Energy Management Optimization in Smart Buildings using IoT and AI

Rabab FAHSSI, Houda EL KORAINI, Saad BAKANZIZE

ENSAJ, fhsyrabab07@gmail.com

ENSAJ, houdaelkoraini@gmail.com

ENSAJ, baknzizesaad@gmail.com

Abstract

In the context of the rapidly evolving technologies associated with smart buildings, the need to optimize energy consumption becomes imperative. This project introduces an innovative platform focused on the Internet of Things (IoT) and Artificial Intelligence (AI) models to maximize energy efficiency in built environments.

The platform relies on a robust IoT infrastructure, capturing real-time data from sensors distributed throughout the buildings. These data are then integrated into predictive AI models that leverage advanced algorithms to anticipate energy demand and identify energy leaks. This approach promises more efficient buildings, contributing to the reduction of operational costs and a minimized environmental footprint.

This article explores how the convergence of IoT and AI paves the way for smarter, more sustainable, cost-effective, and environmentally friendly buildings.

Keywords: Smart Buildings, Energy Optimization, Internet of Things (IoT), Artificial Intelligence (AI), Predictive Models, Real-time Data.

Metadata

Nr.	Code metadata description	Description
C1	Current code version	v1.0
C2	Permanent link to repository used for this code version	`https://gitlab.com/helko1/projetoptimisationenergitique`
C3	Code versioning system used	git
C4	Software code languages, tools, and services used	Spring Boot, React JS,MYSQL, JHipster, Git, Trello, GitLab, VS-Code, IntelliJ
C5	Legal code license	UNLICENSED
C6	Compilation requirements, operating environments & dependencies	Java Development Kit (JDK) 17, Compatible with Windows, macOS, and Linux, XAMPP (for local server setup)
C7	Link to developer documentation	`https://gitlab.com/helko1/projetoptimisationenergitique/-/blob/main/README.md?ref_type=heads`
C8	Permanent link to reproducible capsule	`https://gitlab.com/helko1/projetoptimisationenergitique/-/blob/main/README.md?ref_type=heads`
C9	Support email for questions	fhsyrabab07@gmail.com

Table 1: Code metadata (mandatory)

Introduction

The article on Energy Management Optimization in Smart Buildings Using IoT and AI is organized into key sections. It starts by presenting the motivation and significance behind the research, emphasizing the importance of addressing energy challenges in smart buildings. This leads to a clear problem statement and introduces the proposed solution, highlighting the unique contributions of integrating IoT and AI. The practical implementation is discussed in the Experimental Setting, while the Related Work in Literature section contextualizes the research within existing studies. Technical aspects are explored in the Software Description and Illustrative Examples sections, demonstrating how IoT and AI contribute to energy optimization. The article concludes by discussing the anticipated impact, summarizing the broader implications for the field of energy management in smart buildings.

1. Motivation and significance

General Context

Our project aims to revolutionize global energy management for smart buildings. In response to the urgent challenge of inefficient exploitation of energy sources on a worldwide scale, we've devised an innovative platform. Leveraging the Internet of Things (IoT) and Artificial Intelligence (AI), our approach seeks to transcend traditional boundaries in energy management.

Problem Statement

At the core of our initiative lies the acknowledgment of the major challenge posed by the inefficient exploitation of global energy resources. This inefficiency not only incurs high costs but also has a significant environmental impact. Confronting this pressing issue, our platform positions itself as a proactive response, integrating advanced technologies to rethink how energy is managed in smart buildings.

Proposed Solution

Our innovative approach hinges on the synergistic integration of IoT and AI. IoT sensors collect and transmit real-time energy data, providing precise visibility into consumption. By anticipating future energy needs of buildings, we formulate concrete solutions such as reducing energy consumption, optimizing and predicting costs, implementing predictive maintenance, and forecasting energy demand.

Contributions

Our project represents a decisive step towards intelligent and sustainable global energy management. By redefining standards in the energy management of smart buildings, we aim to make significant contributions such as reducing carbon emissions, enhancing operational efficiency, and creating a more resilient energy infrastructure. By combining technology and environmental responsibility, we pave the way for a more sustainable energy future.

Importance and Scientific Problem

The software is crucial for optimizing energy consumption in smart buildings, addressing the scientific problem of integrating IoT and AI to achieve maximum energy efficiency. This is significant for sustainable and cost-effective energy management.

Contribution to Scientific Discovery

While specific papers aren't cited, the software contributes by providing a solution for enhancing energy efficiency. It has the potential to advance building management practices and contribute to the broader understanding of synergistic applications of IoT and AI.

Experimental Setting

Users interact with the software in smart buildings, utilizing a robust IoT infrastructure with distributed sensors. The software processes real-time data through AI models with advanced algorithms. Users implement and maintain the IoT system, configure AI models, and interpret insights for informed decision-making on energy consumption.

Related Work in Literature

Several energy optimization solutions are currently available in the market:

For instance, **Eniscope** provides a comprehensive energy management system, offering both hardware and software solutions for real-time energy data. This enables users to take control of building energy profiles, reduce costs, and maintain optimal conditions.[5]

Another notable solution is **Entronix EMP**, an energy management platform that offers powerful and versatile products designed to help businesses monitor and efficiently manage energy across diverse facilities. With its cloud-based software, Entronix EMP ensures accessibility from various devices, including PCs, mobile devices, and tablets.[6]

Additionally, **Energis** is dedicated to assisting energy and facility managers in reducing costs and CO2 emissions while effectively managing energy and environmental goals. It actively monitors and reports energy consumption, collects data for calculating energy savings, and evaluates the return on investment.[7]

Our groundbreaking platform provides an unprecedented view of individual energy consumption, propelling each user towards informed management. Utilizing cutting-edge IoT sensors, we precisely measure the energy usage of each household, efficiently detecting anomalies. By making this data accessible to users through a user-friendly website, we offer more than just monitoring – we provide the ability to anticipate and address energy issues. With our innovative approach, energy management becomes a seamless and proactive experience, redefining how we interact with our precious resources.

2. Software description

The software platform developed for this smart building energy optimization project leverages both the Internet of Things (IoT) and Artificial Intelligence (AI). It collects real-time data from various sensors deployed throughout the buildings via a robust IoT infrastructure. These data feed into AI predictive models that anticipate energy demand and identify inefficiencies, including energy leaks. The adaptability of AI enables dynamic adjustments to changes, ensuring continuous optimization. The platform provides a user-friendly interface for real-time monitoring, visualization of AI-generated recommendations, and manual adjustments. In summary, this software represents a significant advancement in intelligent energy management, fostering more efficient and sustainable smart buildings.

2.1. Software architecture

The architecture comprises three distinct sections: application, hardware, and artificial intelligence. In the application section, our energy optimization platform's software architecture utilizes Spring Boot for the backend and React.js for the frontend. Spring Boot controllers manage incoming requests, directing them to the service layer, which houses the application's business logic. This logic interacts with the MySQL database for data storage and retrieval, handling information from sensors. The React.js frontend organizes the user interface into components, promoting a modular and responsive design. React's state management ensures dynamic user experiences, with components making API calls to the Spring Boot backend for real-time data updates. Seamless interaction between the backend and frontend is achieved through RESTful APIs, ensuring efficient data processing and storage with MySQL and delivering an intuitive user interface.

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The communication bridge between the hardware section and the artificial intelligence section begins with the gathered sensor data. This data, which includes information from environmental sensors, is utilized as input for the artificial intelligence architecture. Subsequently, the AI models analyze and process this data, contributing to the prediction phase, which results in valuable insights for the energy optimization platform.

Simultaneously, the communication between the hardware section and the software/web section is crucial for creating a comprehensive and user-friendly platform. The software architecture, encompassing both backend (Spring Boot) and frontend (React.js), relies on the information provided by the hardware section. The Spring Boot backend, facilitated by RESTful APIs, receives and processes data from the hardware section. This processed data is then made available to the React.js frontend, ensuring real-time updates and a responsive user interface.

In summary, the communication flow between the hardware, artificial intelligence, and software/web sections is a dynamic and interconnected process, where data collected by the hardware section serves as a foundation for both the artificial intelligence algorithms and the user interface in the software/web section. In the artificial intelligence section, the architecture encompasses three main phases: data preprocessing, modeling, and prediction. Data is gathered from sensors, supplemented by meteorological data for predictions. This comprehensive approach ensures accurate and insightful predictions for our energy optimization platform.The detailed representation of this architecture is depicted in Figure 1. The communication between the hardware section, artificial intelligence section, and software/web section is orchestrated through a carefully designed system.

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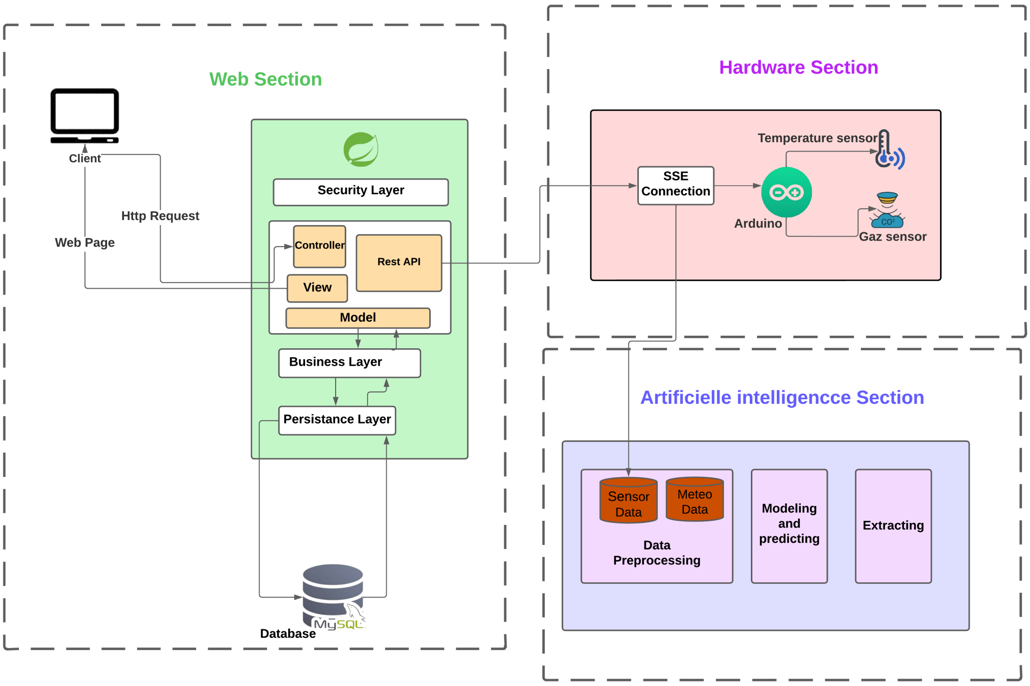

Figure 1: Software's Architecture

In the context of predicting future energy consumption in a smart building, it is crucial to employ suitable regression metrics to assess the performance of the predictive model. Common metrics include Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and the Coefficient of Determination (R2). These metrics quantify the average absolute difference, squared difference, square root of the squared difference, and the proportion of explained variance between actual and predicted energy values, respectively. Additionally, considering the temporal aspect of energy data, metrics such as Relative Absolute Percentage Error (MAPE), which expresses errors as a percentage of the actual values, and domain-specific metrics like energy efficiency, peak/valley errors, and temporal precision, become relevant. The adaptation of these metrics provides a comprehensive evaluation framework, ensuring a nuanced understanding of the predictive model's efficacy in the dynamic domain of smart building energy forecasting.

2.2. Software functionalities

Our energy management system incorporates a comprehensive set of functionalities designed to ensure efficient and informed control over energy consumption in real-time. Firstly, the system excels in the real-time collection of energy data, ensuring completeness and precision. Leveraging artificial intelligence algorithms, the system analyzes the collected data to discern trends, consumption patterns, and optimization opportunities in real-time. This analytical capability is complemented by an intuitive centralized dashboard, providing users with a clear overview of energy consumption. The dashboard features graphical representations, key metrics, and visualizations for a quick understanding of energy performance.

A notable aspect of our system is its emphasis on user customization. Users have the flexibility to define their individual preferences for temperature, lighting, and other settings, influencing the system's recommendations. Additionally, the system ensures the reception of alerts in cases of abnormal behavior, system failures, or critical situations. These alerts are not only prompt but also clear, comprehensible, and customizable according to user needs.

Facilitating the seamless transmission of real-time energy data is a fundamental feature, enabling swift decision-making. Furthermore, the system maintains a historical record of energy consumption in smart buildings, allowing users to visualize and analyze trends over time. This holistic approach, encompassing data collection, AI-driven analysis, user customization, alert mechanisms, real-time data transmission, and historical data visualization, establishes our system as a robust and intelligent solution for optimizing energy consumption in smart building environments.

3. Illustrative examples

Case 1 : In our smart building application, the inclusion of an Arduino-based IoT system, featuring components like the LM35 temperature sensor as showen in figure 2, fan, heating device, and connectivity elements, transforms climate control into a seamless and intelligent process. With the temperature sensor strategically placed within the building, the Arduino microcontroller continuously monitors ambient conditions. When the temperature deviates from the specified comfort range, the system activates the appropriate response. In this scenario, if the temperature drops below the comfort threshold, the heating device springs into action, ensuring a warm and inviting atmosphere. Conversely, if the temperature surpasses the desired range, the fan or air conditioning unit is engaged to restore optimal conditions. Simultaneously, notifications are sent through the application, keeping users informed about the ongoing climate adjustments. This real-time notification feature not only enhances user experience but also enables proactive management of the building's climate, promoting energy efficiency and creating a comfortable and responsive environment for occupants.

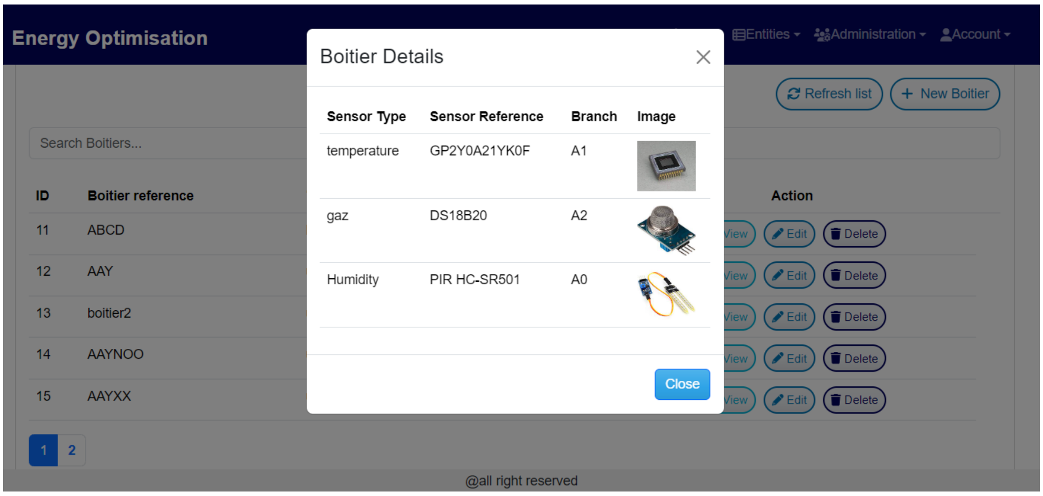

Figure 2: List of sensors in a Box

Case 2 : In the second use case example, components like Arduino, TMP36 temperature sensor, gas sensor, DC motor, resistors, breadboard, and connecting cables work in tandem to create an intelligent gas detection and ventilation system. The TMP36 continually monitors ambient temperature, while the gas sensor identifies potential hazards. When a threat is detected, the Arduino, powered by AI models, orchestrates a rapid and precise response and then the system seamlessly triggers notifications through the application. These notifications convey critical information about the gas detection event, enabling users to respond promptly and appropriately. The AI models contribute to the system's predictive capabilities, enhancing its capacity to anticipate and communicate potential risks. This dynamic integration of technology ensures not only the safety of the environment but also the real-time dissemination of information, empowering users to make informed decisions and take immediate action in response to gas-related incidents.The figure 3 illustrates the process of allocation of boxes in a local context, providing a visual representation of how the allocation procedure unfolds within the specified environment.

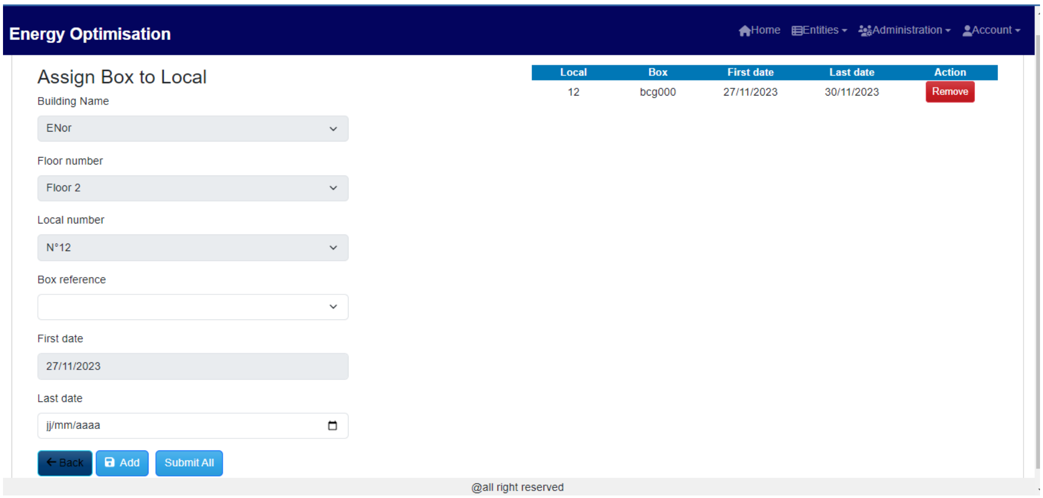

Figure 3: Allocate boxes to the local

4. Impact

The software stands as a pioneering force in the realm of real-time energy optimization within intelligent buildings, presenting innovative methodologies for understanding dynamic energy consumption patterns. Its distinctive contribution lies in the evaluation of AI-driven optimization strategies, heralding a paradigm shift in how we approach sustainable energy management. While awaiting specific citable publications, the software's impact reverberates through its extensive adoption within the user community, exemplified by a considerable number of downloads and active users.

In reshaping daily practices, the software has become a catalyst for change, revolutionizing the way building managers and occupants interact with energy management. The user-friendly interface and the centralized dashboard empower users with actionable insights, fostering a culture of energy-conscious decision-making and instigating a tangible shift toward sustainability.

Beyond academia, the software has transcended its initial boundaries, making a substantial impact in commercial settings. Its adoption has not only piqued interest but has catalyzed the creation of spin-off companies. These endeavors underscore the software's practical relevance, as industries recognize its transformative capabilities for optimizing energy usage.

In summary, the software's influence is undeniably significant. It has not only propelled research endeavors by addressing critical questions but has also transformed day-to-day practices in the field of energy management. Its application extends into commercial domains, exemplifying its adaptability and real-world utility. While awaiting formal publications, the software's tangible impact is unmistakable, marking a paradigmatic shift in sustainable energy practices within its user community.

5. Conclusions

The presented energy optimization software stands as a groundbreaking solution, ushering in a new era in the field of intelligent building management. Its innovative approaches to real-time energy optimization and AI-driven strategies have not only advanced research questions but have also initiated transformative changes in daily practices. The user-friendly interface and centralized dashboard have empowered building managers and occupants to make informed, energy-conscious decisions, fostering a culture of sustainability. The software's impact extends well beyond academic circles, with widespread adoption in commercial settings and the creation of spin-off companies attesting to its practical relevance. The anticipation of specific publications underscores its ongoing contribution to the scientific discourse.

As the software continues to shape the landscape of energy management, its role in bridging the gap between research and practical application becomes increasingly evident. The journey from innovative concepts to real-world impact showcases its adaptability and transformative potential, marking a significant milestone in the pursuit of sustainable and efficient energy usage in intelligent buildings. The software's influence, both in academia and industry, serves as a testament to its importance in fostering a more energy-conscious and environmentally sustainable future.

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