

IOT- BASED OPTIMIZATION FOR THE PERFORMANCE AND SUSTAINABILITY OF COOLING TOWERS

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering Degree in
Electrical and Electronics Engineering

by

F. SHERYN (Register No. 40140034)

M. SURIYAPRIYA (Register No. 40140035)



**DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
SCHOOL OF ELECTRICAL AND ELECTRONICS**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

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BONAFIDE CERTIFICATE

This is to certify that this project report is the bonafide work of **SHERYN.F** (Reg. No. 40140034) and **SURIYAPRIYA.M** (Reg. No.40140035) who carried out the project entitled "IOT-BASED OPTIMIZATION FOR THE PERFORMANCE AND SUSTAINABILITY OF COOLING TOWERS" under our supervision from November 2023 to April 2024.

Dr. P. SIVAGAMI
Internal Guide

Dr. S. RADHIKA
HEAD OF THE DEPARTMENT
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Jeppiaar Nagar, Rajiv Gandhi Salai,
Chennai - 600 119.

Submitted for Viva voce Examination held on 17.04.2024

Name:

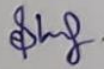
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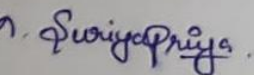
Internal Examiner
External Examiner

(Dr. S. Leelitha Kumari)

DECLARATION

SHERYN F (Reg. No. 40140034) and **SURIYAPRIYA M** (Reg. No. 40140035) who hereby declare that the Project Report entitled "**IOT-BASED OPTIMIZATION FOR THE PERFORMANCE AND SUSTAINABILITY OF COOLING TOWERS**" done by us under the guidance of **Dr. P. SIVAGAMI** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Electrical and Electronics Engineering.

1. 

2. 

DATE: 17.4.24

PLACE: Chennai

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Cooling Towers serve as crucial components within HVAC (Heating, Ventilation, and Air Conditioning) systems across industrial and commercial sectors. Their primary function involves dissipating excess heat generated by HVAC systems, refrigeration units, and various industrial processes. However, relying on manual operation for cooling tower management can result in several drawbacks, including heightened energy consumption, increased operational expenses, and limited adaptability to fluctuating loads. These issues can culminate in shortened equipment life spans, elevated maintenance costs, and challenges in meeting environmental regulations. Furthermore, manual systems often lack remote monitoring capabilities, leading to delayed responses to malfunctions, increased downtime, and compromised reliability, which can pose safety risks. The automation of cooling tower operations is thus deemed essential for optimizing energy utilization, reducing operational costs, and ensuring system reliability. By implementing precise control mechanisms based on real-time demand, energy consumption can be minimized, resulting in significant cost savings. This project specifically focuses on the Central Air-conditioning Plant, where cooling tower fans are automated to maintain a consistent condenser approach of 5 °C. Additionally, emphasis is placed on sustaining the Total Dissolved Solids (TDS) of circulating water below 500ppm. This is achieved through the implementation of an auto bleed-off system, which prevents scaling in the condenser tubes of the Chiller. These critical process parameters are continuously monitored in real-time via IoT-enabled devices, facilitating effective control and management of the cooling tower system.

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LIST OF SYMBOLS AND ABBREVIATIONS

HVAC	-	Heating, Ventilation and Air-Conditioning
TDS	-	Total Dissolved Solids
CAGR	-	Compound Annual Growth Rate
IoT	-	Internet of Things
AI	-	Artificial Intelligence
LCD	-	Liquid Crystal Display

CHAPTER- 1

INTRODUCTION

1.1 GENERAL

The central air-conditioning plant functions through a complex network of five interconnected heat transfer loops (Figure 1.1). Each loop plays a crucial role in maintaining the optimal temperature and efficiency of the system.

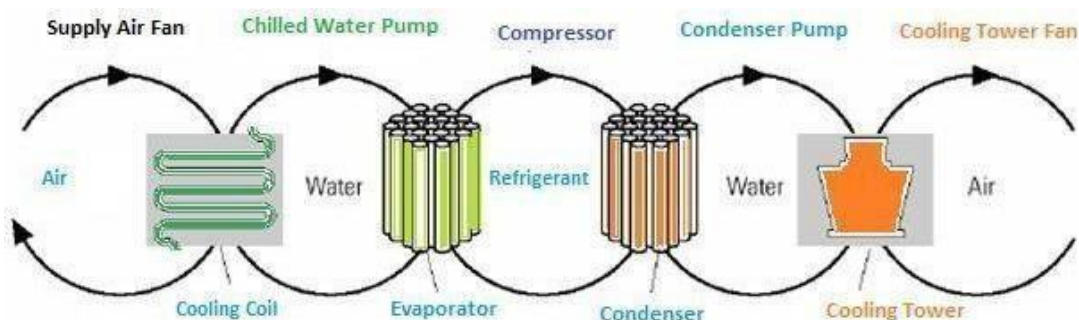


Figure 1.1: Represents the heat transfer loops in a central air-conditioning plant

Firstly, heat extracted from indoor spaces is carried away by the indoor air loop. This heat is then transferred to the chilled water loop through a heat exchanger. Subsequently, the chilled water loop conveys the heat to the refrigerant within the chiller, where it is absorbed. Next, the heat-laden refrigerant releases its heat to the condenser water loop. This loop facilitates the transfer of heat to the atmosphere via a cooling tower air loop. The efficiency and effectiveness of heat transfer within each loop are paramount for the sustained operation of the central air-conditioning system. Any inefficiency or disruption in this intricate process could lead to compromised performance and increased energy consumption.

Cooling towers (Figure 1.2) play a critical role in maintaining the thermal equilibrium of HVAC systems and industrial processes. As hot water flows through the tower, it encounters a vast surface area, typically composed of fill media (Figure 1.4). This interaction allows for efficient heat exchange as water cascades down, coming into contact with upward-flowing air drawn in by powerful fans.



Figure 1.2: Depicts the typical installation of cooling tower in a central air-conditioning plant

By transferring heat from hot water or process fluids to the atmosphere through evaporation, they ensure that equipment operates within safe temperature ranges and maintains efficiency.

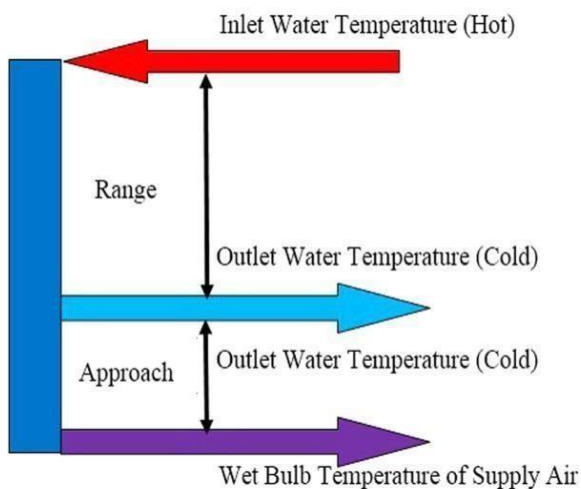


Figure 1.3: Shows approach and range of a cooling tower

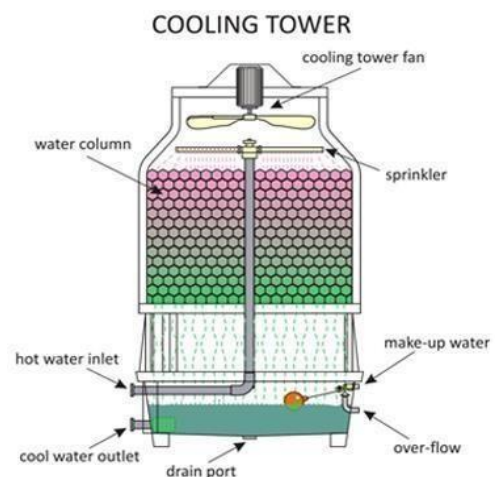


Figure 1.4: Shows the cross-sectional view of a cooling tower

Manual operation of cooling tower fans to maintain the cooling water approach temperature (Figure 1.3) can result in poor performance and increased operational costs. Similarly, scales in a chiller condenser (Figure 1.5) due to high levels of total dissolved solids (TDS) can have a range of negative effects, including reduced heat transfer efficiency, increased energy consumption (Figure

1.6), elevated operating temperatures, decreased system reliability, and water quality issues. Additionally, manual systems may struggle to adapt to fluctuating loads, potentially causing equipment strain and inefficiency.



Figure 1.5: Shows condenser tubes before and after de-scaling

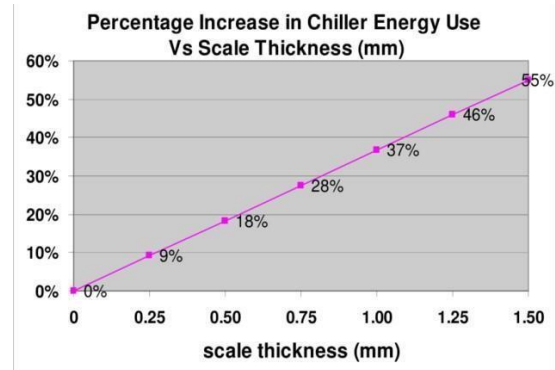


Figure 1.6: Graph shows percentage increase in chiller energy use Vs scale thickness (mm)

Automated cooling tower systems ensure that chillers operate within optimal conditions. By maintaining consistent condenser approach temperatures and controlling Total Dissolved Solids (TDS) levels in circulating water, automation prevents scaling and fouling in chiller tubes. This results in improved chiller efficiency and performance, maximizing cooling capacity and prolonging equipment lifespan. Automated cooling tower systems with IoT enabled devices for real time monitoring can help organizations meet environmental regulations and sustainability goals. By minimizing energy consumption and optimizing water usage, automation contributes to reducing greenhouse gas emissions and conserving resources, aligning with regulatory requirements and corporate sustainability initiatives.

1.2 GLOBAL SCENARIO ABOUT COOLING TOWER AND IT'S AUTOMATION

The global cooling tower market size (Figure 1.7) was estimated at USD 3,730.3 million in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 4.3% from 2023 to 2030. Due to the government environmental regulations, coupled with concerns associated with the plumes generated by power generation and chemical industries, are anticipated to drive the demand for cooling towers during the forecast period.

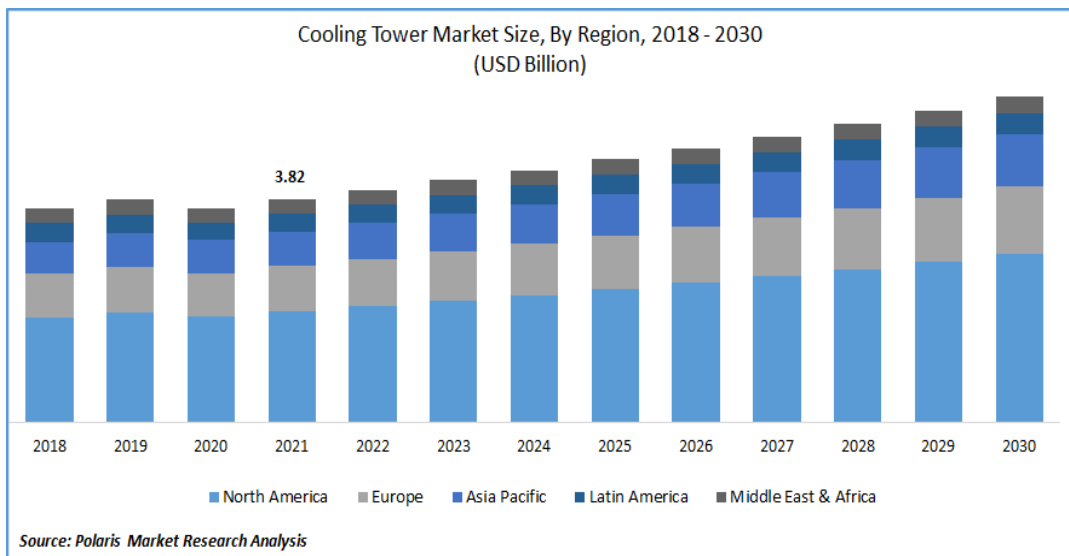


Figure 1.7: Global market size of Cooling tower

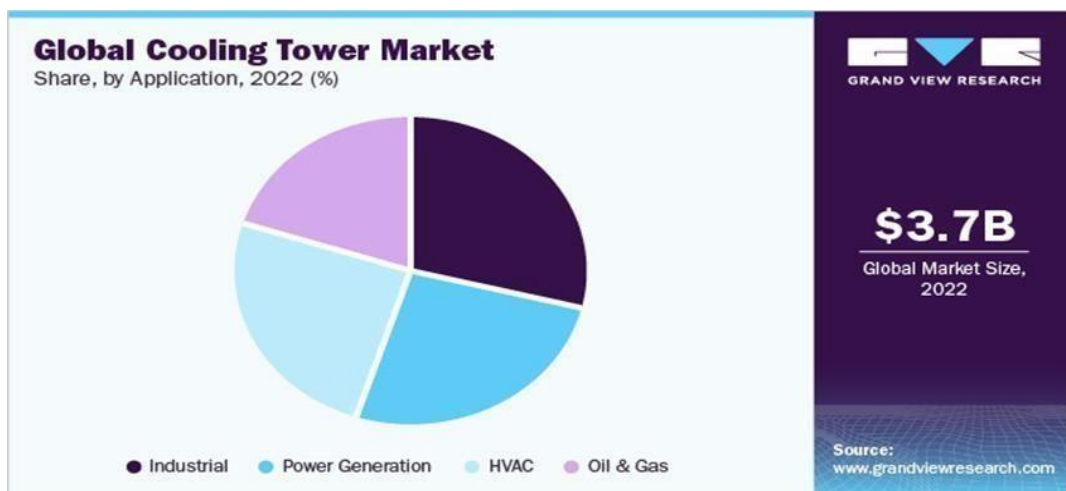


Figure 1.8: Market share of cooling tower in HVAC

Heating, Ventilation and Air-Conditioning (HVAC) contribute a major share in the Global Cooling tower market according to the U.S. Department of Health and Human Services (Figure 1.8). Cooling towers enable the cost-effective and energy-efficient operation of the HVAC system. Over 1,500 industrial enterprises consume a lot of water to keep their equipment cool. Furthermore, HVAC systems are commonly found in large office buildings, schools, and hospitals. The growing adoption of HVAC systems is anticipated to drive the demand for cooling towers over the forecast period.

The global scenario surrounding cooling tower automation reflects a growing recognition of its importance in enhancing energy efficiency, optimizing performance, and ensuring sustainability across various industries including manufacturing, power generation, petrochemicals, pharmaceuticals, and data centers. The market for cooling tower automation is experiencing steady growth globally, driven by factors such as increasing industrialization, urbanization, and infrastructure development. As industries seek to improve operational efficiency and reduce operating costs, the adoption of cooling tower automation solutions is expected to continue to rise.

Technological advancements, including the Internet of Things (IoT), artificial intelligence (AI), and data analytics, are driving innovations in cooling tower automation. These technologies enable real-time monitoring, predictive maintenance, and adaptive control strategies, allowing for more precise and efficient operation of cooling towers.

The environmental regulations and sustainability goals are driving industries to adopt measures to reduce water consumption, minimize chemical usage, and mitigate environmental impact. Cooling tower automation plays a crucial role in achieving these objectives by optimizing water usage, reducing chemical treatment needs, and ensuring compliance with regulatory requirements.

Predictive maintenance has emerged as a key focus area in cooling tower automation. By leveraging IoT sensors and data analytics, operators can monitor equipment health in real-time, detect potential issues before they escalate into costly failures, and schedule maintenance proactively. This approach helps

minimize downtime, extend equipment lifespan, and optimize maintenance costs.

In conclusion, the global scenario surrounding cooling tower automation is characterized by increasing adoption driven by the need for energy efficiency, technological advancements, regulatory requirements, and industry-specific demands. As industries continue to prioritize sustainability and operational optimization, cooling tower automation is expected to play an increasingly vital role in meeting these objectives.

1.3 PROBLEM IDENTIFICATION

The problem statement for implementing Cooling tower process automation in centralized AC plant using IoT device can be stated as follows:

The manual regulation of the cooling tower outlet water temperature to keep it below the optimal level 24/7, across all seasons, through the operation of fans, adds another layer of complexity. Seasonal changes bring about variations in the ambient temperature, directly influencing the performance of the cooling tower. The challenge lies in the fact that manual adjustments may lack the precision and timely responsiveness needed to effectively counteract these dynamic fluctuations. Consequently, achieving and maintaining the desired outlet water temperature becomes an intricate task, requiring constant vigilance and swift, accurate adjustments, especially in the face of varying environmental conditions.

Similarly, continuously overseeing and manually managing Total Dissolved Solids (TDS) to maintain them below the optimal threshold in a cooling tower poses formidable challenges. Achieving and sustaining the ideal TDS levels are paramount to preventing complications such as scale formation and corrosion, both of which can significantly compromise the efficiency and overall lifespan of the cooling system. However, relying on manual monitoring introduces inherent risks, including the potential for human errors and delays. This introduces a level of difficulty in consistently and accurately keeping TDS within the preferred range.

Therefore, the problem statement is to develop a cooling tower process automation system utilizing IoT devices to effectively address the challenges

associated with continuous monitoring and manual management of critical parameters such as Total Dissolved Solids (TDS) and outlet water temperature. The aim is to create an intelligent and responsive solution that enhances operational efficiency, minimizes the risk of human error, and ensures optimal performance of the cooling tower across all seasons. By leveraging IoT technology, the system will enable real-time monitoring leading to improved sustainability, energy efficiency, and cost-effectiveness in cooling tower operations.

1.4 MOTIVATION OF THIS PROJECT

The motivation behind this project lies in the pursuit of optimizing the operation of cooling towers to effectively reduce power and energy consumption in central air-conditioning plants. The central air-conditioning system, primarily reliant on chillers, plays a pivotal role in maintaining comfortable indoor environments. Figure 1.9 shows the energy use of plant with varying cooling tower approach temperature. From the graph, it is known that the chiller plant's energy use is optimum at 9.5°F (5°C) approach temperature.

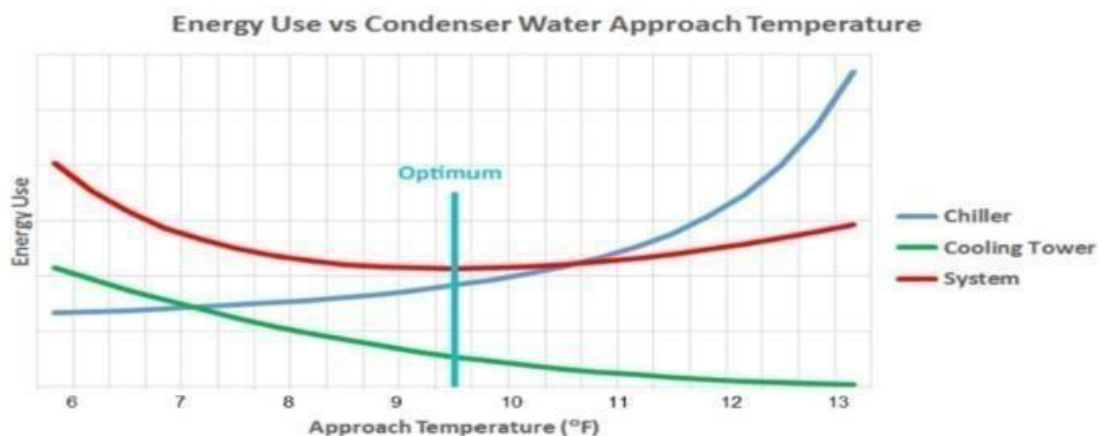


Figure 1.9: Shows the energy use of chiller plant with varying approach temperature

The chiller energy use is also badly affected by the scales in condenser tubes due to high TDS in circulating water. From Figure 1.10, it is evident that 1mm scale in condenser tubes can cause 37% increase in power consumption of chiller.

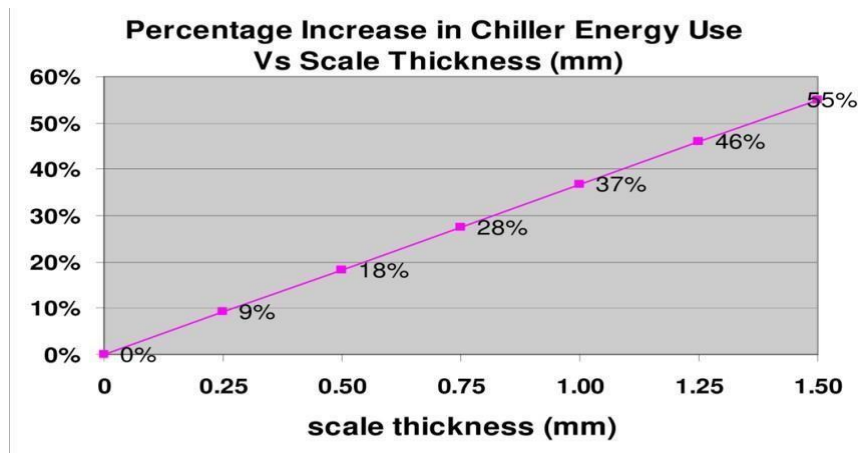


Figure 1.10- Effect of scales on chiller energy use

However, the significant energy demand associated with chiller operation, particularly in tandem with cooling towers, necessitates a strategic approach to enhance overall efficiency. By focusing on the optimization of cooling tower operations, this project aims to minimize the power and energy requirements of chillers. Through careful analysis and implementation of advanced control strategies, the goal is to achieve a more resource-efficient and sustainable central air-conditioning plant. This endeavor not only aligns with the imperative of energy conservation but also holds the promise of reducing operational costs and contributing to a more environmentally conscious and economically viable cooling system. In essence, the project seeks to strike a balance between maintaining optimal indoor conditions and mitigating the environmental impact through the judicious use of energy resources in central air-conditioning plants.

1.5 BENEFITS OF THE PROJECT

The proposed system offers a myriad of advantages aimed at enhancing the overall efficiency, sustainability, and operational ease of the cooling tower. Here are the key advantages:

1. **Reduced Power Consumption:** By utilizing IoT devices for real-time monitoring and automation, the system enables dynamic adjustments to cooling tower operations, optimizing parameters such as fan speed and water flow. This adaptability contributes to reduced power consumption, aligning with energy efficiency goals and potentially leading to substantial cost savings.

2. Minimized Water Loss: The system's automation ensures precise control over water usage within the cooling tower, reducing unnecessary losses and promoting efficient water management. This not only aligns with sustainable practices but also addresses environmental concerns related to water conservation.

3. Complete Process Automation: The elimination of human intervention through full process automation minimizes the risk of errors and ensures consistent adherence to optimal operating conditions. This results in improved system reliability and performance.

4. Elimination of Operator Fatigue: The automated system removes the need for continuous manual monitoring and adjustments, reducing operator fatigue. This not only enhances the well-being of operators but also contributes to a safer and more comfortable working environment.

5. Savings on Energy and Manpower: The combined benefits of reduced power consumption, minimized water loss, and automation lead to significant savings on both energy and manpower. The system offers a cost-effective solution by optimizing resource utilization and reducing the need for constant human oversight.

In summary, the proposed system stands to deliver substantial advantages, ranging from improved energy efficiency and water conservation to enhanced operational reliability and reduced reliance on manual labour. These benefits collectively contribute to a more sustainable and cost-effective cooling tower operation.

1.6 ORGANISATION OF THE REPORT

Chapter 1: Introduction

In this chapter, an introduction is given about role and need of cooling automation for optimizing chiller operation in a central air-conditioning plant. In addition, the global scenario on cooling tower automation, problem identification, motivation behind the project selection and the benefits of the project are also discussed in detail.

Chapter 2: Literature review

In this chapter, literature survey is conducted to identify the grey areas in cooling tower automation for chillers optimization.

Chapter 3: Proposed methodology

In this chapter, a solution is proposed for the identified problem with system architecture, flow charts and a prototype.

Chapter 4: Outcomes and Results

In this chapter, the outcomes and results of the prototype is demonstrated with local display along with trending of parameters with IoT devices.

Chapter 5: Conclusion

In this chapter, the project is concluded with a need for strategic and holistic approach to manage sump temperature and TDS levels for sustaining an efficient and economical cooling tower operation with future scope of improvement.

CHAPTER-2

LITERATURE REVIEW

2.1 GENERAL

The field of cooling tower automation and energy efficiency has seen remarkable advancements driven by innovative research and technological developments. Various studies have focused on enhancing the operational efficiency, safety, and energy conservation in cooling tower systems through intelligent control, IoT integration, and demand-response strategies. A comprehensive understanding of these aspects is crucial for enhancing the efficiency, reliability, and sustainability of cooling tower systems across different industries.

2.2 LITERATURE SURVEY

In this introduction, we delve into the key contributions from recent research papers, each shedding light on distinct facets of cooling tower automation and optimization.

Dharinee.B.S, Rammohan Priyanka, Vishali.R, Sukambika.S: In their paper "Design of Cooling Tower with IoT" presents an intelligent and efficient control system for cooling tower operations. By leveraging IoT capabilities, it allows for remote monitoring and control of critical parameters such as pH levels and pump conditions. The integration of IoT not only enhances the precision of pH control by adjusting pump speeds but also ensures the safety of dosage pumps through real-time monitoring of temperature and vibration. This innovative approach improves operational efficiency, enables proactive maintenance, and enhances overall safety in the cooling tower system.

Eknath D. Kharat, Amit B. Gavali: In the study "Cooling Tower Automation" the focus is on automating and monitoring crucial parameters of a cooling tower system within an automobile industry. They utilize technologies such as Programmable Logic Controller (PLC) and Supervisory Control and Data

Acquisition (SCADA) to track variables like water temperature, pressure, water tank levels, and pump statuses. This automated monitoring system helps maintain optimal functioning and enables timely actions in case of any anomalies, contributing to enhanced efficiency and stability in the cooling tower setup. The paper also suggests future improvements like integrating auto water addition based on tank levels, utilizing TDS sensors for continuous monitoring, and implementing GSM alerts for immediate operator notification in case of system irregularities, envisioning a more streamlined and responsive cooling tower automation.

Changwei Huang: In the paper "Design of Central Air Conditioning Control Acquisition Device Based on IoT Technology" the focus is on creating a robust and efficient central air conditioning control system using IoT technology. The incorporation of a fuzzy algorithm plays a crucial role in enhancing the overall project performance. The author highlights the integration of MCU (Microcontroller Unit) and GPRS (General Packet Radio Service) module, enabling wireless data transmission for monitoring through computer and mobile terminals. This wireless communication facilitates seamless automation, information integration, and efficient monitoring of the system. The acquisition device development, as emphasized in the paper, contributes to elevated comfort and security levels in central air conditioning, promoting better communication between physical equipment and the upper server network. The paper provides a comprehensive analysis of the fuzzy PID algorithm, outlines the system diagram, and underscores the essential steps in system acquisition for central air conditioning control.

Muhammad Aftab, Chien Chen, Chi-Kin Chau, Talal Rahwan: In their paper titled Automatic HVAC control with real-time occupancy recognition and simulation-guided model predictive control in low-cost embedded system have discussed about the designing and implementation of an HVAC control system in a low-cost for occupancy prediction and using Raspberry Pi 3 a powerful embedded system is used to practically prove the real-time recognition of

occupancy by using machine-learning techniques and video-processing. Some of the ML techniques are used for prediction of dynamic analysis and also occupancy patterns. Thus, the HVAC controls are guided by model predictive controls and real-time building thermal response simulations. These systems were evaluated in a mosque which was a good example of large public indoor space occupancy. Their results using practical simulations showed 90% of accuracy in recognition and 85% of accuracy in occupancy prediction. These real time simulations were done using a online open source software called Energy-Plus, which is able to achieve more than 30% energy savings and also maintaining the acceptable range of comfort level within the space.

S. Dhanalakshmi, M. Poongothai, Kaner Sharmaa: In their paper titled IoTBased Indoor Air Quality and Smart Energy Management for HVAC System have proposed a simple HVAC control system that automates the operation in real time by considering energy management policies and user preferences. It is built on an IoT (Internet of Things) framework, where appliances in a laboratory are automated with suitable sensors and thermal parameters are obtained from sensors and user feedback information is collected for real-time processing in the cloud. Blynk Application Programming Interface (API) to monitor the real time data, to obtain user feedback and to adjust the temperature settings. The results show that Energy savings of 0.9 kWh is achieved by this method.

Gaëlle Guyot, Max H. Sherman, Iain S. Walker: In their paper titled “Smart ventilation energy and indoor air quality performance in residential buildings: A review” have provided a literature review on smart ventilation used in residential buildings, based on energy and indoor air quality performance. The meta-analysis in this review includes 38 studies of various smart ventilation systems with control based on CO₂, humidity, combined CO₂ and total volatile organic compounds (TVOC), occupancy or outdoor temperature. Demand controlled ventilation based on CO₂ or humidity improves indoor air quality using smart ventilation strategies. This study shows that, while energy savings up to 60% can be obtained by this, in some cases it also includes an overconsumption of about 26%.

Vladimir Tanasiev, George Cristian Patru, Daniel Rosner, Gabriela Sava, Horia Necula, Adrian Bade: In their paper titled Enhancing environmental and energy monitoring of residential buildings through IoT have explored a solution with the application of IoT, in controlling and monitoring the HVAC system environment, comfort parameters and electrical network in a real building. The architecture proposed in this paper uses a protocol and Lora sensors for monitoring the building. Software integration approach has been used to integrate wired and wireless sensors. The communication between the cloud computing node, edge device and PLC is based on the IoT based protocol, which powers the devices. The system was monitoring and tested in a research laboratory which showed flexible results with the additional features of debugging, updating a specific module and optimizing solution for its normal monitoring of other parameters. Thus the proposed solution was identified by the main consumers which signaled through graphical form of data. Finally resulted in overall reduction of electrical and thermal power usage, it also reduces the greenhouse gas emissions making it very environment friendly.

Kwang Hoon Han, Jensen Zhang: In their paper titled "Energy-saving building system integration with a smart and low-cost sensing/control network for sustainable and healthy living environments: Demonstration case study" have looked at energy savings through a smart integration of HVAC with the use of a smart sensing network, embedded PIR/CO₂ sensors and environmental system modelling while ensuring satisfactory thermal comfort and indoor air quality. A typical office building with multiple zones was utilized as a testbed. Two types of demonstration tests were performed under similar occupancy patterns and weather conditions; a) Baseline Test (3-day) with a normal building-operation following ASHRAE 62.1-2016 requirements, and b) Case Study (3-day) with a smart network-based demand control. The results showed energy savings up to 45% of fan electricity and 36.5% of room cooling/heating energy.

Zhihong Pang, Yan Chen b, Jian Zhang, Zheng O'Neill, Hwakong Cheng, Bing Dong: In their paper "How much HVAC energy could be saved from the occupant-centric smart home thermostat: A nationwide simulation-study,"

conduct a comprehensive analysis to estimate the potential energy savings achievable with an occupant-centric smart thermostat, utilizing a large-scale nationwide simulation infrastructure. Their study focuses on optimizing energy consumption in residential buildings while ensuring occupant thermal comfort through occupancy sensing and temperature adjustments. The simulated results reveal five significant impacts, including adopting energy-efficient heat pumps, adjusting temperature setpoints during occupied and unoccupied periods, utilizing a smart recovery feature, and implementing setback strategies. The findings emphasize the importance of maintaining a comfortable indoor temperature and employing appropriate temperature adjustments to achieve substantial energy savings in HVAC systems.

Sheng Zhang, Zhengtao Ai, Zhang Lin: In their paper titled Novel demand-controlled optimization of constant-air volume mechanical ventilation for indoor air quality, durability and energy saving have proposed a novel on DCV for constant-air-volume mechanical ventilation. The proposed DCV operates the constant-air volume mechanical ventilation continuously and intermittently at full-load/quasi-full-load and partial-load conditions to create highly efficient. A genetic algorithm-based optimization is developed to determine the upper and lower concentration limits to maximize energy efficiency while satisfying the demand in indoor air quality and avoiding excessively frequent on-off operations. This method helps to improve the energy efficiency by 88% while meeting the demand of indoor air quality and durability.

Wang Shu, Lu Wenda: In their paper titled theoretical and experimental solutions of cooling-tower-soil system: there have been many papers on dynamic properties of cooling towers. However, the bottoms of the tower shells were assumed as a fixed boundary, or discrete column systems of towers were considered as elastic boundary conditions. In the present paper, tower shells and discrete supports are treated as before. Furthermore, a dynamic model of an infinite soil is developed, and dynamic properties of the whole system of the cooling tower have been calculated. Model tests of free vibrations of cooling towers on different simulated soils are investigated. The numerical and

experimental results are in agreement. The results show that the elasticity of the soil reduces the natural frequencies of the cooling tower and the reduced value depends on the stiffness of the soil. Some of the mode shapes of the cooling tower are changed much as compared to a built-in tower.

Dong-Bae Kim, Daeung Danny Kim, Taeyeon Kim: In their paper titled Energy performance assessment of HVAC commissioning using long-term monitoring data: A case study of the newly built office building in South Korea have identified variables of the HVAC commissioning process through the help of analysis of energy efficiency of the HVAC system in a newly constructed office building. The energy demands for the case building are simulated by using data collected by BAS, BEMS and IPMVP Option D was used to calibrate conditions of the energy simulation. The results showed a decrease in 2 to 6% of total energy as per the occupancy rates and payback period which is used for development of HVAC commissioning for commercial buildings in the Korea.

Xing Lua, Zheng O' Neilla, Yanfei Liab, Fuxin Niu: In their paper titled "A novel simulation-based framework for sensor error impact analysis in smart building systems: A case study for a demand-controlled ventilation system" have introduced a simulation-based technique to conduct a comprehensive sensor error impact analysis in building systems, which gives a stochastic sensor prioritization through a sensitivity analysis and a deterministic sensor error quantification. A case study of a sensor-rich CO₂-based demand-controlled ventilation system is studied using a whole building simulation program, Energy-Plus, to demonstrate the viability of the methodology as a proof-of-the-concept. The Monte Carlo method is used for sensor error impact prioritization. The results show that ventilation performance is influenced mostly by the accuracy of AHU outdoor airflow sensors and that the zone CO₂ sensor accuracy has more influence on the ventilation performance compared with the zone airflow sensor accuracy. The current implementation might be subject to limitations and uncertainties from multiple sources.

Shady S. Refaat, Haitham Abu-Rub, Amira Mohammed: The paper titled “Smart and Energy Air-Conditioning Systems” discusses an innovative approach to enhance energy efficiency and cost-effectiveness in air conditioning systems while considering customer preferences, comfort, and health. The authors propose an online algorithm that integrates behavioral and technological modifications to optimize energy consumption. The algorithm employs embedded tools to collect and monitor energy information, aiming to minimize energy usage and intelligently manage air conditioner consumption. The proposed system is validated using MATLAB/Simulink software, analyzing energy characteristics and demonstrating the effectiveness of the approach through experimental results and real-time implementation.

Wei Song, Ning Feng, Yifei Tian, Simon Fong: The paper titled “An IoT- Based Smart Controlling System of Air Conditioner for High Energy Efficiency” presents a smart air conditioning control system using IoT technology. This system includes smart meters, a smart gateway, and cloud computing components. The smart meters regulate air conditioner compressor operations based on set temperatures and monitor real-time power usage, transmitting the data wirelessly to a cloud server. Through Zigbee communication, the smart gateway automates meter detection and dispatches control signals. The cloud server processes this data, utilizing an extreme learning machine for energy consumption predictions and generating energy-saving decisions. These decisions help manage air conditioners efficiently, reducing power usage, lessening the load on the power grid, and ultimately contributing to greenhouse gas reduction.

Masayoshi Hamanaka, Shunsuke Horie, Daiki Owaki, Kenshu Nimi, Kazuto Yukita, Toshiro Matsumura, Yasuyuki Goto, Keiichi Hirose: Their paper titled “Demand Response Using Air Conditioner” focuses on demand response utilizing air conditioners as a means to optimize power consumption. Given that air conditioners constitute a significant portion of power consumption in buildings, controlling their usage is crucial for effective demand response. The authors measured CO₂ levels to estimate the number of occupants and experimented

with demand response in a university lecture laboratory. They concluded that utilizing air conditioners for demand response proved to be effective, highlighting the importance of understanding occupancy levels for efficient demand response strategies.

N. Wang, J. Zhang, X. Xia: In their paper titled "Energy Consumption of Air Conditioners at Different Temperature Set Points" the authors emphasize the significance of energy savings in air conditioning systems within building projects due to the substantial portion of energy consumption attributed to air conditioners. While previous research primarily focused on the chiller system and associated control strategies, this study underscores the effectiveness of thermal control strategies, specifically adjusting temperature set points, in achieving energy savings. The paper presents an energy consumption calculation model for a data center in South Africa, aiming to estimate the energy usage of air conditioners when the temperature set points are set at 22°C and 23°C.

Surachai Thongkaew, Chirot Charitkuan: In their paper titled "IoT for Energy Saving of Split-Type Air Conditioner by Controlling Supply Air and Area Temperature," propose an Internet of Things (IoT) platform to optimize energy consumption in split-type air conditioners. The system focuses on controlling the airflow temperature and the room temperature by utilizing the MQTT Protocol for local temperature transmissions. An advanced Temperature Analytics Algorithm is employed to make informed decisions about when to switch off the compressor under appropriate conditions. The control factors include the supply air temperature of the air conditioner and the actual room temperature. If the supply air temperature indicates the evaporator is too cold or the room temperature reaches the desired level, the system instructs the compressor to stop working, thereby reducing its runtime and leading to significant energy savings.

Himadri Nath Saha, Tanishq Banerjee, Somshubhra Roy, Soham Pandit, Sayan Dutta, Subham Sadhukhan, Nityasree Upadhyay, Prerana Chakraborty, Souranshu Ghosh: In their paper titled "An integrated

solution for monitoring domestic appliances using IoT facilitating energy conservation," present an integrated IoT-based solution for monitoring and effectively managing regular domestic appliances, promoting energy conservation. The system leverages IoT to enable remote control and automation of essential household appliances using computers or mobile devices. The solution consists of five sub-projects: automated water tap control, lighting control, door locking, gas detection, and temperature control systems. The automation systems are designed to enhance energy efficiency and security while minimizing human effort. The authors emphasize that their proposed system outperforms existing solutions in terms of energy efficiency, cost-effectiveness, usability, and portability, aiming to reduce energy waste and streamline household operations.

Moath Awawdeh, Anees Bashir, Tarig Faisal, Khawla Alhammadi, Mouza Almansori and Sara Almazrouei: In their paper titled "Embedded Ventilation Air Conditioning System for Protection Purposes with IoT Control," the authors introduce the Embedded Ventilation Air Conditioning (EVAC) system, aiming to create an automated protection system. This system integrates air conditioning, ventilation, smoke extraction, and a protection system into a single smart embedded solution. The goal is to enhance safety by providing early warnings and proactive responses in the event of indoor fire and smoke hazards. The authors utilize the Arduino integrated development environment and IoT platforms, employing sensors and control applications to achieve the system's functionality. The EVAC system incorporates smoke and temperature sensors to detect gases and high temperatures. When sensor readings surpass predefined thresholds, the system automatically shuts off the air conditioning, activates smoke extraction fans, and initiates a series of warnings according to a predefined protection protocol. The paper provides a detailed description of the system's procedures and the prototype model, supported by testing results obtained through experimental readings and verification.

Jingyun Liu, Huiling Zhou, Xiaoguang Zhou, Yang Cao, Huiyi Zhao: In their paper titled "Automotive Air Conditioning System Control - A Survey," the

authors addresses the growing concerns related to air conditioning system (A/C) control as A/C systems become more prevalent. The article provides an overview of various automatic control techniques that have been employed in A/C systems. It outlines the characteristics of A/C systems and discusses the variables that should be controlled. The authors present a classification of control approaches to elucidate the primary features of these strategies in A/C systems. The article underscores the increasing need for advanced A/C control strategies due to improvements in living standards and global concerns about the environment and energy. It summarizes studies on control methods and analyzes the development and emerging trends in A/C control approaches.

Yuming Guo, Fuli Wang, Mingxing Jia¹, Dapeng Niu: In their paper titled "Hybrid Modeling Method for Predicting the Cooling Water Outlet Temperature in Plate Heat Exchanger," the authors focus on the critical role of the circulating cooling water system in ensuring safe production processes in iron and steel enterprises. They emphasize the significance of energy-saving operation, which relies on accurate predictions of cooling water outlet temperature in plate heat exchangers. The authors propose a hybrid modeling method for this prediction. Initially, they establish a mechanistic model by analyzing the heat transfer process based on thermal transfer and balance equations. Subsequently, they integrate a radial basis function neural network (RBFNN) into the mechanistic model to create a hybrid model. The RBFNN corrects errors in the mechanistic model arising from theoretical assumptions and inaccurate parameter values. Simulation results confirm the superior prediction performance of the hybrid model compared to the mechanistic model, laying the groundwork for optimizing the operation of the circulating cooling water system.

G. Kirthika, Dr. S. Charles Raja: In their paper titled "Automation of Regenerative Compressor Cooling System Using Microcontroller," emphasize the importance of regenerative compressor cooling as a means to efficiently utilize limited resources. Compressed air, often referred to as the industry's fourth utility, is condensed and maintained at a pressure greater than atmospheric pressure. Cooling the air before it enters the compressor is a critical task that

impacts the efficiency and quality of the compressed air. The authors propose an embedded-based system with remote monitoring to automate the air-cooling process before it enters the compressor, incorporating state-of-the-art technology. They address the limitations of traditional motorized cam timers by employing a real-time clock, offering greater flexibility and adaptability for events that occur at variable times. The use of a four-way valve and real-time clock aids in optimizing the airflow path within the cooling system, thus enhancing the quality of input air to the compressor. The authors highlight the advantages of their approach, such as eliminating manual intervention, providing time flexibility, achieving power savings, and enabling centralized monitoring from a DCS control room through a PC-based mimic panel.

Kuixing Liu, Neng Zhu, Menglei Wang, Zhe Tian: In their paper titled "Comparative Study of Cooling Tower Performance Evaluation Indicators" discuss three evaluation indicators for cooling towers. They employ three evaluation methods, focusing on the contrast of cooling water, cooling capability, and efficiency coefficient to assess the performance of these cooling towers. However, they observe inconsistencies in the evaluation results obtained through these methods. The paper thoroughly analyzes the reasons behind these variations in results, providing insights into the diverse application scopes and limitations of each evaluation indicator. Additionally, the authors offer recommendations and suggestions for improving the evaluation of cooling towers based on their findings and analysis.

Danxu Zhang, Peter B. Luh, Junqiang Fan: In their paper "Chiller Plant Operation Optimization with Input and Model Uncertainties," the authors highlight the significance of considering uncertainties in input and model parameters for achieving optimal chiller plant operation. They stress that neglecting these uncertainties can result in suboptimal energy consumption. The authors propose a method that selects key parameters based on sensitivity analysis and incorporates uncertainties within bound constraints, effectively reducing the number of constraints. To efficiently reach near-optimal solutions in a mixed-integer problem involving continuous and discrete decision variables,

they utilize a decomposition and coordination method. Their approach demonstrates substantial energy savings, providing near-optimal solutions, shorter CPU times, and improved scalability, ultimately outperforming methods that overlook uncertainties.

Wenhua Zhang, Chunling Meng: In their paper titled "Optimization Design of the GFRP Hyperbolic Cooling Tower Structure," the authors focus on addressing stability issues in the structure of mature application cooling towers, specifically the disequilibrium bar stability problem. They emphasize the importance of ensuring the cooling tower's strength and stability while optimizing the design of the cooling tower rods to achieve a more reasonable structure, ultimately reducing both weight and cost. The research presented in this paper lays the theoretical foundation for autonomously designing efficient cooling towers, offering practical insights and high application value for the field.

Burkov A. F, Sokolova V. S, Zaychenko I. V: In their paper titled "Determination of Parameters of the Gas Absorption System with Air Cooling for Conditioning of Industrial Premises," investigate the potential use of a natural gas absorption system as a conditioning solution for industrial premises during the summer. The authors explore and validate key trends in managing the microclimate of industrial enterprises. They identify challenges associated with integrating absorption cooling machines into industrial facilities and suggest examining the application of localized low-power absorption systems for conditioning. The paper includes a thermal design of an absorption system and heat engineering calculations for a closed cooling tower, meeting the heat diversion requirements during the absorption system's operation. Additionally, the authors conduct an economic design and conclude on the practicality of implementing the proposed solution in industrial facilities based on the analysis of the results.

WU Zhijiang, WANG Nan, ZHU Gongsheng: In their paper titled "Application Research of Evaporative Cooling in Waste Heat Recovery," discuss

the evaporative condenser as a highly efficient and energy-water saving heat exchange equipment. They provide an introduction to the theory and product characteristics of the evaporative condenser. The paper presents a novel application of the evaporative condenser in waste heat recovery, emphasizing its significant energy-saving effects. The authors anticipate a broad application outlook for this technology in various engineering fields due to its potential for efficient waste heat recovery.

Jian-Guo Wang, Qian-Ping Xiao, Juan-Juan Wang, Shi-Wei Ma, Wen-Tao Rao Yong-Jie Zhang: In their paper titled "Soft Sensor Approach for Optimal Operation of Cooling Tower for Energy Conservation," propose a data-driven adaptive soft sensor approach to optimize the performance of cooling towers for energy conservation. The approach involves characterizing the cooling tower process using an adaptive soft sensor with a nonnegative garrote (NNG) variable selection procedure. Subsequently, the authors utilize principal component analysis (PCA) to analyze the influence of environmental temperature and humidity on cooling capacity. Finally, the paper presents an optimal fan operation strategy, demonstrating substantial energy conservation potential through its implementation in a cooling tower.

Tongrui Chenga, Zhenning Zhao, JunfuLv, Han Yu: In their paper titled "Anti-freezing Performances of Novel Natural Draft Dry Cooling Tower with Double-layer Air-cooled Heat Exchanger," explore the anti-freezing capabilities of a novel natural draft dry cooling tower (NDDCT) integrated with a double-layer air-cooled heat exchanger (ACHE). The NDDCT is employed in a 2×660MW dry cooling power plant for cost-effectiveness. The paper investigates the coupling effects of ambient temperature with the circulating water flow rate, circulating water outlet temperature, and heat load on the potential freezing risk during cold days. The study identifies critical anti-freezing parameters and explores strategies, such as reducing the number of operational sectors, to improve anti-freezing performance. The research also considers the impact of wind speed on anti-freezing water flow rates. The findings aim to guide safe and efficient

operation of the NDDCT with double-layer ACHE, particularly in addressing freezing concerns.

Rajashekar P. Mandi & R.K. Hegde, S.N. Sinha: In their paper "Performance Enhancement of Cooling Towers in Thermal Power Plants through Energy Conservation," analyze induced draft cooling tower performances in thermal power plants. They identify current heat transfer effectiveness ranging from 46.4% to 50.9% and overall CT fan efficiencies varying from 25.9% to 42.8%. These values are attributed to design deficiencies and a hesitancy to adopt new technology. The paper presents detailed results showcasing the performance improvements achieved by replacing Glass Reinforced Plastic (GRP) blades with modern Fiber Reinforced Plastic (FRP) blades. Additionally, operational optimization strategies for cooling towers are discussed to enhance their performance and promote energy conservation in thermal power plants.

Danxu Zhang, Peter B. Junqiang Fan, Shalabh Gupta: In their paper on "Chiller Plant Operation Optimization: Energy-Efficient Primary-Only and Primary–Secondary Systems," emphasize the importance of optimizing chiller plant operations to save energy, given the substantial energy costs involved. They analyze chiller plants consisting of chiller, cooling tower, and pump subsystems, considering two major configurations: primary-only and primary–secondary systems. The key focus is on optimizing chilled/condenser water supply temperatures, crucial for enhancing chiller efficiency. However, due to the nonlinear nature of chiller power consumption with respect to these temperatures and the combinatorial complexity arising from the number of active units, solving this optimization problem efficiently is a challenge. The paper presents a decomposition and coordination approach, coupled with sequential quadratic programming (SQP), showcasing its efficiency in achieving significant energy savings compared to benchmark strategies. The proposed approach is scalable and holds potential for broader applications beyond chiller plant optimization.

Yuming Guo, Biao Wang: In their paper titled "Optimal Design of Forced Draft Cooling Tower under Variable Working Conditions," present an optimal design approach for a forced draft cooling tower using a nonlinear programming model. The authors start by analyzing the thermodynamic properties and kinetic characteristics of a forced draft cooling tower. Subsequently, they develop a nonlinear optimization model based on these analyses. The study explores how changes in working conditions due to meteorological conditions and water demand during the main production process impact cooling tower design. The effectiveness of the proposed optimization method is validated using a case study, demonstrating a 21.6% reduction in annual operating cost and a 15.9% reduction in annual comprehensive cost compared to conventional methods. This study's approach proves effective in reducing comprehensive costs by considering changes in working conditions during the design of a cooling tower.

Nyoman Suamir, Nengah Ardita, Made Rasta: In their study, "Effects of Cooling Tower Performance to Water Cooled Chiller Energy Use: a Case Study toward Energy Conservation of Office Building," the authors investigated the influence of cooling tower performance on energy consumption in a water-cooled chiller system within an office building in Jakarta, Indonesia. The research demonstrated that the performance of the cooling towers had a significant impact on energy efficiency. By testing two cooling towers of similar capacity, they found a substantial disparity in efficiency, affecting the chiller's overall performance. Operating the chiller with a less efficient cooling tower led to a notable decrease in chiller efficiency and an increase in power consumption. This study sheds light on the critical role of cooling tower performance in energy conservation efforts for office buildings.

Ioana Opriș, Sorina Costinaș, Cristina-Sorana Ionescu, Daniela-Elena Gogoășe - Nistoran: In their paper, "Improving the Efficiency of Natural Draft Wet Cooling Towers by Using Smart Metering Systems," highlight the importance of smart metering systems in monitoring and enhancing the performance of natural draft wet cooling towers. These cooling towers are sensitive to various factors, including their size, the temperature of warm water

from the condenser, and weather conditions. Monitoring the cooling tower's performance, especially the temperature of cooled water, is crucial as it significantly impacts the overall power plant's efficiency. The paper discusses cooling performance indicators and how a smart metering system can play a vital role in efficient cooling tower operations. Through simulation models, they demonstrate how performance indicators fluctuate with changing input conditions, emphasizing the potential of smart metering systems to optimize the efficiency of natural draft wet cooling towers.

M. A. Green, S. Q. Yang, J. Cobb, P. Lau, W. W. Lau, H. Witte, D. E. Baynham, and T. W. Bradshaw: In their paper titled "The Effect of Magnetic Field on the Position of HTS Leads and the Cooler in the Services Tower of the MICE Focusing Magnet," discuss the impact of magnetic fields on the positioning of components in the MICE (Muon Ionization Cooling Experiment) focusing solenoids. The MICE focusing solenoids incorporate 4 K coolers for the superconducting magnet and liquid absorber, as well as HTS (High-Temperature Superconductor) leads that supply current to the focusing coils. The study focuses on the magnetic fields generated during different operating modes and how these fields influence the selection of coolers and HTS leads. The paper outlines the criteria used to select coolers and HTS leads, taking into account the magnetic field effects and the positioning of these components with respect to the solenoid axis of rotation.

Chang-Koon Choi, Hyuk-Chun Noh: In their paper, "Stochastic Analysis of Shape Imperfection in RC Cooling Tower Shells," address a crucial aspect of reinforced concrete cooling tower shells—shape imperfections. Rather than relying on idealized shapes to model imperfections, they adopt a statistical stochastic analysis that considers shape imperfections as globally distributed stochastic fields. Specifically, the study focuses on the stochastic variability in thickness and radius of the cooling tower shell, revealing how these parameters affect the response variability. Their findings underscore the importance of accurately understanding and accounting for shape imperfections in the structural analysis of cooling tower shells.

P. Srinivasa Rao t, K. Ramanjaneyulu: In their paper titled "Stability of Cooling Tower Shell with Modified Wind Pressure Coefficients," conduct a stability analysis of natural draft cooling tower shells under the influence of non-axisymmetric wind pressure. They utilize finite ring elements for this analysis and introduce the concept of locally enhanced wind pressure coefficients at the top of the cooling tower, supplementing the usual wind pressure variation with height. The paper justifies the use of these modified wind pressure coefficients and proceeds to perform a parametric study evaluating the effects of top ring stiffener dimensions, shell bottom edge thickening, and vertical cracking due to thermal gradient on the buckling behavior of cooling tower shells. The study provides valuable guidelines for choosing appropriate dimensions of the top ring stiffener to prevent top edge buckling, contributing to the stability analysis of cooling tower shells.

Bahaa E. H. Mahmoud, Ajaya K. Gupta: In their paper titled "Inelastic Large Displacement Behavior and Buckling of Cooling Tower," delve into the inelastic, large displacement behavior of reinforced concrete hyperbolic cooling towers. Using a finite-element program developed on the Cray Y-MP supercomputer, the study formulates the effects of large displacement based on the Lagrangian approach, measuring displacements from the original structure configuration. Concrete cracking is modeled using the rotating smeared crack approach, and bending deformation is represented through layering techniques. The concrete's constitutive behavior is characterized by a biaxial inelastic material model, and tension stiffening of concrete is simulated through gradual linear unloading of the stress-strain curve. The study's nonlinear analyses of the Grand Gulf cooling tower reveal that failure is attributed to circumferential buckling near the throat due to reduced stiffness resulting from concrete cracking, challenging previous attributions of failure to yielding of meridional reinforcement.

Jacek Błocki: In the paper titled "Stress States in Cooling Tower Caused by Thermal Field" an analysis of stress states in a hyperbolic cooling tower is presented, specifically focusing on the thermal field-induced stresses. The study employs numerical calculations based on experimental measurements of the temperature field to determine the magnitudes of thermal stresses. Special attention is given to understanding the thermal stresses that manifest near the base of the tower. The insights gained from this analysis are anticipated to be valuable in engineering design processes, providing useful information for the structural assessment of cooling towers under thermal effects.

Gunther Meschke, Herbert A. Mang, Peter Kosza: In their paper, "Finite Element Analyses of Cracked Cooling Tower Shell," the authors conduct a critical evaluation of a concrete cooling tower's structural safety, constructed 25 years ago and now exhibiting numerous long meridional cracks. Employing finite element analysis, they simulate the damage process by considering various thermal load histories followed by incremental wind load application. The study concludes that the degree of corrosion significantly impacts the safety of the cooling tower. Furthermore, they investigate the sensitivity of structural response to tensile strength, analyze the effectiveness of a repair strategy involving stiffening rings, and explore the influence of ring placement on structural response. These insights are vital for ensuring the structural integrity and safety of aging cooling tower structures.

T. Y. Yang, M. ASCE, Rakesh K. Kapania: In their paper titled "Finite Element Random Response Analysis of Cooling Tower," present a comprehensive finite element formulation and Gaussian quadrature procedure. This methodology enables the study of stationary random responses in shell structures, such as cooling towers. The research assumes random distributed loads to be stationary in time but potentially nonhomogeneous in space. The paper employs a specialized 48-degree-of-freedom quadrilateral shell element with bi-cubic Hermitian polynomial interpolation functions as displacement shape functions. These shape functions are pivotal in calculating cross-spectral densities of displacement and stresses, providing valuable insights into the

behavior of cooling tower structures subjected to random wind loads at varying wind velocities. The results contribute to a deeper understanding of structural response in complex scenarios, aiding in design and safety considerations for cooling tower systems.

Wei Li [43] In their paper titled "Oscillatory Fouling in Condensers in Cooling Tower Systems," the author addresses the phenomenon of oscillatory fouling in cooling tower systems. The analysis involves the splitting of the fouling rate into two components: a mean variable and a fluctuating variable. The mean variable demonstrates asymptotic behavior, while the fluctuating variable exhibits oscillatory behavior. The study employs a theoretical analysis based on continuity relationships, providing insights into the physical mechanisms underlying this fouling phenomenon. The experimental validation involved long-term cooling tower water fouling tests on copper helically ribbed tubes. The results showed oscillatory behavior in fouling, both spatially and temporally, shedding light on the dynamics of fouling in cooling tower systems. The paper contributes to a better understanding of fouling mechanisms and aids in optimizing cooling tower performance.

Kenneth S. Limpahan, Rommel R. Viña, Feliciano B. Alagao: In their paper titled Performance Evaluation of Direct-Contact Cooling Tower Used on Thermoelectric Module and Parabolic Trough Collector for Power Generation: Thermoelectric has gained attention for its clean energy generation. It has the potential of converting heat from renewable energy into direct current electricity which will replace our dependency on fossil fuels. This paper presents thermoelectric power generation system which consists of cooling tower that provides direct water cooling and solar thermal collector that provides high heat source on thermoelectric modules. Eight (8) thermoelectric modules connected in series with 40mm x 40mm x 3.5mm in size were sandwich between the absorber plate from parabolic trough collector and cooling water inside the square tube. Cooling tower thermal performance was evaluated using SolidWorks Flow Simulation software and experimental validation in steady-state and transient analysis. Experiment results show that the cooling tower has a

thermal capability of lowering 100°C heated water to 28°C cold water at 2.5l/min. A temperature difference of 97°C across the thermoelectric module was achieved with 28°C maintained on the cold side and 125°C on the hot side. It generated up to 21 Watts at 12.7 Volts. Thermoelectric technology has a significant potential for renewable and sustainable power generation especially when integrated with cooling towers for medium scale and large-scale thermoelectric power generation.

Loui S Elliot: In the paper titled "Cooling Towers for Steam-Electric Stations Economic Applications" the author presents a method for conducting economic comparisons between using a cooling tower and a direct condensing arrangement for a steam station. The paper provides an analysis of a specific problem to illustrate this method. Additionally, the author includes remarks on the optimal placement of cooling towers and highlights areas that require further research in this field. The paper contributes to understanding the economic aspects of employing cooling towers in steam-electric stations.

Josep H Lichtenstein: In the paper titled "Recirculation in Cooling Towers" the author emphasizes the importance of considering recirculation, a characteristic of the surroundings in a cooling-tower installation, in economic calculations and proper cooling tower selection to achieve a desired cold-water temperature. The paper outlines the methods and equations necessary for conducting tests to determine the recirculation factor in cooling-tower installations. It delves into how varying degrees of recirculation impact cold-water temperature and how the size of a cooling tower might need adjustment to maintain a fixed cold-water temperature. Furthermore, the paper explores the relationship between cold-water temperatures and wet-bulb temperatures for different recirculation factors, highlighting the potential for maintaining a relatively consistent cold-water temperature throughout the year if recirculation factors are appropriately managed.

Maoting Li, Xiaokai Gong, Wei Dong and Wenliang Li: In their paper titled "The Cooling Tower Fan System Fault Monitoring based on the Trunk of RS485," address the existing challenges in fault monitoring of cooling tower fan operation. They propose a new fault monitoring system for cooling tower fans that utilizes a PC as the host computer, a microcontroller connected to a new RS485 bus, and a novel monitoring method. The paper provides an overview of the monitoring system's components and explains the monitoring principle, particularly focusing on fault detection related to the cooling tower fan blade shaft. The authors highlight that this monitoring method enhances the reliability of fan fault detection, reducing critical failures of the fan and demonstrating significant application value.

Rohit K. Singla, Ranjan Das: In their paper titled "Retrieval of Controlling Parameter in Induced Draft Cooling Tower Using Inverse Method," demonstrate the application of the Golden Section Search Method (GSSM) to inversely retrieve the controlling parameter that meets a desired performance requirement in an induced draft cooling tower. The Merkel number, a crucial performance parameter in cooling towers, is targeted as it encapsulates various parameters like global heat and mass transfer coefficients, water flow rate, and dimensions within itself. The authors conduct experiments to establish accurate correlations for Merkel number against the controlling parameter, which is the air mass flow rate in this case. They then utilize the inverse optimization technique involving GSSM to estimate the required air flow rate needed to satisfy a given performance parameter. The study concludes that the controlling parameter estimated using GSSM provides an excellent reconstruction of the Merkel number.

Josep H Lichtenstein: In the paper titled "Performance and Selection of Mechanical Draft Cooling Towers," the author emphasis is on the need for standardization in cooling-tower practice and the adoption of a common basic theory for correlating the extensive amount of experimental data available. The author highlights the importance of a unified theory that could significantly aid in calculating performance at the guarantee point based on test data gathered

under various service conditions. The paper utilizes Merkel's differential equation for the cooling tower to derive a fundamental dimensionless equation for calculating cooling-tower performance. The author also presents a graphical method of solution for this basic equation through curves developed as a result of extensive tests. It's noted that the size of a cooling tower for a given set of conditions is influenced not only by theory but also by economic considerations, ultimately serving as the final criterion for selection.

Jiasheng Wu, Guoqiang Zhang, Quan Zhang, Jin Zhou, Yonghui Guo, Wei Shen: "Experimental Investigation of the Performance of a Reversibly Used Cooling Tower Heating System Using Heat Pump in Winter," focus on a de- superheater heat recovery system incorporating a reversibly used cooling tower(RUCT) in subtropical regions of China. The study includes simulations and fieldtests of a RUCT heating system employing a heat pump (RUCTHPS) during winter. Aqueous solution was used as the circulation medium between the RUCTand the heat pump instead of water typically used in summer. The experiments investigated the impact of air mass flow rate, inlet air temperature, inlet solution temperature, and solution mass flow rate on the RUCTHPS's performance during winter. The field test results demonstrated that the RUCTHPS performed effectively when the ambient temperature was near 0°C in winter and highlighted the significant influence of the RUCT on the overall heating system performance.

2.3 SUMMARY

From the literature review it is known that the key focus is on optimizing condenser water supply temperatures, crucial for enhancing chiller efficiency. However, due to the nonlinear nature of chiller power consumption with respect to these temperatures and the combinatorial complexity arising from the number of active units, solving this optimization problem efficiently is a challenge. The gap areas identified are arriving at the ideal temperature set points for cooling tower fan operations and TDS values for operating the central air-conditioning plant with minimum energy consumption.

CHAPTER-3

IMPLEMENTATION OF IOT-BASED SMART MONITORING FOR OPTIMIZED PERFORMANCE OF COOLING TOWERS

3.1 GENERAL

The primary aim of the Cooling Tower Automation project is to elevate the efficiency and sustainability of cooling tower operations through the implementation of an advanced automation system. By integrating Internet of Things (IoT) devices, sophisticated sensors, and real-time monitoring capabilities, the project aims to achieve a multifaceted set of objectives. Firstly, it seeks to optimize operational efficiency by precisely monitoring and controlling critical parameters, such as Total Dissolved Solids (TDS) and water temperature. This optimization ensures that the cooling tower consistently operates at peak efficiency, thereby reducing energy consumption and enhancing overall performance.

A pivotal goal of the project is to minimize human error in the monitoring and adjustment processes. Automation serves as a mechanism to reduce reliance on manual intervention, mitigating potential errors and ensuring that cooling tower parameters remain within optimal ranges consistently. Furthermore, the project aims to contribute to energy conservation by dynamically responding to changing environmental conditions through IoT devices and automated controls. This not only aligns with sustainability goals but also aids in minimizing operational costs.

Additionally, the project emphasizes the importance of proactive maintenance through real-time monitoring and data collection enabled by IoT devices. By identifying potential issues at early stages, the project aims to reduce downtime, extend equipment lifespan, and enhance the overall reliability of the cooling tower system. Furthermore, the project aligns with broader environmental sustainability initiatives by promoting energy-efficient practices and minimizing the ecological impact of cooling tower operations.

While acknowledging the initial investment required for implementing IoT devices and automation, the project is designed to be cost-effective in the long run. The anticipated benefits, including energy savings, reduced maintenance costs, and enhanced equipment longevity, are expected to surpass the initial expenditures, making the Cooling Tower Automation project not only technologically advanced but also economically viable and environmentally responsible.

3.2 OBJECTIVE OF THE PROJECT

The key objectives of this project include:

1. Automation of cooling tower fans to maintain 5°C approach temperature in all seasons of cooling tower operation to optimize energy usage of chiller.
2. Maintaining the total dissolved solids (TDS) of circulating water in cooling tower below 600ppm by automatic operation of bleed-off valves.
3. Maintaining the optimum water level in the cooling tower sump by automatic operation of makeup valve.
4. Real time monitoring of process parameters like water temperature, TDS values, pH and sump water level via IoT devices for effective control and management.

3.3 PROPOSED BLOCK DIAGRAM AND EXPLANATION

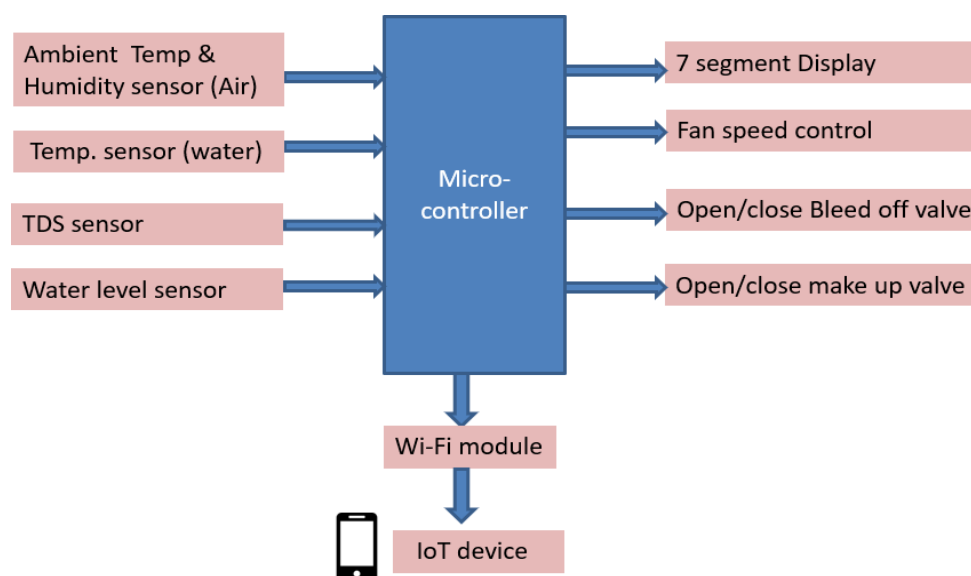


Figure 3.1: Proposed Block diagram

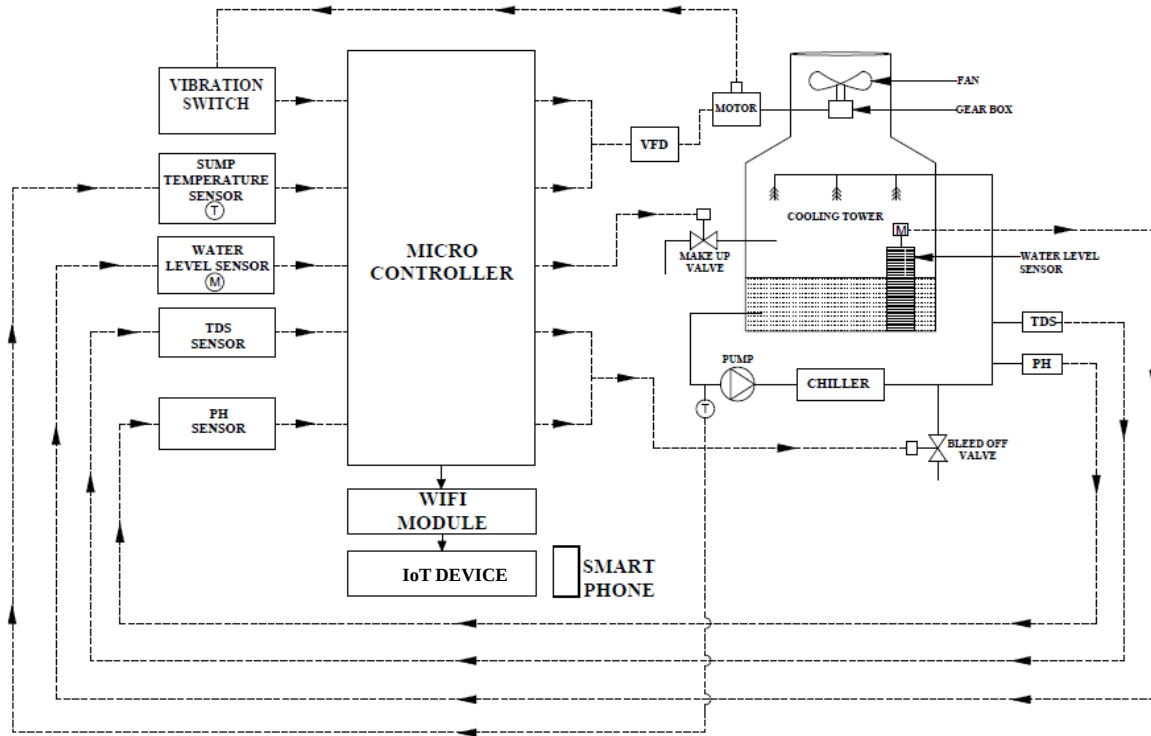


Figure 3.2: Process and Instrumentation Diagram

The proposed solution revolves around leveraging the capabilities of Internet of Things (IoT) devices to automate and streamline cooling tower operations, ensuring that crucial process parameters remain within specified limits. Key components of this solution include strategically deploying IoT-enabled sensors to capture real-time data on temperature, flow rates, pressure, and humidity. This data is then transmitted to a centralized IoT platform, where advanced analytics and automation logic are applied.

The automation logic plays a pivotal role in continuously analyzing the received data and dynamically adjusting cooling tower operations, such as fan speed and water flow. This adaptive approach ensures that process parameters are consistently maintained within permissible ranges, promoting optimal efficiency and performance. Moreover, the implementation of predictive maintenance algorithms adds a proactive dimension to the system by forecasting potential issues based on the analyzed data. This enables operators to take preventive

maintenance actions, reducing downtime and enhancing the overall reliability of the cooling tower equipment.

The IoT-powered automation approach not only promises to enhance operational efficiency but also aims to optimize energy consumption. By precisely adjusting operational parameters based on real-time data, the system can achieve energy savings while extending the lifespan of cooling tower equipment. The solution also emphasizes compliance with vital operational constraints, ensuring that the cooling tower operates within predefined limits.

Additionally, the proposed system facilitates remote accessibility, allowing operators to monitor and control the cooling tower system from any location. This remote capability enhances overall efficiency and sustainability by providing operators with real-time insights and control over the system, contributing to improved decision-making and operational management. In summary, the integration of IoT devices offers a comprehensive and intelligent solution to elevate the efficiency, reliability, and sustainability of cooling tower operations.

3.5 FLOWCHARTS

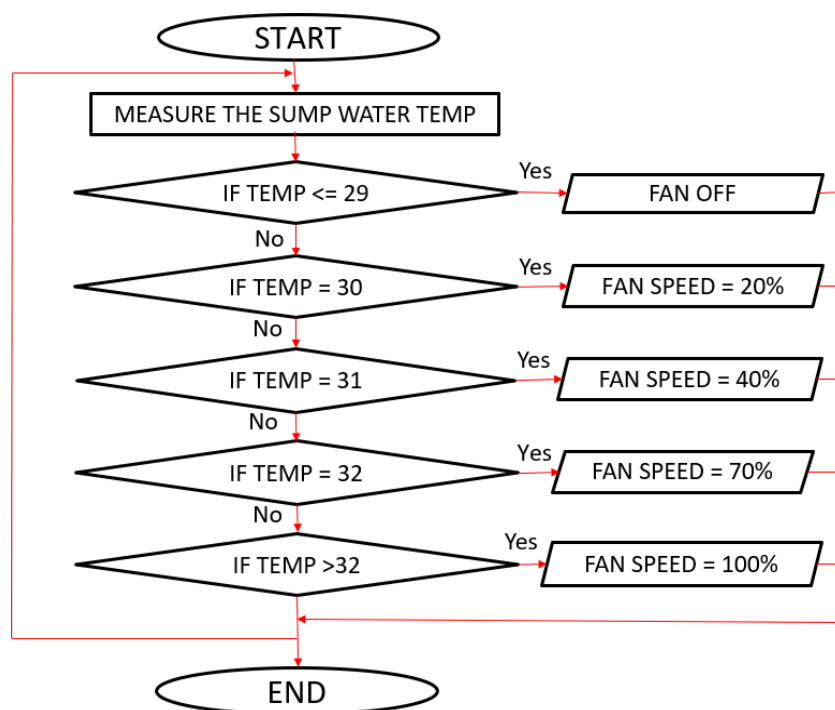


Figure 3.3: Controlling cooling tower Fan Speed

Figure 3.3 presents a flowchart outlining the process for controlling the cooling tower fan speed. This visual representation illustrates the sequence of steps and decision points involved in adjusting the fan speed based on various factors such as temperature, humidity, and system requirements. By breaking down the control process into manageable steps, the flowchart helps in understanding and implementing the logic behind fan speed regulation, facilitating effective management of the cooling tower system.

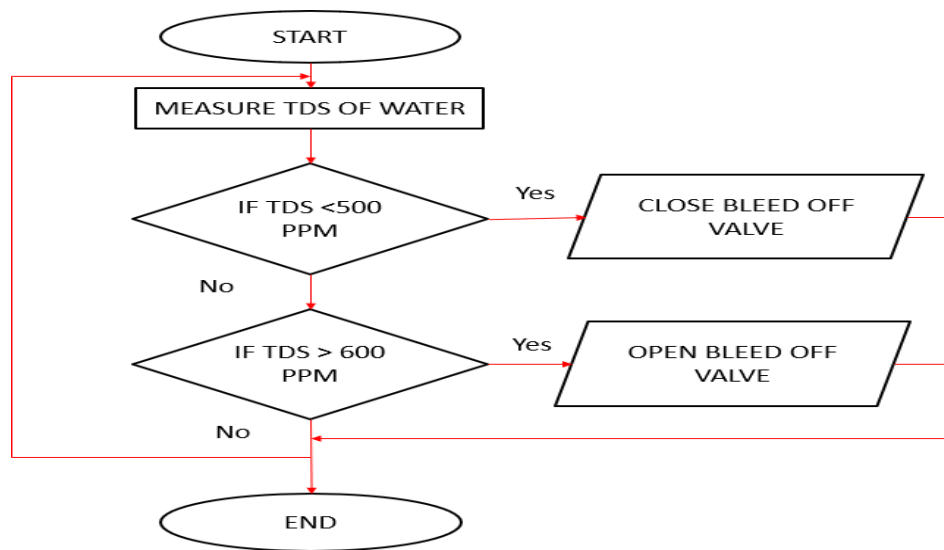


Figure 3.4: Controlling Bleed off valve with TDS Sensor

Figure 3.4 depicts a flowchart detailing the process of controlling the bleed-off valve using a TDS sensor. This visual representation outlines the sequence of steps and decision points involved in monitoring the Total Dissolved Solids (TDS) level in water and adjusting the bleed-off valve accordingly to maintain optimal water quality. By visually organizing the control logic, the flowchart aids in understanding and implementing the automated control of the bleed-off valve based on real-time TDS measurements, ensuring efficient operation of the system.

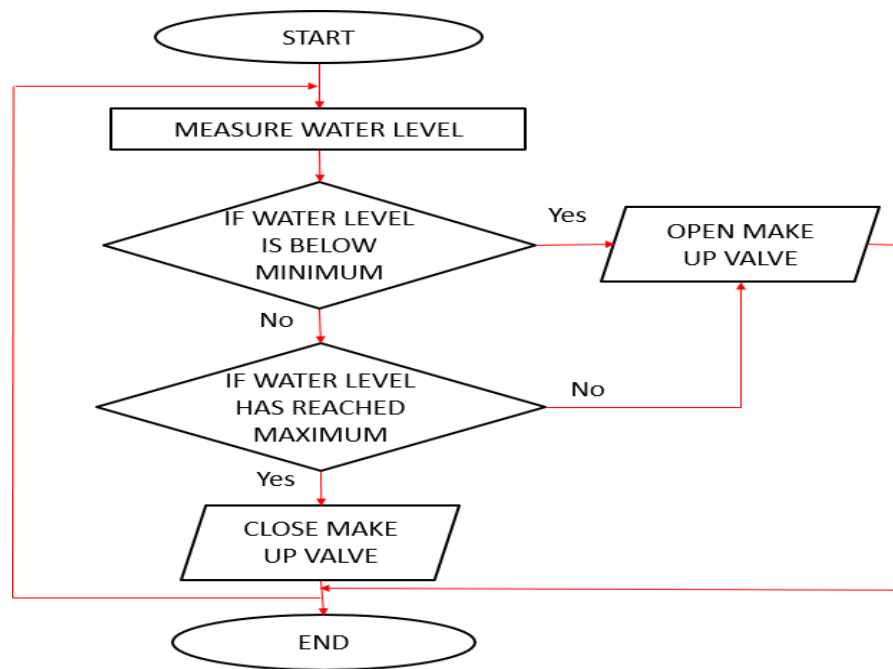


Figure 3.5: Controlling sump water level in Cooling Tower automatically

Figure 3.5 presents a flowchart demonstrating the control process for managing the sump water level in a cooling tower, incorporating the regulation of the makeup valve. This visual representation outlines the series of steps and decision nodes involved in monitoring the water level within the sump and modulating the makeup valve to ensure the desired water level is maintained. By presenting the control logic in a structured format, the flowchart facilitates comprehension and implementation of the automated control system, enhancing the efficient operation of the cooling tower.

3.6 SUMMARY

A prototype is developed for automation of cooling tower to address the automatic operation of cooling tower fans based on cooling tower approach of 5°C at all seasons and to maintain the TDS levels of circulating water below 600ppm by operation of auto-bleed off valve.

CHAPTER 4

OUTCOMES AND DISCUSSIONS

4.1 GENERAL

The prototype developed for automation of cooling tower were put to trial and testing under different simulated conditions and results are recorded for analysis.

4.2 SIMULATION AND OUTPUTS

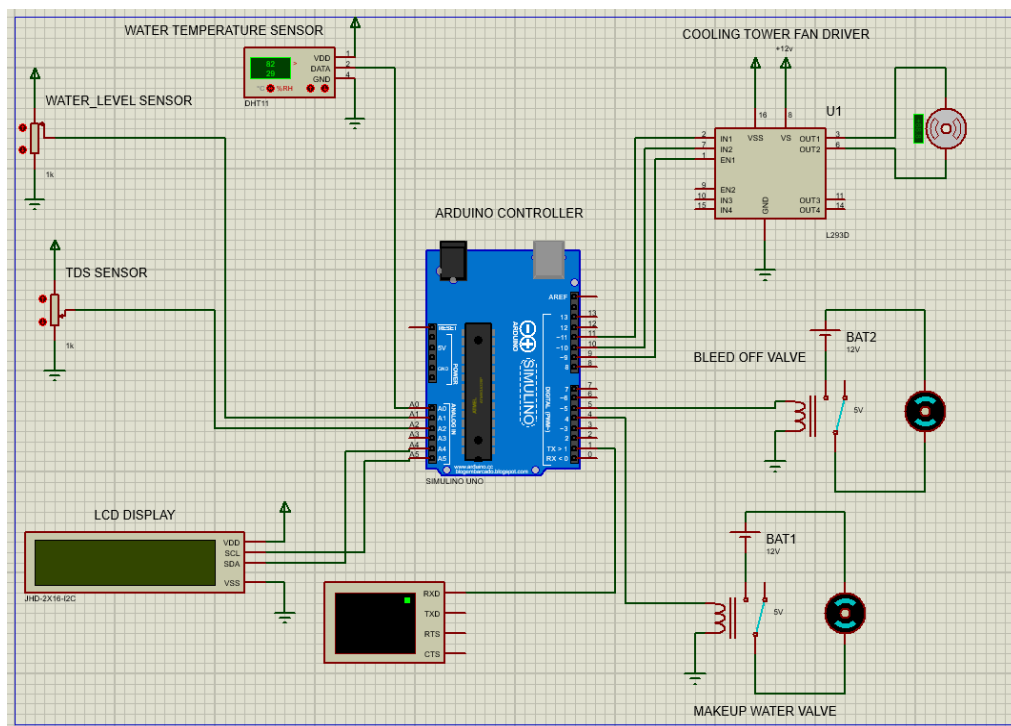


Figure 4.1: Simulated system visualization

Figure 4.1 provides a visual representation of the simulated system, offering a graphical depiction of its components, layout, and behaviour. Through this visualization, users can gain insight into the system's operation, observe its dynamics, and analyze the effects of different parameters or inputs on its performance. This simulated visualization serves as a valuable tool for

understanding and studying the system in a controlled and interactive environment.

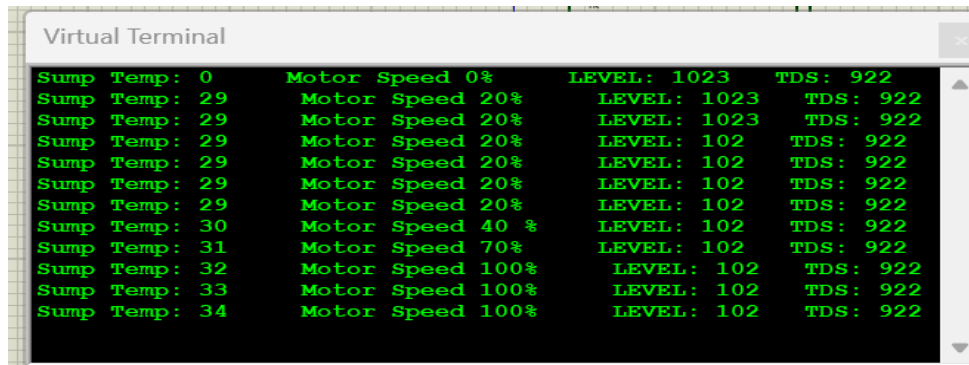


Figure 4.2: Simulation result of water temperature and the corresponding motor speed

Figure 4.2 displays the simulation results depicting the relationship between water temperature within the sump and the corresponding motor speed. This visualization highlights the dynamic interaction between thermal conditions of the water and the performance of the motor over time. By presenting these results graphically, the figure offers insights into how changes in water temperature influence the motor's speed, providing valuable information for analyzing system behavior and optimizing performance.

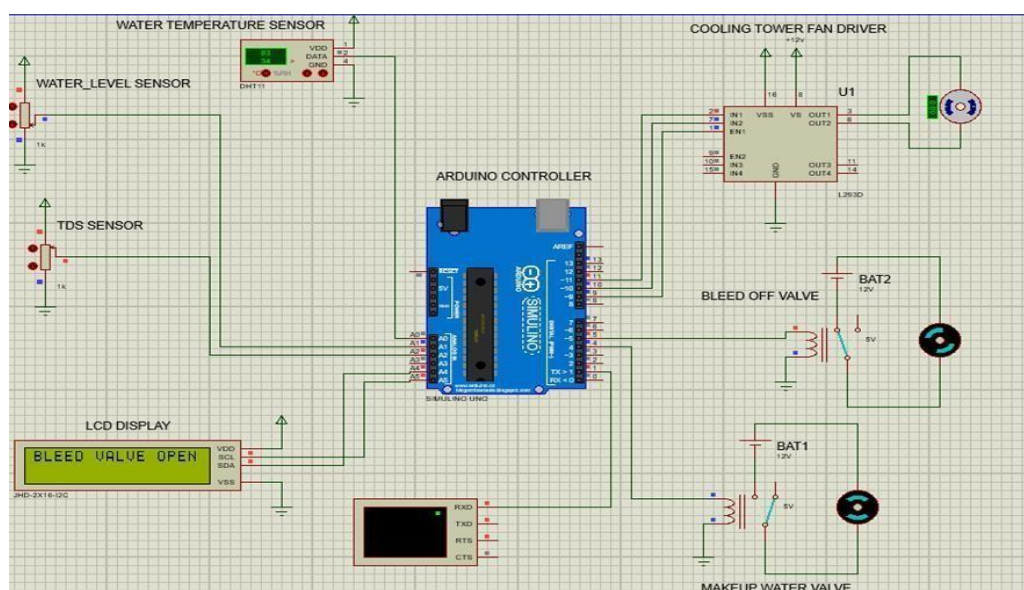


Figure 4.3: Simulation illustrating the effects of elevated TDS level in water

Figure 4.3 illustrates a simulation showcasing the impact of elevated Total Dissolved Solids (TDS) levels in water. As the TDS levels increase, the system automatically initiates the opening of the bleed-off valve to drain and replace the old water, thereby maintaining optimal performance. This visualization highlights the system's adaptive response to changing water quality conditions, ensuring efficiency and effectiveness in operation.

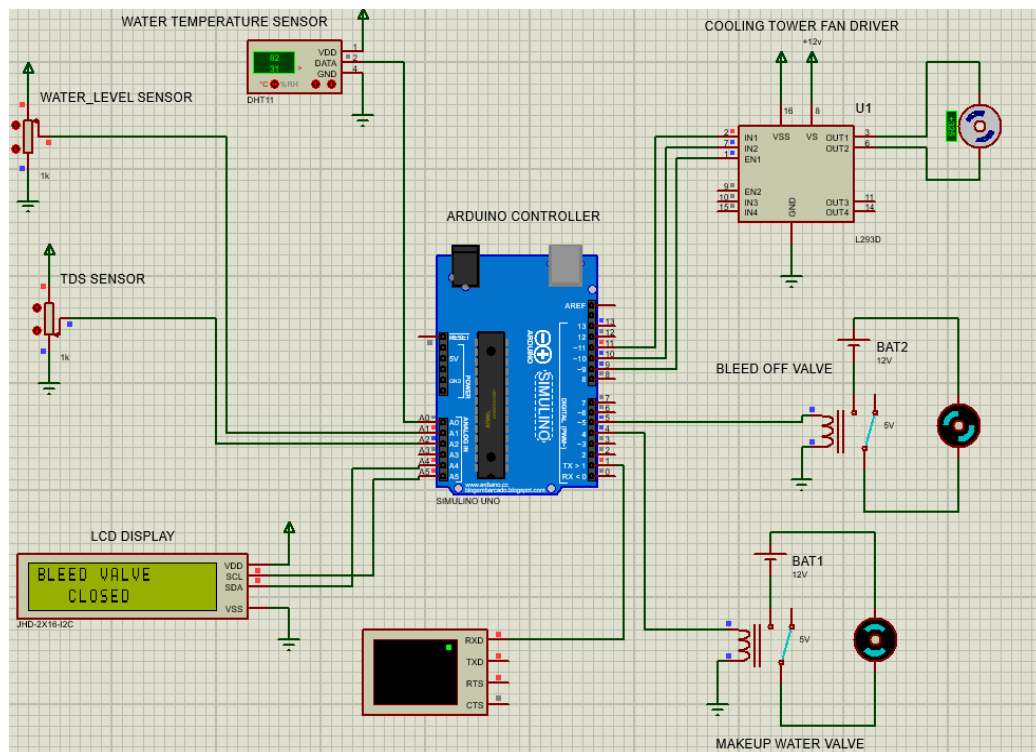


Figure 4.4: Simulation demonstrating the impact of reduced TDS level in water

Figure 4.4 presents a simulation demonstrating the effect of reduced Total Dissolved Solids (TDS) levels in water. As the TDS levels decrease, the system responds by automatically closing the bleed-off valve. This adaptive behaviour ensures that the system maintains appropriate water quality levels, optimizing performance and efficiency. The visualization in Figure 8 highlights the dynamic response of the system to changes in water composition, showcasing its ability to adjust and regulate operations accordingly.

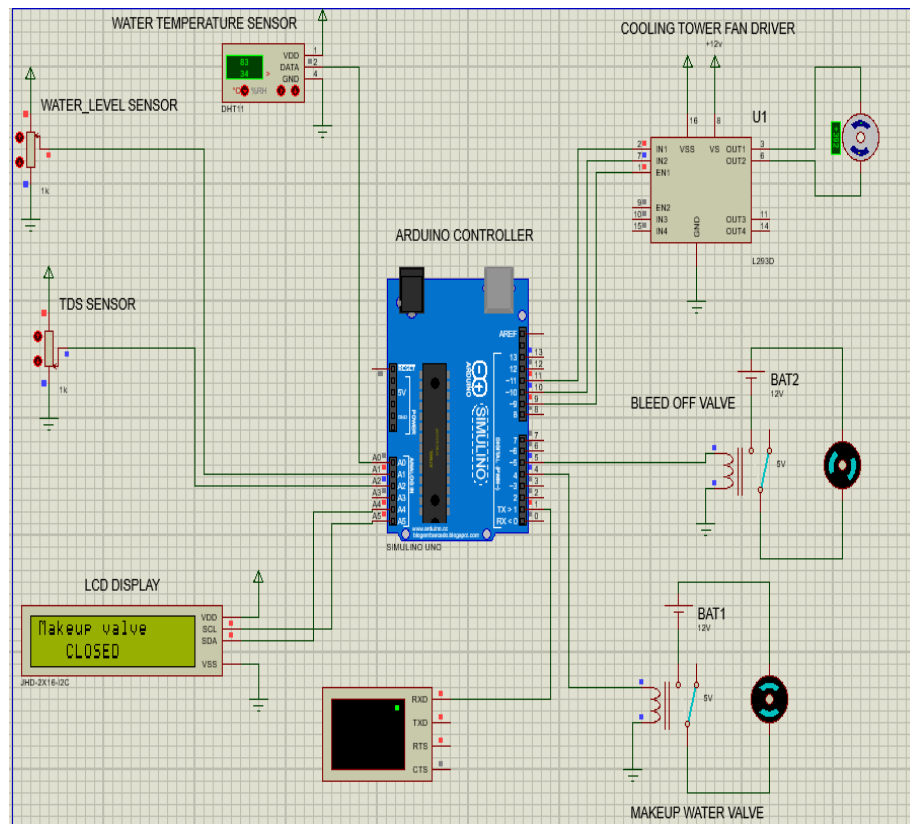


Figure 4.5: Simulation illustrating the effects of elevated sump water level

Figure 4.5 depicts a simulation illustrating the consequences of an elevated sump water level. As the water level rises, the make-up valve is depicted closing automatically to prevent overflow or excessive water accumulation. This visualization demonstrates the system's responsiveness to changes in water level, ensuring proper management and control to maintain optimal operating conditions.

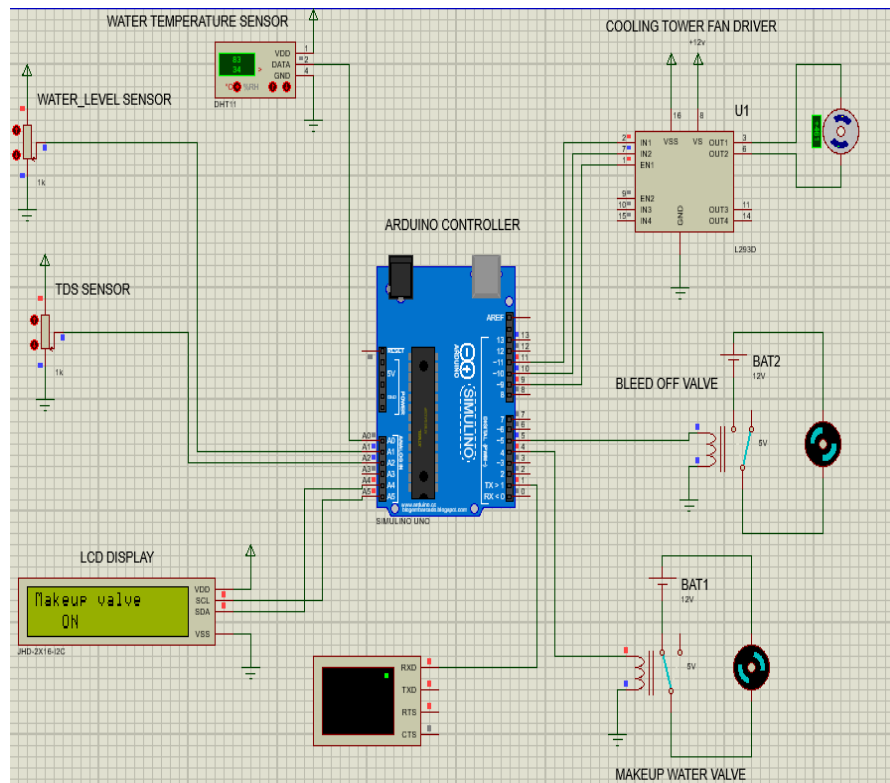


Figure 4.6: Simulation demonstrating the influence of reduced sump water level

In Figure 4.6, a simulation showcases the impact of reduced sump water level on the system. As the water level decreases, the simulation illustrates the system's response by automatically opening the make-up valve to refill water, ensuring optimal performance. This visualization highlights the system's adaptive behavior in maintaining appropriate water levels for efficient operation.

4.3 HARDWARE KIT AND EXPLANATION



Figure 4.7: Layout of Sensors Inside the Cooling Tower

Figure 4.7 visually represents the components inside the cooling tower, including the pH sensor, water level sensor, TDS sensor, temperature sensor, and various other sensors. This depiction offers an overview of the sensors installed within the cooling tower system, highlighting their positions and functions in monitoring different parameters crucial for efficient operation. By providing a visual representation, Figure 14 aids in understanding the sensor layout and their roles in ensuring optimal performance and maintenance of the cooling tower.

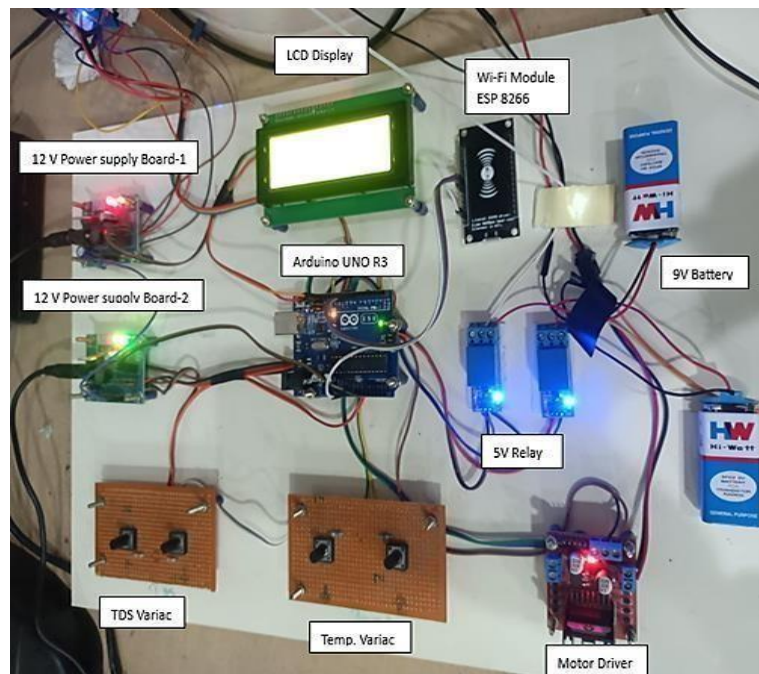


Figure 4.8: Hardware Components

Figure 4.8 presents a visual depiction of the various hardware components. This image showcases the physical elements such as switches, relay, controllers and other relevant hardware used in the construction and operation of the cooling tower system. By visually representing these components, Figure 15 offers an overview of the tangible infrastructure involved in the project, aiding in understanding the system's design and functionality.

4.4 HARDWARE OUTPUT



Figure 4.9: LCD Display for Fan Speed Control Based on Sump Water Temperature

Figure 4.9 illustrates an LCD display showing different fan speeds corresponding to the sump water temperature. This visual representation provides a clear depiction of how the fan speeds are dynamically adjusted based on the real-time temperature of the sump water. By presenting this information on the LCD display, Figure 16 facilitates monitoring and control of the cooling tower system, ensuring optimal performance and energy efficiency in response to varying temperature conditions.



Figure 4.10: LCD Display Showing Bleed Valve Open Status as Output

Figure 4.10 displays the LCD interface indicating the status of the bleed valve as "Open." This visual representation allows users to quickly assess the current state of the bleed valve, facilitating efficient monitoring and control of the system's operation.



Figure 4.11: LCD Display Showing Makeup Valve Open as Output

Figure 4.11 depicts an LCD display indicating the status of the makeup valve, which is shown as "Open." This display provides real-time feedback on the operational state of the makeup valve, enabling users to monitor its status at a glance. By visually confirming that the makeup valve is open, operators can ensure proper functioning and control within the system, contributing to efficient and effective operation.



Figure 4.12: IoT Screen Monitoring pH and Water Level Fluctuations

Figure 4.12 illustrates an IoT screen displaying the fluctuating values of pH and water level before stabilizing. This visualization provides real-time monitoring of both pH levels and water levels, showing their dynamic changes over time before reaching a steady state. The depiction on the IoT screen serves as a valuable tool for monitoring and managing both pH and water levels in the system, ensuring stability and optimal conditions.

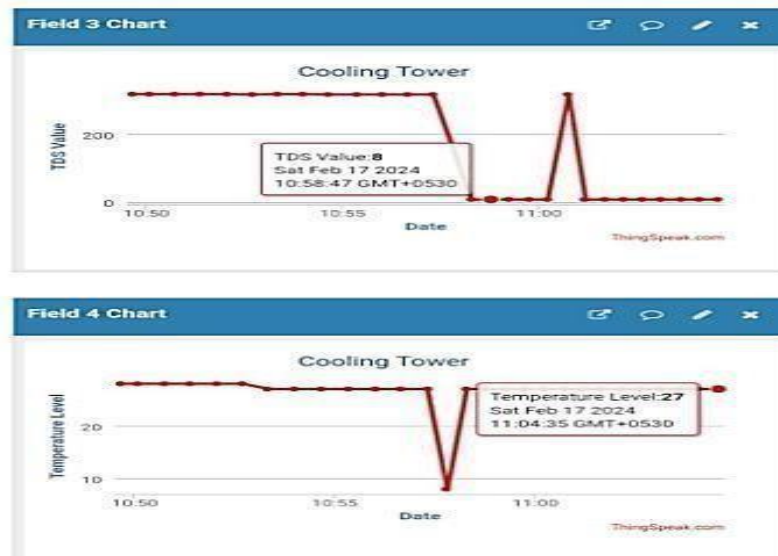


Figure 4.13: IoT Screen Monitoring TDS and Water temperature Fluctuations

Figure 4.13 presents an IoT screen providing live updates on the fluctuations of Total Dissolved Solids (TDS) and water temperature. This visual representation offers a real-time glimpse into the dynamic changes of these parameters, aiding in the constant monitoring and adjustment of water quality within the system. Through this interface, Figure 18 facilitates ongoing surveillance of TDS levels and water temperature, guaranteeing optimal operational conditions for the cooling tower.

4.5 SUMMARY

The prototype of this project cooling tower automation was successfully demonstrated using Arduino. The outputs were simulated for various real time conditions with respect to water sump temperature and TDS values and the results are locally displayed in LCD screens and trended on IoT enabled devices.

CHAPTER 5

CONCLUSION

5.1 GENERAL

Maintaining optimal process parameters, particularly sump temperature and Total Dissolved Solids (TDS) levels, is of paramount importance in the context of cooling tower operations. Elevated sump temperatures exceeding the critical threshold of 32°C can have adverse effects on the heat transfer efficiency within the condenser. This reduction in efficiency places an increased demand on the chillers, resulting in higher power consumption. The correlation between sump temperature and chiller power consumption highlights the need for vigilance in temperature control to ensure energy efficiency.

Similarly, high levels of Total Dissolved Solids (TDS) in the water used within the cooling tower led to scaling within the condenser tubes. Scaling acts as an insulating layer, impeding the efficient exchange of heat between the water and the surrounding air. This exacerbates the workload on the chillers, as they must compensate for the compromised heat transfer efficiency. The consequence is a further escalation in power consumption, underscoring the impact of TDS levels on the overall energy efficiency of the cooling system.

To mitigate these challenges, a proactive approach is essential. Regular monitoring of sump temperature and TDS levels allows operators to detect deviations promptly. Precise control of parameters through the utilization of IoT-enabled devices and automation systems ensures that sump temperature and TDS levels are consistently maintained within optimal ranges. This not only minimizes energy consumption but also contributes to the longevity of the cooling system.

Effective water quality management strategies, including filtration and chemical treatment, are pivotal in preventing scaling and maintaining optimal TDS levels. These measures safeguard the integrity of the condenser tubes and sustain the efficiency of heat exchange processes.

Furthermore, the implementation of predictive maintenance algorithms adds a layer of foresight to the management of sump temperature and TDS levels. By forecasting potential issues, operators can undertake proactive maintenance actions, preventing system failures, minimizing downtime, and extending the lifespan of equipment.

5.2 BENEFITS AND LIMITATIONS

Benefits:

1. Real-time Monitoring of process parameters
2. Automated Control Actions to minimize energy and water consumption. Energy consumption can be minimized, resulting in significant cost savings.

A 1°C decrease in the condenser entry water temperature results in a power saving of 0.01 kilowatts per ton of refrigeration (kW/TR) for the chiller.

For a 500-Ton centrifugal chiller:

Power saving potential for one chiller = $0.01 \text{ kW/TR} \times 500 \text{ TR} = 5 \text{ kW}$

Daily power savings for one chiller = $5 \text{ kW} \times 24 \text{ hours} = 120 \text{ kWh (or 120 units)}$

Annual power savings for one chiller = $120 \text{ units} \times 365 \text{ days} = 43,800 \text{ units}$

Total cost savings for one chiller per year = $43,800 \text{ units} \times \text{Rs. } 8 / \text{unit} = \text{Rs. } 3,50,400/-$

Therefore, the implementation of such energy-saving measures could result in a significant total cost savings of Rs. 3,50,400 per year for one 500-ton centrifugal chiller.

3. The implementation of these energy-efficient upgrades is projected to have a simple payback period. Payback period calculation for Upgrades:

Cost of Actual implementation

- Variable Frequency Drive (VFD) for fan: Rs. 1,75,000/-
- Direct Digital Controller: Rs. 95,000/-
- Sensors (PH, TDS, Temp, solenoid valves): Rs. 1,00,000/-

- Cabling works: Rs. 30,000/-

Total Investment Rs. 4,00,000/-

Total Savings: Rs. 3,50,400/-

Simple Payback Period:

Payback Period = Total Investment / Total Savings

Payback Period = Rs. 4,00,000 / Rs. 3,50,400 = 1.14 years or 14 months

Therefore, the implementation of these energy-efficient upgrades has a simple payback period of around 1.14 years, making it a cost-effective investment with substantial savings.

4.Minimization of Human Error in ensuring consistency and accuracy in maintaining parameters within optimal ranges.

5. Predictive Maintenance Strategies by leveraging real-time data collection to identify potential issues early, thereby reducing downtime, extending equipment lifespan, and improving overall system reliability.

Limitation:

The project is limited by the non-usage of IoT devices for controlling of cooling towers remotely due to poor strength of internet.

5.3 FUTURE SCOPE

The future scope of this project can be expanded by introducing progressive artificial intelligence in cooling tower automation for optimization of chiller plants.

5.4 SUMMARY

In conclusion, a strategic and holistic approach to managing sump temperature and TDS levels is imperative for sustaining an efficient and economical cooling tower operation. The interplay between these parameters, when carefully monitored and controlled, contributes to optimal operational efficiency, reduced energy consumption, and the overall health and longevity of the cooling system.

REFERENCES

1. Bahaa E. H. Mahmoud, Ajaya K. Gupta, Inelastic Large Displacement Behavior and Buckling of Cooling Tower, J. Struct. Eng., 1995, 121(6): 981-985
2. Burkov A. F, Sokolova V. S, Zaychenko I. V, Determination of Parameters of the Gas Absorption System with Air Cooling for Conditioning of Industrial Premises, 2018 International Multi-Conference on Industrial Engineering and Modern Technologies.
3. Chang-Koon Choi, Hyuk-Chun Noh, Stochastic Analysis of Shape Imperfection in RC Cooling Tower Shells, Journal Of Structural Engineering / March 2000
4. Changwei Huang, Design of Central Air Conditioning Control Acquisition Device Based on IoT Technology, Journal of Physics: Conference Series 2143 (2021) 012002
5. Danxu Zhang, Peter B. Luh, Junqiang Fan, Shalabh Gupta, Chiller Plant Operation Optimization with Input and Model Uncertainties, 2018 IEEE 14th International Conference on Automation Science and Engineering (CASE)
6. Danxu Zhang, Peter B. Junqiang Fan, Shalabh Gupta, Chiller Plant Operation Optimization: Energy-Efficient Primary-Only and Primary–Secondary Systems, IEEE Transactions on Automation Science and Engineering, Vol. 15, No. 1, January 2018.
7. Dharinee.B.S, Rammohan Priyanka, Shri Vishali.R, Ms.Sukambika.S, Design of Cooling Tower with IoT International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 , Volume: 04 Issue: 03 | Mar -2017 www.irjet.net p-ISSN: 2395-0072.
8. Dong-Bae Kim, Daeung Danny Kim, Taeyeon Kim. Energy performance assessment of HVAC commissioning using long-term monitoring data: A case study of the newly built office building in South Korea
9. Eknath D. Kharat Amit B. Gavali, COOLING TOWER AUTOMATION, International Conference on Convergence of Technology – 2014
10. G.Kirthika, Dr.S.Charles Raja, Automation of Regenerative Compressor Cooling System Using Microcontroller, 2015 International Conference on Circuit, Power and Computing Technologies [ICCPCT]
11. Gaëlle Guyot, Max H. Shermanc, Iain S. Walker, Smart ventilation energy and indoor-air quality performance in residential buildings: A review
12. Gunther Meschke, Herbert A. Mang, Peter Kosza, Finite Element Analyses of Cracked Cooling Tower Shell, J. Struct. Eng., 1991, 117(9): 2620-2638
13. Himadri Nath Saha, Tanishq Banerjee, Somshubhra Roy, Soham Pandit, Sayan Dutta, Subham Sadhukhan, Nityasree Upadhyay, Prerana Chakraborty, Souranshu Ghosh, An integrated solution for monitoring domestic appliances using IoT facilitating

energy conservation ©2018 IEEE

14. Ioana Opriș, Sorina Costinaș, Cristina-Sorana Ionescu, Daniela-Elena Gogoășe-Nistoran, Improving the Efficiency of Natural Draft Wet Cooling Towers by Using Smart Metering Systems, ©2017 IEEE

15. Jacek Błocki, Stress States in Cooling Tower Caused by Thermal Field, J. Struct. Eng., 1988, 114(12): 2633-2651

16. Jian-Guo Wang, Qian-Ping Xiao, Juan-Juan Wang, Shi-Wei Ma, Wen-Tao Rao, Yong-Jie Zhang, Soft Sensor Approach for Optimal Operation of Cooling Tower for Energy Conservation, 2014 26th Chinese Control and Decision Conference (CCDC)

17. Jiasheng Wu, Guoqiang Zhang, Quan Zhang, Jin Zhou, Yonghui Guo, Wei Shen, Experimental Investigation of the Performance of a Reversibly Used Cooling Tower Heating System Using Heat Pump in Winter, ©2011 IEEE.

18. Jingyun Liu, Huiling Zhou, Xiaoguang Zhou, Yang Cao, Huiyi Zhao, Automotive Air Conditioning System Control - A Survey, 2011 International Conference on Electronic & Mechanical Engineering and Information Technology

19. Josep H Lichtenstein, Recirculation in Cooling Towers, November, 1951

20. Josep H Lichtenstein, Performance and Selection of Mechanical Draft Cooling Towers, The A.S.M.E October, 1943

21. Kenneth S. Limpahan, Rommel R. Viña, Feliciano B. Alagao, Performance Evaluation of Direct-Contact Cooling Tower Used on Thermoelectric Module and Parabolic Trough Collector for Power Generation, 7th IEEE International Conference Humanoid, Nanotechnology, Information Technology Communication and Control, Environment and Management (HNICEM) The Institute of Electrical and Electronics Engineers Inc. (IEEE)

22. Kuixing Liu, Neng Zhu, Menglei Wang, Zhe Tian, Comparative Study of Cooling Tower Performance Evaluation Indicators, 2011 IEEE

23. Kwang Hoon Han and Jensen Zhang, Energy-saving building system integration with a smart and low-cost sensing/control network for sustainable and healthy living environments: Demonstration case study"

24. Loui S Elliot, Cooling Towers for Steam-Electric Stations Economic Applications, November, 1951

25. M. A. Green, S. Q. Yang, J. Cobb, P. Lau, W. W. Lau, H. Witte, D. E. Baynham, T.

W. Bradshaw, The Effect of Magnetic Field on the Position of HTS Leads and the Cooler

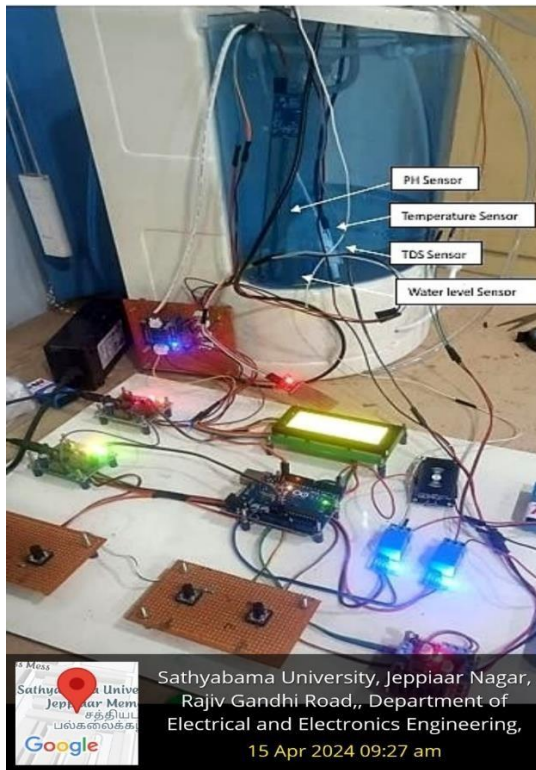
in the Services Tower of the MICE Focusing Magnet, IEEE Transactions On Applied Superconductivity, Vol. 18, No. 2, June 2008

- 26.** Maoting Li, Xiaokai Gong, Wei Dong and Wenliang Li, The Cooling Tower Fan System Fault Monitoring based on the Trunk of RS485 2011 International Conference on Electronic & Mechanical Engineering and Information Technology
- 27.** Masayoshi Hamanaka, Shunsuke Horie, Daiki Owaki, Kenshu Nimi, Kazuto Yukita, Toshiro Matsumura, Yasuyuki Goto, Keiichi Hirose, Demand Response Using Air Conditioner, ©2017 IEEE
- 28.** Moath Awawdeh, Anees Bashir, Tarig Faisal, Khawla Alhammadi, Mouza Almansori, and Sara Almazrouei, Embedded Ventilation Air Conditioning System for Protection Purposes with IoT Control ©2018 IEEE
- 29.** Muhammad Aftab, Chien Chen, Chi-Kin Chau, Talal Rahwan, Automatic HVAC control with real-time occupancy recognition and simulation-guided model predictive control in low-cost embedded system. Energy and Buildings, 154, 141-156
- 30.** N. Wang, J. Zhang, X. Xia, Energy Consumption of Air Conditioners at Different Temperature Set Points, IEEE Africon 2011 - The Falls Resort and Conference Centre, Livingstone, Zambia, 13 - 15 September 2011
- 31.** Nyoman Suamir, Nengah Ardita, Made Rasta, Effects of Cooling Tower Performance to Water Cooled Chiller Energy Use: a Case Study toward Energy Conservation of Office Building, 2018 International Conference on Applied Science and Technology (ICAST)
- 32.** P. Srinivasa Rao t, K. Ramanjaneyulu, Stability of Cooling Tower Shell with Modified Wind Pressure Coefficients, J. Eng. Mech., 1993, 119(11): 2207-2225
- 33.** Rajashekar P. Mandi & R.K. Hegde, S.N. Sinha, Performance Enhancement of Cooling Towers in Thermal Power Plants through Energy Conservation.
- 34.** Rohit K. Singla, Ranjan Das, Retrieval of Controlling Parameter in Induced Draft Cooling Tower Using Inverse Method, 2016 2nd International Conference on Control Science and Systems Engineering
- 35.** S. Dhanalakshmi, M. Poongothai, Kaner Sharma, IoT Based Indoor Air Quality and Smart Energy Management for HVAC System, Procedia Computer Science, 171, 1800-1809.
- 36.** Shady S.Refaat, Haitham Abu-Rub, Amira Mohammed, Smart and Energy Air-Conditioning Systems, NPRP award [NPRP 7-106 -2-053], Qatar National Research Fund
- 37.** Sheng Zhang, Zhengtao Ai, Zhang Lin, Novel demand-controlled optimization of constant-air volume mechanical ventilation for indoor air quality, durability and energy saving
- 38.** Surachai Thongkaew, Chirot Charitkuan, IoT for Energy Saving of Split-Type Air

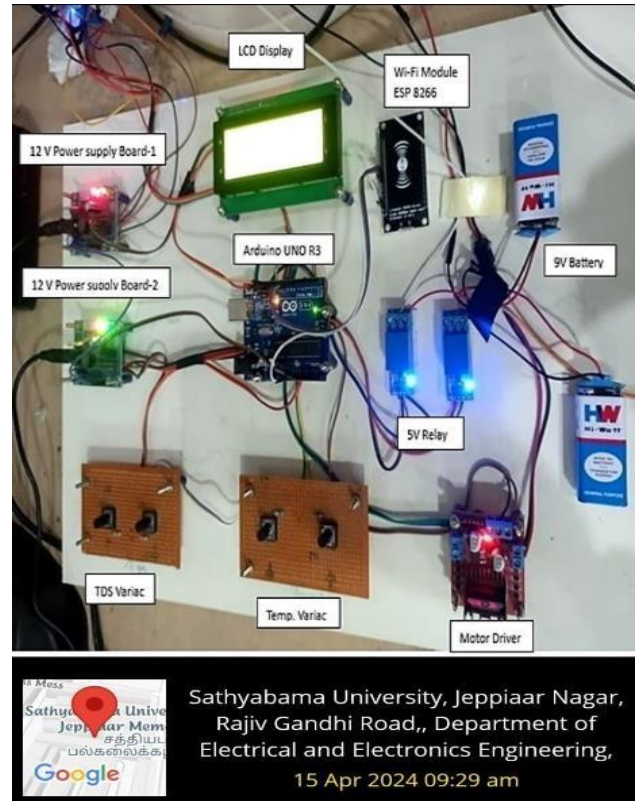
Conditioner by Controlling Supply Air and Area Temperature, ©2018 IEEE

- 39.** T.Y. Yang, M. ASCE, Rakesh K. Kapania, Finite Element Random Response Analysis of Cooling Tower. J. Eng. Mech., 1984, 110(4): 589-609
- 40.** Tongrui Chenga, Zhenning Zhao, Junfu Lv, Han Yu, Anti-freezing Performances of Novel Natural Draft Dry Cooling Tower with Double-layer Air-cooled Heat Exchanger, 2021 IEEE 4th International Conference on Automation, Electronics and Electrical Engineering (AUTEEE)
- 41.** Vladimir Tanasiev, George Cristian Patru, Daniel Rosner, Gabriela Sava, Horia Necula, Adrian Bade, Enhancing environmental and energy monitoring of residential buildings through IoT
- 42.** Wang Shu, Lu Wenda, Theoretical and experimental solutions of cooling-tower-soil system, J. Eng. Mech., 1990
- 43.** Wei Li, Oscillatory Fouling in Condensers in Cooling Tower Systems, Journal of Thermal Science and Engineering Applications APRIL 2020, Vol. 12
- 44.** Wei Song, Ning Feng, Yifei Tian, Simon Fong, An IoT-Based Smart Controlling System of Air Conditioner for High Energy Efficiency, IEEE International Conference on Internet of Things and IEEE Green Computing and Communications and IEEE Cyber, Physical and Social Computing and IEEE Smart Data, 2017
- 45.** Wenhua Zhang, Chunling Meng, Optimization Design of the GFRP Hyperbolic Cooling Tower Structure, 2013 International Conference on Mechanical and Automation Engineering
- 46.** Wu Zhijiang, Wang Nan, Zhu Gongsheng, Application Research of Evaporative Cooling in Waste Heat Recovery, 2010 International Conference on Digital Manufacturing & Automation
- 47.** Xing Lua, Zheng O' Neilla, Yanfei Liab, Fuxin Niu "A novel simulation-based framework for sensor error impact analysis in smart building systems: A case study for a demand-controlled ventilation system
- 48.** Yuming Guo, Fuli Wang, Mingxing Jia, Dapeng Niu, Hybrid Modeling Method for Predicting the Cooling Water Outlet Temperature in Plate Heat Exchanger, 2016 28th Chinese Control and Decision Conference (CCDC)
- 49.** Yuming Guo, Biao Wang, Optimal Design of Forced Draft Cooling Tower under Variable Working Conditions, 41st Chinese Control Conference July 25-27, 2022, China
- 50.** Zhihong Pang, Yan Chen b, Jian Zhang, Zheng O'Neill, Hwakong Cheng, Bing Dong, How much HVAC energy could be saved from the occupant-centric smart home thermostat: A nationwide simulation-study.

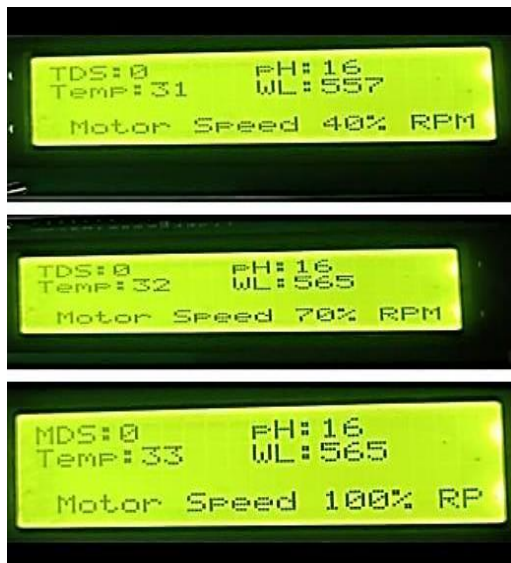
APPENDIX



Layout of Sensors Inside
the Cooling Tower



Hardware Components



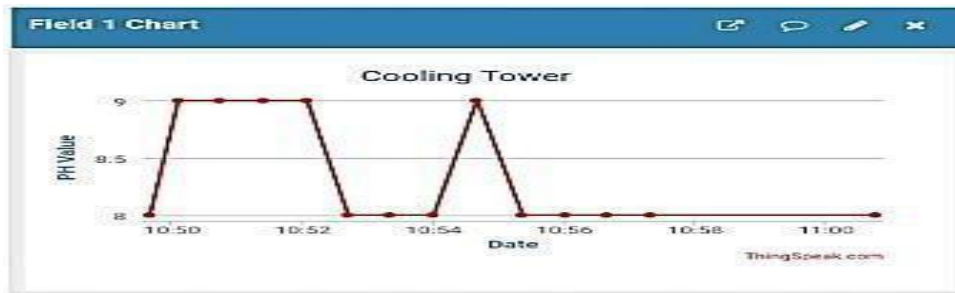
LCD Display for Fan Speed Control Based on
Sump Water Temperature



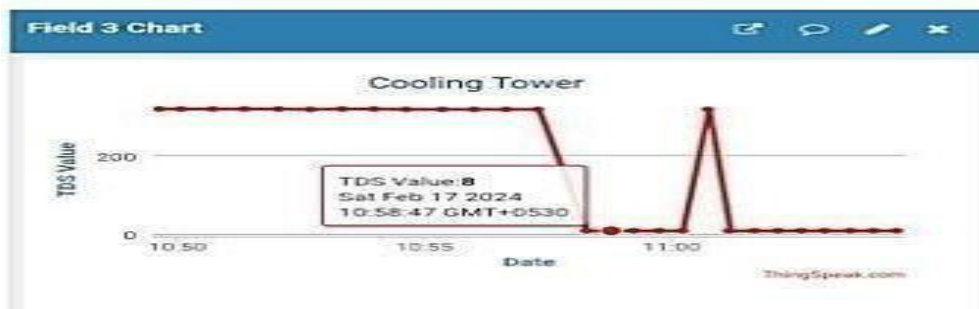
LCD Display Showing Bleed Valve Open Status as
Output



LCD Display Showing Makeup Valve Open as Output



IoT Screen Monitoring pH and Water Level Fluctuations



IoT Screen Monitoring TDS and Water temperature Fluctuations

Efficient Cooling Tower Automation: Harnessing IoT for Optimal Performance and Sustainability

Abstract: Efficient cooling tower automation is vital for optimizing energy usage, reducing costs, and ensuring system reliability. Precise control based on real-time demand minimizes energy consumption, leading to substantial cost savings. Conversely, the absence of automation results in higher energy consumption, increased operating costs, and reduced adaptability to variable loads. This can shorten equipment lifespan, elevate maintenance costs, and hinder compliance with environmental regulations. The lack of remote monitoring leads to delayed responses to malfunctions, increasing downtime and compromising reliability. Safety concerns arise with manual systems lacking advanced features present in automated setups. In essence, the need for efficient cooling tower automation stems from its ability to address these drawbacks, ensuring optimal performance, cost-effectiveness, and environmental responsibility across various industrial applications. This study focuses on the implementation of an advanced cooling tower automation system utilizing IoT devices to precisely monitor and control essential process parameters. The proffered methodology is to maintain these parameters within specified limits to enhance operational efficiency and prolong equipment life. IoT-enabled sensors are strategically deployed to collect real-time data related to temperature, flow rates, pressure, and humidity. The data is transmitted to a centralized IoT platform where sophisticated analytics and automation logic are applied. Through this system, proactive adjustments are made to cooling tower operations, ensuring that critical process parameters remain within permissible ranges. Predictive maintenance algorithms are employed to foresee potential issues, enabling timely intervention and preventing downtime. This paper showcases the effectiveness of IoT-powered automation in optimizing cooling tower performance while adhering to operational thresholds, thereby leading to substantial energy savings, cost efficiencies, and sustainable practices.

Keywords: Energy optimization, reliability, energy consumption, remote monitoring, safety, IoT devices, sensors, data collection, analytics, automation logic, predictive maintenance, sustainability.

1. Introduction

Cooling towers play a crucial role in various industrial processes, HVAC systems, and thermal power plants by efficiently dissipating heat through the process of evaporative cooling. As advancements in technology and energy conservation continue to evolve, there is a growing interest in optimizing the design, control, and operation of cooling towers to enhance their performance, energy efficiency and cost-effectiveness. The field of cooling tower automation and energy efficiency has seen remarkable advancements driven by innovative research and technological developments. Various studies have focused on enhancing the operational efficiency, safety, and energy conservation in cooling tower systems through intelligent control, IoT integration, and demand-response strategies. A comprehensive understanding of these aspects is crucial for enhancing the efficiency, reliability, and sustainability of cooling tower systems across different industries. In this introduction, we delve into the key contributions from recent research papers, each shedding light on distinct facets of cooling tower automation and optimization. Dharinee. B.S Et Al. introduced an intelligent cooling tower control system leveraging IoT capabilities, enabling remote monitoring and precise control of critical parameters such as pH levels and pump conditions, thereby improving operational efficiency and safety [1]. Eknath D. Kharat and Amit B. Gavali emphasized the importance of automation and monitoring in cooling tower systems within the automobile industry, proposing the integration of PLC and SCADA

technologies for real-time tracking and anomaly detection, contributing to enhanced efficiency and stability [2]. Changwei Huang focused on creating a robust central air conditioning control system using IoT technology, incorporating a fuzzy algorithm for improved performance and wireless communication for seamless automation and monitoring [3]. Muhammad Aftab Et Al presented an innovative HVAC control system utilizing machine learning techniques for occupancy prediction and model predictive control for real-time thermal response simulations, demonstrating significant energy savings and maintaining comfort levels [4]. S. Dhanalakshmi Et Al. Proposed an IoT- based indoor air quality and smart energy management system for HVAC systems, achieving real-time automation based on energy management policies and user preferences, resulting in considerable energy savings [5]. Gaëlle Guyot and Max H. Sherman conducted a literature review on smart ventilation systems in residential buildings, highlighting the energy and indoor air quality performance benefits of demand-controlled ventilation strategies [6]. Vladimir Tanasiev Et Al. Explored the application of IoT in enhancing environmental and energy monitoring in residential buildings, emphasizing the integration of wired and wireless sensors for effective control and optimization of HVAC systems [7]. Kwanghoon Han and Jensen Zhang demonstrated the integration of smart sensing networks with HVAC systems in office buildings, achieving substantial energy savings while maintaining satisfactory thermal comfort and indoor air quality [8]. Zhihong pang Et Al. conducted a nationwide simulation study to estimate the potential energy savings achievable with an occupant-centric smart thermostat, emphasizing the importance of temperature adjustments and energy-efficient heat pumps in optimizing HVAC energy consumption [9]. Sheng Zhang Et Al. proposed a novel demand-controlled optimization approach for constant-air-volume mechanical ventilation systems, utilizing genetic algorithm-based optimization to maximize energy efficiency while ensuring indoor air quality and durability [10]. Wang Shu and Lu Wenda [11] introduced a dynamic model for cooling towers that considers the interaction with the surrounding soil, demonstrating how soil elasticity affects the natural frequencies and mode shapes of cooling towers. Their study emphasizes the importance of understanding soil dynamics for accurate structural analysis and optimization of cooling tower systems. Dong-bae Kim, Daeung Danny Kim, and Taeyeon Kim [12] conducted a comprehensive energy performance assessment of HVAC systems in office buildings, using long-term monitoring data to optimize HVAC commissioning processes. Their study highlights the significance of data-driven approaches in improving energy efficiency and reducing overall energy consumption in commercial buildings. Xing Lua, Zheng, Neilla, Yanfei Liab and Fuxin Niu [13] proposed a novel simulation-based framework for sensor error impact analysis in smart building systems, focusing on demand-controlled ventilation systems. By conducting sensitivity analyses and deterministic error quantifications, their study provides insights into optimizing sensor placements and enhancing the reliability of building automation systems. Shady S. Refaat, Haitham Abu-rub, and Amira Mohammed [14] presented an innovative approach to optimize energy consumption in air conditioning systems through smart algorithms and real-time monitoring. Their study emphasizes the integration of behavioural and technological modifications to minimize energy usage while ensuring customer comfort and health. Wei song, Ning Feng, Yifei Tian, and Simon Fong [15] introduced an IoT-based smart controlling system for air conditioners, leveraging smart meters and cloud computing for real-time energy consumption predictions and energy-saving decisions. Their study demonstrates how IoT technology can contribute to reducing power usage and greenhouse gas emissions in air conditioning systems. Masayoshi Hamanaka Et Al. [16] explored

demand response strategies using air conditioners to optimize power consumption in buildings. By measuring Co₂ levels and understanding occupancy patterns, their study highlights the effectiveness of utilizing air conditioners for demand response, contributing to overall energy efficiency. N. Wang, J. Zhang, and x. Xia [17] investigated the energy consumption of air conditioners at different temperature set points, emphasizing the importance of thermal control strategies in achieving energy savings. Their study provides insights into optimizing temperature set points to reduce energy usage in air conditioning systems. Surachai Thongkaew and chirot Charitkuan [18] proposed an IoT platform for energy-saving control of split-type air conditioners, focusing on optimizing supply air temperature and room temperature to reduce compressor runtime and achieve significant energy savings. Himadri Nath Saha Et Al. [19] presented an integrated IoT-based solution for monitoring and managing domestic appliances, promoting energy conservation and streamlining household operations. Their study highlights the potential for IoT technology to enhance energy efficiency and reduce energy waste in residential settings. Moath Awawdeh Et Al. [20] introduced the embedded ventilation air conditioning system, integrating air conditioning and ventilation with a protection system for enhanced safety in indoor environments. Their study Demonstrates the feasibility of using IoT control and sensor technologies to detect fire hazards and initiate protective measures in buildings. Jingyun Liu, Huiling Zhou, Xiaoguang Zhou, Yang Cao, and Huiyi Zhao [21] provide a comprehensive survey of automatic control techniques for automotive air conditioning systems, underscoring the increasing need for advanced control strategies in response to evolving environmental and energy concerns. Yuming Guo, Fuli Wang, Ming Xing Jia, and Dapeng Niu [22] focus on the importance of accurate prediction of cooling water outlet temperature in plate heat exchangers, proposing a hybrid modelling method to optimize the operation of circulating cooling water systems in iron and steel enterprises. G. Kirthika and Dr. S. Charles Raja [23] emphasize the significance of automating regenerative compressor cooling systems using microcontroller-based embedded systems, highlighting the benefits of real-time monitoring and optimization for improving compressed air quality and efficiency. Kuixing Liu, Neng Zhu, Menglei Wang, and Zhe Tian [24] conduct a comparative study of cooling tower performance evaluation indicators, providing insights into the diverse methodologies and limitations associated with assessing cooling tower efficiency. Danxu Zhang, Peter B. Luh, and Junqiang Fan [25] address the challenges of optimizing chiller plant operation in the presence of input and model uncertainties, proposing a method that effectively integrates uncertainty considerations into optimization algorithms for achieving near-optimal energy Consumption. Wenhua Zhang and Chunling Meng [26] focus on optimizing the structural design of Cooling towers to enhance stability and efficiency, offering practical insights for designing efficient cooling tower structures. Burkov A. F, Sokolova V. S, and Zaychenko I. V [27] investigate the potential use of gas absorption systems with air cooling for conditioning industrial premises, exploring thermal design and economic feasibility considerations. Wu Zhijiang, Wang Nan, and Zhu Gongsheng [28] discuss the application of evaporative cooling in waste heat recovery, highlighting the energy-saving potential of evaporative condensers in various engineering applications. Jian-Guo Wang, Qian-Ping Xiao, Juan-Juan Wang, Shi-Wei Ma, Wen-Tao Rao, and Yong-Jie Zhang [29] propose a data-driven soft sensor approach for optimizing cooling tower performance, aiming to achieve energy conservation through adaptive fan operation strategies. Tongrui Chenga, Zhenning Zhao, Junfulv and Han Yu [30] explore the anti-freezing capabilities of novel natural draft dry cooling towers with double-layer air-cooled heat exchangers, addressing critical concerns related to freezing risk during

cold weather conditions. Yuming Guo and Biao wang [31] presents a nonlinear programming model for the optimal design of forced draft cooling towers. The study explores changes in working conditions caused by meteorological conditions and water demand, demonstrating significant Reductions in operating costs and comprehensive costs compared to conventional methods. Zijian Yu Et Al. [32] proposes a data-driven control approach based on deep reinforcement learning to improve the control performance of cooling towers in HVAC systems. The deep Q network method is utilized to learn robust feedback control laws, leading to improved control performance compared to traditional methods. Danxu Zhang Et Al. [33] addresses the challenges of optimizing chiller plant operation in the presence of input and model uncertainties. The study considers uncertainties in key parameters and utilizes a decomposition and coordination method to obtain near-optimal solutions efficiently, resulting in significant energy savings. S Madhura Et Al. [34] presents a microcontroller and embedded software-based product for alarm monitoring in cooling tower systems. The system utilizes gsm communication to transmit vibration signals from cooling fans, providing audio-visual indications and notifications to control room personnel. Jian-Guo wang Et Al. [35] introduces a data-driven adaptive soft sensor approach to optimize the operation of cooling towers for energy conservation. The study demonstrates significant potential for energy conservation through optimal fan operation strategies. Zhe Liu Et Al. [36] proposes a decentralized optimization method for optimal setpoint control in HVAC systems. The method divides the HVAC system into multiple subsystems and utilizes a decentralized optimization algorithm to achieve local/global optimal solutions, leading to significant energy savings while preserving human comfort requirements. I. Nyoman Suamir Et Al. [37] investigates the impact of cooling tower performance on the energy consumption of water-cooled chiller systems in office buildings. The study highlights the importance of cooling tower performance in energy-efficient building operations. Rajarshi Gupta Et Al. [38] provides an overview of cooling tower applications, efficiency improvement strategies, and uses in civil engineering design. The study discusses various components and working principles of cooling towers, emphasizing efficiency improvement measures. Jie Zhang and Dapeng Niu [39] proposes a design optimization study for cooling towers in the circulating cooling water system of the iron and steel industry. The study utilizes an optimization model and nested algorithm to reduce system investment and operating costs, leading to improved economic efficiency. Khaled Salaheldin Mohamed and Hamdy Ahmed Ashour [40] investigates energy conservation opportunities for cooling towers in steel production factories. The study focuses on optimizing cooling tower operation during winter months to achieve significant energy savings. Ji Amin Et Al. [41] explore tower cooling technology for energy-saving applications during transition seasons. The study presents experimental results demonstrating the energy-saving effectiveness of tower cooling technology in specific climatic conditions. These papers collectively contribute to the advancement of knowledge and technology in the field of cooling tower optimization, energy conservation, and performance improvement, addressing challenges and proposing innovative solutions for various industrial and environmental applications.

This paper discusses mainly about the automatic operation of cooling tower fan speed based on the condenser water temperature and maintaining total dissolved solids (TDS) within allowable limits by auto bleed off system to improve the operational efficiency of chillers in a central air-conditioning plant.

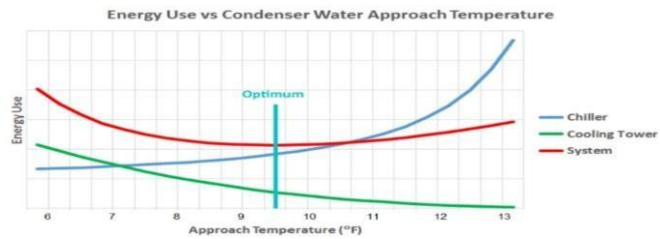


Figure 1: Typical performance chilled water system

In Fig 1, it is evident from the chiller curve (Blue) that as the approach increases, the chiller energy consumption increases, whereas the cooling tower power curve (Green) reduces as the approach increases. Therefore, in a system curve (i.e., summation of chiller power and cooling tower power) shown in red colour; it is seen that the system power consumption of the Ac plant is minimum at 9.5 °F. The aim of this project is to operate the fans automatically to keep the condenser approach close to 9.5 °F.

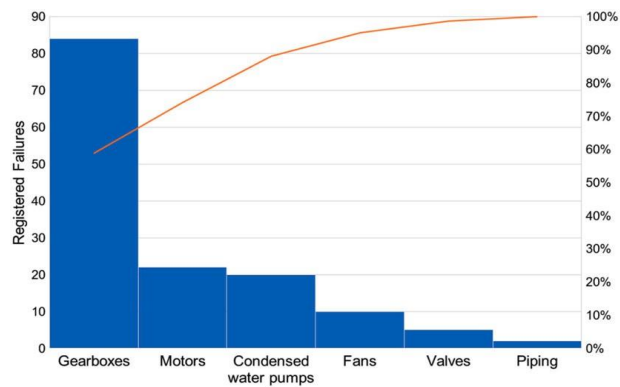


Figure 2: Cooling tower common failures overview

Figure 2 represents the common failure that are likely to occur in a cooling tower. An industrial cooling tower can be larger than an HVAC system and is used to remove the heat absorbed in the circulating cooling water systems used in power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food processing plants, and other industrial facilities.

The red line in the graph indicates that the 85% failures in cooling tower are due to gear box failure. Gear box in a cooling tower is used to reduce the speed of the fan. This is addressed in the project by introducing vibration switch which will trip the motor on excessive vibration.

2. Proffered Methodology

The proposed solution involves the integration of IoT devices to automate cooling tower operations and ensure process parameters remain within predefined allowable limits. IoT-enabled sensors will be strategically deployed to capture real-time data related to key parameters like temperature, flow rates, pressure, and humidity. This data will be transmitted to a centralized IoT platform, where advanced analytics and automation logic will be applied. The automation logic will continuously analyze the received data and dynamically adjust cooling tower operations, such as fan speed and water flow, to maintain the process parameters within permissible ranges. Predictive maintenance algorithms will also be employed

to forecast potential issues, allowing for proactive maintenance actions. This IoT-powered automation approach promises to enhance operational efficiency, optimize energy consumption, and extend the lifespan of cooling tower equipment while ensuring compliance with vital operational constraints. Additionally, remote accessibility will be facilitated, enabling operators to monitor and control the system from anywhere, thereby improving overall efficiency and sustainability of the cooling tower operations.

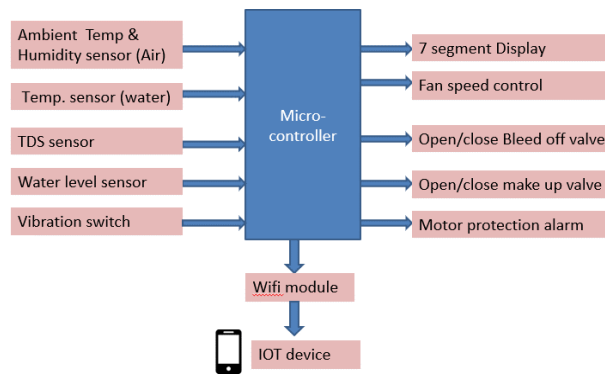


Figure 3: Proposed control architecture

The proposed control architecture, as depicted in Figure 3, outlines a streamlined approach to managing system operations. It encompasses distinct layers including sensing and data acquisition, signal processing, decision-making, and actuation. Beginning with data collection from sensors, the architecture progresses through processing, decision logic application, and ultimately, physical action implementation.

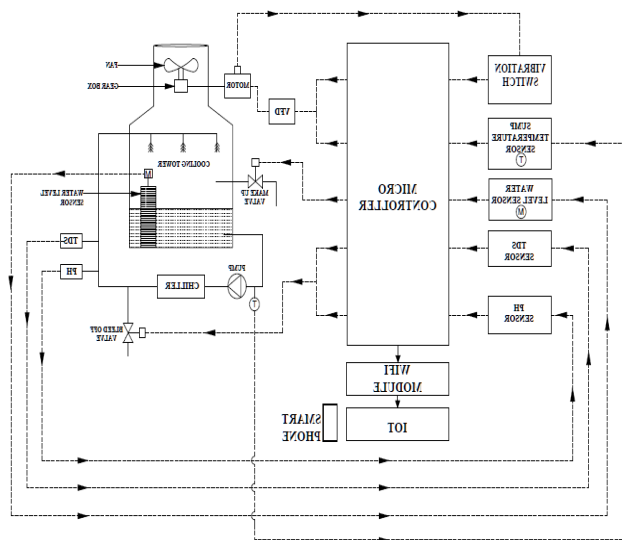


Figure 4: Process and Instrumentation Diagram

Figure 4 presents a simplified Process and Instrumentation Diagram illustrating the process flow and instrumentation details of the system. The diagram visually represents the various components involved in the process, such as equipment, valves and control loops. Through clear and concise symbology, it offers an overview of how the system operates.

3. Simulation

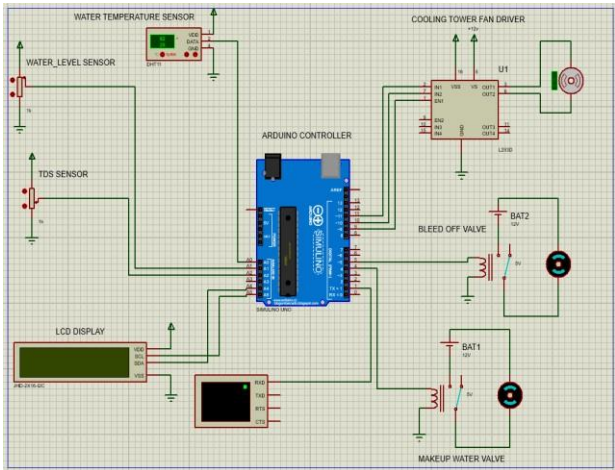


Figure 5: Simulated system visualization

Figure 5 provides a visual representation of the simulated system, offering a graphical depiction of its components, layout, and behaviour. Through this visualization, users can gain insight into the system's operation, observe its dynamics, and analyse the effects of different parameters or inputs on its performance. This simulated visualization serves as a valuable tool for understanding and studying the system in a controlled and interactive environment.

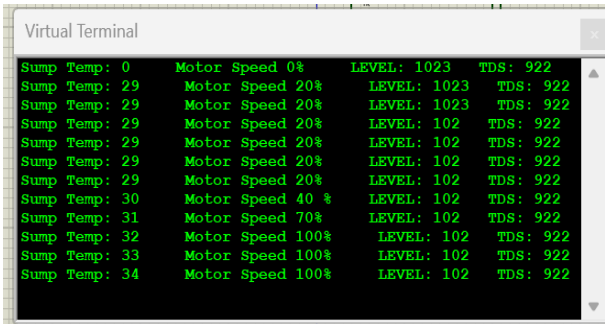


Figure 6: Simulation result of water temperature & the corresponding motor speed

Figure 6 displays the simulation results depicting the relationship between water temperature within the sump and the corresponding motor speed. This visualization highlights the dynamic interaction between thermal conditions of the water and the performance of the motor over time. By presenting these results graphically, the figure offers insights into how changes in water temperature influence the motor's speed, providing valuable information for analysing system behaviour and optimizing performance.

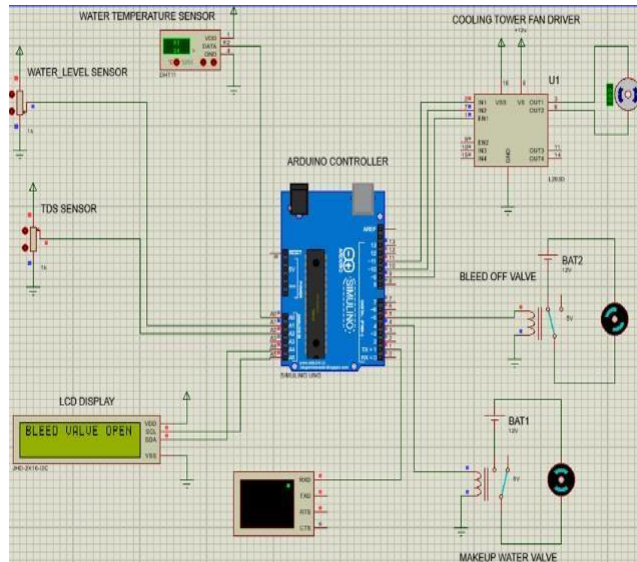


Figure 7: Simulation illustrating the effects of elevated TDS level in water

Figure 7 illustrates a simulation showcasing the impact of elevated Total Dissolved Solids (TDS) levels in water. As the TDS levels increase, the system automatically initiates the opening of the bleed-off valve to drain and replace the old water, thereby maintaining optimal performance. This visualization highlights the system's adaptive response to changing water quality conditions, ensuring efficiency and effectiveness in operation.

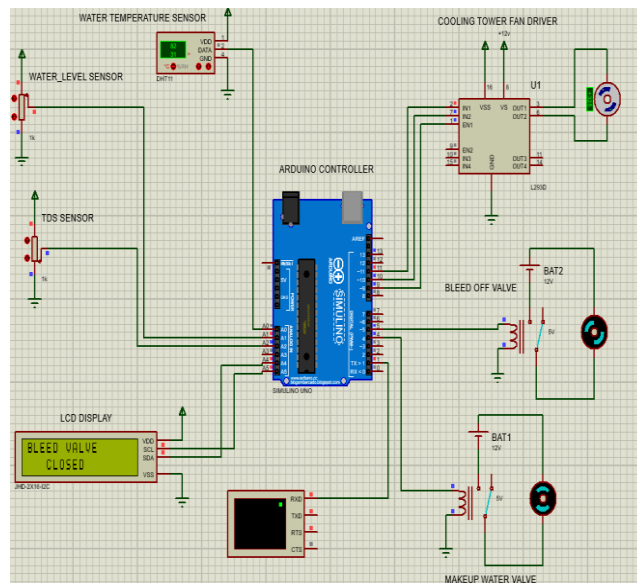


Figure 8: Simulation demonstrating the impact of reduced TDS level in water

Figure 8 presents a simulation demonstrating the effect of reduced Total Dissolved Solids (TDS) levels in water. As the TDS levels decrease, the system responds by automatically closing the bleed-off valve. This adaptive behaviour ensures that the system maintains appropriate water quality levels, optimizing performance and efficiency. The visualization in Figure 8 highlights the dynamic response of the system to changes in water composition, showcasing its ability to adjust and regulate operations accordingly.

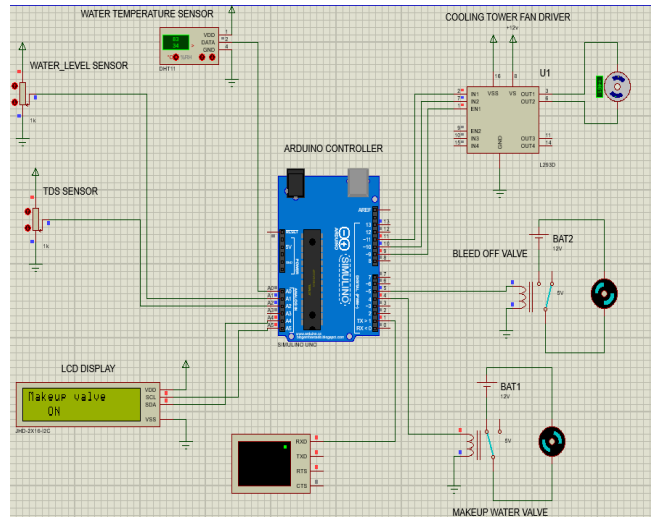


Figure 9: Simulation demonstrating the influence of reduced sump water level

In Figure 9, a simulation showcases the impact of reduced sump water level on the system. As the water level decreases, the simulation illustrates the system's response by automatically opening the make-up valve to refill water, ensuring optimal performance. This visualization highlights the system's adaptive behaviour in maintaining appropriate water levels for efficient operation.

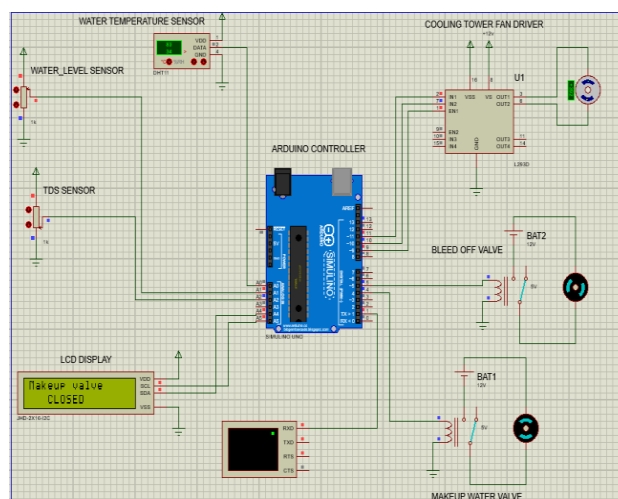


Figure 10: Simulation illustrating the effects of elevated sump water level

Figure 10 depicts a simulation illustrating the consequences of an elevated sump water level. As the water level rises, the make-up valve is depicted closing automatically to prevent overflow or excessive water accumulation. This visualization demonstrates the system's responsiveness to changes in water level, ensuring proper management and control to maintain optimal operating conditions.

4. Hardware Implementation

4.1 Flowcharts

The flow chart illustrates the step-by-step sequence of actions or decisions within a process or algorithm. It provides a visual representation of the logical flow of

activities, typically using symbols to represent different actions, conditions, or inputs.

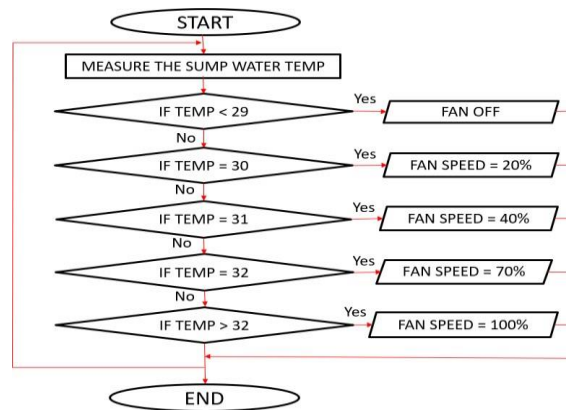


Figure 11: Controlling cooling tower Fan Speed

Figure 11 presents a flowchart outlining the process for controlling the cooling tower fan speed. This visual representation illustrates the sequence of steps and decision points involved in adjusting the fan speed based on various factors such as temperature, humidity, and system requirements. By breaking down the control process into manageable steps, the flowchart helps in understanding and implementing the logic behind fan speed regulation, facilitating effective management of the cooling tower system.

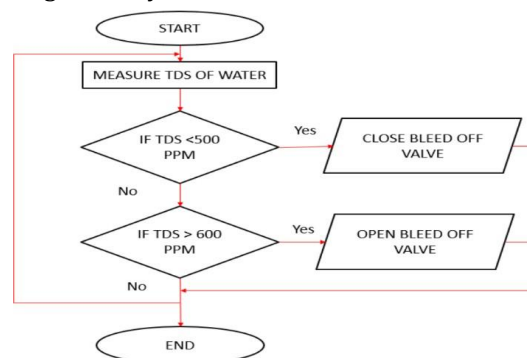


Figure 12: Controlling bleed off valve with TDS Sensor

Figure 12 depicts a flowchart detailing the process of controlling the bleed-off valve using a TDS sensor. This visual representation outlines the sequence of steps and decision points involved in monitoring the Total Dissolved Solids (TDS) level in water and adjusting the bleed-off valve accordingly to maintain optimal water quality. By visually organizing the control logic, the flowchart aids in understanding and implementing the automated control of the bleed-off valve based on real-time TDS measurements, ensuring efficient operation of the system.

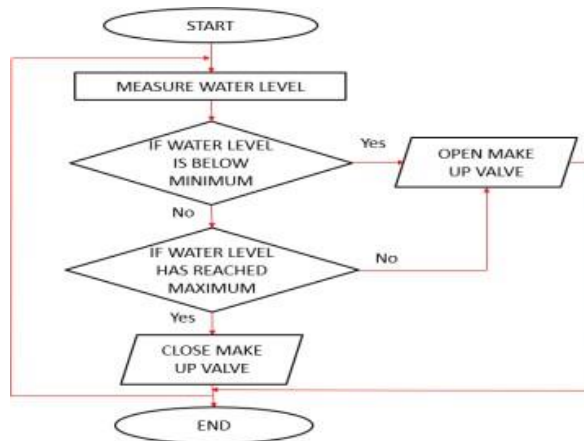


Figure 13: Controlling sump water level in Cooling Tower

Figure 13 presents a flowchart demonstrating the control process for managing the sump water level in a cooling tower, incorporating the regulation of the makeup valve. This visual representation outlines the series of steps and decision nodes involved in monitoring the water level within the sump and modulating the makeup valve to ensure the desired water level is maintained. By presenting the control logic in a structured format, the flowchart facilitates comprehension and implementation of the automated control system, enhancing the efficient operation of the cooling tower.

4.2 Photographs of Hardware

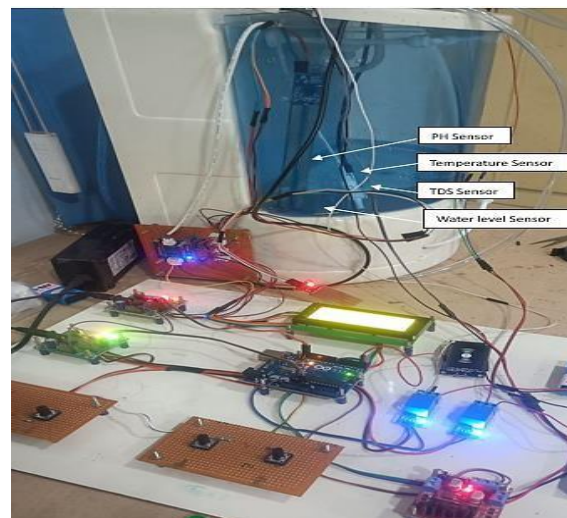


Figure 14: Layout of Sensors Inside the Cooling Tower

Figure 14 visually represents the components inside the cooling tower, including the pH sensor, water level sensor, TDS sensor, temperature sensor, and various other sensors. This depiction offers an overview of the sensors installed within the cooling tower system, highlighting their positions and functions in monitoring different parameters crucial for efficient operation. By providing a visual representation, Figure 14 aids in understanding the sensor layout and their roles in ensuring optimal performance and maintenance of the cooling tower.

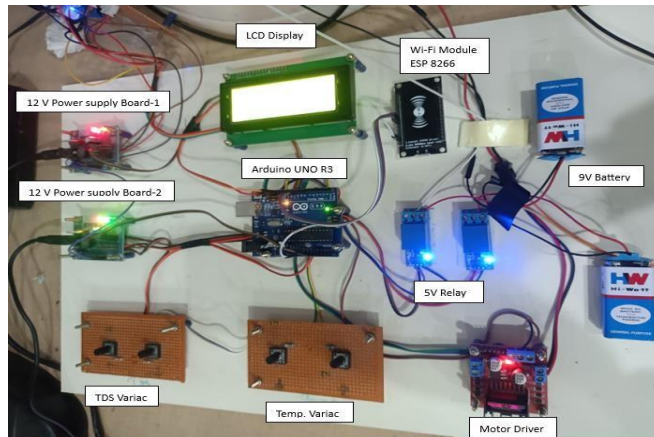


Figure 15: Hardware Components

Figure 15 presents a visual depiction of the various hardware components. This image showcases the physical elements such as switches, relay, controllers and other relevant hardware used in the construction and operation of the cooling tower system. By visually representing these components, Figure 15 offers an overview of the tangible infrastructure involved in the project, aiding in understanding the system's design and functionality.

4.3 Hardware Output



Figure 16: LCD Display for Fan Speed Control Based on Sump Water Temperature

Figure 16 illustrates an LCD display showing different fan speeds corresponding to the sump water temperature. This visual representation provides a clear depiction of how the fan speeds are dynamically adjusted based on the real-time temperature of the sump water. By presenting this information on the LCD display, Figure 16 facilitates monitoring and control of the cooling tower system, ensuring optimal performance and energy efficiency in response to varying temperature conditions.

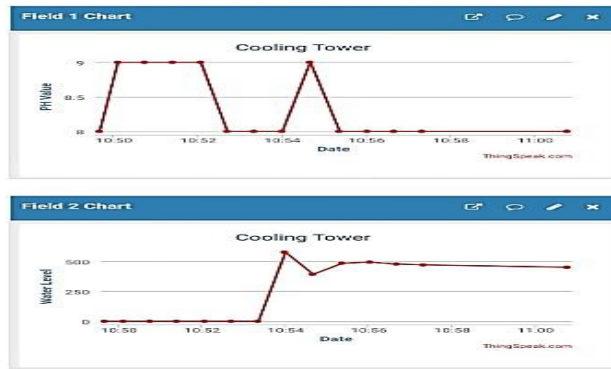


Figure 17: IoT Screen Monitoring pH and Water Level Fluctuations

Figure 17 illustrates an IoT screen displaying the fluctuating values of pH and water level before stabilizing. This visualization provides real-time monitoring of both pH levels and water levels, showing their dynamic changes over time before reaching a steady state. The depiction on the IoT screen serves as a valuable tool for monitoring and managing both pH and water levels in the system, ensuring stability and optimal conditions.



Figure 18: IoT Screen Monitoring TDS and Water temperature Fluctuations

Figure 18 presents an IoT screen providing live updates on the fluctuations of Total Dissolved Solids (TDS) and water temperature. This visual representation offers a real-time glimpse into the dynamic changes of these parameters, aiding in the constant monitoring and adjustment of water quality within the system. Through this interface, Figure 18 facilitates ongoing surveillance of TDS levels and water temperature, guaranteeing optimal operational conditions for the cooling tower.

4.4 Cost Savings

A 1°C decrease in the condenser entry water temperature results in a power saving of 0.01 kilowatts per ton of refrigeration (kW/TR) for the chiller.

For a 500-ton centrifugal chiller:

Power saving potential for one chiller = 0.01 kW/TR x 500 TR = 5 kW

Daily power savings for one chiller = 5 kW x 24 hours = 120 kWh (or 120 units)

Annual power savings for one chiller = 120 units x 365 days = 43,800 units

Total cost savings for one chiller per year = 43,800 units x Rs. 8 /unit = Rs. 3,50,400/-

Therefore, the implementation of such energy-saving measures could result in a significant total cost savings of Rs. 3,50,400 per year for one 500-ton centrifugal chiller.

Payback Period Calculation for Energy Efficiency Upgrades:

Cost of Actual implementation

- Variable Frequency Drive (VFD) for fan: Rs. 1,75,000/-

- Direct Digital Controller: Rs. 95,000/-

- Sensors (PH, TDS, Temp, solenoid valves): Rs. 1,00,000/-

- Cabling works: Rs. 30,000/-

Total Investment Rs. 4,00,000/-

Total Savings: Rs. 3,50,400/-

Simple Payback Period:

Payback Period = Total Investment / Total Savings

Payback Period = Rs. 4,00,000 / Rs. 3,50,400 = 1.14 years or 14 months

Therefore, the implementation of these energy-efficient upgrades is projected to have a simple payback period of around 1.14 years, making it a cost-effective investment with substantial savings.

5. Conclusion

In conclusion, maintaining optimal process parameters, particularly sump temperature and Total Dissolved Solids (TDS) levels in cooling tower operations, is paramount to ensure energy efficiency and cost-effectiveness. Elevated sump temperatures beyond 32°C adversely affect heat transfer efficiency in the condenser, resulting in increased power consumption by the chillers. Similarly, high TDS levels lead to scaling within the condenser tubes, further hindering heat exchange and amplifying power consumption. To mitigate these challenges, proactive measures, such as regular monitoring, precise control of parameters, water quality management, and predictive maintenance, must be employed to uphold operational efficiency, reduce energy consumption, and prolong the lifespan of the cooling system. Ultimately, a strategic approach to managing these parameters is essential for sustaining an efficient and economical cooling tower operation.

6. Limitations

While the adoption of IoT-enabled cooling tower automation presents numerous advantages, including enhanced efficiency and cost savings, certain limitations should be acknowledged. These limitations, while relatively minor compared to the benefits, include initial investment costs, integration complexity, cybersecurity risks, and reliance on network connectivity. However, with proper planning and mitigation strategies, these limitations can be effectively managed, allowing organizations to fully leverage the benefits of IoT-powered cooling tower automation.

References

1. Mar 2017-Dharinee. B. S, Rammohan Priyanka, Shri Vishali. R, Ms. S. Sukambika, Design of Cooling Tower with IoT International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056, Volume: 04 Issue: 03, www.irjet.net p-ISSN: 2395-0072.
2. 2014-Eknath D. Kharat Amit B. Gavali, Cooling Tower Automation, International Conference on Convergence of Technology
3. 2021-Changwei Huang, Design of Central Air Conditioning Control Acquisition Device Based on IoT Technology, Journal of Physics: Conference Series 2143 (2021) 012002
4. 17 Aug 2017- Muhammad Aftab, Chien Chen, Chi-Kin Chau, Talal Rahwan, Automatic HVAC control with real-time occupancy recognition and simulation-guided model predictive control in low-cost embedded system. Energy and Buildings, 154, 141-156
5. 2020- S. Dhanalakshmi, M. Poongothai, Kaner Sharma, IoT Based Indoor Air Quality and Smart Energy Management for HVAC System, Procedia Computer Science, 171, 1800-1809.
6. 15 April 2018- Gaëlle Guyot, Max H. Shermanc, Iain S. Walker, Smart ventilation energy and indoor air quality performance in residential buildings: A review
7. 2021-Vladimir Tanasiev, George Cristian Patru, Daniel Rosner, Gabriela Sava, Horia Necula, Adrian Bade, Enhancing environmental and energy monitoring of residential buildings through IoT
8. February 2020-KwangHoon Han and Jensen Zhang, Energy-saving building system integration with a smart and low-cost sensing/control network for sustainable and healthy living environments: Demonstration case study”
9. 18 January 2021 -Zhihong Pang, Yan Chen b, Jian Zhang, Zheng O'Neill, Hwakong Cheng, Bing Dong, How much HVAC energy could be saved from the occupant-centric smart home thermostat: A nationwide simulation-study
10. 23 April 2021 -Sheng Zhang, Zhengtao Ai, Zhang Lin, Novel demand-controlled optimization of constant-air volume mechanical ventilation for indoor air quality, durability and energy saving
11. 1990-Wang Shu, Lu Wenda, In their paper titled theoretical and experimental solutions of cooling-tower-soil system, J. Eng. Mech
12. 7 October 2019 -Dong-Bae Kim, Daeung Danny Kim, Taeyeon Kim. Energy performance assessment of HVAC commissioning using long-term monitoring data: A case study of the newly built office building in South Korea
13. 2020-Xing Lua, Zheng O'Neill, Yanfei Liab, Fuxin Niu “A novel simulation-based framework for sensor error impact analysis in smart building systems: A case study for a demand-controlled ventilation system
14. November 2017-Shady S.Refaat, Haitham Abu-Rub, Amira Mohammed, Smart and Energy Air-Conditioning Systems, NPRP award [NPRP 7-106 -2-053], Qatar National Research Fund
15. 2017 -Wei Song, Ning Feng, Yifei Tian, Simon Fong, An IoT-Based Smart Controlling System of Air Conditioner for High Energy Efficiency, IEEE International Conference on Internet of Things (I Things) and IEEE Green Computing and Communications (Green Com) and IEEE Cyber, Physical and Social Computing (CPS Com) and IEEE Smart Data (Smart Data),
16. 2017-Masayoshi Hamanaka, Shunsuke Horie, Daiki Owaki, Kenshu Nimi, Kazuto Yukita, Toshiro Matsumura, Yasuyuki Goto, Keiichi Hirose, Demand Response Using Air Conditioner, © IEEE
17. 13 - 15 September 2011- N. Wang, J. Zhang, X. Xia, Energy Consumption of Air Conditioners at Different Temperature Set Points, IEEE Africon 2011 - The Falls Resort and Conference Centre, Livingstone, Zambia,
18. 2018 - Surachai Thongkaew, Chirot Charitkuan, IoT for Energy Saving of Split-Type Air Conditioner by Controlling Supply Air and Area Temperature, © IEEE
19. 2018- Himadri Nath Saha, Tanishq Banerjee, Somshubhra Roy, Soham Pandit, Sayan Dutta, Subham Sadhukhan, Nityasree Upadhyay, Prerana Chakraborty, Souranshu Ghosh, An integrated solution for monitoring domestic appliances using IoT facilitating energy conservation © IEEE
20. 2018 -Moath Awawdeh, Anees Bashir, Tarig Faisal, Khawla Alhammadi, Mouza Almansori, and Sara Almazrouei, Embedded Ventilation Air Conditioning System for Protection Purposes with IoT Control ©IEEE
21. 12-14 August, 2011-Jingyun Liu, Huiling Zhou, Xiaoguang Zhou, Yang Cao, Huiyi Zhao, Automotive Air Conditioning System Control - A Survey, 2011 International Conference on Electronic & Mechanical Engineering and Information Technology
22. 2016 - Yuming Guo, Fuli Wang, Mingxing Jia, Dapeng Niu, Hybrid Modeling Method for Predicting the Cooling Water Outlet Temperature in Plate Heat Exchanger, 28th Chinese Control and Decision Conference (CCDC)
23. 2015- G.Kirthika, Dr.S.Charles Raja, Automation of Regenerative Compressor Cooling System Using Microcontroller, International Conference on Circuit, Power and Computing Technologies [ICCPCT]
24. 2011-Kuixing Liu, Neng Zhu, Menglei Wang, Zhe Tian, Comparative Study of Cooling Tower Performance Evaluation Indicators, IEEE

25. 2018-Danxu Zhang, Peter B. Luh, Junqiang Fan, Shalabh Gupta, Chiller Plant Operation Optimization with Input and Model Uncertainties, IEEE 14th International Conference on Automation Science and Engineering (CASE)
26. 2013- Wenhua Zhang, Chunling Meng, Optimization Design of the GFRP Hyperbolic Cooling Tower Structure, International Conference on Mechanical and Automation Engineering
27. 2018- Burkov A. F, Sokolova V. S, Zaychenko I. V, Determination of Parameters of the Gas Absorption System with Air Cooling for Conditioning of Industrial Premises, International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon)
- 28.2010 Wu Zhijiang, Wang Nan, Zhu Gongsheng, Application Research of Evaporative Cooling in Waste Heat Recovery, International Conference on Digital Manufacturing & Automation
29. 2014 Jian-Guo Wang, Qian-Ping Xiao, Juan-Juan Wang, Shi-Wei Ma, Wen-Tao Rao, Yong-Jie Zhang, Soft Sensor Approach for Optimal Operation of Cooling Tower for Energy Conservation, 26th Chinese Control and Decision Conference (CCDC)
- 20.2021-Tongrui Chenga ,Zhenning Zhao, JunfuLv, Han Yu, Anti-freezing Performances of Novel Natural Draft Dry Cooling Tower with Double-layer Air-cooled Heat Exchanger, IEEE 4th International Conference on Automation, Electronics and Electrical Engineering (AUTEEE)
31. 2022 -Yuming Guo; Biao Wang, Optimal Design of Forced Draft Cooling Tower under Variable Working Conditions, 41st Chinese Control Conference (CCC), IEEE
32. 2020- Zijian Yu;Xu Yang;Feng Gao;Jian Huang;Rang Tu;Jiarui Cui A Knowledge-based reinforcement learning control approach using deep Q network for cooling tower in HVAC systems, Chinese Automation Congress (CAC) ,IEEE
33. 2018 - Danxu Zhang; Peter B. Luh;Junqiang Fan;Shalabh Gupta Chiller Plant Operation Optimization with Input and Model Uncertainties, IEEE 14th International Conference on Automation Science and Engineering (CASE), IEEE
34. 2017 - S Madhura Raghumala; M Poojalakshmi; S Shreeyas Pravin GSM based annunciation system, International Conference on Innovative Mechanisms for Industry Applications (ICIMIA), IEEE
25. 2014- Jian-Guo Wang; Qian-Ping Xiao; Juan-Juan Wang; Shi-Wei Ma; Wen-Tao Rao; Yong-Jie Zhang Soft sensor approach for optimal operation of cooling tower for energy conservation 26th Chinese Control and Decision Conference (2014 CCDC) IEEE
36. 2013- Zhe Liu;Xi Chen;Xingtian Xu;Xiaohong Guan A decentralized optimization method for energy saving of HVAC systems IEEE International Conference on Automation Science and Engineering (CASE), IEEE
37. 2018- I. Nyoman Suamir; I. Nengah Ardita;I. Made Rasta Effects of Cooling Tower Performance to Water Cooled Chiller Energy Use: a Case Study toward Energy Conservation of Office Building, International Conference on Applied Science and Technology (iCAST), IEEE
38. 2022, Rajarshi Gupta; Abhishek Mukherjee; Amit Deb; Parikshit Vasisht; Sudhakar Ranjan; Comprehensive Study on the Types, Performance, and Application of Cooling Tower, International Conference on Smart and Sustainable Technologies in Energy and Power Sectors (SSTEPS), IEEE
39. 2023 -Jie Zhang; Dapeng Niu Design optimization study of cooling tower in circulating cooling water system of iron and steel industry, 35th Chinese Control and Decision Conference (CCDC), IEEE
40. 2021 -Khaled Salaheldin Mohamed; Hamdy Ahmed Ashour STUDY OF COOLING TOWER SYSTEM ENERGY SAVING OPPORTUNITIES WITHIN STEEL PRODUCTION FACTORY ,22nd International Middle East Power Systems Conference (MEPCON), IEEE
41. 2011- Ji Amin-He Li; Yue Zhiqiang; Jie Li; Gang Yin; Zhang Qinggang Experiment Study on Tower Cooling Energy-Saving Technology,2011 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, IEEE



Sheryn F <sherynn2003@gmail.com>

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Implementation Of IoT For Fire Protection System In Unitary Air Conditioners

Sheryn.F
UG Scholar,EEE
Sathyabama Institute Of Science
&Technology,
Chennai,India
Sherynn2003@gmail.com
Pushpavalli.M
Assistant Professor ,EEE
Sathyabama Institute Of Science
&Technology
Chennai,India
pushpa.murugan@gmail.com

Sivagami.P
Assistant Professor ,EEE
Sathyabama Institute Of Science
&Technology,
Chennai,India
sivagamitec@gmail.com
Abirami.P
Assistant Professor,EEE
B.S. Abdur Rahman Crescent Institute
of Science & Technology,Chennai,India
abiramirankumar@gmail.com

Suriyapriya.M
UG Scholar,EEE
Sathyabama Institute Of Science
&Technology
Chennai,India
Surya14042002@gmail.com
Nilananthanna. S
UG Scholar,ECE
St.Joseph's Institute Of Technology
Chennai,India
Nilananthanna13@gmail.com

Abstract— With the increasing global temperatures and climate fluctuations, air conditioning has transitioned from a luxury to a necessity in daily life. In the Indian market, room air-conditioners dominate, offering a broad range of affordable products from various brands. While these systems contribute significantly to human comfort and productivity, the neglect of electrical and fire safety features poses a potential threat to both human safety and property. This paper addresses the critical issue of fire hazards in unitary air conditioners and proposes a solution through the implementation of a modified fire protection circuit. By enhancing the electrical and fire safety features of these systems, the aim is to mitigate the risk of fire incidents and safeguard human lives and property. Additionally, the paper explores the integration of Internet of Things (IoT) devices to alert occupants in real-time in the event of a potential fire, providing an extra layer of safety and responsiveness. Through this research, the proposed modifications seek to strike a balance between the increasing demand for air conditioning and the imperative need for robust fire safety measures. The paper aims to contribute to the ongoing discourse on sustainable and secure HVAC systems, fostering a safer environment for individuals and businesses alike.

Keywords— Internet of things-IoT; Fire safety, Electrical safety, Fire protection circuit, IoT devices, Real-time alerts, Human safety, Risk mitigation.

I. INTRODUCTION

In modern living, air conditioning systems have shifted from being a luxury to becoming a vital element of comfort. With the rising temperature and shifting climate patterns on Earth, it has become more crucial to effectively regulate temperature and humidity in residential and work spaces. Room air-conditioning units, particularly air conditioners, have become popular in India due to their affordable prices and diverse selection from various brands. Yet, the increase in the use of air conditioning technology has emphasized a key problem: the insufficient focus on electrical and fire safety components in these units.

The risks that air conditioners represent in our homes, offices, and commercial buildings—if safety precautions are not taken—were recently brought to our attention by an article about a fire break-out occurrence at a commercial complex in Anna Salai, Chennai, Tamil Nadu. According to data from the Tamil Nadu Fire Department, air conditioners are involved in about 20% of electrical fires. When the ACs are overworked, the majority of these accidents happen late at night or early in the morning. The Delhi Fire Service reports that electric short circuits, overheating, and overloading are the main causes of around 60% of fires. An

estimated 25,000 people in India pass away from flames and related causes each year on average. Considering that an AC fire is, every year, about 25,000 persons die due to fires and related causes. Considering that one of the main causes of these mishaps is fire from air conditioning units, the quantity of fatalities from these units is unquestionably significant. Such fires result in severe property loss in addition to the deaths. The figure 1 schemes the fire accidents due to electrical malfunctioning. The figure 2 shows the losses in millions due to fire accidents.

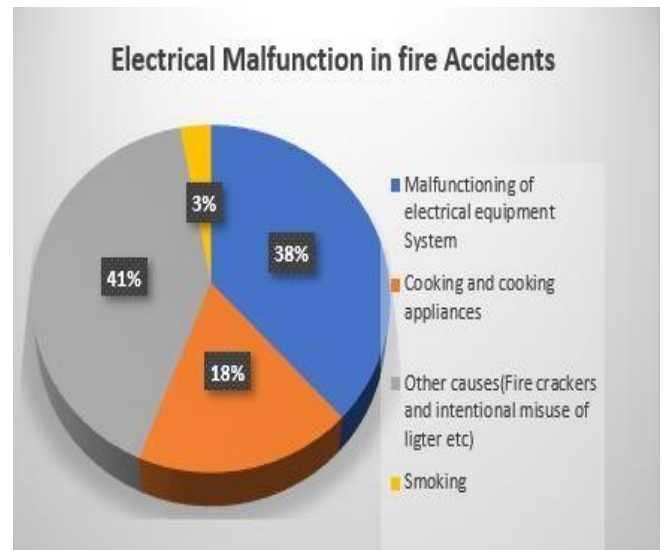


Fig. 1. Sketches the malfunctioning of electrical equipment in fire accidents

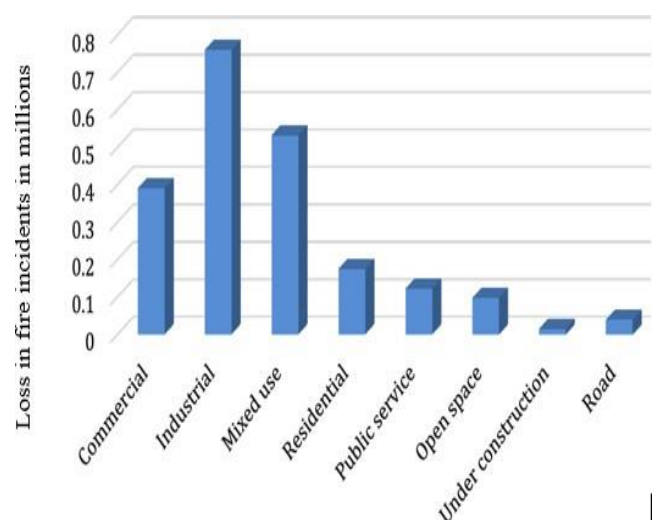


Fig. 2. Loss in fire accidents in millions

Smoke inhalation is a major factor in indoor fire fatalities. Inhaling smoke can lead to serious consequences and breathing difficulties. In US, NFPA discovered that for every 100 residences that experienced a fire between 2009 and 2013, the number of fatalities from home fires was reduced by less than half when smoke alarms were in operation. Compared to 1.18 deaths in homes without smoke alarms, there were 0.53 deaths reported in house fires with working smoke alarms [1]. In the first half of 2017, 928 building fires were reported by the UAE's Civil Defense Centers, resulting in 12 fatalities and 115 injuries. It is also claimed that public education campaigns on fire hazards, quick reaction to fire occurrences, the use of modern fire prevention technology, and professional firemen are essential components of a good fire emergency system [2]. Many initiatives and strategies are being led by the Abu Dhabi Civil Defense General Directorate with the goal of lowering the number of fire occurrences based on Gulf News, September 2016, about accidents in the United Arab Emirates. A mortality rate of 0.023 fatalities per 10,000 people was recorded by the UAE. Its fire accident rate exceeded that of several developed nations, including US, UK, and France, between 2010 and 2014 [3].

The potential dangers from fires in air conditioning systems pose a major risk to both people and property [5]. The primary reasons for fires in individual air conditioning units is discussed and it proposes an all-encompassing solution. The main emphasis is on creating and putting into action a revised fire protection circuit to tackle the significant safety issues in current systems [6]. The goal to decrease the chance of fires and their effects on people and property by improving electrical and fire safety measures is suggested. Moreover, this also seeks to leverage the capabilities of the internet of things (IoT) in order to enhance safety measures through the integration of IoT devices. In case of a potential fire, immediate notifications to occupants will not only reduce risks but also enable people to react quickly, reducing the consequences of these situations [4]. Crucial development in balancing the increasing need for air conditioning with the essential requirement for strong safety precautions is recommended, by promoting creativity in fire protection technology and integrating advancements in IoT.

We delve into the key contributions from recent research papers, each shedding light on distinct facets of air conditioners and optimisation. Researchers focused on creating a robust central air conditioning control system using IoT technology, incorporating a fuzzy algorithm for improved performance and wireless communication for seamless automation and monitoring [7]. The paper discusses about IoT-based indoor air quality and smart energy management systems for HVAC systems that provide real-time automation based on user preferences and energy management policies, leading to significant energy savings [8]. An evaluation of smart ventilation systems for residential buildings is presented, emphasizing the advantages of demand-controlled ventilation techniques for indoor air quality and energy efficiency [9]. Additionally, researchers looked into how IoT may be used to improve energy and environmental monitoring in residential buildings, with a focus on integrating wired and wireless sensors for efficient HVAC system control and optimization [10]. The study demonstrated the integration of smart sensing networks with HVAC systems in office buildings,

achieving substantial energy savings while maintaining satisfactory thermal comfort and indoor air quality [11]. A comprehensive energy performance assessment of HVAC systems was conducted in office buildings, using long-term monitoring data to optimize HVAC commissioning processes. Their study highlights the significance of data-driven approaches in improving energy efficiency and reducing overall energy consumption in commercial buildings [12]. The paper presents an innovative approach to optimize energy consumption in air conditioning systems through smart algorithms and real-time monitoring. Their study emphasizes the integration of behavioral and technological modifications to minimize energy usage while ensuring customer comfort and health [13].

Researchers also introduced an IoT-based smart controlling system for air conditioners, leveraging smart meters and cloud computing for real-time energy consumption predictions and energy-saving decisions. Their study demonstrates how IoT technology can contribute to reducing power usage and greenhouse gas emissions in air conditioning systems [14]. An IoT platform for energy-saving control of split-type air conditioners, focusing on optimizing supply air temperature and room temperature to reduce compressor runtime and achieve significant energy savings is proposed [15].

Introducing the embedded ventilation air conditioning system, integrating air conditioning and ventilation with a protection system for enhanced safety in indoor environments. Their study demonstrates the feasibility of using IoT control and sensor technologies to detect fire hazards and initiate protective measures in buildings [16]. A decentralized optimization methodology for optimal setpoint control in HVAC system is suggested. This method divides the HVAC system into multiple subsystems and utilizes a decentralized optimization algorithm to achieve local/global optimal solutions, leading to significant energy savings while preserving human comfort requirements [17]. Investigation of the energy consumption of air conditioners at different temperature set points, emphasizing the importance of thermal control strategies in achieving energy savings is schemed. Their study provides insights into optimizing temperature set points to reduce energy usage in air conditioning systems [18]. Proffered a novel simulation-based framework for sensor error impact analysis in smart building systems, focusing on demand-controlled ventilation systems. By conducting sensitivity analyses and deterministic error quantifications, their study provides insights into optimizing sensor placements and enhancing the reliability of building automation systems [19]. An innovative HVAC control system utilizing machine learning techniques for occupancy prediction and model predictive control for real-time thermal response simulations, demonstrating significant energy savings and maintaining comfort levels is contemplated [20]. Thus, incorporating IoT prevent possible disasters and protect the community.

II. PROFFERED METHODOLOGY

A methodical approach has been put in place to deal with the reoccurring problem of components failing often in the current circuit, which could result in fire risks through a fish bone diagram shown in figure 3.

improve the overall dependability and safety of individual air conditioners, resulting in a more robust and secure system.

The AC unit controller is powered through a robust 40A Residual Current Circuit Breaker (RCCB), which efficiently pre-set modes such as cool, dry, and fan. The operational sequence initiates with the activation of the indoor fan, followed by a deliberate 3-minute delay before the compressor engages in cool mode. Incorporating advanced safety measures, the system has a smoke sensor designed to promptly espy any smoke within the room. By detecting the presence of smoke, the system takes immediate action by shutting off the AC power, prioritizing the safety of occupants and preventing potential fire incidents.

To further bolster safety protocols, a comprehensive fire detection system employs both a fire sensor and a Passive Infrared (PIR) sensor. This dual-sensor setup ensures efficient and accurate fire detection. In the event of a fire, the system utilizes a Wi-Fi connection to access an Internet of Things (IoT) server. The collected sensor data is then transmitted over the internet. For seamless integration and user-friendly monitoring, the proffered methodology utilizes the IOT-Gecko open platform to develop a web-based IoT interface. As soon as the IoT-Gecko system receives sensor data, it undergoes a verification process, checking the device ID from which the data was sent. Subsequently, it displays the device ID, corresponding to the specific area or flat, where the incident has occurred. The figure 4 shows the modified AC control circuit with IoT interface.

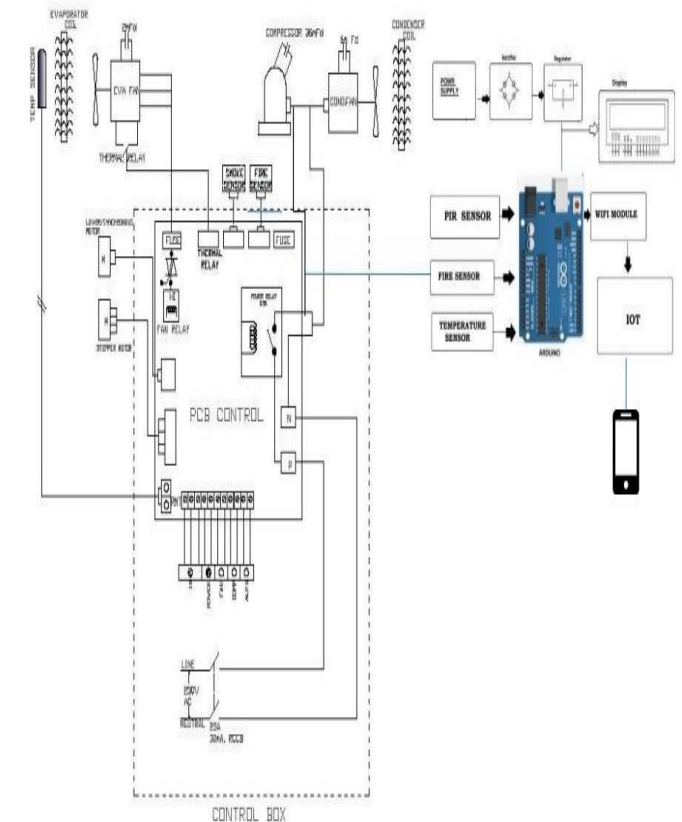


Fig. 4. Modified AC control circuit with IoT Interface

In the event of a fire incident, the system responds by triggering an alarm buzzer and promptly notifying the fire department and flat owner via the internet. This proactive

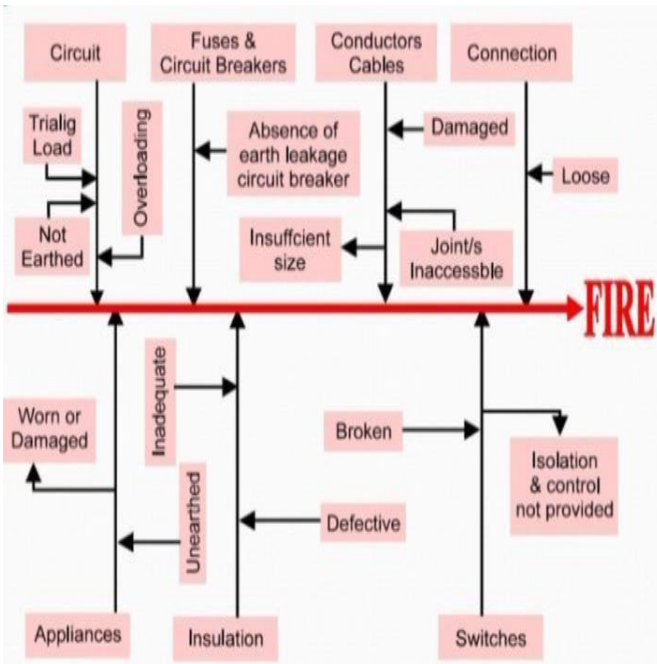


Fig. 3. Fish bone diagram to identify the electrical components failure in air conditioners

To address the recurrent issue of components failing frequently in the existing circuit, leading to potential fire hazards, a systematic identification and replacement strategy has been implemented. The aim is to enhance the safety of unitary air conditioners by substituting problematic components with fail-safe alternatives in the newly devised circuit. The following table 1 outlines the components that have been replaced in the old circuit:

Table 1. Outline of Component replacement

Old Circuit Component	Replacement with Fail-Safe Component
Clip type connectors	Screw type connectors
Plastic body Capacitor	Metal body type capacitor
Thermal fuse for compressor	Bi-metal relay for compressor
All combustible material enclosed in ABS plastic enclosure	All combustible material enclosed in fire containment box
PVC power and control cable	Fire retardant low smoke (FRLS) cables for power and control circuits
MCB are used	Residual Current Circuit Breaker (RCCB) is used
No smoke detector and alerting mechanism	Smoke detector with occupant alerting system with IOT

This focused substitution method guarantees that every problematic component is replaced with a fail-safe alternative, effectively minimizing the chances of component failure and potential fire risks. The altered circuit aims to

approach ensures that relevant authorities and occupants are promptly alerted, enabling them to take necessary actions to mitigate the impact of the incident. The use of IoT technology not only enhances safety measures but also facilitates swift and informed decision-making in critical situations.

III. PROTOTYPE IMPLEMENTATION AND RESULTS

A prototype of the modified control circuit was modeled with all safety features and IoT interface to demonstrate the fire protection in unitary air-conditioners. The figure 5 and 6 shows the AC controller with IoT module and the inside hardwares for fire protection of the air-conditioner.

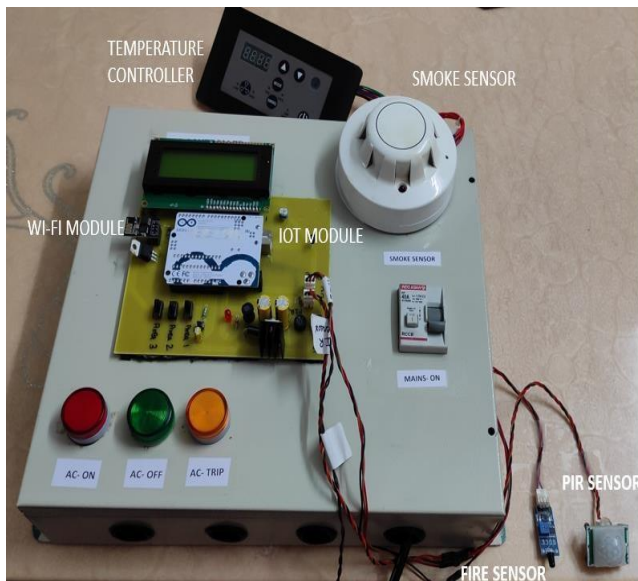


Fig. 5. Prototype of AC controller with IoT module

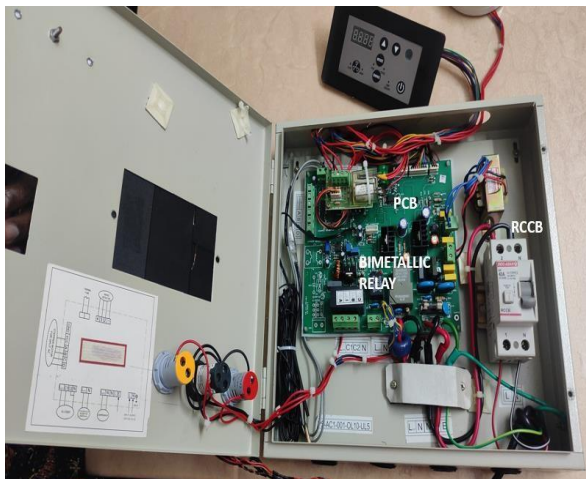


Fig. 6. Inside view of AC controller

The figure 7 visually represents the activation of the air conditioner (AC) controller, indicating the commencement of the cooling system. The figure 8 schemes the system status with an LCD display showing "All OK" in Area-2. The figure 9 represents the operational sequence begins with the activation of the indoor fan, followed by a deliberate 3-minute delay before the compressor engages in cool mode.



Fig. 7 AC controller switched ON



Fig. 8. LCD Display showing all OK in Area-2



Fig. 9. AC compressor switches on after 3 minutes

Figure 10 illustrates the transmission of data to a mobile device through a Wi-Fi module using IoT, capturing information before the occurrence of a fire incident



Fig. 10. Data sent to mobile through Wi-Fi module using IoT before FIRE

The figure 11 depicts the activation of the fire sensor in response to the presence of an open flame or naked fire, serving as a critical detection mechanism in the system. The figure 12 showcases the LCD display indicating the detection of a fire within the IoT module, providing a clear visual alert of the critical event.



Fig. 11. Demonstration of activation of Fire sensor by naked flame.



Fig. 12. LCD shows fire detected in IoT module

The figure 13 provides a visual depiction of the crucial process involved in transmitting post-fire incident data to a mobile device through a Wi-Fi module using IoT.

Upon the detection of a fire incident, the system promptly initiates a proactive response by activating an alarm buzzer and immediately dispatching notifications to both the fire department and the flat owner through the internet. This rapid and comprehensive approach ensures swift alerting of relevant authorities and occupants, empowering them to take prompt and necessary actions to effectively mitigate the impact of the incident.

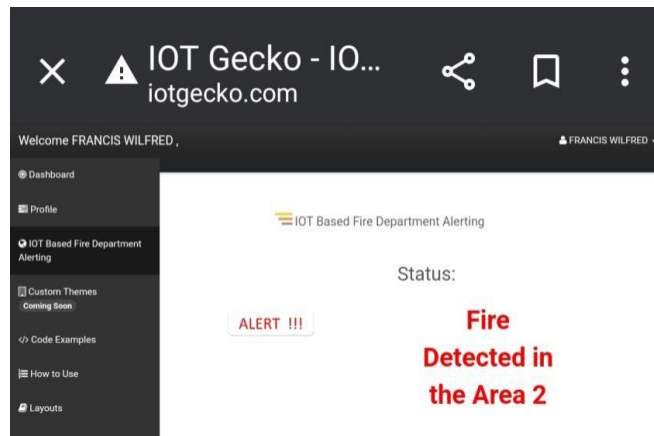


Fig. 13. Data sent to mobile through Wi-Fi module using IoT after FIRE

IV. CONCLUSION

The escalating frequency of air conditioner-related fire incidents poses a growing threat to society, coinciding with a steep rise in the demand for air conditioning systems. Recognizing the imperative need for safety enhancements in these ubiquitous appliances, the proposed modifications stand as a crucial intervention for the secure operation of air conditioners. The overarching goal is to curtail fire risks and safeguard human lives and property. By implementing the identified modifications, we embark on a significant stride towards ensuring the safety of individuals and their belongings. This societal application underscores the commitment to prioritizing safety aspects without compromising the surging demand for air conditioning. While the modifications may entail additional costs, the investment in enhanced safety features is not merely an expenditure but a strategic measure to avert potential disasters and uphold the well-being of the community. The table 2 sketches the advantages of the existing with the methodology proposed.

Table 2. Proliferates the advantages of Modified AC controller over Existing AC controller

Old AC Controller	Modified AC controller
All combustible components are placed inside ABS plastic enclosure in air-conditioner.	All combustible components are replaced with non-hazardous alternates and placed separately in a metallic enclosure outside air-conditioner
Fire hazard is high	Fire hazard completely removed
No fire alarm	Fire alarm using IoT devices

In essence, the proposed modifications represent a proactive and responsible approach to address the growing paradox of increasing air conditioning demands and the rising incidence of fire accidents. The societal impact of these safety measures extends far beyond the immediate context, contributing to a safer and more secure living environment for all. In the pursuit of technological advancements, the safety of individuals and communities should remain paramount, and these modifications serve as a testament to that commitment.

REFERENCES

- [1] Smoke Alarms in U.S. Home Fires”, National Fire Protection Association – (NFPA)- News and Research, Quincy, Marty Ahrens, M.,“ MA. September 2015.
- [2] <https://gulfnews.com/goingout/society/41-decrease-in-uae-fire-accidents-civil-defence1.2056240>.
- [3] <https://gulfnews.com/uae/houseslacking-smoke-detectors-highly-susceptible-to-fires-1.1986339>.
- [4] Shreya Gosrani,Abhishek Jadhav,Krutika Lekhak,Devesh Chheda. “Fire detection,monitoring and alerting system based on IoT, International Journal of Research in Engineering, Science and management Volume-2, Issue, April 2019.
- [5] IEEMA Journal- Feb 2023-Causalities due to fire in air conditioners
- [6] V.Rathnakumar, C.Chandran .Control circuit modification in room air-conditioners for safe operation during 4th National Conference on Refrigeration and Air Conditioning (NCRAC-2015) held at Rajalakshmi Engineering College, Chennai, 28th to 30th October 2015.
- [7] Changwei Huang, Design of Central Air Conditioning Control Acquisition Device Based on IoT Technology, Journal of Physics: Conference Series 2143 (2021)
- [8] S. Dhanalakshmi, M. Poongothai, Kaner Sharma, IoT Based Indoor Air Quality and Smart Energy Management for HVAC System, Procedia Computer Science, 171, 1800-1809. (2020)
- [9] Gaëlle Guyot, Max H. Sherman, Iain S. Walker, Smart ventilation energy and indoor air quality performance in residential buildings: A review-15 April 2018.
- [10] Vladimir Tanasiev, George Cristian Patru, Daniel Rosner, Gabriela Sava, Horia Necula, Adrian Bade, Enhancing environmental and energy monitoring of residential buildings through IoT- 2021
- [11] KwangHoon Han and Jensen Zhang, Energy-saving building system integration with a smart and low-cost sensing/control network for sustainable and healthy living environments: Demonstration case study”-February 2020.
- [12] Dong-Bae Kim, Daeung Danny Kim, Taeyeon Kim. Energy performance assessment of HVAC commissioning using long-term monitoring data: A case study of the newly built office building in South Korea-7 October 2019.
- [13] Shady S.Refaat, Haitham Abu-Rub, Amira Mohammed, Smart and Energy Air-Conditioning Systems, NPRP award [NPRP 7-106 -2-053],Qatar National Research Fund- November 2017
- [14] Wei Song, Ning Feng, Yifei Tian, Simon Fong, An IoT-Based Smart Controlling System of Air Conditioner for High Energy Efficiency, IEEE International Conference on Internet of Things (I Things) and IEEE Green Computing and Communications (Green Com) and IEEE Cyber, Physical and Social Computing (CPS Com) and IEEE Smart Data (Smart Data)- 2017
- [15] Surachai Thongkaew, Chirod Charitkuan, IoT for Energy Saving of Split-Type Air Conditioner by Controlling Supply Air and Area Temperature, © IEEE-2018
- [16] Moath Awawdeh, Anees Bashir, Tarig Faisal, Khawla Alhammadi, Mouza Almansori, and Sara Almazrouei, Embedded Ventilation Air Conditioning System for Protection Purposes with IoT Control ©IEEE 2018
- [17] Zhe Liu;Xi Chen;Xingtian Xu;Xiaohong Guan A decentralized optimization method for energy saving of HVAC systems IEEE International Conference on Automation Science and Engineering (CASE), IEEE 2013
- [18] N. Wang, J. Zhang, X. Xia, Energy Consumption of Air Conditioners at Different Temperature Set Points, IEEE Africon 2011 - The Falls Resort and Conference Centre, Livingstone, Zambia-13 - 15 September 2011.
- [19] Xing Lua, Zheng O'Neill, Yanfei Liab, Fuxin Niu “A novel simulation-based framework for sensor error impact analysis in smart building systems: A case study for a demand-controlled ventilation system-2020.
- [20] Muhammad Aftab, Chien Chen, Chi-Kin Chau, Talal Rahwan, Automatic HVAC control with real-time occupancy recognition and simulation-guided model predictive control in low-cost embedded system. Energy and Buildings, 154, 141-156-17 Aug 2017.