Monitoring and Control of a Cooling System in a Commercial Store

Ricardo Freitas, Filomena Soares, Vitor Vieira, Jose Machado

***Abstract*-This paper presents a case-study for the optimization, the monitoring and the automatic control of a refrigeration system in a commercial store. The existing controllers were replaced by Omron temperature controllers, connected to an industrial network and linked to a central computer for data monitoring and temperature control using a LabView software. In case of an alarm occurrence, this system includes a routine that automatically sends a GSM message to alert the person responsible for the store. This functionality is not yet available in commercial systems.**

***Index Terms* — Automation, Monitoring System, Process Control, Programmable Logic Controllers.**

1. INTRODUCTION

The objective of a refrigeration plant is to cool down articles or substances and maintain them at a temperature lower than the ambient temperature. Therefore, refrigeration can be defined as a process that removes heat.

Refrigeration systems are thus fundamental to ensure the quality and preservation of the various products in the food industry, including the conditioning store of perishable food products and the conservation of pre-frozen products. Refrigeration slows down the proliferation of bacteria in food: the technique used in practice is based on the extremely rapid and intense action of the cooling effect, which allows the organoleptic properties of the food to be preserved, thus extending the conservation time.

In the cooling process two methods are used: mechanical refrigeration and refrigeration by ice [1]:

• In Mechanical Refrigeration refrigerant fluids are used. The fluid follows through the different stages of the system, where heat is absorbed and transported to another area, through fluid compression, condensing, expansion and evaporation processes. A refrigerant, therefore, must have properties whereby it evaporates at a low temperature and pressure, absorbing heat, and then gives up this heat by condensing at a higher temperature and pressure. This procedure requires energy.

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Commonly, the mechanical method of cooling is employed in domestic use and in commercial stores.

• Refrigeration by ice is seldom employed. This method is based on a two compartment thermal isolated system where ice is placed in the upper compartment and the food in the other room. Refrigeration process lasts until the ice melts.

The main refrigeration units used for the conservation of food are: Cold rooms, Maturing rooms, Cabinets, Display cases.

The systems designed and installed for both industrial and retail applications are based on standard procedures and techniques. In particular, butcher stores follow the HACCP system (Hazard Analysis and Critical Control Point) [2] that guaranty the quality and the meat conservation. One of the principles of this system is the recording of temperature at pre-determined intervals. Often, this is done twice a day by an employee, generally in the morning and in the evening.

Formerly, the temperature control of the cooling systems was carried out by analog thermostats governing the maximum and minimum temperatures. Today, electronic temperature controllers are used for automatically set the maximum and minimum temperatures, define the temperature display, specify the thawing process and program the alarm activation. Some controllers have the possibility of being placed and connected to a network for a continuous registration of temperature profiles [3].

A monitoring system for cooling processes is then characterized by the measurement of temperature in pre-determined moments, including the generation of alarms, as for example in case of occurrence lack of energy.

The need for measurement of temperature led to the emergence of new software for data monitoring. There are some commercial interactive refrigeration systems from specialized companies in the field.

The ADAP-KOOL system from Danfoss® Company is an example [4]. This system includes a refrigeration control system, AKM that allows the temperature monitoring via a Personal Computer (PC) which includes the following functionalities:

- Centralized management;
- Optimized cold system;
- Alarms;
- Emergency operations;
- Data acquisition and communication.

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ADAP-KOOL® system can be employed in small, medium and large equipments.

Carel systems are another example of commercial refrigeration systems [5].

An example of commercial software is the Portuguese company Domopor holding system TCS.wireless. This system allows the temperature registration from wireless probes, placed in the cold stores [6]. Among others, the system has the following characteristics:

- Possibility of sending the information to the maintenance companies;
- Alarm generation;
- Real-time control of occurrences;
- Temperature monitoring in a centralized computer;
- Elaboration of reports, graphs and statistics;
- Report printing;
- Remote access, via the Internet, to temperature profiles in each store and equipment, guarantying the efficiency of the refrigeration system.

This paper is focused on the optimization of a refrigeration system, still manually operated, in order to improve system efficiency. The existing controllers were replaced by Omron [7] temperature controllers, connected to an industrial network and linked to a central PC for data monitoring and temperature control. In case of alarm, this system includes a GSM (Global System for Mobile communications) functionality, which is not available in any commercial systems in the market.

The paper is divided in four sections. In section 1, a brief overview of the subject as well as an overview of the commercial equipment existent is presented. Section 2 explains the commercial store (butcher) layout. Then, in section 3, the monitoring system is explained and in section 4, the control system is described. Finally, the conclusions and the future work are detailed.

2. The Butcher shop

The refrigeration system consists of four elements: a compressor, a condenser, an expansion valve and an evaporator. The entire system is filled with a refrigerant fluid whose thermodynamic features changes. The system is controlled by an electronic thermostat which gets the temperature from the cold room and switches the system devices in accordance to the measurement temperature and the set point temperature in the controller.

The butcher shop has five display cases for meat and three refrigerated cold storage rooms. The display case is composed by: one fan of evaporator with heater resistances; a solenoid valve to control movement of fluid refrigerant; temperature sensors - for room temperature display and for the defrost process and one digital controller of Carel company to control the refrigeration process. These five display cases are linked to the compressor located outside the shop.

The three refrigerated cold storage rooms have different objectives. One room is intended to freezing, and has an evaporator with heater resistances for defrost. The shop has a room to conservation and another for meat cutting, where the meat is processed. Each room has a compressor group and a digital controller of Eliwell, model ID974 [8].

The cold storage rooms and display cases have a dedicated electrical board. This board allows the power down of each group compressor. It has an indication light of thermal relay for protection of compressor and an indication light for start and stopping the compressors.

The layout of the butcher shop is illustrated in Fig 1.

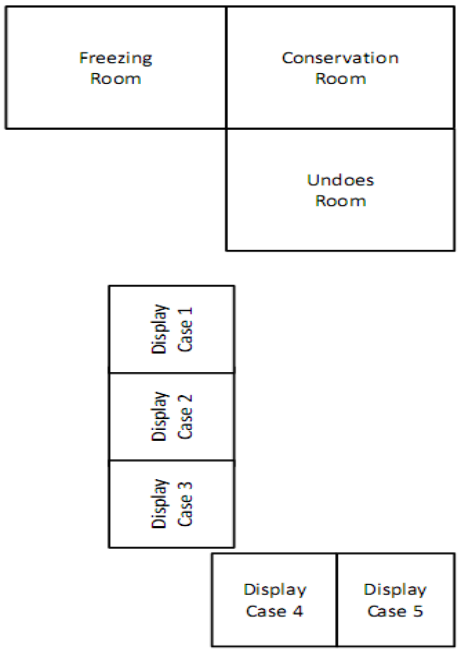

Fig 1 Layout of the butcher store

3. The monitoring system

In the following sub-sections the monitoring system is presented and explained in detail.

A. *System Description*

This project is focused on the development of a monitoring and control system for a refrigeration process. It records the temperature at pre-determined hours from the different temperature controllers, installed in the display cases and in the cold rooms. These temperatures profiles are stored in a Programmable Logic Controller (PLC). This PLC is connected to a Personal Computer where an application developed in LabView [9] collects the temperature, to be saved in a Microsoft Access 2007 database. This application has several functionalities detailed in the following section.

B. *Software Features*

The LabView program allows displaying the graphics of the temperature profiles of the refrigeration room or the

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showcases (after selecting the room/showcase identification number and the date). The program shows the maximum, minimum and average temperature in each refrigeration device. The software available in the market for monitoring systems is implemented in Visual C++ or MFC programming languages. This case-study is a new approach for monitoring and control of a commercial store using graphical language LabView.

The monitoring program allows the generation of reports of the temperatures profiles (in Excel format or PDF), to be presented to the authorities. Also, the system allows performing a statistics analysis and a configuration of the defrost parameters The system includes an alarm generation function in case of a power failure or some malfunction that automatically sends a message via GSM to the person responsible for the store.

C. System Overview

The equipment used in the monitoring system is a personal computer, an OMRON Programmable Logic Controller model CJ1M with communication module SC41, and two temperature controllers model E5CN with RS485 communication.

The E5CN belongs to a general-purpose family of temperature controllers. The main features of this controller are the choice of control mode (Proportional, Integral and Derivative type controller, PID, or ON/OFF controller), the type of control output such as relay, relay hybrid, linear current or voltage. This controller can easily be configured, either manually or through connection to the PC with parameter cloning, setting and tuning.

The communication between the PC and the PLC is established by the standard transmission RS232 and the protocol of communication is the proprietary Factory Interface Network Service (FINS) [10], owned by OMRON (Figure 2).

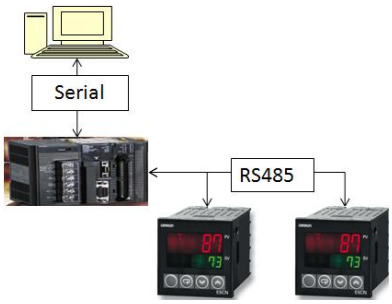

Fig 2 Overview transmission method

The RS-485 is a transmission method capable of providing robust communication in a multipoint configuration, which can connect up to 32 network devices, separated by several hundred meters away. This method of transmission is widely used in industry control systems because the cost of installation and maintenance for local networks is low. Through the RS485 network different types of communication protocols can be used. The protocols of communication available on the temperature controller E5CN are CompoWay/F and Modbus® [11]. The Modbus® is a general purpose communication protocol which allows the connection to PLCs of other manufacturers.

The communication between the PLC and the temperature controllers is performed by RS485 transmission method and using the protocol of communication Compoway/F from OMRON.

An overview of the transmission method and the communication protocol between PC and PLC and temperature controllers can be seen in Figure 2 and Figure 3.

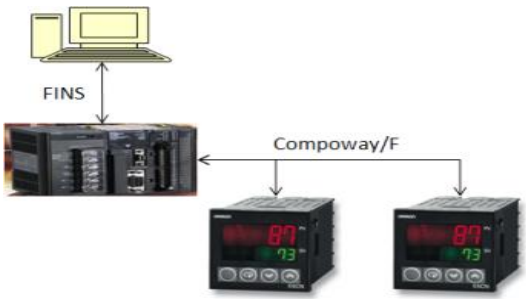

Fig 3 Overview of communication protocol

D. Collection of temperature of temperature controller by PLC

The collection of temperature profiles from the different controllers located in the display cases/cold rooms is done at pre-determined hours through the PLC. These intervals can be set to different values in the PLC Data Memory (DM) area. The PLC request to the temperature controller in display case, wait for response and then store temperature information in memory. The algorithm used in PLC to obtain temperature is represented in the flowchart (Figure 4).

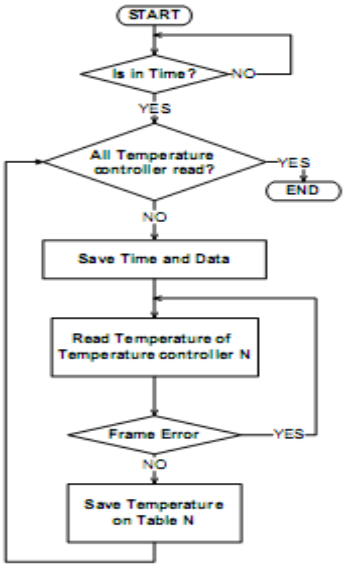

Fig 4 Flowchart of temperature profiles acquisition

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E. Temperatures transmission to LabView

The application in LabVIEW installed in the PC is used to collecting and storing the temperature in a database. To communicate with PLC it is necessary to use FINS Protocol. The algorithm developed to transfer temperatures values to tables is shown in the flowchart in Figure 5.

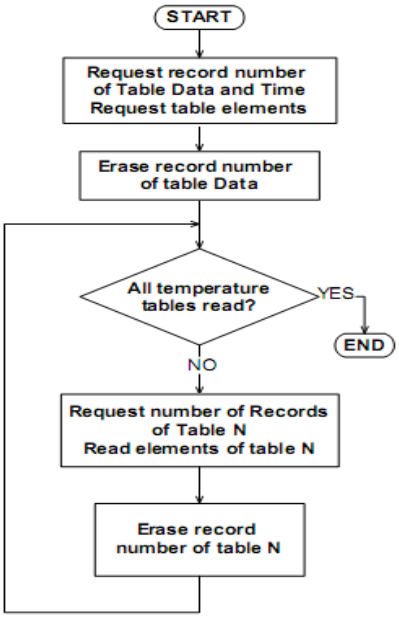

Fig 5 Flowchart of transference between PLC and LabView

F. Microsoft Access Database

The database is used to permanently store the temperatures profiles recorded by the PLC. This database was developed in Microsoft Access 2007. For the communication with LabView software it was used a module developed by National Instruments, called Database Connectivity Toolset 1.0.1 [12].

The LabView Database Connectivity Toolkit is an easy tool that allows quick connection to local and remote databases and the operations of Structured Query Language (SQL). The program allows the connection to Microsoft Access, SQL Server, and Oracle. The advantage of using the database versus file system are the reduction of the development time, sharing of data in the application level, data security, data integrity, reduction of redundancy and the modified data are immediately available.

The design of the database is done by the construction of the Entitiy - Relantionship diagrams, reflecting the perception that users have to the data, which are independent from any physical implementation. The diagram entities - relationships uses a graphic convention which aims to give a simple, intuitive and fast understanding of the configured entities and the corresponding relationships between them. The attributes or data fields of an entity provide relevant information, a particular entity and the attributes characterizing an entity.

The database developed consists of three tables with different purposes:

- Chamber - features cold room/display cases: Number of room/display, description (display or cold room), maximum and minimum temperature allowed;
- Record – store the temperature of each chamber. The table fields are: register number, date of registration, time of registration, chamber temperature, chamber number;
- User: save the data of the users of the program in LabView, such as the login and password of employees, telephone number, position, phone, priority of transmission.

The relationships between tables are presented in Figure 6.

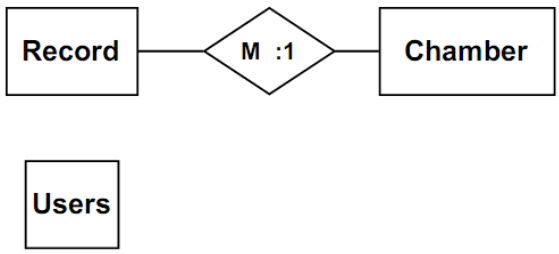

Fig 6 Diagram Entity - Relationship

To view the graph of the temperature profile over 24 hours, it is necessary to select the registration date of temperature and the cold room/ display case identification number (Figure 7).

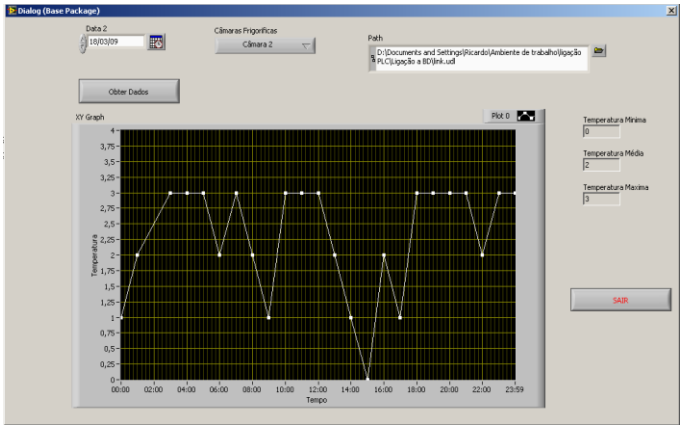

Fig 7 Visualization of temperature in cold room during 24 hours

The program generates a SQL query to obtain the temperature values. The program also shows maximum, minimum and average temperatures. These values are searched through SQL query, shown in Figure 8.

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SQL QUERIES

SELECT HORA, TEMPERATURA FROM REGISTO WHERE
DATA=#MM-DD-YY# AND CAMARA=NUMERO

SELECT MAX(TEMPERATURA) FROM REGISTO WHERE
DATA=#MM-DD-YY# AND CAMARA=NUMERO

SELECT MIN(TEMPERATURA) FROM REGISTO WHERE
DATA=#MM-DD-YY# AND CAMARA=NUMERO

SELECT AVG(TEMPERATURA) FROM REGISTO WHERE
DATA=#MM-DD-YY# AND CAMARA=NUMERO
```

Fig 8 SQL queries

G. Software Interface

When the user starts the program, the window to identify the user is shown, where he/she enters his/her login and password, Figure 9. By input a password it prevents the access of an unauthorized person to the program, thus protecting the data cold room and display case.

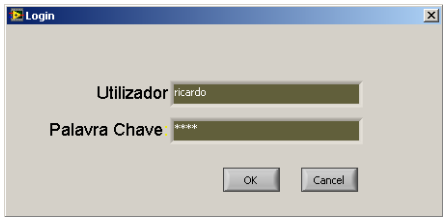

Fig 9 Login Window

After validating the access, a main window with several buttons related to different functions is shown. Depending of the user permissions (manager or employee), different options are available. If the user is a manager, the menu consists of the following items:

- Introduction and preview of employees;
- Employees to be advised;
- Temperatures Reports;
- Display of temperatures;
- View temperature in real-time;
- Change of password.

If the user is an employee the system shows the following features: temperature reports, temperature display, temperature display in real time and changing the password.

Figure 10 shows a menu for introduction the staff elements, in particular the employee's name, address, phone number, the user login, and password and password confirmation. This window is only available to the user with the function of manager.

If the user forgets to fill any of the fields, a pop-up window appears to warn that it lacks to fill up a field. An example is the case of a wrong password, where it appears the following message "Wrong Password". If multiple fields are unfilled, the following message will be showed "Fill the missing fields". It must be referred that the program is written in Portuguese.

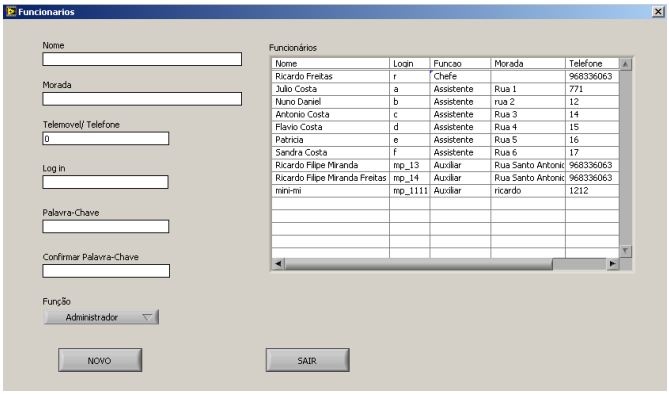

Fig 10 Introduction of staff

The system manager must define the list of employees to be advised, by sending a SMS message (Short Message Service) via the GSM modem, in case of an alarm generation. The order by which the employees are warned is defined by the priority. It is possible that two employees have the same priority, thus, they are informed at the same time with a message.

The temperature reports window allows the user to obtain reports of the temperature by month, within a given period of time, in a year. This time period is related to one cold room or display case. These reports can be generated in Excel or PDF Formats.

In the View temperature window, it allows the selection of a refrigerator or display case and the visualization of the corresponding temperature display in real time.

The user password can be changed in the password window, Figure 11. This window asks for the user old password, the new password and the confirmation of the new password. In order to confirm this operation it is necessary to press the button *Mudar* (Change).

Fig 11 Changing user's password

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4. THE CONTROL SYSTEM

The control system manages the temperature in each device in order to preserve perishable articles and food. Also, it executes the defrost operation. In the following sub-sections, the control system is presented and explained.

A. Control of Refrigeration

The cooling system is controlled by an E5CN controller that permits conserve the perishable articles. The temperature in the cooling system is controlled through manipulation of the compressor and the evaporator by a digital thermostat. The thermostat receives the information regarding the temperature on the display case through a temperature probe. Depending on the temperature measured at the probe, the thermostat activates the compressor and the evaporator. If the temperature measured is above the desired (considering hysteresis), the compressor and evaporator are activated. When the temperature is lower than the desired temperature, the cooling is interrupted, and so the compressor and evaporator.

The controller is connected to PLC by a relay. The PLC is connected to the compressor, evaporator and electric resistance by relays.

B. Evaporator Defrost

The control system allows the configuration of the evaporator defrosts. This process is present in all controllers of refrigeration equipments. The purpose of defrost is to remove the extra ice on the evaporator avoiding the overloading in the cooling system. There are various methods of defrosting: hot gas, electric, water, air, among others. In these methods, the time between defrosts and the process duration are the common parameters. The method used was electric defrost but it is possible to choose air, just in case of equipment does not allow electric defrost.

In defrosts the software developed allows choosing between defrost with or without resistance in evaporator. The software configures the time between defrosts and the time parameters of phase defrost.

Defrost is performed by the PLC that controls the electric resistance, compressor and evaporator in different stages of defrost.

5. CONCLUDING REMARKS AND FUTURE WORK

In this paper we presented a new system for monitoring and control a cooling process in a commercial store. It samples and records the temperature in pre-determined moments from the temperature controllers, installed in the display cases and in the cold rooms, that are placed in an industrial network. These temperatures profiles are stored in a Programmable Logic Controller which is connected to a Personal Computer. Here, a LabView custom developed application collects the temperature, plots the temperature profiles in graphical environments (registering maximum, minimum and average values) and saves the results in a Microsoft Access 2007 database. The software has different levels of permission access. Also, a statistics analysis can be performed as well as the configuration of defrost evaporator parameters. The control system controls the cooling system and performs evaporator's defrost.

We strongly believe that this structure meets all the proposed requirements, making it a useful and versatile system for a correct use in commercial systems.

The future work includes the integration of a GSM modem connected to the PLC, with the purpose to send a message in case of a power failure or an equipment malfunction.

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