Intelligent Monitoring and Management of Smart Buildings using Machine Learning: Optimizing User Behavior and Energy Efficiency

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Abstract-- *Smart buildings are a crucial component of smart cities and smart grids, contributing to a more intelligent urban environment. The efficient utilization of energy in buildings is now a significant concern for sustainable societies. Whether they are residential or industrial. Smart buildings consume the majority of the energy produced, but in the context of smart grids, they are also designed to generate energy and help stabilize demand. Even small fluctuations in peak demand can result in substantial budget saving for customers and utilities. In this research, we explore the applicability of machine learning (ML) methods for load forecasting in smart buildings using smart sensor data that infers user behavior. Here, we utilized a smart building dataset encompassing four floors, 51 rooms, and 255 integrated sensors. Each smart building room comprises five types of calculations, including a PIR Sensor that helps to capture motion, a Carbon dioxide concentration sensor to check the purity of air, a Sensor to calculate temperature, a humidity sensor to maintain good conditioning, and a luminosity sensor. By using this data from these sensors, we can optimize and manage the energy saving. To evaluate the prediction performance of the input variables, we used to compare them we use mean squares error, mean absolute error and root mean square error.*

Keywords—*key words, PIR sensor, luminosity sensor, Humidity sensor, carbon dioxide sensor, machine learning.*

I. Introduction

In contemporary times, the energy efficiency of buildings has become a significant area of interest for sustainable societies. The enhancement of building energy efficiency is imperative in terms of managing energy expenses, minimizing the negative impact on the environment, and augmenting the value of smart buildings[1]. As per the findings of Y.M.Lee [2], the optimization of consumer energy efficiency can have a significant impact of over 50% towards the total world power conservation efforts. Therefore, the efficient use of energy is a critical aspect in attaining a feasible and low-carbon society, as stressed by X.Deng [3].

According to researchers, merging technology and infrastructure in this manner has the capacity to elevate the standard of living for residents and foster greater engagement with urban surroundings[4]. This is accomplished by connecting various technological components within a city's infrastructure, including smart buildings, temperature sensors, IoT devices, etc. This integration brings about the concept of a smart city[5], and constructing smart buildings is viewed as a critical component in achieving this goal. By doing so, it can facilitate better resource management and enhance the quality of life for the individuals residing in the smart city or building[6].

Smart Grids are used to supply the energy to different comodities among the smart buildings are one. Smart buildings serve as the primary components of smart grids and consume a considerable amount of the generated electrical energy. In the US, the energy consumption of various types of buildings have been highly increasing compared to industries and commercial spaces. These structures exhibit intelligence in the form of advanced features that promote a superior level of comfort, high efficiency of energy, and Eco-friendliness. This is achieved by harnessing renewable energy sources and utilizing efficient systems like smart grids and smart buildings[7].

II. Smart Building Architecture

The architecture used in the study consisted of six key components, each serving a unique purpose in the smart energy management system:

A. Wireless Sensor Network (WSN)

These are responsible for collecting information from sensors in a wireless network. These sensors can measure various environmental factors, such as temperature, humidity, and air quality, and transmit that data to the rest of the system[8].

B. Data Analytics Platform

This platform serves as the central hub for storage and processing the data collected by the WSN. By analyzing the data in real-time, the platform can provide valuable insights into energy usage patterns and make decisions based on that information[9].

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C. *Wireless Actuator Network*

This component is made up of wirelessly connected actuators that can respond to the data provided by the WSN and the analytics platform. For example, if the analytics platform detects that energy usage is high, the wireless actuator network could be used to turn off non-essential appliances to conserve energy[10].

D. *NI CompactRIO*

This controller is responsible for making crucial decisions regarding energy usage. It determines whether the energy generated by the solar panels should be stored or fed back into the power grid.. By doing so, it ensures that the energy produced is being used in the most efficient way possible[11].

E. *Solar Parking Lot*

This component serves as the main source of renewable energy for the system. The solar panels installed in the parking lot generate energy that can be used to power the various components of the system[12].

F. *Storage*

The final component of the system is the storage unit, which contains of hydrogen batteries. These batteries can store excess energy produced by the solar panels and making it available, when needed. By doing so, the system can ensure that there is a steady supply of energy available even when the solar panels aren't producing as much energy as they could be[13].

Together, these six components make up a comprehensive smart energy management system that can help cities and communities better manage their energy usage and reduce their carbon footprint. By utilizing renewable energy sources and cutting down on energy waste, these systems have the potential to create a more sustainable future for all. The data is acquired from the sensor network, The wireless actuator network then receives signals from the platform and translates them into actionable tasks. The NI CompactRIO acts as the main controller in the system, making decisions on whether the energy produced by the solar panels should be stored or injected into the grid.

III. Types of Smart Buildings

A. *Smart private homes*

Smart homes are equipped with advanced technologies that enhance residents' safety, comfort, and convenience. With remote control capabilities, homeowners can automate household appliances, schedule home maintenance tasks, and monitor energy usage[14]. Assistive technologies such as wearable sensors and smart medical devices help in monitoring the well-being of residents, including the elderly and children. Security sensors play a crucial role in detecting gas and water leaks, as well as potential security threats. By utilizing these technologies, smart homes provide a more efficient, secure, and convenient way of living.[15]

B. *Smart offices and commercial buildings*

Smart commercial complexes and office buildings leverage an IoT network to enable centralized and automated control of various functions such as lighting, waste management, emergency exits, etc. In the retail sector, IoT sensors can serve to gather customer data to streamline store layouts, track inventory levels, monitor employee conduct, and facilitate automated checkouts.[16].Commercial IoT solutions are aimed at creating a comfortable consumer experience in public places like malls, hotels and many. Edge computing is a growing trend that allows devices to collect and process data close to its source without having to send it to a data center[17].

C. *Smart workplaces*

Smart workplaces leverage both hardware and software to foster improved communication and collaboration among employees, incorporating tools such as video conferencing and other technologies and automated monitoring of IT security vulnerabilities[18]. Sensors can also track business assets such as laptops, while digital business assistants can handle mundane tasks like scheduling conference rooms and catering for meetings. New employees can receive pop up to guide them around the office and provide access to specific areas. Smart workplaces can also ensure a seamless experience for visitors by providing amenities like parking spaces and well-maintained facilities[19].

D. *Smart factories and warehouses*

Smart factories and warehouses are managed over industrial IoT networks, combining smart industrial machinery, logistics, and supply chains. Robots equipped with sensors and connected to IIoT networks improve production efficiency and quality control. Advanced inventory management systems with IoT sensors enable real-time inventory optimization[20]. Predictive analytics anticipate maintenance needs and minimize equipment downtime, reducing operational costs and increasing productivity. Worker safety is prioritized with IoT sensors monitoring conditions such as temperature and hazardous gas levels. Smart machinery detects and responds to operational issues in real-time, reducing downtime and increasing uptime. Smart industrial ecosystems have the potential to revolutionize the industrial sector by improving efficiency, productivity, and safety, while reducing costs and environmental impact.[21]

IV. Benefits and Challenges of Smart Buildings

A. *Benefits of Smart Buildings*

1) Energy savings: Smart buildings allow for real-time monitoring and control of energy usage, enabling individuals and businesses to save on energy costs. This is achieved through the use of sensors and automated systems that can adjust lighting, heating, cooling, and other systems to optimize energy consumption[22].

2) Environmental friendliness: By saving energy, Smart buildings help to reduce carbon emissions and minimize their impact on the environment. This is an important factor for both individuals and businesses who want to operate sustainably and reduce their carbon footprint[23].

3) Increased resale value: The use of smart technologies in buildings can increase their resale value, as they are seen as more modern, efficient, and technologically advanced. This is

an added benefit for property owners who want to maximize their return on investment[24].

4) Safety: Smart buildings are equipped with smoke, fire, and gas sensors that can quickly detect and alert occupants to potential hazards. This helps to built a good living environment, reducing the risk of injury or property damage[25].

5) Automated maintenance: Smart building monitoring systems can automate Timetables for upkeep and identification of glitches in household equipment and industrial machinery. This enables early intervention and repairs, reducing the risk of costly breakdowns and downtime[26].

6) Reduced personnel costs: Wireless technologies in smart buildings can reduce personnel costs by automating tasks such as activating lighting and sprinklers. This reduces the need for building managers to manually control these systems, freeing up time for other tasks[27].

7) Remote monitoring: Smart buildings allow for remote monitoring of safety devices like CCTV cameras and fire extinguishers[28]. This enables quick response times in the event of an emergency and improves overall safety and security .

B. Challenges in Smart Buildings

1) Tracking and Monitoring Employees in Workplaces: Keeping track of employees in the workplace will be a issue for organizations to track, especially when it comes to privacy and data concerns. Organizations need to be mindful of employee rights and legal requirements when implementing employee monitoring systems[29]. Tracking can involve various methods such as cameras, GPS, and time tracking software. Employers need to be transparent with their employees regarding the purpose of the tracking and how the data is being used. In case of any discrepancies, legal assistance may be required to address the issues[30].

2) Investing in Smart Buildings : Smart buildings are becoming increasingly popular as they allow for efficient management of building systems and operations[31]. However, implementing a smart building can require a substantial investment in technology, including building management systems (BMS) or building automation systems (BAS), These systems serve as a central digital hub, enabling control and monitoring of the devices and applications used within the building.. It's essential to carefully evaluate the cost-benefit analysis of investing in smart buildings before making a decision[32].

3) Intimidation of Smart Technologies :While smart technologies offer various benefits, they can also be intimidating for some individuals, particularly when things go wrong. Technical glitches such as sensor failures or confusing error messages from connected devices can create anxiety and frustration. To mitigate this, organizations should provide adequate training to employees and end-users on how to use and troubleshoot smart technologies. This can minimize the risk of mistakes and confusion[33].

4) Reliance on Persistent Internet Connections : Smart buildings are highly reliant on persistent internet connectivity to function properly. This means that any disruptions to internet service could negatively impact the building's functionality. Organizations should have backup plans in place to ensure that smart building systems can continue to function during internet outages. This could include backup power supplies, failover systems, or other contingency plans[34].

V. Data Acquistion

After the text edit has been completed, the paper is ready for the template. The Internet of Things (IoT) refers to a collection of physical objects, such as devices, which are equipped with sensors and network connectivity. This allows them to gather and share data, enabling communication between the objects themselves, as well as with other internet-connected devices and services, creating a connected ecosystem that can be used for a variety of applications[35].

oT finds one of its most widely used applications in Smart Grids. Smart Grids refer to modernized electrical grids that employ information and communication technology to enhance the efficiency, dependability, and safety of power transmission and distribution. Smart Grids rely on wireless sensing devices, such as smart meters, which collect and transmit data on electricity consumption and grid conditions in real-time[36].

The collected data is then forwarded to the processing unit, which is known as the Big Data Analytics Platform (BDAP). The BDAP analyzes the data using advanced algorithms and machine learning techniques to identify patterns, anomalies, and trends that can be used to optimize the grid's performance, reduce energy waste, and prevent power outages.[37]

Wireless Sensor Networks (WSNs) are used for data acquisition in Smart Grids, as they allow for the deployment of small, low-power sensors that can be placed throughout the grid to collect and transmit data wirelessly. These sensors can be integrated with various devices, such as smart meters, and can be used to monitor the grid's health, detect faults, and identify potential risks in real-time[38].

In summary, the IoT is a concept that allows for the interconnection of physical objects and devices with the internet, enabling them to collect and exchange data. The Smart Grids application of IoT relies on wireless sensor networks for data acquisition, which are used to collect data from various sensors and devices in real-time, enabling efficient management and optimization of the grid's performance.

VI. Implementation and Results of Smart Buildings Using Machine Learning

In today's world, maintaining a comfortable and healthy indoor environment is crucial for human well-being. The indoor environment is affected by several factors such as temperature, humidity, air quality, lighting, and occupancy status. Hence, it is essential to measure and analyze these factors to improve the indoor environment and human comfort. This research work presents an analysis of various parameters recorded in each room for a week from August 23 to August 31, 2015.The study collected data from the PIR motion sensor every 10 seconds and from other sensors every 5 seconds. The collected data included timestamps, measured in Unix Epoch Time, and actual sensor readings, which were recorded in each file. The study analyzed the PIR sensor data to identify the occupancy condition of the flat. The results showed that around 6% of the PIR data indicated that the room was occupied, while the remaining 94% of the data suggested that the room was empty.

The findings rely on a study of assaults and identification, carried out with Python and Google Colab through machine learning algorithms and a number of Python libraries. The smart Building dataset is used for analysis which contain of 5 sensors in each room including a PIR Sensor that helps to capture motion, a Carbon dioxide concentration sensor to check the purity of air, a Sensor to calculate temperature, a humidity sensor to maintain good conditioning, and a luminosity sensor, The entire set comprises 51 chambers and 255 detectors. The data set consists of individual information for all the apartments. Additionally, for each apartment, there are five distinct records corresponding to each sensor as shown in the below figure 1.

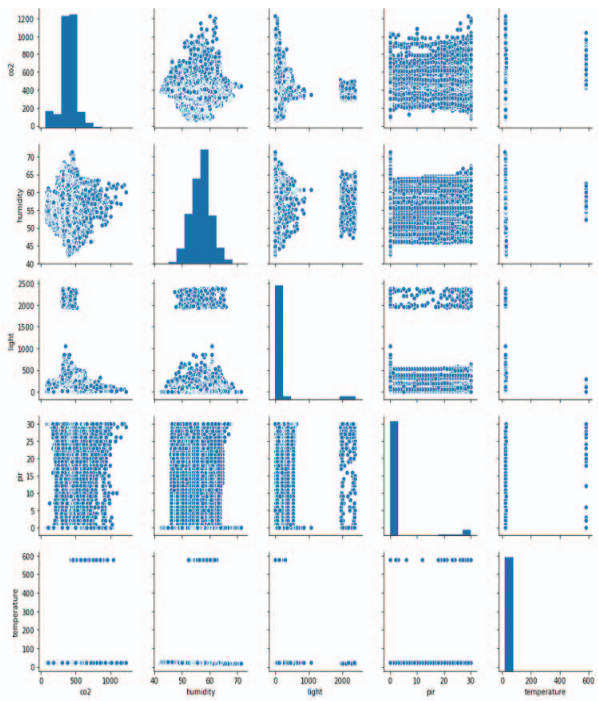

Figure 1: Plots of all Sensors

Every dataset is expected to have outliers, which can potentially have a significant impact on the overall analysis. Therefore, it is crucial to identify these outliers early on in the data analysis process. This requires conducting a thorough analysis to identify any potential outliers.One of the most common methods of identifying outliers is through the use of a box plot. By generating box plots for each of the independent sensors, we can visually inspect the distribution of the data, including any potential outliers. If outliers are identified, they can be removed from the dataset to ensure that they do not skew the results.By conducting a clear analysis of the data and leveraging tools such as box plots to detect outliers, we can ensure that our analysis is accurate and reliable as shown in the figure 2. This, in turn, can lead to more informed decision-making and better outcomes.

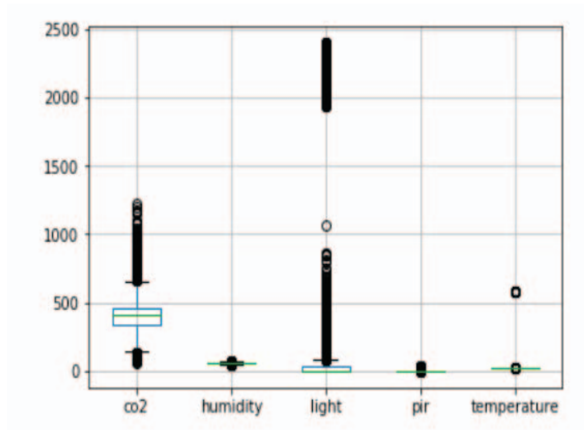

Figure 2: Box plot to detect outliers for 5 Individual Sensors

Figure 2 provides a wealth of information regarding the sensors, which can be useful in understanding their behavior. Additionally, from Figure 2, we can also observe the mean values of all the sensors, which are presented in Table 1. Understanding the data presented in both Figure 2 and Table 1 can aid in the analysis and interpretation of the data collected by the sensors.

Sensors	Mean Values
CO2 Sensor	399.2717
Humidity Sensor	56.892174
Temperature Sensor	23.415878
Light Sensor	140.574399
PIR Sensor	1.666467

Table1:Each individual sensor Mean Values

The sentence you provided states that a Python code was utilized to calculate the status of each room individually. This was accomplished by analyzing the data collected from five sensors placed in each room. By analyzing the data from these sensors, it is possible to determine the status of each room, which could be something like whether the room is occupied or not.To obtain the best possible results from the data analysis, various machine learning algorithms were used. Machine learning is a method of teaching computers to recognize patterns and make decisions based on those patterns. In this case, the algorithms are used to analyze the data collected from the sensors and determine the status of each room. It is important to note that not all sensors can be considered as independent features. This is because if one feature is affected, it may have a positive or negative correlation with other features. This is illustrated in Figure 3, which presents a correlation matrix for the sensors. By examining the correlations between the sensors, we can gain a better understanding of how changes in one feature may impact the other features. Therefore, it is important to take into account the correlations between the sensors when analyzing the data.

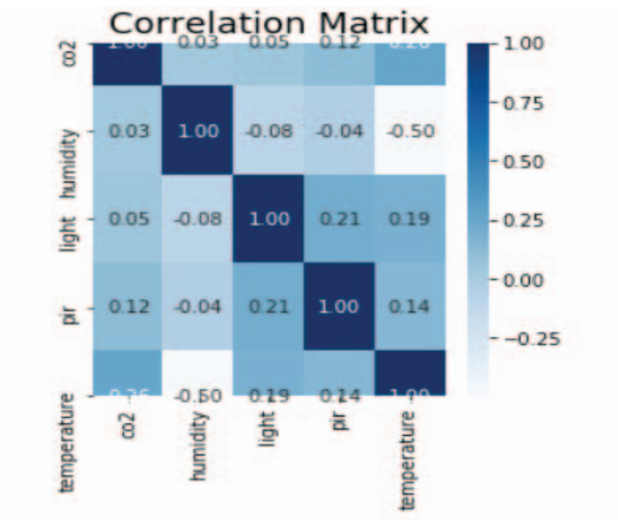

Figure 3: Correlation matrix of all the Features

Once the data analysis is complete and the status of each room is determined, the results are plotted. By visualizing the data in this way, it is easier to interpret and understand the results and finally all the machine learning algorithms are applied on the data to data to see which algorithms works good and we also need to cross check the results with mean squares error, mean absolute error and root mean square error and many as shown in the table 2.

During our analysis, we employed multiple machine learning algorithms to process the data. We found that many of these algorithms provided excellent results, with an accuracy rate of over 98%. This outstanding level of accuracy indicates that the selected algorithms were effective in processing the data and identifying patterns or trends. The high level of accuracy achieved through the machine learning algorithms can provide confidence in the accuracy and reliability of the analysis results.

Algorithm	Linear Regression	Decsion Tree Regression	Random Forest Regressor	KNeighbors Regressor	AdaBoost Regressor	Gradient Boosting Regressor
Mean Squared Error (MSE):	0.0	0.0	0.0	0.3168	0.0747	0.0002
R- Squared (R-square):	1.0	1.0	1.0	0.9647880557677688	0.99804132236412 07	0.9999999986688 043
Root Mean Squared Error (RMSE):	0.0	0.0	0.0	0.5628498911788116	0.27331300737432 895	0.0141421356237 3095
Mean Absolute error (MAE):	9.6890367718 28156e -15	2078799552023621 42e-14	1.6016144477952 72e-14	0.0260296805896946 05	0.00767146155718 7108	2.8351579223609 228e-05
Mean Squared Error (MSE):	0.0	0.0	0.0	0.393	0.0779	0.0002
R- Squared (R-square):	1.0	1.0	1.0	0.952922925653548	0.99815131084399 82	0.9999999874715 687
Root Mean Squared Error (RMSE):	0.0	0.0	0.0	0.6268971207462992	0.27910571473905 726	0.0141421356237 3095
Mean Absolute error (MAE):	9.8923120126 66457e -15	2.77391412313672 15e-14	1.5935251345679 037e-14	0.0340079775446890 46	0.00835116559092 2523	2.9804786469828 754e-05

Table 2: Results of all Algorithms

VII. Conclusion

This research work provides an in-depth analysis and importance of smart buildings and we have applied machine learning algorithms on various parameters recorded in each room using smart building sensors. By analyzing the data collected from the sensors, we were able to determine the occupancy status of each room, which is crucial for maintaining a comfortable and healthy indoor environment. We utilized machine learning algorithms and Python libraries to analyze the data and identify patterns or trends. The results showed that many of these algorithms provided excellent results, with an accuracy rate of over 98%. By employing tools such as box plots to detect outliers and examining the correlations between the sensors, we ensured that our analysis was accurate and reliable. The high level of accuracy achieved through the machine learning algorithms provides confidence in the accuracy and reliability of the analysis results. Overall, the insights gained through this analysis can aid in improving the indoor environment and human comfort, ultimately leading to more informed decision-making and better outcomes. As a Future Enhancement, our focus will be directed towards leveraging real-time smart building data to promote energy efficiency.

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