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# Advanced Energy Monitoring in Buildings: A Pathway to Meet the Requirements of Sustainable Development Goals

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***Abstract:***

***Purpose:*** *This papers focused on analysis the potential of application dedicated IT system allowing to monitor and optimization the energy consumption to indicate the role of such systems in achieving higher energy efficiency in buildings. The following research questions were considered: Q1 – Does the application of systems that allow for monitoring and optimizing energy consumption significantly reduce its consumption (level of energy efficiency increase)?; Q2 – How can the functional scope of the system and the inclusion of data from various sources (meters, sensors, other systems, etc.) and relating to different areas of building characteristics affect effective energy management in buildings?; Q3 – How does a dedicated IT system support users in the decision-making process regarding the optimization of systems whose operation causes energy consumption?; Q4 – How does the use of an IT system focused on increasing energy efficiency in buildings fit into the provisions of the sustainable development goals?.*

***Design/Methodology/Approach:*** *The case study analysis has been provided. It included, on the one hand, an analysis of the comprehensiveness of the solution used to monitor and optimize energy consumption to achieve a higher level of energy efficiency in buildings, and, on the other hand, the results of implementing the system in the facilities of a production plant to highlight the savings achieved in this manner.*

***Findings:*** *Based on an in-depth analysis of the functionalities of the imperiusFM platform and the savings achieved through its application, the fundamental importance of using such systems was demonstrated in the context of meeting the requirements of the Sustainable Development Goals (SDGs) and related to them EU directives, in particular from the Energy Performance of Buildings Directives (EPBD) group (Sustainable Development Goals, 2024), (EUR-Lex, 2024). The analyzed case of system implementation highlighted the scale of savings achieved as a result of more efficient energy management in buildings.*

***Practical Implications:*** *The construction sector has not yet fully exploited the potential offered by innovative IT tools to monitor and optimize energy consumption. The research highlights the useful features of such tools and presents the real benefits of their application for effective energy management in buildings. The obtained results provide valuable recommendations for project managers to invest in these solutions, implement them, and achieve tangible benefits.*

***Originality/Value:*** *The key value of the analysis lies in presenting the comprehensiveness of solution enabling energy consumption monitoring and optimization and highlighting its potential for implementation in the context of achieving the SDGs.*

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## 1. Introduction

The sustainable development concept is a crucial determinant of many actions taken to meet the needs of current generations with respect for the environment and taking into account the needs of future generations (Fearnside, 2019), (Kuhlman and Farrington, 2010). It plays the significant role in world strategies and plans to reduce poverty and inequality, protect the planet, ensure peace, health, justice, and prosperity.

The adoption in 2015 the Paris Agreement and the Agenda 2030 with the 17 Sustainable Development Goals (SDGs) outlined the direction of actions taken at international, national, sectoral and individual level (Balukja, 2024), (Sustainable Development Goals, 2024), (Yadav and Thorat, 2022), (Grainger-Brown, and Malekpour, 2019). One of the crucial is energy efficiency in the processes of production, transmission and consumption alike (Golden and Devi, 2022).

It has significant impact on different sectors of economy, like transport, industry, agriculture or construction, in which the energy efficiency is required to be increased by investments in innovative technologies and energy infrastructure as well as application of advanced information systems that allows to monitor and analysis the energy demand and supply (Cismas and Lab Members, 2021).

Considering the energy needs in construction, which belongs to one of the highest energy consumers, the application of sustainable-related innovations to reduce energy consumption, saving costs and minimalizing the negative impact on environment has a crucial meaning.

Alongside the modernization of buildings, the development of eco-friendly and energy-efficient construction, the use of renewable energy sources, and the implementation of innovative solutions for lighting, as well as heating, ventilation, and air conditioning (HVAC), increasing importance is being placed on the use of IT systems enabling continuous real-time monitoring of energy consumption and dynamic responses to any anomalies (EUR-Lex, 2024; Yang *et al.,* 2017).

The article focuses on determining the potential of dedicated IT system and its application in efficient energy management in buildings. The benefits of using the system were analyzed, along with the implementation of indicators and alerts for real-time monitoring of energy consumption. These elements serve as the foundation for optimizing the performance of energy-utilizing systems and achieving savings associated with reduced energy demand.

The conducted analyses aimed to answer the following research questions:

*Q1 – Does the application of systems that allow for monitoring and optimizing energy consumption significantly reduce its consumption (level of energy efficiency increase)?;*
*Q2 – How can the functional scope of the system and the inclusion of data from various sources (meters, sensors, other systems, etc.) and relating to different areas of building characteristics affect effective energy management in buildings?;*
*Q3 – How does a dedicated IT system support users in the decision-making process regarding the optimization of systems whose operation causes energy consumption?;*
*Q4 – How does the use of an IT system focused on increasing energy efficiency in buildings fit into the provisions of the sustainable development goals?*

The article analyzes the potential of the imperiusFM system by Promar as a comprehensive solution for integrating data from technical systems, available sensors and meters, as well as building automation devices, in the context of reducing energy consumption in buildings, detecting operational issues in equipment, and supporting user decision-making based on available data and developed indicators (imperiusFM, 2024). An instance of system's implementation in production plant buildings was presented to demonstrate potential benefits and its orientation towards meeting the sustainable development challenges.

The system supports the achievement of sustainable development goals in particular by reducing energy consumption in buildings, which consequently contributes to lowering the greenhouse gas emissions and the carbon footprint.

The practical impact of utilizing the system on reducing energy consumption levels has been demonstrated, highlighting the unique characteristics of the solution coming from including the ability to consolidate data into a single system, personalize available indicators, facilitate decision-making related to optimization of energy demand, precise monitoring and analysis of energy efficiency to identify areas requiring improvement, as well as raise users awareness about more rational energy use. Additionally, data analysis revealed the scale of savings possible to be achieved through the system's implementation.

## 2. Literature Review

The concept of sustainable development represents one of the key challenges of the modern world and its citizens. The term itself, although has its origin in 1713 with the publication of Carlowitz in the context of the forestry industry, gained broader attention through the Brundtland Report (Our Common Future) in 1987 (Yadav and Thorat, 2022). It the report the sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The emphasis on balancing economic development, environmental protection, and the improvement of quality of life for both present and future generations led to the adoption of Agenda 21 and the Rio Declaration on Environment and Development, which outlined global action plans for sustainable development and the reduction of greenhouse gas emissions level (Sustainable Development Goals, 2024; Yıldırım and Yıldırım, 2020; Grainger-Brown, and Malekpour, 2019).

The importance of actions toward sustainable development and their strategic directions became the foundation for the adoption of eight Millennium Development Goals (MDGs) by the United Nations in 2000, which were expanded to 17 Sustainable Development Goals (SDGs) and 169 related targets with the adoption of Agenda 2030 in 2015 (Indiana and Pahlewi, 2023), (Mishra *et al.*, 2023).

The SDGs provide a framework for addressing global challenges, including climate change and environmental degradation, loss of biodiversity, irresponsible consumption and production, lack of access to education, inequality, injustice, hunger, poverty and the need of improving citizens' quality of life. These goals represent a roadmap for creating a more sustainable and equitable future for all (Sustainable Development Goals, 2024; Mishra *et al.*, 2023; Ginting, 2020).

Introducing innovative and environmentally friendly solutions, promoting environmental protection, energy transformation, and enhancing human well-being have become the basis of sustainable development strategies within the EU. Every economic sector is expected to meet these challenges and adapt its practices to comply with emerging directives and regulations. Many industries, including energy, transport, agriculture, manufacturing, tourism, and construction, are undergoing significant transformations.

The construction sector, in particular, has been identified as a key area for change, as buildings account for 40% of the EU's final energy consumption and 36% of greenhouse gas emissions related to energy, while 75% of buildings in the Union remain energy-inefficient (EUR-Lex, 2024). Addressing this issue has been a focus of the Energy Performance of Buildings Directives (EPBDs).

Starting with Directive 2002/91/EC and culminating in Directive (EU) 2024/1275, these regulations outline steps toward zero-emissions buildings and achieving carbon neutrality in the building sector (EUR-Lex, 2024), (EUR-Lex, 2002). The guidelines developed within these directives align with the achievement of multiple SDGs, particularly: Goal 6: Clean Water and Sanitation, Goal 7: Affordable and Clean Energy, Goal 9: Industry, Innovation, and Infrastructure (Implementing sustainable technologies in industry), Goal 11: Sustainable Cities and Communities, Goal 12: Responsible Consumption and Production and Goal 13: Climate Action. By implementing these directives, the EU is paving the way for a more sustainable and climate-resilient future.

In the face of challenges confronting the construction sector, several strategic directions can be outlined to support the fulfillment of the set requirements. Among these, significant emphasis has been placed on using environmentally friendly materials, absorbing CO2, recycling of construction materials, and recovering resources from demolitions. Investments are increasingly guided by the principles of circular, inclusive, and climate-resilient construction, capable of withstanding extreme weather conditions such as hurricanes and floods.

A key priority is also improving the energy efficiency of buildings (Karki *et al.*, 2022). The provisions of Directive (EU) 2024/1275 oblige Member States to achieve carbon-neutral status of buildings for new public buildings by 2028, all other new buildings by 2030, and all existing buildings across Europe by 2050 (EUR-Lex, 2024).

Designing and constructing zero-emissions buildings has brought additional focus to implementing long-term renovation strategies for existing residential and non-residential buildings. This necessitates widespread thermal modernization efforts, including the adoption of efficient and eco-friendly heating, ventilation, and cooling systems (HVAC), building automation, renewable energy sources, application of energy-efficient lighting, improved building insulation, replacement of windows and doors, and the application of heat recovery systems (Castaño-Rosa *et al.*, 2024).

As highlighted (Akram *et al.*, 2022; Yang *et al.*, 2017), the use of intelligent measurement solutions and advanced energy management technologies is of paramount importance. These include intelligent sensors, smart meters, IoT technologies, as well as advanced analytical tools and artificial intelligence solutions.

Leveraging these technologies creates extensive analytical opportunities related to the operation of devices and systems responsible for energy distribution and consumption in buildings. Real-time data collection, combined with monitoring and controlling of applied devices' operation, pave the way for achieving higher levels of energy efficiency.

However, the diversity of solutions - along with the need to work across various technologies, use different communication protocols, handle dispersed data, and manage multiple independent applications - complicates the process of conducting multidimensional analytics in the field of energy efficiency.

From this perspective, it is crucial to integrate different technologies into a single system. However, this is a highly complex task due to the variety of solutions and the nature of the data collected, which may be in different formats, incomplete, or outdated.

Therefore applying appropriate solutions, which are able to incorporating integration features, multidimensional analysis, and predictive capabilities is essential to process the available data and, based on the results, reduce operational energy consumption, develop energy usage patterns, and enhance energy efficiency over both short- and long-term horizons (Thomyapitak *et al.*, 2024; Iturralde Carrera *et al.*, 2024).

Currently, there are various solutions on the market - ranging from basic to highly advanced - focused on improving building energy efficiency and incorporating diverse building attributes (Digitemie and Ekemezie, 2024; Saleem and Ahmed, 2023; Anjos *et al.*, 2021). Their dynamic development highlights the growing demand for systems capable of managing multiple energy sources on a single platform while considering different building characteristics to provide tailor-made strategies for reducing energy consumption.

## 3. Research Methodology

The provided research were conducted with the applicability of case study, which from one side lets to understand the role and importance of IT systems allowing to monitor and optimize the level of energy efficiency in buildings, and on the other hand enables to provide multidimensional analysis raising awareness about necessary improvements, that must be implemented to achieve better results of energy efficiency indicators and bringing financial benefits on the basis of implemented changes.

A specific solution, dedicated to facility management, has been chosen for the research - the imperiusFM system, whose features include not only aspects related to the analysis of energy consumption, but also the functioning of the building as a whole, in which the tasks of improving energy efficiency are considered comprehensively.

In connection with the above, the functional scope of the system was analyzed. The possibility of its integration with external devices was considered as well as obtaining and integrating data from different sources for the purposes of conducting analyses and defining indicators related to energy consumption in buildings, supporting the decision-making process in the field of energy consumption optimization and building modernization.

Various sources were applied to collect information about the system and provide a detailed recognition of the system's assumptions and the scope of work of its functional modules, including technical documentation, interviews with company representatives and observations of the system's operation.

The qualitative analysis conducted for this purpose focused on examining the functionality of the system to meet challenges related to the energy optimization of buildings, as outlined by the Agenda 2030 and SDGs, the Fit for 55 package, and subsequent EU directives directly related to the construction sector.

The assessment of the feasibility of implementing a specialized IT system was confirmed by a review of its implementations, one of which was described in the results section, and measurable results as a result of the indicator analysis, which can be the basis for actions towards better energy efficiency.

The savings obtained as a result of the system implementation were cited in numbers to emphasize the scope of improvement in the use of energy. The research results were compared with the literature on the subject, which allowed for the formulation of application conclusions and the development of conclusions for similar initiatives.

## 4. Research Results and Discussion

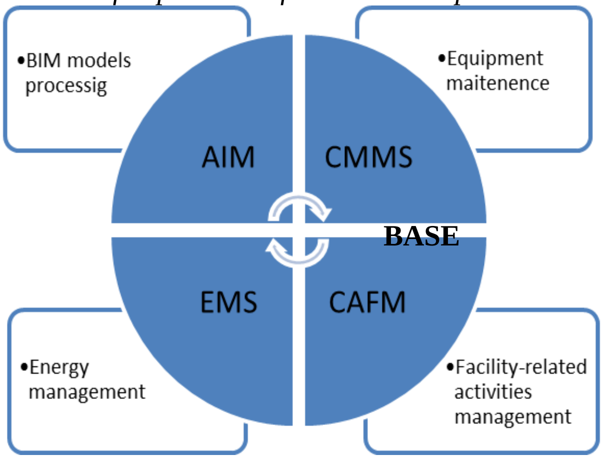
Increasing energy efficiency in buildings and reducing the greenhouse gas emissions is a comprehensive task that requires coordinated actions in various areas. On one hand, this requires the thermal modernization of buildings and the use of eco-friendly solutions in lighting or HVAC systems, investing in smart metering and measurement technologies, and diversifying the energy sources through renewable energy investments. On the other hand, the application of modern IT solutions capable to conduct multi-dimensional analyses in the field of energy management plays a crucial role. There are numerous solutions available on the market, such as:

- EnergyCAP (EnergyCAP, 2024),
- Honeywell Forge Energy Management (Honeywell Forge Energy Management, 2024),
- IBM TRIRIGA (IBM TRIRIGA , 2024),
- imperiusFM (imperiusFM, 2024),
- Siemens - Desigo CC (Siemens - Desigo CC, 2024),
- Siemens Ecomodus (Siemens Ecomodus, 2024),
- Schneider Electric EcoStruxure (Schneider Electric EcoStruxure, 2024).

In further research the imperiusFM system and its applications will be considered to present complex approach to energy management and potential coming from monitoring of energy system parameters to increase the energy efficiency in buildings.

ImperiusFM, as a cloud platform, enables monitoring and remote management of installations and devices integrated with the system to optimize energy media and water in facilities. There are four integrated modules distinguished to cover different aspect of building functioning, configurated in BASE technical environment, as presented in Figure 1.

***Figure 1.*** *The structure of imperiusFM functional components*




***Source:*** *Own study.*

The AIM (Asset Information Model) module is responsible to process the BIM (Building Information Modeling) model in multiple dimensions. The module provides all data relating to all building element that has been input into the BIM model. These data serve as a structured database accompanied by advanced filtering and search tools. The AIM module serves as a data source for other modules and can also be used as a data presentation layer for them (e.g., presenting indicators related to specific devices on the 3D building model).

CMMS (Computerized Maintenance Management System) serves as a centralized database for managing and tracking the maintenance activities and technical performance of installed equipment. It enables facility managers and technicians to effectively monitor the health, functionality, and maintenance requirements of applied devices. CMMS provides valuable insights into equipment performance trends and patterns, facilitating data-driven decision-making for optimizing maintenance strategies and resource allocation.

The EMS (Energy Management System) module plays a crucial role in optimizing energy consumption within a building. It gives the ability to integrate with different building systems and gather real-time energy data from energy meters, sensors, and other monitoring devices to track energy usage across various areas and systems within the building. EMS offers advanced analytics and algorithms to analyze energy consumption patterns, identify areas of inefficiency and recommend energy-saving measures.

It can provide insights into peak energy demand periods, equipment performance, and energy usage trends, enabling users to make data-driven decisions for optimizing energy usage recommending appropriate lighting levels, HVAC settings, and equipment operations. The reporting and alerts enable to track energy usage, compare performance in relation to set targets, identify areas for improvement and more effective energy management strategies development.

The CAFM (Computer Aided Facility Management) module provides support for facility management and managing the space utilization within buildings. It provides detailed floor plans, occupancy data, and allocation of rooms for various purposes to optimize this space allocation and ensure efficient use of available resources.

CAFM encompass a wide range of features enabling to enhance operational efficiency. It constitues a source to data-driven decision-making adjusting the energy consumptions to the actuall needs.

The most significant factor that distinguishes imperiusFM platform from other solutions is its architecture, designed to facilitate data sharing from external sources, which allows to utilize the gathered data in a manner that significantly extends their original applicability. The platform has built-in communication mechanisms and information exchange channels like: REST API, SOAP API, GraphQL, OPC DA, OPC UA, JDBC, BACnet, Modbus, MQTT, KNX, M-Bus, LonWorks, etc.

It is also equipped with a tool for creating dedicated drivers for systems and devices that do not have open protocols (e.g., dedicated manufacturer protocols). This enables the possibility of direct integration with third-party devices like IoT, LoRa, PLC, intelligent building modules, Smart Grid meters etc., and utilization of collected and unified data to offer advanced analysis in one system.

The integration of data from various systems into a single solution enhances the analytical process and enables multidimensional analyses that take into account different factors, which would not be feasible with separate solutions. The implemented process of collecting and analyzing data in various configurations, considering the diverse needs of end users, also contributes to decreasing the costs of conducting such analyses compared to using multiple separate solutions.

The gathered from external systems and tools data are proceed in real time for the purpose of analyses, reports, suggestions for user, notifications and alerts. Platform offers robust data analytics and visualization features and employs advanced algorithms and data processing techniques to generate actionable insights and visual representations, including charts, graphs, and interactive dashboards.

The advanced analytics algorithms allow users quickly understand and analyze key metrics related to energy consumption, environmental impact, space utilization, and other relevant aspects of building energy system functioning.

These analytics capabilities enable facility managers to gain deeper insights into building performance, identify inefficiencies, and make informed decisions regarding energy management and operational improvements. By combining powerful analytics with intuitive visualization, the imperiusFM platform empowers users to optimize operations related to building systems, improve energy efficiency, and enhance overall facility management processes.

The advanced mechanism of fault detection and energy analytics capabilities are powered by artificial intelligence to continuously learn and improve fault detection algorithms, ensuring accurate and efficient identification of errors and anomalies within the building systems. The fault detection and energy analytics tool incorporates predefined indicators (Key Performance Indicators - KPIs) and efficiency metrics.

These indicators are programmed into the system to assess the performance of various building systems and identify potential areas for improvement. By analyzing these indicators, the platform helps to improve energy efficiency and effectively detects faults or malfunctions in building equipment and installations.

Additionally, platform utilizes trend analysis to identify patterns and deviations in building performance. The system can detect long-term trends and anomalies in energy consumption taking into account occupancy patterns, and other relevant metrics.

This analysis enables proactive decision-making and development of optimization strategies for energy efficiency and resource utilization. It helps to identify areas where optimization can be applied to decrease energy consumption, thus reducing the carbon footprint of the building.

To make analyses and prepare forecasts more aligned with weather conditions, the platform leverages integration with weather forecasting services. By using available weather forecast data, it is possible to recommend energy-saving measures to the users by reducing lighting intensity in sunny days or adjusting air conditioning settings to minimize energy usage.

The integration with weather forecasting and building management contributes to effective energy reduction and cost optimization, while also promoting a more sustainable approach to building operations.

The results of the functioning of energy systems in the building are presented to the users in a user-friendly form, in a tabular format, as graphs, or as a dashboard element, in which the results of the building's energy installations are continuously monitored. Figure 2 presents a graph of daily energy consumption. The graphical representation shows the share of energy from photovoltaic panels (PV panels) in relation to the total energy consumption.

This data are the basis for analyzing trends of energy consumption coming from different sources and determining the extent to which production from PV panels covers the existing energy demand.

In Figure 3, an example of an analytical dashboard is presented. The displayed indicators enable the monitoring of selected aspects related to the functioning of the building's energy system, including electricity consumption, energy production from photovoltaic panels, heating system efficiency, $CO_2$ emissions, and energy demand per person.

The presented data allow users to track energy demand over a selected time period and identify periods of peak demand as well as growth and decline trends. Comparing energy consumption with $CO_2$ emissions further highlights the relationship between energy processes (energy consumption) and their environmental impact. This is particularly significant in the context of monitoring and reducing greenhouse gas emissions.

An interesting indicator is the comparison of energy demand per person, which can serve as a basis for developing strategies to optimize consumption (e.g. related to the use of electrical devices), responding to unexpected increases in consumption and analyzing the causes of such occurrences.

Additionally, it allows for examining the extent to which a higher number of people in the building contributes to increased energy consumption during specific periods. Ongoing monitoring of the heating system efficiency enables the assessment of how effectively these systems operate and helps indicate any decreases in the efficiency of existing installations.

This can provide insight for identifying technical issues and implementing maintenance and modernization activities for specific devices. The available reports can be used to optimize energy consumption through better management of devices usage schedules and monitoring the performance of systems installed in the building.

Through advanced energy analytics, the platform identifies areas for optimization and reduction of energy consumption. It enables effective management of lighting, heating, ventilation, and air conditioning systems, adapting them to real-time needs, which can lead to a significant decrease in operational costs related to i.eg. electricity or heating.

By gathering data on the technical equipment used in the building, the platform facilitates the effective organization of maintenance processes. Regular monitoring of maintenance activities, repairs, and technical audits helps maintain devices in good technical condition and allows for better planning of maintenance schedules and equipment replacements. Additionally, information about device repairs serves as a valuable source of knowledge and an indicator of the durability and quality of the equipment.

***Figure 2.*** *Daily energy consumption chart incorporating the share of energy from photovoltaic (PV) panels*


***Source:*** *Own study.*

***Figure 3.*** *Dashboard with energy indicators for monitoring selected parameters of the building's energy system performance*


***Source:*** *Own study.*

Linking building structures and installations in CAFM, CMMS, EMS, and AIM modules allows the platform to establish connections between the building's structural elements, such as room occupancy, equipment, and the operations of electricity and HVAC systems.

This integration enables holistic facility management, precise asset tracking, and optimized energy consumption, as evidenced by numerous implementations of the imperiusFM system in over 2,500 various buildings across Poland, the USA, Canada, France, and Slovenia, often in combination with modernization activities and equipment replacement.

In general, the measurable financial benefits of system implementation are observed within a short period of use. Results indicate that the already implemented solutions have reduced energy consumption by an average of 25%.

Using an example of one of these implementations, the scope of achieved savings can be demonstrated. The implementation task involved analyzing data on the operation of cooling systems to adjust control algorithms for the production and distribution processes using the imperiusFM system. The project scope included optimizing the cooling system, which consisted of:

- 4 chillers with a total cooling power of 640 kW, responsible for efficiently cooling water in the main circuit,
- 3 circulation pumps (15 kW each) for the water system, ensuring stable circulation of the cooling liquid in the system,
- 4 circulation pumps (12 kW each) for the glycol circuit, ensuring efficient system operation at low temperatures,
- a dry cooler unit equipped with 3 fans (15 kW each), responsible for dissipating excess heat from the system.

As part of the undertaken activities, data from the entire cooling system were collected and analyzed, the automation system of the chillers was upgraded, new control algorithms were implemented, and the control algorithms for the circulation pumps were modified. Table 1 presents the main results of observations and measurements as well as the improvements implemented within the existing facility.

In addition to the savings shown in the table, which collectively resulted in a reduction of electricity consumption by 201,500 kWh, the costs associated with maintaining the operation of the systems were also decreased.

These include, for example, costs related to oil changes in chillers, reduced equipment wear due to alternating operation, and the ability to forecast potential faults based on operational data and the alert system.

***Table 1**. Characteristics of the scope of implementation and utilization of the imperiusFM system for the purpose of optimizing energy consumption in production plant buildings*

| **Identified sources of problems in the cooling system through analyses using the imperiusFM platform** | **Implemented changes** | **Scope of benefits achieved** |
|---|---|---|
| The existing automation system did not optimize the operation of the chiller cascade. The system sequentially activated the chillers without monitoring the efficiency of the system's operation or the achieved parameters in the return loop. | Correlating the system's operation with the demand of the receiving installation.<br><br>By analyzing chillers loads and correlating data from the receiving installation, insight were gained on when to activate next chiller. A load management system for chillers in a cascade arrangement was subsequently implemented. | Reducing excessive chiller operation reduced energy consumption by 10 kW. By eliminating inefficiencies in the system operation for 5 hours a day, annual savings amounted to 18,000 kWh.<br><br>Changes in control algorithms and the deactivation of unnecessary chillers reduced the number of operating circulation pumps, saving an additional 12 kW of power. This increased annual savings to 22,000 kWh. |
| In the Dry Cooler, 3 fans operated in parallel.<br><br>The Dry Cooler pumps operated in an on/off mode. | Correlation of system operation data with the building's demand.<br><br>Separation of electrical circuits for individual fans and the installation of an inverter for each of them, enabling precise and independent adjustment of their operation within a range from 0% to 100%. | Demonstration that at an outside temperature below 0°C, the dry cooler can only operate with 20% capacity to cover the building's cooling energy demand. Assuming that the outside temperature remains below 0°C for 20 days per year, the expected range of savings is 17,000 kWh annually.<br><br>Enabling the operation of only one chiller in the system allows for the deactivation of one glycol circuit circulation pump with a power of 12 kW, resulting in annual energy savings of approximately 22,000 kWh through this optimization. |
| In the existing technological system, the circulation pumps operated under the regime of 2 pumps always running and 1 on standby. By installing a flowmeter on the return circuit and conducting a precise data analysis, it was demonstrated that the flow rates in the system are lower than the design assumptions, and the return fluid temperature is as much as 5°C higher. | Integration of circulation pumps with the automation system. Real-time analysis of pump performance and correlation of these results with the parameters achieved in the receiving installation. | Currently, only one pump operates at a load below 50%, which provides sufficient power to meet the system's demand. The energy requirement for powering the pumps has been reduced from 24 kW to 7.5 kW, resulting in an annual energy savings of 144,500 kWh. |

***Source:** Own study.*

In addition to the savings shown in the table, which collectively resulted in a reduction of electricity consumption by 201,500 kWh, the costs associated with maintaining the operation of the systems were also decreased. These include, for example, costs related to oil changes in chillers, reduced equipment wear due to alternating operation, and the ability to forecast potential faults based on operational data and the alert system.

The implementation of the imperiusFM system also enabled the calculation of cooling energy demand using data from circulation pumps, eliminating the need for additional measuring devices. The provided implementation included also calculating the total cooling demand for the entire complex as well as for individual buildings, performing energy consumption analyses by aggregating readings from existing sub-meters, and calculating the cooling system efficiency indicator in real time.

The achieved results emphasized the role that an advanced IT system plays in the process of monitoring and optimizing energy consumption. As indicated by the case study of the imperiusFM system, integrating data from various sources in one system and conducting multidimensional analyses enables decision-making regarding improvements that significantly reduce energy usage. This, in turn, positively impacts the reduction of greenhouse gas emissions. Optimization efforts are an essential step toward achieving sustainable development goals and protecting the environment.

The achieved results emphasized the role that an advanced IT system plays in the process of monitoring and optimizing energy consumption. Its innovative nature and versatility gives the ability to apply system in various types of buildings, what reflects the assumptions outlined in SDG 9.

As indicated by the case study of the imperiusFM platform, integrating data from various sources in one system and conducting multidimensional analyses enables decision-making regarding improvements that significantly reduce energy usage (SDG 7, SDG 12). This, in turn, positively impacts the reduction of greenhouse gas emissions (SDG 13). Optimization efforts and innovative character of IT system are as presented an essential step toward achieving sustainable development goals and protecting the environment.

## 5. Conclusions, Proposals, Recommendations

The sustainable development paradigm strongly influences many actions undertaken at international, national, regional, and local levels, stemming from binding provisions, directives, treaties regulations and one’s own beliefs. Maintaining a balance between economic growth, human well-being and environmental protection requires every sector of the economy to adjust its practices to meet the principles of sustainable development.

Significant changes can be observed in the construction sector, where, alongside the development of passive and zero-emission buildings as well as the renovation and thermal modernization of buildings, advanced IT systems for energy consumption monitoring and optimization are increasingly applied.

In the article the role such a system is underlined on the basis of imperiusFM platform. The analysis of its functionalities provided a deeper understanding of the importance of multidimensional analyses derived from data collected from various systems, tools, and meters. This understanding is crucial for at least two reasons. First, it facilitates the creation of appropriate measurement scenarios and indicators to assess the energy efficiency of buildings. Second, it supports decision-making processes aimed at reducing energy consumption.

The provided results show that the complexity of the system and implemented modules give the ability to define and monitor diverse indicators, detect and signal undesirable behavior in systems that consume and supply energy to the building as well as analyzing energy consumption trends. Based on the collected data and analysis results, it becomes possible to develop optimization strategies both for the use of energy system components in buildings, as well as provide durability and continuity of system operation.

Although the presented findings are grounded in a thorough analysis of the system's functionalities and supported by the benefits of implementing the imperiusFM platform, they may limit the ability to generalize the results. Furthermore, the case study introduces an element of subjectivity in evaluating the solution. Nevertheless, this study opens an important avenue for further research. It would be valuable to expand the analysis of implementations and examine the mechanisms used for indicator analysis.

Additionally, given the large number of system implementations, it would be worthwhile to outline trends in energy efficiency across various building types and institutions. Since the system stores data related to building users, analyzing the impact of user behavior on energy consumption also offers an intriguing field of study. These directions could, in the future, serve as the foundation for developing targeted sustainable development strategies for different types of facilities and users.

**References:**

Akram, M.W., Zublie, M.F.M., Hasanuzzaman, M., Rahim, N.A. 2022. Global Prospects, Advance Technologies and Policies of Energy-Saving and Sustainable Building Systems: A Review. Sustainability, 14(3), 1316.

Anjos, M., Gómez-Herrera, J.A., McKinnon, K., Salerno, I. 2021. Adaptable Energy Management System for Smart Buildings. Journal of Building Engineering, 44, 102748.

Balukja, I. 2024. Sustainable development goals and corporate strategy: Bridging the gap. Academic Journal of Business, Administration Law and Social Science, 10(2), 12-

20.
Castaño-Rosa, R., Pelsmakers, S., Wang, J., Cao, S.J. 2024. Building Management Systems in residential buildings: their role in energy and indoor climate resilience. Architectural Research in Finland, 8(1), 41-62.
Cismas, L.M., Lab Members. 2021. Dynamics of Implementation of SDG 7 Targets in EU Member States 5 Years after the Adoption of the Paris Agreement. Sustainability, 13(15), 8284.
Digitemie, W.N., Ekemezie, I.O. 2024. A Comprehensive Review of Building Energy Management Systems (BEMS) for Improved Efficiency. World Journal of Advanced Research and Reviews, 17(2), 54-65.
EUR-Lex. 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Available at: https://eur-lex.europa.eu/eli/dir/2002/91/oj.
EUR-Lex. 2024. Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024L1275.
EnergyCAP. 2024. Available at: https://www.energycap.com/.
Fearnside, P.M. 2019. Sustainable development. In: David Gibson (ed.) Oxford Bibliographies in Ecology. Oxford University Press, New York.
Ginting, P. 2020. Sustainable Growth and Development. Advances in Economics, Business and Management Research, 127, 482-486.
Golden, S.A.R., Devi, B.D. 2022. Ensuring sustainable future in Constrction Industry. NIU International Journal of Human Rights, 9(II), 103-108.
Grainger-Brown, J., Malekpour, S. 2019. Implementing the Sustainable Development Goals: A review of strategic tools and frameworks available to organisations. Sustainability, 11(5), 1381.
Honeywell Forge Energy Management. 2024. Available at: https://www.honeywellforge.ai/us/en/products/buildings/honeywell-forge-sustainability-plus-for-buildings-carbon-and-energy-management.
IBM TRIRIGA. 2024. Available at: https://www.ibm.com/products/tririga.
imperiusFM. 2024. Available at: https://imperius.pl/#o-systemie.
Indana, F. Pahlevi, R.W. 2023. A bibliometric approach to Sustainable Development Goals (SDGs) systematic analysis. Cogent Business and Management, 10(1), 1-12.
Iturralde Carrera, L.A., Ramírez Ceballos, J.C., Molina-Santana, E., Rodriguez, J., Peralta-Soto, A., García-Villalobos, F., Sánchez-Ramírez, P. 2024. Integration of Energy Management and Efficiency System for Buildings With Zero Carbon Emissions: A Case of Study. IEEE Access, 12, 64237-64251.
Karki, V., Mostafa, R., Gopalakrishnan, B., Johnson, D.R. 2023. Determination of Effectiveness of Energy Management System in Buildings. Energy Engineering, 10(2), 1-26.
Kuhlman, T., Farrington, J. 2010. What is Sustainability? Sustainability, 2(11), 3436-3448.
Mishra, M., Desul, S., Guimarães Santos, C.A., Mishra, S.K.K., Mustafa, A.H., Goswami, S., Kalumba, A.M., Biswal, R., Da Silva, R.M., Costa dos Santos, C.A., Baral, K. 2023. A bibliometric analysis of sustainable development goals (SDGs): A review of progress, challenges, and opportunities. Environment, Development and Sustainability, 26(5), 11101-11143.
Saleem, S., Ahmed, K. 2023. Artificial Intelligence-Based Energy Management System for Energy-Efficient Buildings. International Journal of Energy and Environmental

Engineering, 14(3), 245-259.
Schneider Electric EcoStruxure. 2024. Available at: https://www.se.com/ww/en/about-us/sustainability/.
Siemens - Desigo CC. 2024. Available at: https://www.siemens.com/global/en/products/buildings/desigo-building-automation/building-management/desigo-cc.html.
Siemens Ecomodus. 2024. Available at: https://www.siemens.com/global/en/products/buildings/digital-building-lifecycle/ecodomus-software.html.
Singh, R., Utkurovich, K.R., Alkhayyat, A., Alkhayyat, A., Waghulde, K.B., Others. 2024. Machine Learning Applications in Energy Management Systems for Smart Buildings. E3S Web of Conferences, 540(08002), 1-8.
Sustainable Development Goals. 2024. Available at: https://www.un.org/sustainabledevelopment/.
Singh, R., Utkurovich, K.R., Alkhayyat, A., Saritha, G., Jayadurga, R., Waghulde, K.B. 2024. Machine Learning Applications in Energy Management Systems for Smart Buildings. E3S Web of Conferences, 540(08002), 1-8.
Thomyapitak, T., Saengsikhiao, P., Vessakosol, P., Taweekun, J. 2024. A Study on the Energy Efficiency of an Energy Management System for Convenience Stores. Energies, 17(19), 4941.
Yadav, V.K., Thorat, M. 2022. Analysing Connotation, Contradiction and Construction of Sustainable Development. Dogo Rangsang Research Journal, 12(10), 106-113.
Yang, T., Clements-Croome, D.J., Marson, M. 2017. Building Energy Management Systems. In: Abraham M. (Ed.), Encyclopedia of Sustainable Technologies (1st ed.). Elsevier, 291-309.
Yıldırım, S., Yıldırım, D. 2020. Achieving Sustainable Development Through a Green Economy Approach. International Journal of Advanced Research in Science, Communication and Technology, 1-22.