# Smart Refrigeration Equipment based on IoT Technology for Reducing Power Consumption


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***Abstract*—In developed countries, companies active in the food retail sector consume about 20% of the total power required for cooling and are therefore ranked among them with the largest energy footprint after the industries. For this reason, refrigeration equipment manufacturers are increasingly focusing on methods that will reduce the power consumption required for its efficient operation. The solutions that are currently implemented mainly focus on interventions in the development phase of freezer units (better insulation, variable frequency compressors, etc.), which, however, do not adequately address the problem. This paper presents the development of an IoT-based technology device which, using machine learning techniques, aims to reduce the power consumption of refrigeration equipment and consecutively, the energy footprint of food retailers.**



***Index Terms*—Internet of Thing (IoT), smart refrigerator, embedded system, wireless sensor network (WSN), artificial intelligence (AI) algorithms**


## I. Introduction

The continuous movement of the population during the last decades towards the urban environments has led to an increase in the consumption of chilled and frozen food [1]. Refrigeration of these foods requires significant amounts of electricity, corresponding to 50% of the consumption of businesses operating in the field of food retail [2]. According to the estimation of the International Institute Refrigeration [3], the percentage of electricity consumed worldwide for cooling is 17%. Given the fact that the population in urban environments will rise to 85% from the current 75%, the amount of power consumed for cooling will further increase in the forthcoming years [4].

In developed countries, companies in the food retail sector are rated second in terms of the energy footprint behind industries. As a result, refrigeration equipment manufacturers are increasingly focusing on approaches that will lower the amount of power necessary for optimal operation. The solutions implemented up to day, which mostly focus on interventions in the construction phase of cold chambers (improved insulation, variable frequency compressors, etc), do not adequately address the problem. Furthermore, due to the unprecedented energy crisis that the whole of Europe is experiencing during the last months, the operating costs of these companies have increased significantly. During the opening hours of the companies in the food retail sector, there are considerable losses in the cooling of the freezer units, due to the repeated of their opening and closing by the customers. To quickly cover these losses and to maintain the temperature of the air inside the freezer units within the appropriate limits, they are adjusted to operate at temperatures lower than expected, which significantly increases their consumption. However, when a business is closed or when the client attendance is minimal (as evidenced by hourly transaction data), the operation of refrigeration equipment can be adjusted to a higher degree without any risk for food safety.

The main goal of the proposed approach in this paper is to reduce the power consumption of refrigeration equipment. Therefore, the energy footprint of companies operating in the food retail sector, by implementing strategies for efficient programming of their refrigerators' operating temperatures, will also be reduced. By mitigating the utilized amount of electricity, the carbon dioxide emissions to the environment are also reduced. As a result, one of the European Union's key policies to reduce greenhouse gases and climate change in general according to EU directive 2006/32/EC can also be achieved.

The remainder of the paper is organized as follows. Section II presents related work on temperature monitoring devices. Section III describes in more detail the architecture of the proposed system. Finally, Section IV denotes some concluding remarks of this work.

## II. Related Work

In recent years, the need to design smart refrigerators has become apparent. Many researchers are working on how to increase the performance of these devices while reducing their operating costs. In [5], the authors proposed a design using a NodeMCU, a temperature sensor, and photodiodes. The goal is to notify the user about the expiration date of the stock goods and the cooling temperature. The user can determine the minimum and maximum quantity of all stored items. Then, the system can automatically place an order when the number of items is smaller than the threshold set.

In [6], the authors used three various types of sensors, grove-gas, temperature, and humidity sensor, to monitor gasses, temperature, and humidity, respectively, inside a refrigerator. The data are stored and processed by an Arduino UNO board. The user can monitor the parameters of the system through an IoT platform.

Moreover, in [7], the authors proposed a smart-refrigerator design. More particularly, they used a variety of sensors, like air quality, pressure, infrared, temperature, and humidity sensor, to manage the stored foods and avoid or reduce food waste. The total system is controlled by the 32-bit STM32F103, an STM32 family microcontroller based on an Arm Cortex-M3 processor.

In [8], Aheleroff et al. presented how to change a conventional refrigerator into an IoT-enabled smart refrigerator. They used the nRF52832 microcontroller as the central control unit of their design. The controller is responsible for receiving information from the refrigerator's mainboard, reading the states of the various sensors and actuators, sending and receiving data to and from the IoT platform. The End-user is informed at all times about the system's parameters through the IoT platform.

Moreno-Peñalosa et al. [9] implemented a Raspberry Pi 4 based design for monitoring a freezer. They used an Arduino UNO board to acquire and process temperature. Also, they utilized the freeware project MyOpenLab to develop the graphical user interface (GUI) of their design. The GUI includes visual alarms, records of food storage and expiration dates, and the freezer's temperature.

In the following Section, we present the architecture of the proposed system.

## III. Proposed System Architecture

The proposed system aims at the design and development of innovative, low-cost, monitoring, recording, storage, management, and automation system using machine learning techniques. The proposed system adopts the technology of the Internet of Things (IoT) and in particular, the combination of Wireless Sensor Networking (WSN) technologies and embedded Artificial Intelligence (AI) algorithms.

The proposed system is developed based on the utilization of the DS18B20 digital temperature sensor, which is manufactured by Dallas Semiconductor Corp. The adoption of the specific sensor is made to keep the system's cost as low as possible, since it is one of the most widely used temperature sensors on the market. In addition to its low cost, the proposed temperature sensor offers good accuracy in a fairly large temperature range (from $-55$ °C to 125 °C), as well as the ability to communicate via the 1-Wire protocol. The 1-wire protocol was primarily developed to provide a convenient way to add multiple sensors into a single data bus, through which the master module activates and controls the communication with one or more slave modules [10]. Until the advent of the 1-wire communication protocol, each digital temperature sensor had to be connected to a microcontroller via its own dedicated bus, in order to properly receive the measurement values. This restriction resulted in a major increase to the cost of acquiring the necessary equipment for temperature monitoring in medium and large firms' refrigeration equipment.

The single-board computer (SBC) Raspberry Pi Zero W, which is manufactured by the Raspberry Pi Foundation in the United Kingdom, has been chosen as the microcontroller for this work. In the global market, there are several conventional microcontrollers, such as Arduino, Esp8266, Esp32, etc., which operate as simple low-power computers. However, these microcontrollers exhibit a certain drawback; they do not support multitasking. On the contrary, the Raspberry Pi Zero W is a general-purpose computer running the Debian Linux operating system. The main advantage of this single-board computer is the ability to execute multiple tasks simultaneously. Thus, it provides more operational capabilities than the previously mentioned conventional microcontrollers.

Generally speaking, the conventional microcontrollers can communicate with a computer via various connection interfaces through the software installed in their ROM (firmware) to give access to their features. Once the source code of the application to be executed is loaded into their ROM via the computer, the microcontroller can be anywhere connected to start its operation immediately. This operation is viable since it does not require any restart or selection of the application to run, or physical connection to a keyboard, or a mouse to enter data. Therefore, their use is limited to simple repetitive tasks (e.g. reading the values of various sensors) as they perform the task for which they have been programmed directly. However, in several other cases, such as when performing more complex calculations or running many applications at the same time, a complete computer that utilizes an operating system to allocate its available resources is required. Therefore, the use of a powerful microcontroller, such as the Raspberry Pi Zero W is the ideal solution for embedded systems or tasks that require more interactivity and, of course, more processing power. Being a small but fully functional computer, it offers features that are not exhibited in conventional microcontrollers. The main features, which have been included in the proposed system as well are:

1) *Data storage*. Due to the large volume of data that are produced, the existence of adequate storage capacity is mandatory. Indicatively, the proposed system can collect 96 temperature values per day from each DS18B20 temperature sensor. The Raspberry Pi Zero W has a built-in SD memory card, whereas conventional microcontrollers usually can store a comparatively smaller number of measurements.
2) *Networking*. The Raspberry Pi Zero W has a built-

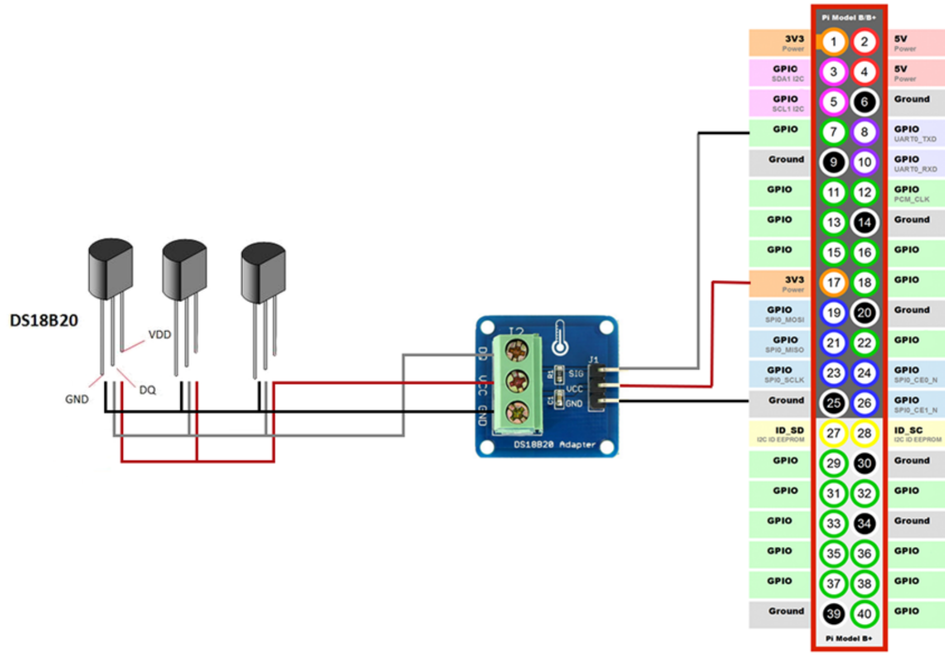


Fig. 1. Indicative depiction of multiple DS18B20 temperature sensors connected via the 1-wire protocol incorporated with Raspberry Pi Zero W in the proposed system.

in wireless network adapter. Therefore, it provides the ability to transfer and exchange data with the cloud server when necessary.

3) *Processing power*. A modern approach to avoid the cloud server overload is the technique of edge computing, i.e., the processing of collected data to the local processing unit of a microcontroller. Within the proposed system, the pre-processing stage of the collected data, i.e., the raw data of the monitored parameters, such as the temperature of the freezer units will be carried out at the edge processing unit of the selected microcontroller. Therefore, it is essential that the microcontroller must have sufficient computing power to perform all the necessary pre-processed tasks.
4) *User interaction*. The lack of keyboard, mouse, and screen support does not allow the application installed on conventional microcontrollers to interact with the end-user. On the other hand, the Raspberry Pi Zero W supports keyboard and mouse connectivity via USB or Bluetooth wireless communication protocol. Moreover, the presence of a graphics processor with an HDMI output allows the connection with an external monitor. Therefore, these extra options of the selected microcontroller provide significantly increased usability.
5) *Integrated real-time clock chip (RTC)*. Conventional microprocessors do not have the ability to receive the current time and date since they do not have a complete real-time clock chip. Therefore, they can be considered as not suitable for the specifications of the proposed system, which require the recording of date and time for every collected sample of the temperature in the freezer units.

Fig. 1 illustrates the indicative connections of the DS18B20 temperature sensors to the selected microcontroller of the proposed system. The Raspbian operating system has a built-in 1-wire protocol driver for the communication of the Raspberry Pi Zero W as a master module along with the slave modules (temperature sensors). The physical pin 7 of the utilized microcontroller is applied to connect all the slave modules, as well as any other peripheral devices of the proposed system. The physical pin 17 provides 3.3V to the overall system, whereas the physical pin 25 is the ground.

The temperature sample data at the control points (i.e., the interior space of freezer units) should be recorded every 15 minutes, according to the HACCP system's guidelines [11]. Moreover, the EN12830 standard requires that the freezer unit ID, as well as the date and the time, should also be recorded in each sampled measurement of temperature. Because the Raspberry Pi, as previously stated, features an RTC chip, it complies with the EN12830 standard.

The temperature values of sample data that have been recorded by the sensors of the proposed system, can be continuously stored in ASCII format, along with the corresponding timestamp (date and time), and the unique 64-bit ID of each temperature sensor. This feature allows the measurements to be classified according to different criteria (e.g., per day, per sensor, etc.). Moreover, systematic theoretical calculations of energy losses for predetermined time intervals can be performed. The proposed system adopts the following ASCII data format for the storage of the measurement values:

**[Sampling timestamp (date and time); DS18B20 64 bit ID; Temperature value]**

From the stored temperature data values, which are distinguished by timestamp and sensor ID, we can determine the available time intervals where the selected freezer unit can safely operate at a higher temperature than the default one, without any risk to the quality of stored food. This approach allows to save power for each business unit. The proposed system will utilize artificial intelligence methods, such as machine learning models, and optimization techniques, to correlate all the basic parameters that contribute to the operation of a freezer unit, and extract the maximum time intervals of the freezer unit that can operate at a higher temperature than the predetermined one. The optimal regulation at specific intervals, depending on the environmental conditions and the period of operation, will result to the reduction of power consumption in a business unit. To determine the above maximum time intervals, the internal temperature of the area where the refrigeration equipment is installed, as well as the customer flow density will also be taken into account.

According to EN 153 standard, the nominal consumption of the freezer units by the manufacturers is determined by considering the indoor temperature of about 25 °C. Moreover, it is estimated that freezer units cooling losses are reduced when the number of customers at a given time period is relatively small. Within the proposed system, the effect of the temperature variation per season on the total power consumption of the refrigerator equipment will be examined. Additionally, the correlation between the number of customers within an indoor space, typically where the freezing units are installed, and the variation of the cooling losses will also be investigated.

The objective of the proposed system is to map the operation of the freezer units in a business and, to propose through regular reports temperature control strategies based on a matrix of optimal settings, in order to minimize the power consumption. The analysis and processing of the above data will conclude the operation of the chambers so that the application can then propose through energy reports the optimal settings to minimize their consumption.

Finally, the online platform of the system will be implemented through which, all the information will be available (history of temperature values in each freezer unit, history of temperature values indoors, notifications, proposed strategies) concerning the management of the cooling equipment in a business. This information will be provided in an comprehensive way to the users of the application through the appropriate interfaces. The overall architecture of the system is illustrated in Fig. 2.

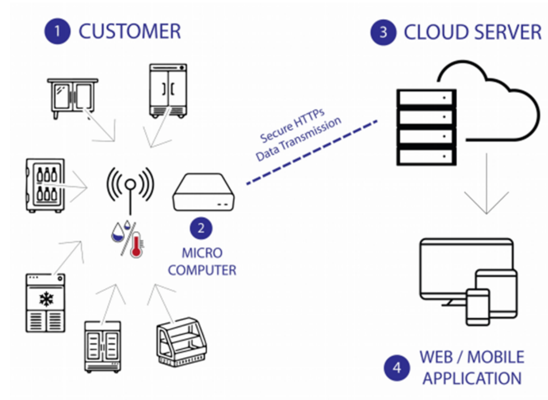


Fig. 2. Overall proposed system architecture.

## IV. Conclusion

In this paper, an IoT-based system aimed to reduce the power consumption of refrigerators is designed. The proposed system combines Wireless Sensor Networking (WSN) technologies and embedded Artificial Intelligence (AI) algorithms. It uses the 1-wire protocol incorporated with the SBC Raspberry Pi Zero W. The objective is to map the operation of the freezer units and propose temperature control strategies based on a matrix of optimal settings. Future work includes the implementation and performance evaluation of the overall system.

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