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Optimizing Building Operations with IoT-Enabled Energy Monitoring System

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***Abstract*—Over the past years, global electricity consumption has surged significantly, highlighting the critical need for effective energy management strategies. These strategies are essential for conserving resources, reducing costs, and promoting sustainable energy use. Buildings alone account for approximately 60% of global energy consumption. Optimally utilizing current technologies can potentially reduce this consumption by 30 to 80%. Collecting extensive building energy consumption data enables the application of data-driven approaches, such as statistical and machine learning techniques, over traditional physics-based methods. An energy management system (EMS) automates data collection and visualization, aiding users in monitoring, analyzing, and managing energy resources. Historical data can be leveraged to develop strategies for optimized energy use, identifying peak and off-peak usage, thereby reducing costs. Commercially available building management solutions are often costly for small and medium-sized buildings, IoT technologies offer a cost-effective alternative. IoT systems connect devices and appliances to a network, facilitating seamless communication and data exchange. Essential components include sensors, actuators, data processing units, and communication networks. Various IoT architectures aim to enhance communication, scalability, security, and efficiency. This paper reviews key literature on IoT-based energy management systems, highlighting research gaps, system architectures, communication standards, real-world implementations. Based on this review a suitable system was developed at Kathmandu University, and the data obtained from the system is analyzed to highlight the critical need for effective energy management strategies.**

I. Introduction

Over the past years, there has been a significant increase in global electricity consumption. Within a time span of 23 years from 2000 to 2023, consumption surges from 15,277 TWh to 29,479 TWh [1]. Around 77% of global energy is derived from fossil fuels, showcasing the still minimal contribution of renewable sources in comparison [2]. The negative environmental impact, limited fossil fuel resources, and rising energy costs underscore the critical importance of various energy management strategies [3]. These strategies are essential for conserving resources, reducing costs, and promoting sustainable energy use.

The Buildings alone is responsible for about 60% energy consumption worldwide [4]. Optimum utilization of currently available technologies can help reduce electricity consumption in buildings by approximately 30 to 80% [5]. Obtaining large amount of building energy consumption data will enable us to apply data driven approaches instead of traditional physics based approaches for effective energy management [6].

The energy management system is an automation system that collects energy measurement data from the field and makes it available in the form of visualization/graphics so that it is easily understood by users for monitoring, analyzing, and managing energy resources [7]. The availability of historical measurement information can be analyzed and utilized for developing strategies and decisions to optimize energy use. The real time monitoring of the energy consumption will inform user about electrical usage during the peak hours and off-peak hours and conducting an analysis to for saving energy and cost of electricity bill [8]. The Currently commercially available building management solutions are cosier to be implemented in small and medium-sized buildings thus making it challenging for gathering and accessing data from energy measurement devices and appliances [9]. However, the use of Internet of Things (IoT) technologies a cost effective real time energy monitoring system can be obtained.

IoT refers to a platform where all our devices and appliances connect to a network, enabling communication between devices and humans. This interconnected ecosystem relies on several key elements working in harmony:

1) Sensors: These devices detect changes in the environment, capturing data such as temperature, humidity, motion, or light levels.
2) Actuators: Actuators respond to control signals by altering environmental parameters. For instance, they might adjust room temperature, open or close valves, or activate alarms.
3) Data Processing Unit: Responsible for processing the data collected by sensors. This unit analyzes, filters, and transforms raw data into meaningful insights.
4) Communication Network: The backbone of IoT, providing connections between various devices. Whether through wired or wireless channels, this network facilitates seamless information exchange among IoT devices.

Researchers have proposed diverse IoT architectures, including Three-Layer, Four-Layer, Five-Layer, Cloud and Fog-based models, Social IoT, and Representative Architectures. Each architecture aims to optimize communication, scalability, security, and efficiency within the IoT ecosystem [10].

The remainder of the paper is organized as follows: Section II reviews various models used for energy forecasting, highlighting their applications and effectiveness. Section III provides a literature review on managing energy with IoT, summarizing major contributions from each paper in tabular format. Section IV describes the methodology used to implement an energy monitoring system at Kathmandu University, detailing the steps and processes involved. Section V presents the data description, summarizing the load demand patterns across various buildings as observed from the installed energy monitoring system. Finally, Section VI concludes the paper, summarizing the key findings and suggesting directions for future research in this field.

II. Load Forecasting Model Development

Electrical Power Load Forecasting (EPLF) is the process of accurately predicting electrical load demand over a given period, a crucial task for enhancing the reliability of power supply and enabling informed decision-making in future planning and management within the electricity industry [11]. EPLF is classified based on the planning horizon into three categories: Short-Term Load Forecasting (STLF) for periods less than 1 day, Medium-Term Load Forecasting (MTLF) for periods ranging from 1 day to 1 year, and Long-Term Load Forecasting (LTLF) for periods spanning 1 to 10 years [12]. Various techniques have been applied for load forecasting, including multiple regression, exponential smoothing, iterative reweighted least-squares, adaptive load forecasting, stochastic time series, ARMAX models based on genetic algorithms, fuzzy logic, and neural networks. Among these methods, significant research has focused on stochastic and dynamic forecasting techniques [13].

A. Autoregressive Moving Average (ARMA) Model

The ARMA model is a widely used stochastic method for load forecasting due to its relative simplicity and effectiveness. ARMA models combine autoregressive (AR) and moving average (MA) components, where the current value of the series is expressed linearly in terms of its past values and the current and previous values of a stochastic error term. This dual approach enables ARMA models to capture both the momentum and shock effects in the data, making them robust for various forecasting applications [14]. Mathematically, an ARMA model is expressed as follows:

$$Y_t = \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j \epsilon_{t-j} + \epsilon_t \tag{1}$$

where Y_t represents the current value, ϕ_i are the parameters of the autoregressive part, θ_j are the parameters of the moving average part, and ϵ_t is the white noise error term.

III. Literature Review

In [9], a cost-effective Internet of Things (IoT) solution for smart buildings was introduced, aimed at the remote monitoring and control of power consumption at the appliance level. The proposed system architecture was divided into four layers: the Power Layer, the Data Acquisition Layer, the Communication Network Layer, and the Application Layer. The system was implemented and tested in the Engineering Building at Universidad Técnica Federico Santa María in Valparaíso, Chile, across three different environments: an office, a classroom, and a laboratory. A functional platform that aggregated energy consumption data was achieved, contributing to energy awareness and conservation initiatives.

In [6], a building energy management system (BEMS) developed at Chulalongkorn University using the open standard IEEE1888 was presented. This system was installed, and a comprehensive dataset was obtained from a seven-story, 11,700 square meter office building in Bangkok, Thailand. The dataset detailed the building-level electricity consumption, broken down into each zone and floor. The CU-BEMS dataset recorded the operation of individual air conditioning (AC) units, lighting, and plug loads in each zone of the building at one-minute intervals. Additionally, indoor environmental sensor data, including temperature, humidity, and ambient light, were captured at the same frequency for each zone. The detailed nature of this dataset allowed for several potential reuse applications, including load forecasting at various levels (zone, floor, and building), building simulation model development and validation, coordinated control of AC units, control of AC, lighting, and plug loads, anomaly detection, and building-level data analytics.

In [15], a standardized methodology for defining, collecting, presenting, and analyzing building energy data was developed by the authors. These developed methods were applied to a standardized energy monitoring platform, encompassing both hardware and software components, which facilitated the collection and analysis of building energy usage data. Offline statistical data and online real-time data from buildings in two countries were compiled in the study. This comprehensive approach was aimed at enhancing our understanding of the current state of building energy use.

An optimal IoT communication network that seamlessly integrated with the existing smart grid infrastructure and overcame limitations inherent in the pre-existing architecture was identified by the authors in [16]. A novel IoT architecture was developed by the team, harnessing the power of fast prototyping platforms (ESP32 LoRa and ESP8266) to enable efficient non-wireless communication with the central server. The research findings underscored the substantial performance and functionality enhancements achieved by this new IoT architecture within the University Campus Micro Smart Grid network.

The paper [17] delved into smart campus technology, exploring its features and architectural aspects that had been successfully implemented in real-world scenarios. Through a Systematic Literature Review (SLR), thirty-two relevant papers were analyzed by the authors with the ultimate goal of providing a valuable reference for smart campus designers, researchers, and practitioners aspiring to create innovative and efficient smart campus systems.

Based on the comprehensive literature review, IoT based energy monitoring system has been successfully deployed at Kathmandu University considering affordability, simplicity, and practical feasibility within the context of our institution's resources and infrastructure.

IV. Methodology

The building Energy monitoring system is implemented in Kathmandu University Dhulikhel, Nepal. The Energy management system is installed across four different block:

- Physics Department Block
- Bio Tech Block
- Department of civil engineering
- Department of Management information

The system is designed using four layer architecture.

1) Power Layer : The layer consists of devices connected to the college electrical distribution system. The load includes Lighting loads, Computers, Laboratory equipment's, printer etc which have been istalled in across various department.
2) Data Acquisition Layer : The layer is responsible for collecting the total energy consumption of various block. Three phase Smart meter from manufacture Iammeter is used for data collection in power layer. The meter uses Current Transformer and Potential transformer for measuring electrical parameter. The meter is capable of sending measured data to server via Wifi using MQTT protocol.
3) Communication Layer : The communication layer is responsible for sending the sensor data to Application Layer. Data is send through WiFi to application layer from smart meter.
4) Application Layer : Application layer is responsible for storing and visualization of data received from communication layer.
   The implemented system is used to collect data, which is then analyzed to identify patterns in energy consumption. Various plots are created to visualize these patterns, and data forecasting is performed. Subsequently, an ARMA model is employed for forecasting future data.
   As an application, the implemented system is used to collect data, which is then analyzed to identify patterns in energy consumption. Various plots are created to visualize these patterns, providing insights into consumption trends. An ARMA model is developed for data forecasting and subsequently employed to predict future energy consumption. This enables more accurate predictions and better decision-making for energy management.

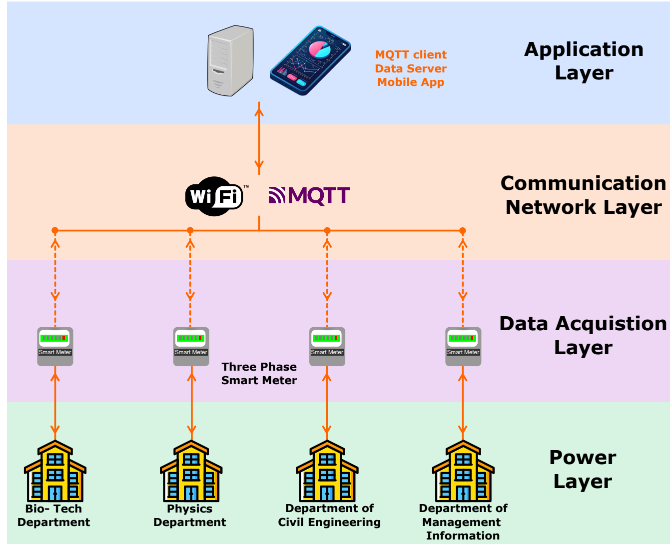

Fig. 1. System Description

V. Data Description

The plot in "Fig. 2" illustrates the daily load curve for the Civil Department block in May 29, 2024. This curve reveals a distinct pattern of energy consumption: lower usage during the morning and evening, with a peak in consumption during the daytime. This pattern is attributed to office activities within the department during working hours, including increased use of lighting, computers, and other office equipment.

TABLE I
SUMMARY OF RELATED WORK FOR DIFFERENT IOT BASED BEMS

Ref	Paper Title	Contribution
[18]	Internet of Things-Based Smart Electricity Monitoring and Control System Using Usage Data	Development of a practical, accurate, and user-friendly system that leverages IoT, cloud technology, and mobile applications to enhance home electricity control.
[19]	Design, Implementation, and Deployment of an IoT Based Smart Energy Management System	Deployment and validation of an IoT based Smart Energy Management System (SEMS) strategy and its related benefits to overcome challenges of energy management at consumer side
[20]	Design and Implementation of Energy Management System Based on Spring Boot Framework	Designs and implements an energy management system based on the Spring Boot framework
[21]	Application of IoT-Based System for Monitoring Energy Consumption	Reviews the development of IoT Technology-based Applications and research in energy management that so far has been in Indonesia
[8]	Real-Time Residential Energy Monitoring Device	Implementation of energy monitoring System, based on open source IoT platform for accessing and managing data remotly
[22]	IoT Based Smart Energy Metering System for Monitoring the Domestic	Implementstion of IoT based smart metering using PLC and SCADA for detecting and monitoring electricity theft in household's locations
[23]	Design of Small Smart Home System using Arduino	Design and create a Small Smart Home System using an Arduino microcontroller and WLAN network
[24]	Testing and Evaluation of Low-Cost Sensors for Develoiping Open Smart Campus System BAsed on IoT	Development of sustainable, adaptable, and reusable solutions for smart campuses and buildings using cost-effective sensors and the Internet of Things (IoT)
[7]	Development of smart energy monitoring using NB-IOT and Cloud	Creation of low cost IoT-based electric meter surveillance system using an Arduino Uno and an optical sensor and a smartphone application autonomously reads the meter data for reducing human error and energy expenses
[25]	LoBEMS—IoT for Building and Energy Management Systems	Optimizing energy consumption by deploying an energy management system based on LoBEMS (LoRa Building and Energy Management System) platform

The plots from ”Fig. 3” show daily load curves for various days of the week within February. The plots clearly show that load demand is lower on Saturdays and public holidays compared to other weekdays. This reduction in energy usage aligns with typical patterns due to fewer occupants and activities within the building on these days.

”Fig. 4” presents a box plot illustrating fluctuation of electrical load demand throughout a day for a Civil department, showcasing key statistical measures such as mean, median, upper quartile, and lower quartile of energy consumption.

”Fig. 5” compares actual energy consumption with forecasted data obtained from an ARMA model for the Management Information Department, allowing evaluation of the accuracy of the ARMA model's forecasts by assessing alignment with actual energy consumption.

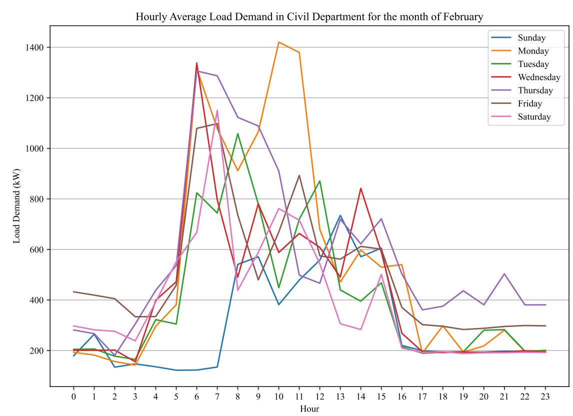

Fig. 3. Hourly Average Load Demand in Civil Department

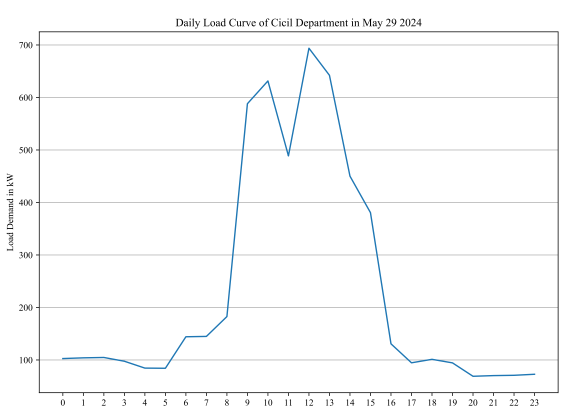

Fig. 2. Daily Load Curve of Civil Department in May 29 2024

VI. CONCLUSION

In conclusion, the implemented energy management system (EMS) coupled with Internet of Things (IoT) technologies has proven effective in collecting and analyzing energy consumption data. Through the analysis of data patterns and visualization using various plots, valuable insights into consumption trends have been gained. The utilization of an ARMA model for data forecasting has further enhanced the system's capabilities, enabling accurate predictions of future energy consumption. This comprehensive approach to energy management facilitates informed decision-making, leading to more efficient resource allocation and improved sustainability practices. Moving forward, continued refinement and optimization of the system will contribute to ongoing advancements in energy management and conservation efforts.

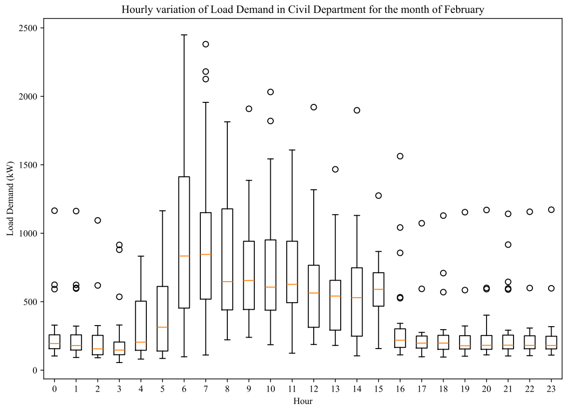

Fig. 4. Hourly variation of Load Demand for Civil Department

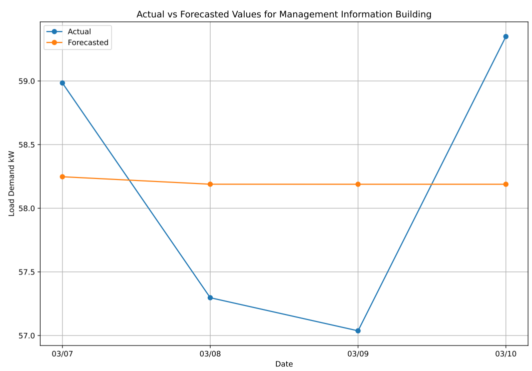

Fig. 5. Comparison between Forecasted and Actual Data

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