70-71	D0-D1	*w*
Apparent power	*kV·A L2*	4C-4D	AC-AD	10C-10D	*w*
Power factor	*PF L2*	12-13	72-73	D2-D3	*x 100*
Voltage phase	*V L3*	14-15	74-75	D4-D5	*V x10*
Current	*A L3*	16-17	76-77	D6-D7	*mA*
Active power	*kW L3*	18-19	78-79	D8-D9	*W*
Reactive power	*Kvar L3*	1A-1B	7A-7B	DA-DB	*W*
Apparent power	*kV·A L3*	4E-4F	AE-AF	10E-10F	*w*
Power factor	*PF L3*	1C-1D	7C-7D	DC-DD	*x 100*
Temperature	*ºC*	50-51	B0-B1	110-111	*ºC x 10*

Fig. 4 Circutor CVM_MINI three-phase power analyser (middle) used for the acquisition of electrical power and energy consumption of the installation, showing its electrical connection to the installation (left) and some of its internal data registers, accessible using the Modbus protocol (right).

Finally, a communication controller has been installed, that is able to collect data from the field devices, and to store, process and send the results to the IoT cloud. In this case, the industrial gateway Siemens SIMATIC IOT2040 has been selected. It has been integrated in an electrical cabinet, along with the CVM-MINI power analyser, and connected to it and to the EWCM9100 controller using a Modbus serial network. This cabinet has been installed in each of the three supermarkets under supervision. Fig. 5 shows its electrical schema, as well as the connection to the EWCM9100 controller Modbus port, and Fig. 6 shows its physical layout.

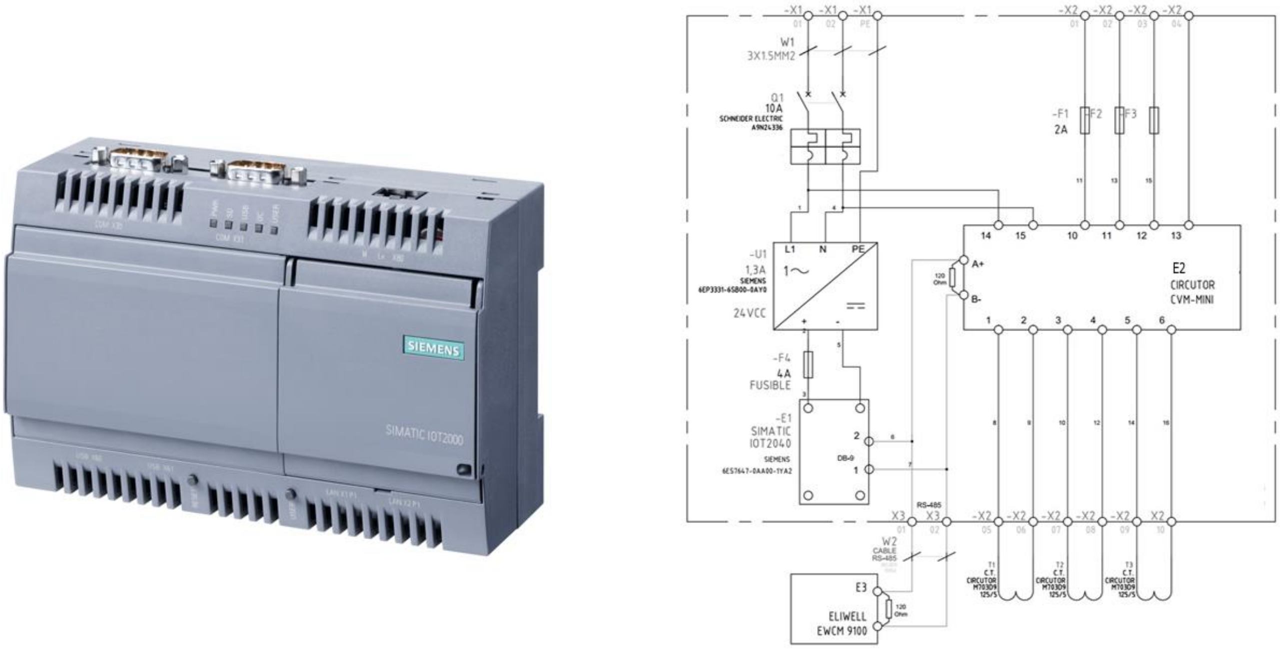


Fig. 5 SIMATIC IOT2040 gateway used in this project (left) and its connection to the EWCM9100 controller and the CVM-MINI power analyser using a Modbus serial network, integrated in a custom-built electrical cabinet (right).

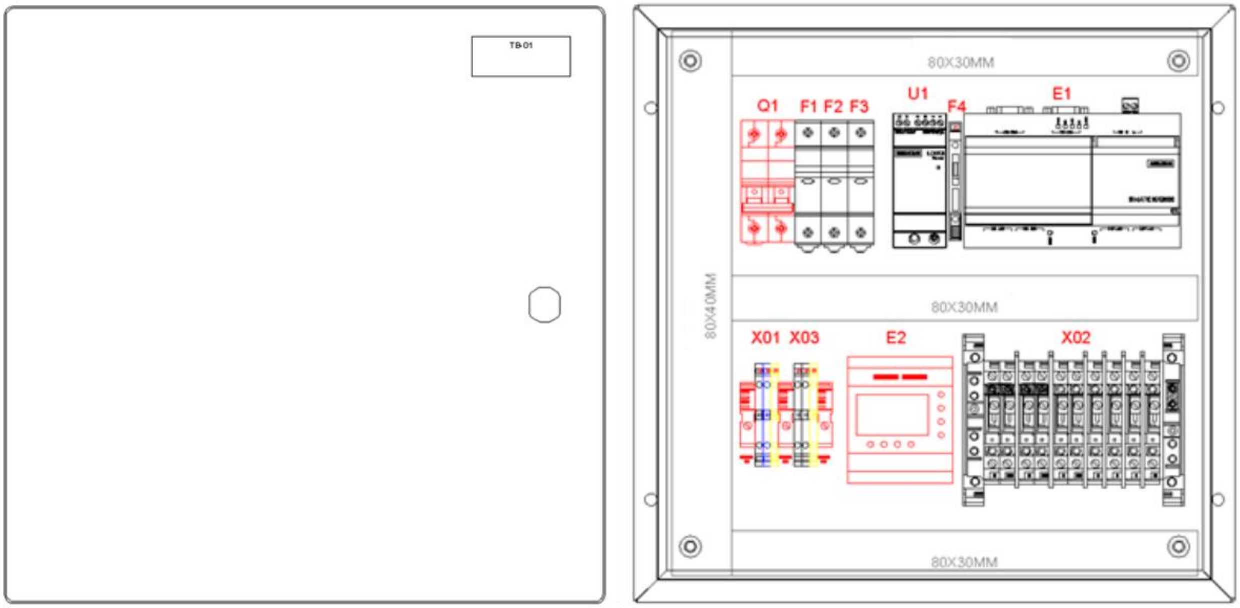
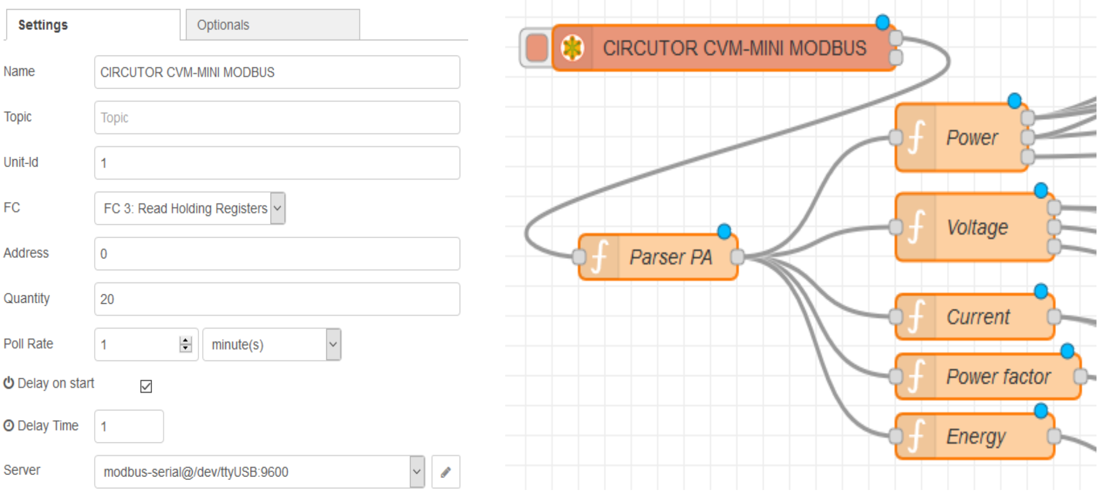


Fig. 6 Electrical cabinet built for housing the additional components needed in each supermarket. Left: output view. Right: internal view, showing the SIMATIC IOT2040 gateway (E1), the CVM-MINI power analyser (E2), the power source (U1), and the switchgear, and the connections for the current transformers (X02) and the Modbus network (X01-X03).

3. **Description of the IoT solution implemented**

The IoT solution implemented in this project consists of the components shown in Fig. 7. It is based on the use of Node-RED, a programming tool for wiring together hardware devices, APIs and online services. It is programmed using a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime in a single-click. The Node-Red server runs in the SIMATIC IOT2040 gateway.

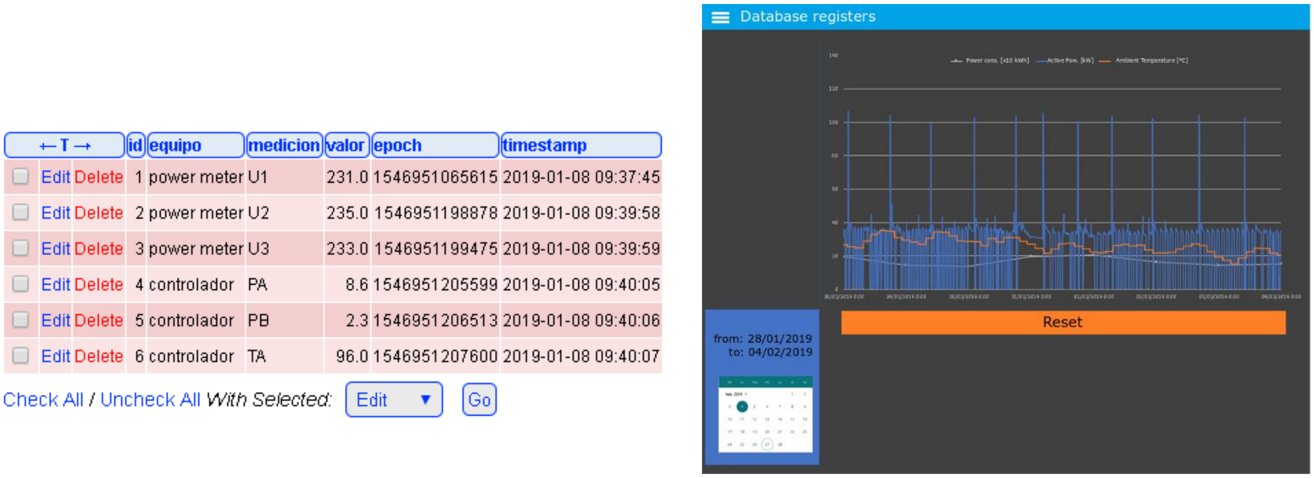
To wire the different components of the installation, specialized Node-RED flows have been used. The communications with the EWCM9100 controller and the CVM-MINI through Modbus has been programmed using the node-red-contrib-modbus (https://flows.nodered.org/node/node-red-contrib-modbus), which provides TCP, C701, Telnet, Serial, RTU buffered, and ASCII Modbus connections. Data is sent using long message transfers (20 registers) to maximize the communications performance, as seen in Fig. 7, left, and it is splitted in its individual components using a custom-made parser function, shown in Fig. 7, right.



Name: CIRCUTOR CVM-MINI MODBUS
Topic: Topic
Unit-Id: 1
FC: FC 3: Read Holding Registers
Address: 0
Quantity: 20
Poll Rate: 1 minute(s)
Delay on start ☑
Delay Time: 1
Server: modbus-serial@/dev/ttyUSB:9600

Fig. 7 Node-RED flow for collecting data from the CVM-MINI power analyser. Every minute a buffer of data is collected in a single Modbus message (left), which is splitted into the electrical quantities of interest in the flow (right). A similar flow has been implemented for collecting data from the EWCM9100 controller.

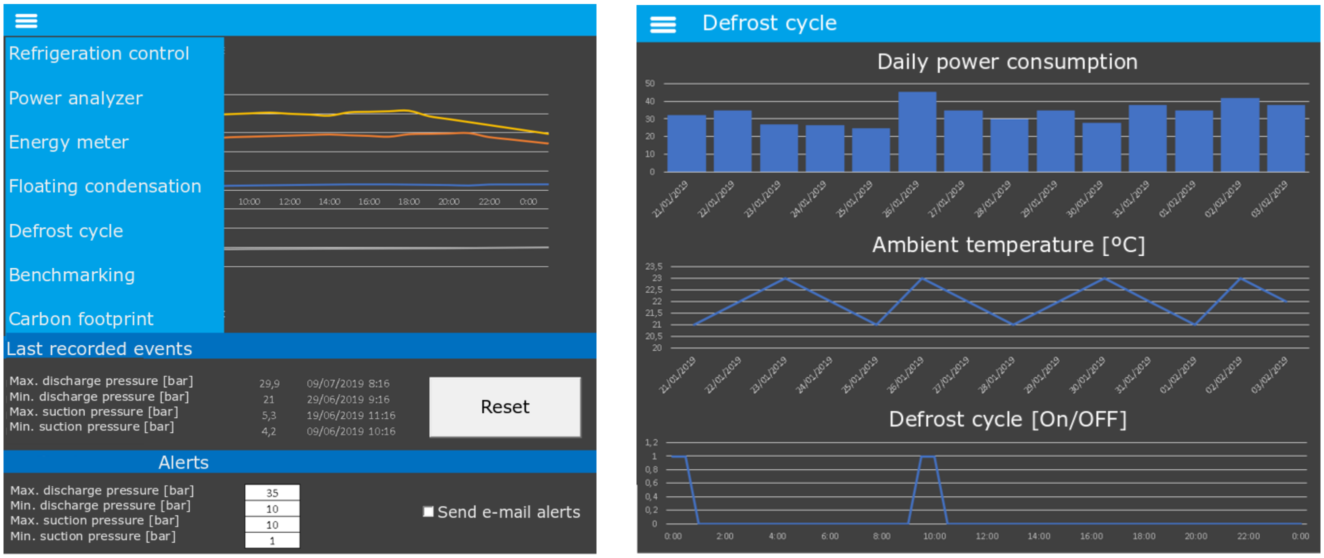
The data collected from the devices is stored in a SQLite database, which is preinstalled in the SIMATIC IOT2040 operating system. Table management has been performed using phpLiteAdmin 1.9.7 (https://www.phpliteadmin.org/). Data collected form the EWCM9100 and the CVM-MINI power analyser are inserted every minute in the database, using a specialized node, the node-red-node-mysql (https://flows.nodered.org/node/node-red-node-mysql). Fig. 8, left, shows a snapshot of the database contents and Fig. 8, right, shows its graphical representation in a given period of time, build using the Node-RED dashboard functionality (https://flows.nodered.org/node/node-red-dashboard). Further data aggregations are performed in the database for obtaining reports for a selectable period. These reports can be obtained in a built-in visualizer, using Node-RED dashboard, or exported with a .csv format to be further processed with a spreadsheet software.



←T→		id	equipo	medicion	valor	epoch	timestamp
☐	Edit Delete	1	power meter	U1	231.0	1546951065615	2019-01-08 09:37:45
☐	Edit Delete	2	power meter	U2	235.0	1546951198878	2019-01-08 09:39:58
☐	Edit Delete	3	power meter	U3	233.0	1546951199475	2019-01-08 09:39:59
☐	Edit Delete	4	controlador	PA	8.6	1546951205599	2019-01-08 09:40:05
☐	Edit Delete	5	controlador	PB	2.3	1546951206513	2019-01-08 09:40:06
☐	Edit Delete	6	controlador	TA	96.0	1546951207600	2019-01-08 09:40:07

Fig. 8 Database snapshot of the recorded sensors data of the installation (left) and its graphical representation during a time interval (right).

The database allows reporting about the daily operation of the installation, such as power consumption, On/Off cycle states, etc. (see Fig. 9), and aggregated data over a selected period of time.



Last recorded events

Max. discharge pressure [bar]	29,9	09/07/2019 8:16
Min. discharge pressure [bar]	21	29/06/2019 9:16
Max. suction pressure [bar]	5,3	19/06/2019 11:16
Min. suction pressure [bar]	4,2	09/06/2019 10:16

Alerts

Max. discharge pressure [bar]	35
Min. discharge pressure [bar]	10
Max. suction pressure [bar]	10
Min. suction pressure [bar]	1

Fig. 9 Main menu for monitoring the installation (left) and Database snapshot of the recorded sensors data of the installation (left) and its graphical representation during a time interval (right).

Access to the main menu can be done either locally or through a VPN to the internal network of each supermarket.

Finally, besides providing a detailed view of each of the supermarkets refrigeration installation, a single view with key performance indicators (KPI) from all the connected supermarkets has been designed. The selected KPI has been defined as the energy consumption per month and per square meter of the installation. This indicator is calculated locally at each supermarket and sent to an MQTT message broker, CloudMQTT, using a Node-RED "mqtt out" component. Data from the rest of branches is collected using the "mqtt in" component, and in this way, a benchmarking dashboard has been built showing the combined energy indicators of all the branches in a single dashboard, as shown in Fig. 10.

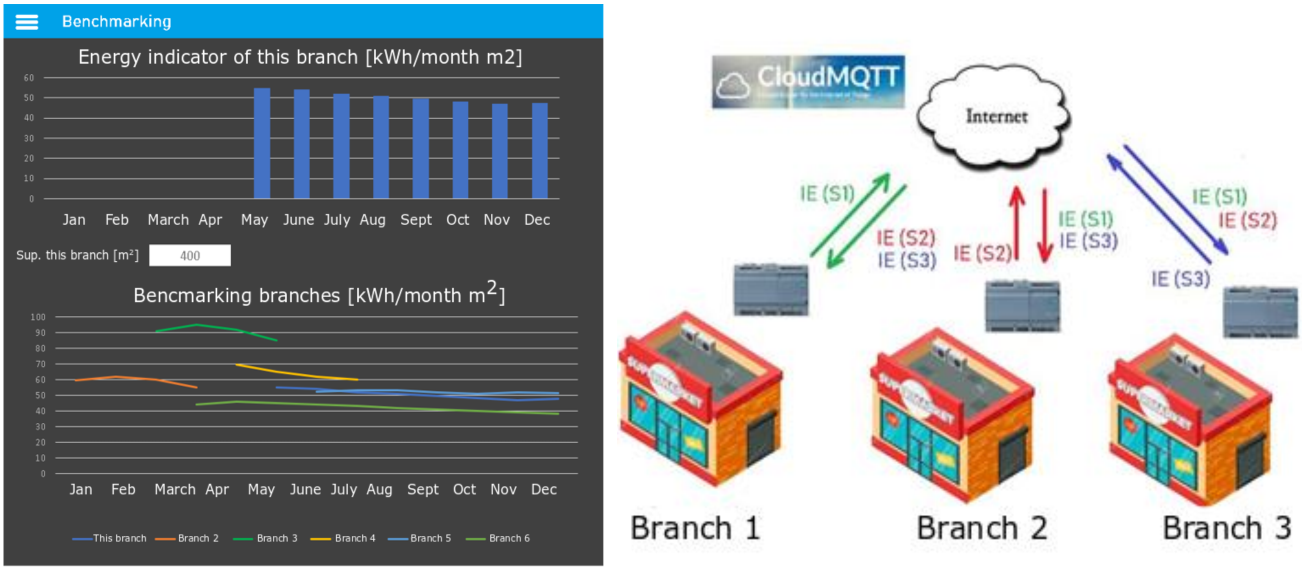


Fig. 10 Comparative display (left) with the energy indicators that each installation sends to the CloudMQTT message broker (right).

3. Conclusions

The IoT solution developed for the monitoring of the refrigerators installation in different supermarkets has been presented in this work. The proposed solution relies on collecting relevant installation data from existing controllers and from new power meters, linked with a serial Modbus network to an industrial gateway, running Node-RED. Supervisory screens are designed using Node-RED dashboards that can be accessed either locally or remotely, through dedicated VPNs. Besides, KPIs from each installation are sent to a MQTT message broker, which makes it possible to design a single panel with the simultaneous values of the supermarket KPIs. The proposed solution offers a high reliability, being based on industrial components designed to operate in harsh environments (Siemens SIMATIC IOT2040 gateway, Circutor CVM-MINI three-phase power analyser), it has a minimal footprint (a small electrical cabinet), it is easy to install (it needs just three current transformers), and it has a reduced cost, being based on open source software components. In this way, a scalable platform can be used to increase the energy performance of refrigerator installations.

ORCID Id of authors

Sapena-Bano, Angel:	https://orcid.org/0000-0002-3888-6498
Pineda-Sanchez, Manuel:	https://orcid.org/0000-0001-7844-8831
Burriel-Valencia, Jordi:	https://orcid.org/0000-0002-1680-4412
Puche-Panadero, Ruben:	https://orcid.org/0000-0003-2090-1941
Martinez-Roman, Javier:	https://orcid.org/0000-0001-7544-8481

Acknowledgements

This work was supported by the Spanish "Ministerio de Ciencia, Innovación y Universidades (MCIU)", the "Agencia Estatal de Investigación (AEI)" and the "Fondo Europeo de Desarrollo Regional (FEDER)" in the framework of the "Proyectos I+D+i - Retos Investigación 2018", project reference RTI2018-102175-B-I00 (MCIU/AEI/FEDER, UE

References

[1] Minoli, D., Sohraby, K. & Occhiogrosso, B. (2017) IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems. IEEE Internet of Things Journal. 4, 269-283.

[2] Konanahalli, A., Marinelli, M. & Oyedele, L. (2020) Drivers and Challenges Associated With the implementation of Big Data Within U.K. Facilities Management Sector: An Exploratory Factor Analysis Approach. IEEE Transactions on Engineering Management. 1-14.

[3] Tayyaba, S., Khan, S. A., Ashraf, M. W. & Balas, V. E. (2019) Home Automation Using IoT. Intelligent Systems Reference Library. 343-388.

[4] Derens-Bertheau, E., Osswald, V., Laguerre, O., Alvarez, G. (2015) Cold chain of chilled food in France. Int. J. Refrig. 52, 161–167.

[5] Giusto, E., Gandino, F., Greco, M.L., Grosso, M., Montrucchio, B., Rinaudo, S. (2019) An investigation on pervasive technologies for IoT-based thermal monitoring. Sensors. 19, 663.

[6] De Jesús Ballestas Ortega, O. & Villa, J. L. (2018) Failures Monitoring in Refrigeration Equipment Communications in Computer and Information Science. 136-146.

[7] Mazzei, D., Baldi, G., Montelisciani, G. & Fantoni, G. (2018) A full stack for quick prototyping of IoT solutions. Annals of Telecommunications. 73, 439-449.

[8] Krčo S, Pokrić B, Carrez F (2014) Designing IoT architecture(s): a European perspective. In: 2014 IEEE world forum on internet of things (WF-IoT). 79–84.

[9] Ramírez-Faz, J., Fernández-Ahumada, L. M.; Fernández-Ahumada, E. & López-Luque, R. (2020) Monitoring of Temperature in Retail Refrigerated Cabinets Applying IoT Over Open-Source Hardware and Software. Sensors. 20, 846.

[10] Aheleroff, S., Xu, X., Lu, Y., Aristizabal, M., Velásquez, J. P., Joa, B. & Valencia, Y. (2020) IoT-enabled smart appliances under industry 4.0: A case study. Advanced Engineering Informatics. 101043.

[11] Trappey, A.J.C., Trappey, C.V., Hareesh Govindarajan, U., Chuang, A.C., Sun, J.J. (2017) A Review of essential standards and patent landscapes for the internet of things: a key enabler for industry 4.0. Advanced Engineering Informatics. 33, 208-229.

[12] Aghenta, L. O. & Iqbal, M. T. (2019) Low-Cost, Open Source IoT-Based SCADA System Design Using Thinger.IO and ESP32 Thing. Electronics. 8, 822.

[13] Qutqut, M. H., Al-Sakran, A., Almasalha, F. & Hassanein, H. S. (2018) Comprehensive survey of the IoT open-source Oss. IET Wireless Sensor Systems. 323-339.

[14] Stergiou, C., Psannis, K. E., Gupta, B. B. & Ishibashi, Y. (2018) Security, privacy & efficiency of sustainable Cloud Computing for Big Data & IoT Sustainable Computing. Informatics and Systems. 19, 174-184.