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A Case Study on Applying MQTT Communication to Improve Cold Storage Safety and Quality Management

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ABSTRACT

This paper investigates the use of the MQTT protocol for monitoring cooling systems and discusses the advantages of this approach. Cooling systems play a critical role in many areas such as the food, pharmaceutical and chemical industries, and their proper functioning is vital for product quality and safety. However, monitoring and managing these systems often presents major challenges. Traditionally, the monitoring of these systems has been carried out by dedicated on-site staff or personnel, which can be risky, time-consuming and costly.

The MQTT protocol is a fast and efficient communication protocol designed for data communication between IoT devices. In this study, how the MQTT protocol can be used for monitoring cooling systems and the advantages of this protocol are examined in detail. The use of MQTT can facilitate remote monitoring of cooling systems and thus significantly reduce response and reaction times. Thanks to a web application developed to store and display the data received through the MQTT protocol, it becomes easier to remotely monitor the storage room temperature values and intervene when necessary. End users can instantly view storage room temperatures via phone, tablet or computer and make intervention decisions when necessary.

Keywords: Cold chain, Internet of Things, MQTT, web application.

1. INTRODUCTION

Today, as technology advances, solutions are being sought to improve the quality of life in all domains. Many formerly manual chores can now be automated, freeing up more time for life (1).

One of the most effective factors in food preservation is temperature. Temperature causes physical, chemical and microbial changes in food products. It directly affects the taste, spoilage, quality and shelf life of food (2).

It is known that there are different applications in foods stored by freezing or cold storage methods in order to preserve the structural properties of the products. However, the interactions of these applications with the components of the food are not fully known (3). For this reason, the importance of the cold chain with known reliability comes to the fore.

In order not to spoilage the chemical, microbiological and textural structure of the product, the control of external factors such as temperature and humidity in processes such as product storage and shipment increases the importance of cold chain traceability.

Nowadays, with the increase in the demand for fresh and natural consumption of foods, the importance of cold storage, which is one of the food preservation methods, has increased. During cold storage, chemical reactions in food biochemistry, enzymatic activities and proliferation rates of microorganisms slow down and the durability of food is prolonged (4) (5). For this reason, temperature measurements can be monitored at every stage of the food production process and should be carried out appropriately.

In many countries, traceability has been made mandatory for agricultural and food products in accordance with legal regulations (6). Information technologies used in the food sector provide fast information access throughout the chain, reduce costs, provide instant access to data supporting processes and operations, facilitate operational decisions, and provide the opportunity to cooperate with stakeholders (7).

There are some applications for temperature monitoring during the processing, storage and shipment of food. Studies have been carried out on the usability of systems such as RFID (Radio Frequency Identification) systems, satellite and SMS tracking systems, The Internet of Things (IoT), ERP, blockchain. The traceability of a product gives the ability to track its movement and location in the supply chain by using digital technologies with documentation, labelling, coding and other tracking tools of the process from raw material supply to the consumer (8).

In this study, the IoT, one of the developing information technologies in the food supply chain, and its applications in the sector were investigated.

IoT is a technology consisting of smart devices that can identify objects through various communication networks and sensing methods and transfer the information they produce to each other (9). The Internet of Things has become a significant component in many fields, including scientific research, the information technology sector, energy, security, production, agriculture, transportation, and trade applications, since it provides possibilities in both time and material difficulties (10). IoT devices can generate data at varying intervals and/or continuously depending on the need and their structure. This data, which is continuously generated and accumulated depending on time, creates needs such as increased bandwidth, storage unit and processing capacity. IoT communication protocols with various communication models have been developed to minimise these needs in the communication of IoT devices. One of these communication protocols is MQTT (11).

In this research, the ESP32 wireless development module, to which the relevant sensors to be placed in cold storage conditions are connected, has been used to transmit real-time temperature data to the

Table 1. Comparison of MQTT messaging protocol with some of the other IoT messaging protocols

	MQTT	**CoAP**	**AMQP**	**HTTP**
Base Protocol	TCP	UDP	TCP	TCP
Archirecture	Client/Broker	Client/Server, Client/Broker	Client/Server, Client/Broker	Client/Server
Paradigm	Publish/Subscribe	Request/Response Publish/Subscribe	Publish/Subscribe Request/Response	Request/Response
Header Size	2 Bytes	4 Bytes	8 Bytes	Undefined
Message Size	Small and Undefined	Small and Undefined	Negotiable and Undefined	Large and Undefined
Methods	Publish,Subscribe, Connect,Disconnect, Unsubscribe,Close	Post,Get, Put,Delete	Consume,Ack, Get,Deliver, Publish, Reject, Select,Delete, Nack,Recover, Open,Close	Post,Get,Head, Put,Options, Patch,Connect, Delete
Reliability	QoS 0-At most once QoS 1-At least once QoS 2-Exactly once	Confirmable or Non-confirmable Message	Settle Format or Non-settle Format	Limited(via TCP)
Licensing	Open Source	Open Source	Open Source	Free
Standart	OASIS, Eclipse Foundation	IETF, Eclipse Foundation	OASIS, ISO/IEC	IETF and W3C

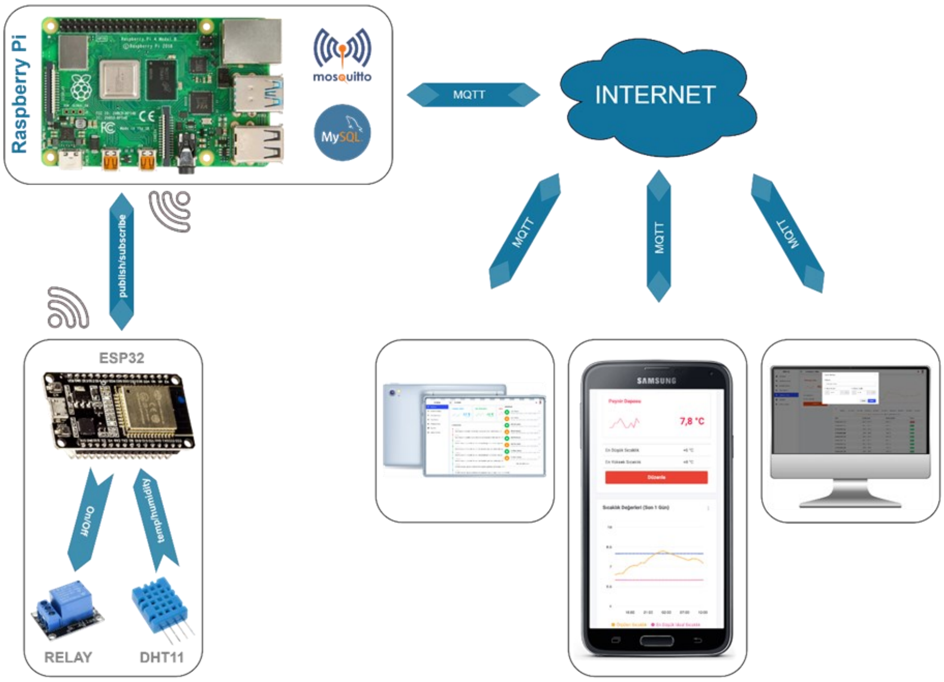


Figure 1. Process of temperature data collection from storage room and display on the web application.

server using the MQTT protocol. The server records these data in a MySQL database, and they can be viewed through the prepared web application. End users of the web application can monitor the real-time temperature values of each storage facility, as well as access temperature data for specific date and time intervals retrospectively. These reports can be downloaded to their computers in PDF or Excel format or printed out, depending on their needs or preferences. Thanks to this developed system, real-time monitoring of the cold chain has been conducted, allowing for immediate notification of potential or existing problems in the chain and enabling rapid response.

In the food industry, this system will greatly facilitate applications such as supply chain management, food traceability, reliability, and recall.

The MQTT messaging protocol, as seen in Figure 2, is an open-source protocol that enables communication between networks and devices. It is designed to collect messages from various devices within a certain network at a central point and to route these messages to the relevant devices. MQTT is built upon a publisher/subscriber structure and manages communication between the relevant devices through broker and topics (12).

When examining the conducted studies, it has been observed that the MQTT protocol is of great importance for stakeholders in the supply chain and consumers in terms of increasing food quality from production to consumption and ensuring food safety. While it is applicable to all food products subject to the cold chain, the research has provided a solution to the problems of the industry in terms of tracking potential breaches in the cold chain.

The MQTT protocol offers three different levels of service quality to its users: QoS 0, QoS 1, and QoS 2. The lowest service quality level is called QoS 0. At the QoS 0 level, a message is sent only once, and there is no check to ensure that the message has been received. The same rules apply to both the sender and the receiver of the message. QoS 1 is the service quality level where it is guaranteed that a message is delivered at least once. The message is stored by the sender until confirmation of receipt from the receiver is obtained. In case of a timeout, if the confirmation message does not reach the sender, the stored message is resent to the receiver. The highest service quality level is QoS 2. This level aims to prevent message loss and duplication. It is guaranteed that the message is sent to the receiver once and received only once.

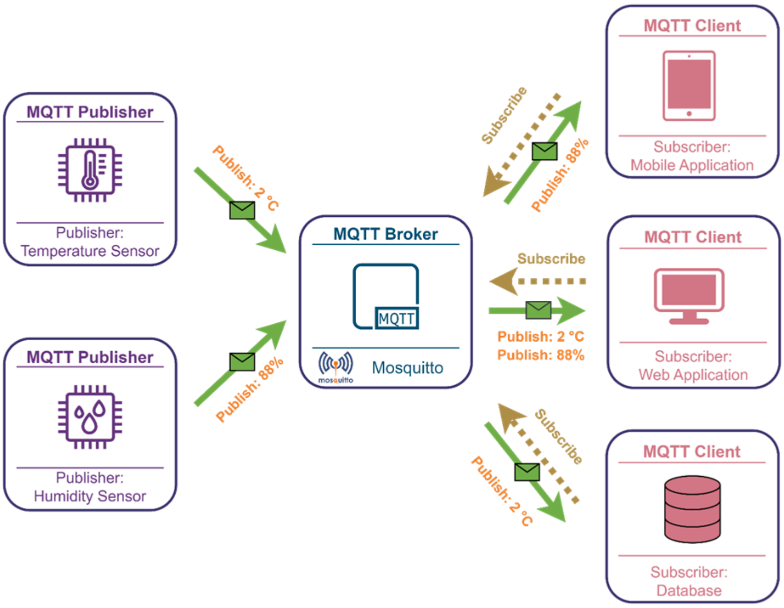


Figure 2. Architecture of MQTT messaging protocol.

This requires a two-stage acknowledgment process, which means additional control messages are needed for both sender and receiver compared to other levels (13).

Among the most common protocols that operate at the application layer like MQTT are CoAP, HTTP, XMPP, DDS, AMQP, SMQTT, and Restful protocols . The MQTT protocol has a wider usage rate compared to other application layer protocols (14). The widespread use of the MQTT protocol can be attributed to its simplicity and lightweight nature, as well as its minimal requirements for processing power and network bandwidth (15). Particularly for battery-operated devices, the MQTT protocol is more suitable compared to other similar protocols (16).

In a study conducted in 2015, a cost-effective, sensor-based IoT system was proposed for real-time traceability of food during logistics. The system utilized sensors for detecting temperature and humidity, with the possibility of including additional sensors depending on the specific requirements of the food being monitored. In this research, RFID was used to obtain data after the food products were loaded onto logistic vehicles, although it was noted that NFC or Bluetooth could also be used. The data obtained were transmitted to a Central Monitoring System (CMS) and tracked during logistics via the internet using a GSM/GPRS module. At this stage, a low-cost computer card served as a central processing unit that accessed sensor data and communicated with end-users. Different sensor types, depending on the target parameter, formed the sensing module (17).

In another study conducted by Lue and Wang (2016), a cloud computing-based IoT system was developed to improve quality control of perishable food products (such as vegetables, fruits, frozen desserts, meat etc.) in the cold chain industry. Critical data are collected, transmitted, and stored in a cloud-based database system. The speed and location of refrigerated vehicles are tracked, allowing real-time and historical data to be displayed on a digital map. The conditions of food products in storage are determined, and real-time data related to the foods are analyzed to monitor environmental conditions. The physical flow of foods throughout the cold chain is monitored, and notification messages are sent to designated users when the determined values are exceeded. This system ensures food safety and maintains food quality by enabling real-time monitoring of the food products' status during storage and logistics; it allows timely detection of risks such as temperature breaches and route deviations through analysis of environmental conditions (18). Culman et al. (2017), an IoT-based solution named PalmNET was developed for monitoring soil conditions in a palm oil operation. PalmNET automatically collect soil moisture data and transmit to a web server via ZigBee for short range and GPRS network for long range. The servers act as interfaces for data visualization. In this way, users can collect, evaluate, and store real-time data (19).

Rao et al. (2018) a Raspberry Pi-based room temperature monitoring system that uses ThingSpeak as an online API. The gathered data is processed over the internet, and graphical results are shown to people all around the globe (20).

Zakaria et. al (2018) has designed a compact and portable gadget to constantly monitor the body temperature of infants, ensuring their comfort throughout usage. It provides immediate assistance to parents by promptly notifying them when the baby's body temperature rises by more than one degree over the usual range. This method utilizes a wearable sensor to monitor the crucial critical parameter of body temperature. The information is then sent to their parents over a wireless network (21).

IoT was used to monitor data center temperature and humidity in real time by Ab Rahman et al. (22). Temperature and humidity correlation and discrepancy across measurement sites were examined using a simple monitoring system.

In another study conducted by Uzunkaya in 2021, a software was developed that analyzes data from sensors via IoT devices using the MQTT communication protocol. This software and the collected data can be used to predict potential failures in advance and to perform preventive maintenance activities (23).

Boyacıgil and Uzun (2023), a Raspberry Pi-based image processing application was developed with the aim of enabling image processing-based quality control in businesses. A conveyor which use IoT technologies was designed for this purpose. Images of the products passing over the conveyor belt are captured, and an image processing algorithm is used to determine whether the products are defective or non-defective. Selection of the products is made based on this detection (24).

Güler (2023), an AES-based IoT application was developed to monitor energy consumption and error notifications in refrigeration units. Utilizing the ESP32 series, all necessary data for connecting refrigerators to the internet in the field were encrypted with AES over the MQTT protocol and transmitted to the MQTT server. The decrypted data, through a Windows operation system service application, were recorded in a database located in the same environment. The developed application and the web-based interface were used to track historical data, and temperature changes and reasons for errors were identified. (25).

Daniel et al. (2023) investigated the optimal temperature and humidity levels for hostels. In the research, the room values were assessed using IoT-based temperature and humidity sensors installed in several rooms. When the humidity level rose, the

Figure 3. Image of the Burdur Mehmet Akif Ersoy University Dairy Products and Technologies Application and Research Center, Dairy Factory, Final Product Storage Room.

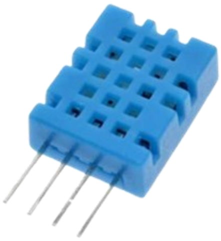


Figure 4. DHT11 temperature and humidity sensor.

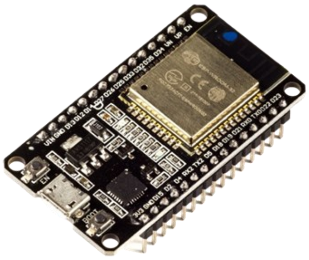


Figure 5. ESP32 development module.

dehumidifier was engaged, and the room's humidity reached its peak. The same sensor was utilized to regulate the room temperature (26).

2. MATERIALS AND METHODS

The applications of this study were carried out using the storage facilities located at the Dairy Products and Technologies Application and Research Center, affiliated with Burdur Mehmet Akif Ersoy University.

ESP32 wireless development modules equipped with DHT11 temperature and humidity sensors were placed in cold storage rooms. One module is placed in each room. These modules were utilized to continuously monitor the environmental conditions within the storage areas. Utilizing the MQTT protocol, an effective method for IoT communication, the ESP32 modules transmitted real-time temperature and humidity data to an MQTT service configured on a Raspberry Pi. This server served as a central point for data collection and processing, storing the received data into a MySQL database. This step was crucial for ensuring data integrity and facilitating long -term data analysis. The final component of the system was a web application with access to the MySQL database. This application was designed to relay the collected data to various subscribers efficiently, handling user requests and providing timely updates on the conditions within the cold storage. As a result, better management of the storage facilities was achieved, and rapid responses to environmental changes became possible.

2.1. DHT11 Temperature and Humidity Sensor

The DHT11 is a widely recognized digital sensor known for its dual measurement capabilities of temperature and humidity, making it a staple in various low-cost environmental monitoring systems. Characterized by its compact size and digital output, the DHT11 sensor stands out for its ease of interfacing with microcontrollers, such as Arduino, facilitating a broad range of applications from home automation to basic weather stations. Unlike analog sensors, the DHT11 provides direct digital outputs, eliminating the need for analog-to-digital conversion and simplifying its integration into digital systems. This sensor operates on a simple principle: a thermistor measures the temperature, and a capacitive humidity sensor gauges the moisture level in the air. The readings are then converted into digital signals, which can be easily read by a microcontroller. The DHT11's operational range for temperature is typically from 0 to 50 degrees Celsius with a ±2-degree accuracy, while its humidity measurement ranges from 20% to 80% with a ±5% accuracy, making it suitable for indoor environments where extreme accuracy is not the primary requirement (27).

2.2. ESP32 Development Module

The ESP32, developed by Espressif Systems, is a low-power, low-cost system on a chip (SoC) microcontroller with integrated Wi-Fi and dual-mode Bluetooth capabilities. It has quickly gained popularity in the world of IoT (Internet of Things) due to its rich feature set and versatility. At its core, the ESP32 boasts a powerful Tensilica Xtensa LX6 microprocessor, which comes in both single-core and dual-core variants, enabling robust performance for complex computational tasks. This microcontroller stands out for its extensive set of peripherals, including standard communication interfaces like SPI, I2C, UART, CAN, and Ethernet, as well as unique features like capacitive touch sensors, hall effect sensors, and a rich set of GPIO pins.

Its integrated Wi-Fi and Bluetooth support make it particularly attractive for modern IoT applications, allowing for easy integration into smart home devices, wearable electronics, and industrial automation systems. Furthermore, the ESP32's low power consumption makes it ideal for battery-powered applications, a critical consideration in portable IoT devices.

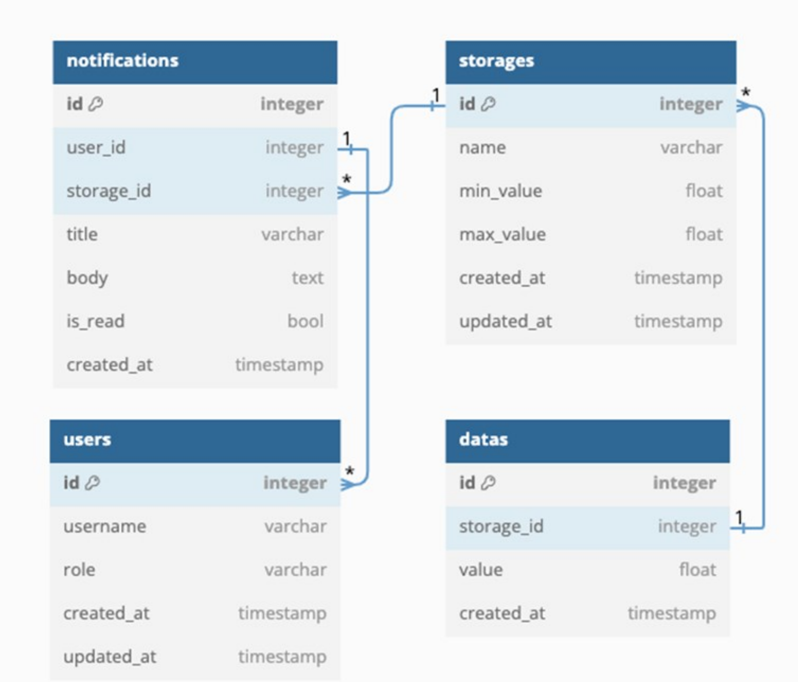
Despite its many advantages, the ESP32 does present some challenges, particularly in terms of its learning curve for new users and its power management for battery-operated devices. The complexity of its feature set can be daunting for beginners, although the extensive community support and development resources available have made it more accessible over time. Power management in ESP32 is a critical aspect to consider, especially in applications where battery life is crucial. The microcontroller's deep sleep and light sleep modes are essential features that allow for efficient power usage but require careful programming to optimize battery life. In summary, the ESP32 represents a significant advancement in the field of microcontrollers, offering a cost-effective, versatile, and powerful solution for a wide range of applications. Its capabilities in handling complex tasks, along with its wireless connectivity options, make it an ideal choice for innovators and developers looking to push the boundaries of what's possible in IoT and embedded systems (28).

2.3. Raspberry Pi Single Board Computer

The Raspberry Pi is a series of small single-board computers developed by the Raspberry Pi Foundation in the United Kingdom with the intention of promoting the teaching of fundamental computer science in educational institutions and in developing countries. Since its inception, the Raspberry Pi has transcended its educational purposes, becoming immensely popular among hobbyists, educators, and professionals alike. Its low cost, modularity, and open design make it accessible for a wide range of projects, from simple educational tools to sophisticated home automation systems and IoT devices. The Raspberry Pi comes in various models, each differing in size, power, and complexity, but commonly featuring a Broadcom system on a chip (SoC) with an integrated ARM-compatible central processing unit and on-chip graphics processing unit, a range of input/output (I/O) options, and memory capacity. This versatility allows the Raspberry Pi to be used for tasks ranging from basic computing and educational projects to complex machine learning applications and server hosting.

One of the key strengths of the Raspberry Pi lies in its robust community and the vast array of available software and libraries, making it an ideal platform for experimentation and learning. Its ability to run various operating systems, including Linux-based distributions and even a version of Windows 10, offers users flexibility in software development and application deployment. However, while the Raspberry Pi is a powerful tool, it is not without limitations. Its performance can be constrained when handling intensive computational tasks, and it lacks the real-time processing capabilities of microcontrollers like the Arduino or ESP32, making it less suitable for certain types of embedded systems applications. Despite these limitations, the Raspberry Pi continues to be a revolutionary tool in the world of

Figure 6. Raspberry Pi single-board computer (SBC).



notifications	
id	integer
user_id	integer
storage_id	integer
title	varchar
body	text
is_read	bool
created_at	timestamp

storages	
id	integer
name	varchar
min_value	float
max_value	float
created_at	timestamp
updated_at	timestamp

users	
id	integer
username	varchar
role	varchar
created_at	timestamp
updated_at	timestamp

datas	
id	integer
storage_id	integer
value	float
created_at	timestamp

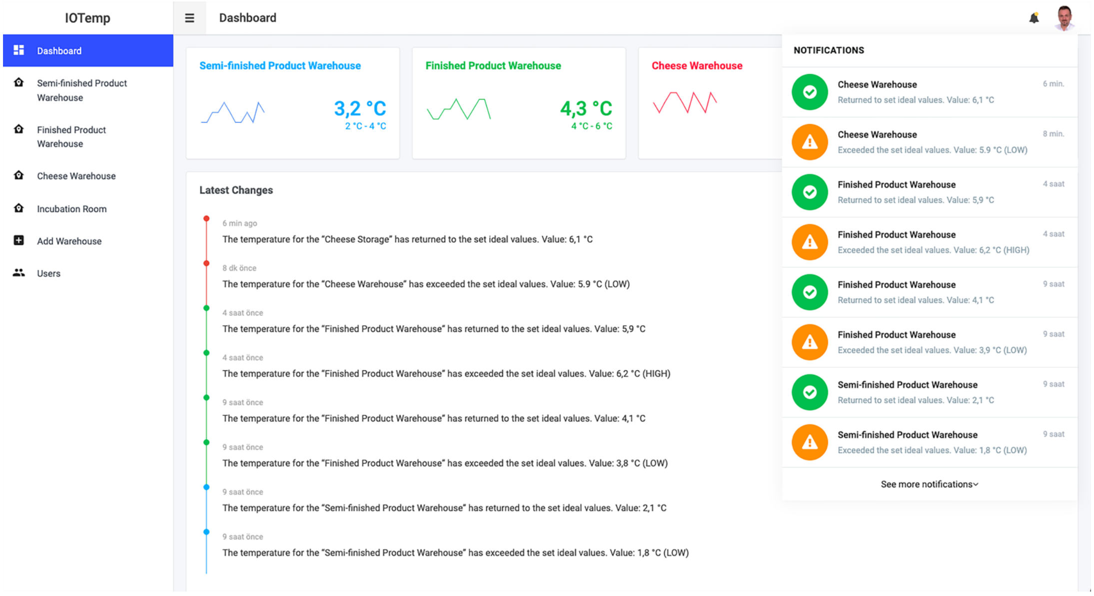
Figure 7. Web application database diagram.

computing, democratizing access to technology and enabling people around the world to learn, create, and innovate in new and exciting ways (29).

In the research, instantaneous temperature values were monitored using MQTT protocol by means of temperature sensors placed in three cold storage and one incubation storage in the Burdur Mehmet Akif Ersoy University Dairy Products and Technologies Application and Research Centre. ESP32 wireless development module with DHT11 temperature and humidity sensors was installed in one semi-finished product, one cheese, one final product storage room and one incubation storage room in the facility. Real-time temperature values were broadcasted over this module via wireless network using MQTT protocol. These published values were processed to the MySQL database on the Raspberry Pi used as a server and instantly displayed via the web application. Figure 7 shows the database diagram of the web application. In case of exceeding the specified temperature ranges, designated users were notified via e-mail, SMS or push notification methods. Thus, operational decisions were made much faster and problems that may occur were responded to more quickly.

3. RESULT AND DISCUSSION

At the research facility, the real-time temperature



Latest Changes

6 min ago
The temperature for the "Cheese Storage" has returned to the set ideal values. Value: 6,1 °C

8 dk önce
The temperature for the "Cheese Warehouse" has exceeded the set ideal values. Value: 5.9 °C (LOW)

4 saat önce
The temperature for the "Finished Product Warehouse" has returned to the set ideal values. Value: 5,9 °C

4 saat önce
The temperature for the "Finished Product Warehouse" has exceeded the set ideal values. Value: 6,2 °C (HIGH)

9 saat önce
The temperature for the "Finished Product Warehouse" has returned to the set ideal values. Value: 4,1 °C

9 saat önce
The temperature for the "Finished Product Warehouse" has exceeded the set ideal values. Value: 3,8 °C (LOW)

9 saat önce
The temperature for the "Semi-finished Product Warehouse" has returned to the set ideal values. Value: 2,1 °C

9 saat önce
The temperature for the "Semi-finished Product Warehouse" has exceeded the set ideal values. Value: 1,8 °C (LOW)

NOTIFICATIONS

Cheese Warehouse — 6 min.
Returned to set ideal values. Value: 6,1 °C

Cheese Warehouse — 8 min.
Exceeded the set ideal values. Value: 5.9 °C (LOW)

Finished Product Warehouse — 4 saat
Returned to set ideal values. Value: 5,9 °C

Finished Product Warehouse — 4 saat
Exceeded the set ideal values. Value: 6,2 °C (HIGH)

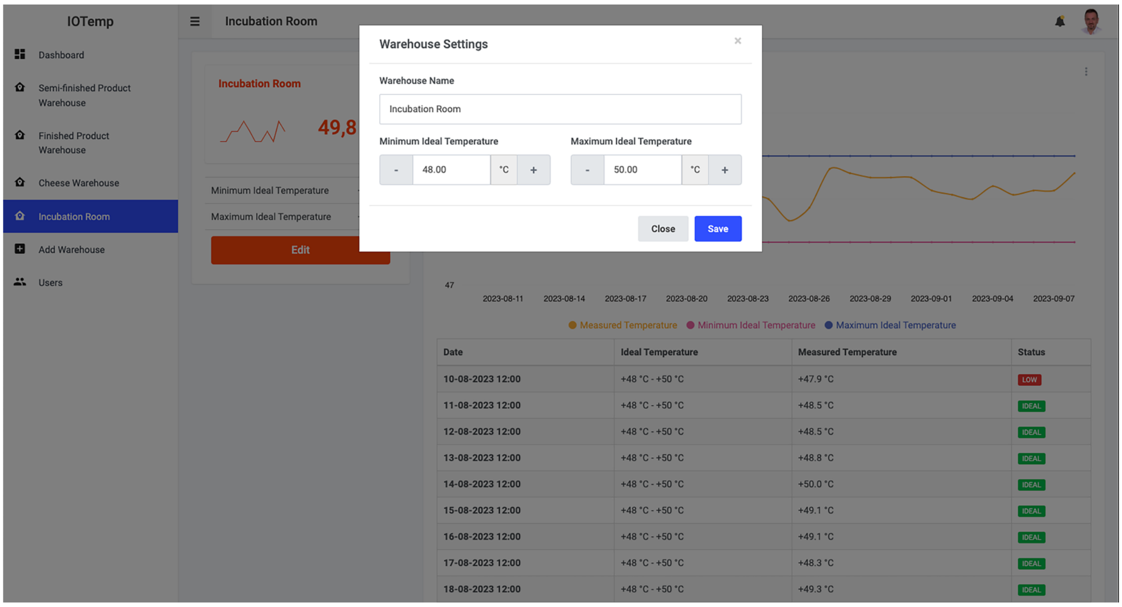
Finished Product Warehouse — 9 saat
Returned to set ideal values. Value: 4,1 °C

Finished Product Warehouse — 9 saat
Exceeded the set ideal values. Value: 3,9 °C (LOW)

Semi-finished Product Warehouse — 9 saat
Returned to set ideal values. Value: 2,1 °C

Semi-finished Product Warehouse — 9 saat
Exceeded the set ideal values. Value: 1,8 °C (LOW)

Figure 8. Dashboard page and notification panel of the web application.



Warehouse Settings

Warehouse Name: Incubation Room

Minimum Ideal Temperature: 48.00 °C

Maximum Ideal Temperature: 50.00 °C

Date	Ideal Temperature	Measured Temperature	Status
10-08-2023 12:00	+48 °C - +50 °C	+47.9 °C	LOW
11-08-2023 12:00	+48 °C - +50 °C	+48.5 °C	IDEAL
12-08-2023 12:00	+48 °C - +50 °C	+48.5 °C	IDEAL
13-08-2023 12:00	+48 °C - +50 °C	+48.8 °C	IDEAL
14-08-2023 12:00	+48 °C - +50 °C	+50.0 °C	IDEAL
15-08-2023 12:00	+48 °C - +50 °C	+49.1 °C	IDEAL
16-08-2023 12:00	+48 °C - +50 °C	+49.1 °C	IDEAL
17-08-2023 12:00	+48 °C - +50 °C	+48.3 °C	IDEAL
18-08-2023 12:00	+48 °C - +50 °C	+49.3 °C	IDEAL

Figure 9. Storage room settings page of the web application.

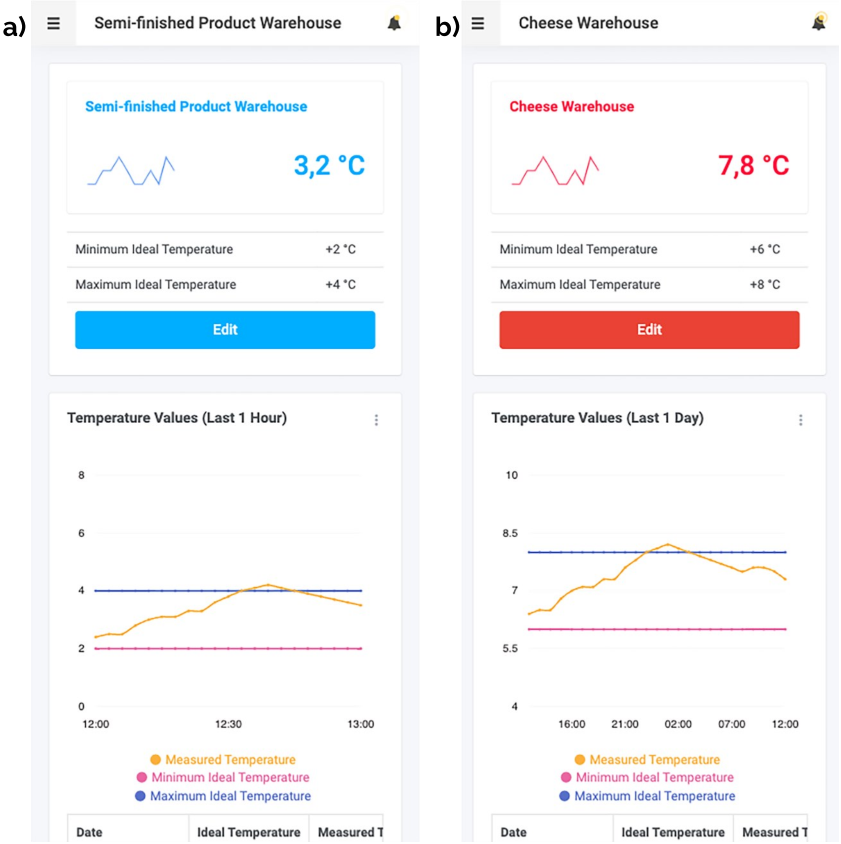
values and optimum values of three cold storage units and one incubation room can be viewed through a web application.

On this screen, it is observed that the optimum temperature range for the semi-finished product storage room is defined as 2-4˚C, with the current temperature measured at 3.2˚C. For the final product storage room, the optimum temperature range is defined as 4-6˚C, with the current temperature measured at 4.3˚C.

It is noted that the cheese storage room should maintain a temperature range of 6-8˚C, while the current temperature is measured at 7.3˚C.

Regarding the incubation room, the ideal temperature values are stated to be between 48-50˚ C, with the current temperature measured at 49.1˚C.

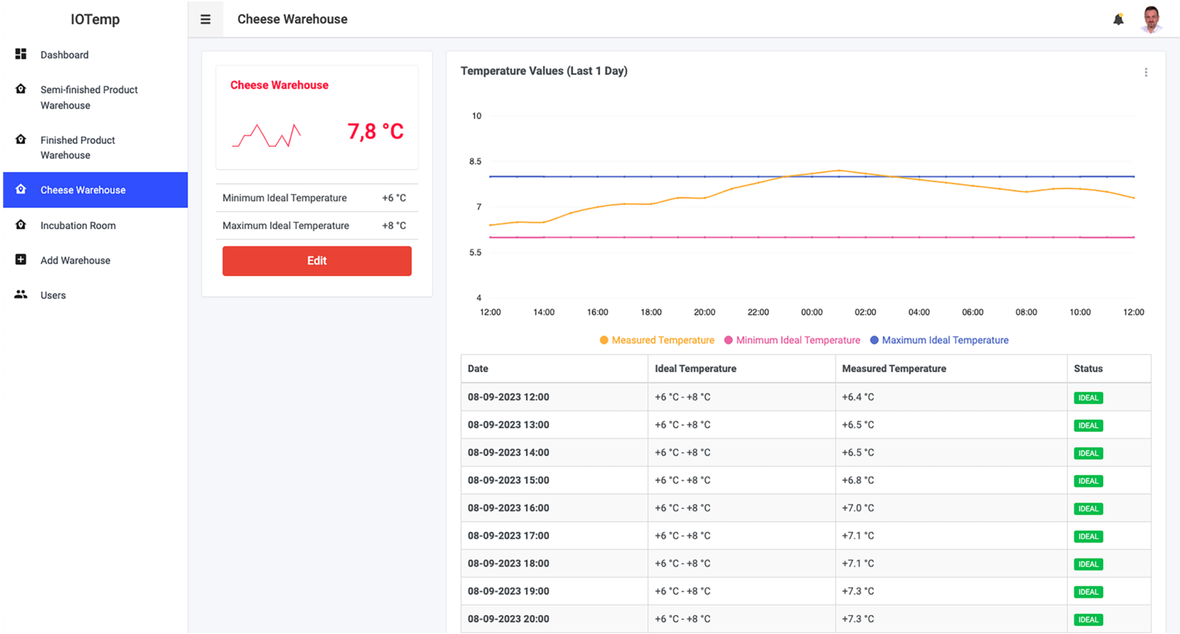
All real-time temperature fluctuations are also displayed on the homepage. If the measured



a) Minimum Ideal Temperature +2 °C
Maximum Ideal Temperature +4 °C

b) Minimum Ideal Temperature +6 °C
Maximum Ideal Temperature +8 °C

Figure 10. a) Hourly temperature data page of the web application on mobile device (mobile phone) b) Daily temperature data page of the web application on mobile device (mobile phone).



Minimum Ideal Temperature	+6 °C
Maximum Ideal Temperature	+8 °C

Date	Ideal Temperature	Measured Temperature	Status
08-09-2023 12:00	+6 °C - +8 °C	+6.4 °C	IDEAL
08-09-2023 13:00	+6 °C - +8 °C	+6.5 °C	IDEAL
08-09-2023 14:00	+6 °C - +8 °C	+6.5 °C	IDEAL
08-09-2023 15:00	+6 °C - +8 °C	+6.8 °C	IDEAL
08-09-2023 16:00	+6 °C - +8 °C	+7.0 °C	IDEAL
08-09-2023 17:00	+6 °C - +8 °C	+7.1 °C	IDEAL
08-09-2023 18:00	+6 °C - +8 °C	+7.1 °C	IDEAL
08-09-2023 19:00	+6 °C - +8 °C	+7.3 °C	IDEAL
08-09-2023 20:00	+6 °C - +8 °C	+7.3 °C	IDEAL

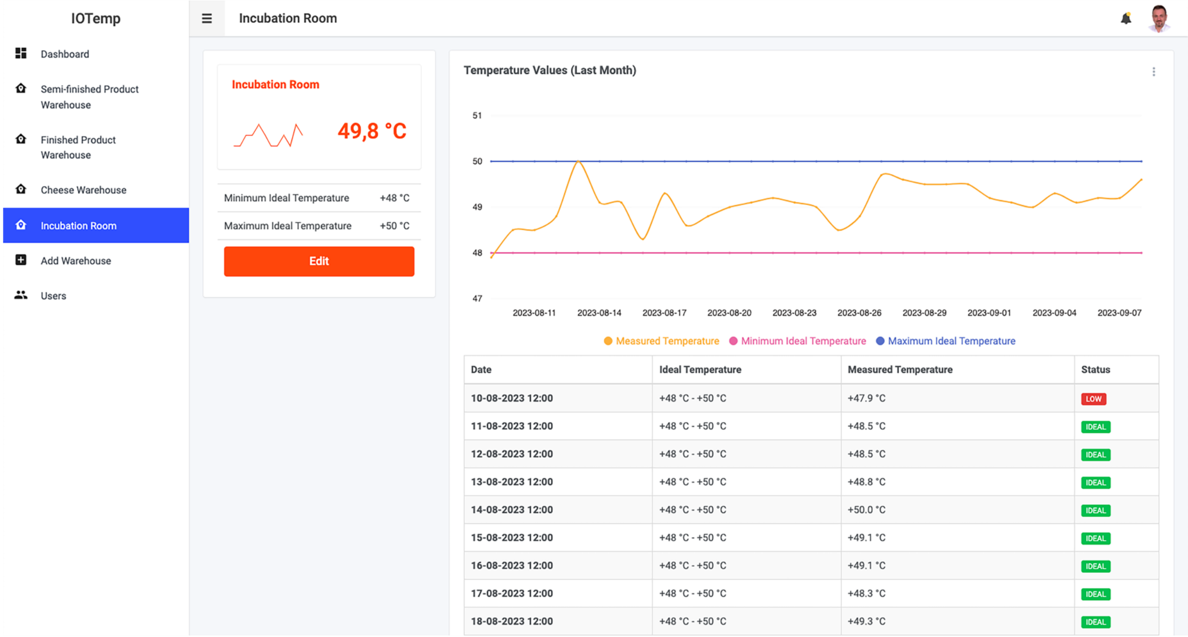
Figure 11. Daily temperature data page of the web application.

temperature deviates from the specified ideal temperature range, the temperature movements displayed on the homepage of the web application indicate whether it is "Low" or "High".

In Figure 8, the real-time temperature values of all storage rooms and the menu on the left side are displayed, and if the temperature is detected outside the ideal temperature values determined for the storage rooms, the user is informed about the situation with instant notifications. The notification list on the right side of the screen shows the notifications that the ideal temperature values have been exceeded or that the ideal temperature value has been reached again. Issues such as how long the products stay outside the ideal temperature values and in which time interval they reach the desired temperature again can be monitored. In foods that require cold chain, deterioration caused by breaking the chain can be eliminated.

In Figure 9, besides the capability to define a new storage unit within the system, there is also a screen where temperature variations of previously created storage units can be adjusted. On this screen, the name of the storage unit and its ideal minimum and maximum temperature values can be modified.

Figure 10 represents the temperature values of the storage units defined in the system, along with a



Minimum Ideal Temperature	+48 °C
Maximum Ideal Temperature	+50 °C

Date	Ideal Temperature	Measured Temperature	Status
10-08-2023 12:00	+48 °C - +50 °C	+47.9 °C	LOW
11-08-2023 12:00	+48 °C - +50 °C	+48.5 °C	IDEAL
12-08-2023 12:00	+48 °C - +50 °C	+48.5 °C	IDEAL
13-08-2023 12:00	+48 °C - +50 °C	+48.8 °C	IDEAL
14-08-2023 12:00	+48 °C - +50 °C	+50.0 °C	IDEAL
15-08-2023 12:00	+48 °C - +50 °C	+49.1 °C	IDEAL
16-08-2023 12:00	+48 °C - +50 °C	+49.1 °C	IDEAL
17-08-2023 12:00	+48 °C - +50 °C	+48.3 °C	IDEAL
18-08-2023 12:00	+48 °C - +50 °C	+49.3 °C	IDEAL

Figure 12. Monthly temperature data page of the web application.

table and graph indicating the changes in temperature over the past hour.

The measured values are presented in tabular format, with the system having the capability to measure temperature every 3 minutes. Additionally, the status of the measured temperature compared to the ideal temperature values is indicated.

In Figure 11, the temperature values of the storage unit have been recorded over a period of 24 hours. These recorded values are compared to the ideal values, and the current status is presented in both table and graph formats. The measurement interval is set to 1 hour.

The Turkish Food Codex states that temperatures below 6˚C are applied during the preservation, transportation, and marketing processes of food products, excluding powdered/dried fermented dairy products (27). Therefore, especially for food items requiring a cold chain, temperature monitoring is carried out monthly using similar forms as specified in Appendix 1. It is the responsibility of the storage room manager or production technicians to fill out these forms daily. However, this process is vulnerable to errors and incorrect declarations due to human factors, leading to a low level of reliability.

On the screen shown in Figure 12, the instantaneous temperature of the storage room is recorded daily. The temperature is measured at the same time every day. The measured temperature is compared with the ideal temperature and the result of this comparison is also indicated in the table. Thus, the system is freed from human dependency, records the data automatically every day, and its reliability is maximised as there is no possibility of external manipulation.

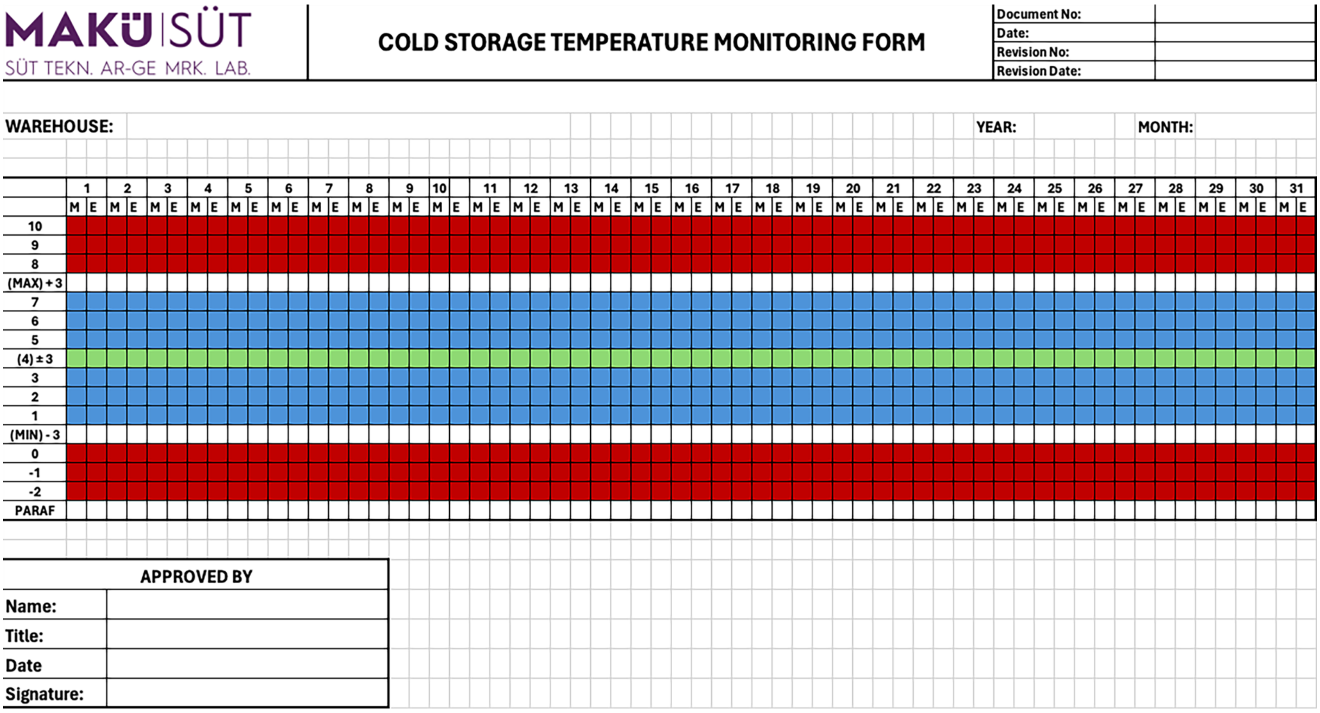
In the process from field to fork in the food chain, the variability of environmental parameters poses significant risks for food safety and human health. The importance of the use of information technologies is increasing in terms of shelf life of food and traceability of quality criteria.

Thanks to the web application developed by processing the collected data, the necessary environments can be monitored instantly from all over the world, minimizing the human impact and maximizing food safety.

4. CONCLUSION

Considering the food waste in the world, the change in the storage conditions that may be experienced will prevent the food from being disposed of before it is consumed and will contribute to operating costs. Additionally, it has been observed that the gaps in the

Appendix-1. Cold Storage Temperature Monitoring Form



MAKÜ|SÜT
SÜT TEKN. AR-GE MRK. LAB.

COLD STORAGE TEMPERATURE MONITORING FORM

Document No:
Date:
Revision No:
Revision Date:

WAREHOUSE:
YEAR:
MONTH:

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	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E	M	E
10	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
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record-keeping procedures in food production can be filled with this system, and the level of reliability has been elevated to higher levels.

This study investigated temperature fluctuations during the cold and hot storage processes using the MQTT communication protocol. In this application Qos1 service quality was used to save traffic. During the research, temperature sensors placed in storage room wirelessly broadcast the ambient temperature thanks to the wireless transmission modules they were connected to. The published data was again collected wirelessly and recorded in a database hosted on a configured server.

Thanks to the developed web application, temperature values published via the MQTT protocol can be monitored in real-time, and the environmental temperatures can be examined retrospectively using the values stored in the database. In this web application, a JavaScript library (React), was used in the frontend, and a PHP framework (Laravel) was used in the backend.

The variability of environmental parameters in the food processing chain directly impacts factors such as the shelf life and quality criteria of food products. Additionally, it is observed that power outages in storage areas, doors left open, or leaks due to deformations in doors can alter storage temperatures. Utilizing information technologies to be instantly informed about these changes and to take necessary precautions is becoming increasingly important. Therefore, it is seen that the advantages gained from the implementation of this system are beneficial in terms of addressing these challenges.

While this study demonstrated the viability of using MQTT for remote cold chain monitoring, there are several avenues for further development. First, expanding the sensor network to include additional environmental and operational parameters would provide more comprehensive facility oversight. Sensors to measure humidity, power usage, door openings etc. could offer deeper insights. Integrating predictive analytics and machine learning models would enable proactive issue detection. By analyzing historical temperature patterns and correlations, anomalies could be spotted earlier. Forecasting algorithms could also anticipate equipment maintenance needs or product spoilage risks.

This study provides users with the opportunity to monitor in real time through a lightweight and modular web application. Although there are many similar studies on the MQTT protocol in the literature, this study is supported by a web application. For the front-end of the web application that was developed, the React native user interface was chosen, and for the back-end, the Laravel PHP Framework was applied.

Developing mobile apps for on-the-go access would strengthen user experience. Dashboards and alerts optimized for phones/tablets would support responsive handling of excursions from workers in the field. Location-based services could automate handoffs between shift teams. Testing across more facilities under different conditions would prove robustness at scale. Varying sizes, throughputs, climate zones etc. could expose edge cases. Participation from multiple industry partners may uncover new use cases.

Finally, upgrading MQTT elements with security protocols like SSL/TLS would fortify the platform for mission-critical deployments. Role-based access controls and message encryption would satisfy compliance needs. Caching or redundant broker configurations could ensure continuous data availability. Advancing the system along these lines would realize MQTT's full potential for optimizing cold storage operations through predictive visibility and proactive intervention capabilities.

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