Electronics and Information Technologies, 2025, 29, 79–94
http://publications.lnu.edu.ua/collections/index.php/electronics/index

UDC 004.78

ENERGY CONSERVATION AS ONE OF THE COMPONENTS OF THE MANAGEMENT SYSTEM FOR THE SMART SUSTAINABLE WORKSPACES

Maksym Yakubovych*, Vasyl Lyashkevych, Roman Shuvar
Department of System Design,
Ivan Franko National University of Lviv
50 Drahomanova St., UA-79005 Lviv, Ukraine

Yakubovych, M.Y., Lyashkevych, V.L., & Shuvar, R.Y. (2025). Energy Conservation as One of the Components of the Management System for the Smart Sustainable Workspaces. *Electronics and Information Technologies*, 29, 79-94. https://doi.org/10.30970/eli.29.8

ABSTRACT

Background. "Smart technologies" have grown rapidly thanks to advanced achievements in artificial intelligence (AI) and IoT. Big companies are interested in the concept of "smart rooms" or "smart workplaces" because these technologies allow them to reduce the costs of maintaining workplaces and focus on sustainable production without redundant waste.

Energy conservation is a crucially important part of a smart sustainable workplace management system therefore it has been analyzed in this paper. Considering the features of smart workplaces we highlighted that this approach offers a flexible and convenient way to make the workplace more comfortable and productive with a more accurate device management strategy.

Materials and Methods. Aiming our goals we have investigated the tasks which were related to models and methodologies for energy consumption management based on accessible technical resources and standards. Thus, we have used a systematic approach to selecting material, methods of inductive and logical analysis, observation and so on. The appropriate sensors and devices for energy management in smart workplaces were considered as well.

Results and Discussion. We paid the most attention to the devices available to us, such as Google Home, Mi Home, and Domoticz and their predefined functional characteristics. Amidst models, the most widespread ones for energy management were reviewed. Specifically noting that energy management in smart workplaces based on fuzzy logic does not require a complex mathematical model for system management and can rely directly on the experience of qualitative users.

Conclusion. Taking into account other components of a smart sustainable working space management system, we can conclude that modern information technologies and data analytics are becoming powerful tools for optimizing energy consumption and enhancing comfort and productivity in working spaces.

Keywords: smart sustainable workplace, smart sustainable workplace management system, energy consumption, energy conservation, adaptive-intelligent management.

INTRODUCTION

The implementation of advanced information technologies and data analytics is becoming a key factor in developing effective energy conservation methods. Data collection and analysis systems, such as “smart homes” or “smart grids”, allow for monitoring and optimizing energy consumption in real time. Buildings where software takes care of security, energy conservation, and resident comfort are called "smart" [1]. Thanks to IoT and data transmission technologies, household appliances are integrated into a unified system, which enables [2]:

- autonomous lighting control, turning off lights in empty rooms;
- monitoring the condition of water pipes and air quality, warning about possible leaks and contamination;
- receiving notifications about the risk of breakdowns.

Currently, energy management systems face rather stringent requirements, as excessive energy consumption leads to excessive consumption of planetary resources. [15] For these considerations, a number of requirements and recommendations are being developed that must be taken into account when planning workspaces. [4] Therefore, in modern conditions, we are talking about smart sustainable workspaces. [2]

The implementation of such systems is based on the application of modern technologies that:

- increase employee productivity;
- ensure efficient and economical use of workspaces [17].

Automatic regulation of lighting, heating, ventilation, and air conditioning based on data analysis of energy load and consumption allows: reducing unnecessary costs and providing optimal working conditions with minimal energy consumption while minimizing the use of natural resources.

Initial understanding of a sustainable workspace [5] is focused primarily on the responsible use of resources. A sustainable workspace was defined as an environment where products and services are created in a manner that does not deplete irreplaceable resources without compromising the quality of the output. This definition is intentionally broad, applicable to diverse settings ranging from offices to production lines, emphasizing that the core principle of sustainability lies in the nature of the work itself and the materials involved. The central idea is to minimize reliance on resources that cannot be replenished, thereby ensuring the long-term viability of operations and reducing the ecological footprint.

Expanding on this foundational view, the concept of a sustainable workplace culture introduces a more comprehensive perspective. This approach emphasizes environmental, social, and economic mindfulness across all facets of business operations.

The key characteristic of a sustainable workspace is a strong emphasis on energy efficiency through the adoption of renewable energy, the use of efficient technologies, and the optimization of building design and operational practices. Waste reduction was another critical element, moving beyond basic recycling to embrace circular economy principles like reuse, upcycling, and the minimization of single-use items. The selection of sustainable materials, characterized by recycled content, renewability, low environmental impact, and non-toxic properties, was also a defining feature. Furthermore, the concept of a sustainable workspace increasingly incorporated a focus on fostering employee well-being through factors like natural light, biophilic design, healthy materials, and supportive work environments. Finally, the social dimension extended to encompass the broader community through ethical practices, local engagement, and a commitment to corporate social responsibility.

Smart work environments: current state and terminology. Considering the current state and terminology in the field of smart spaces, we can establish that such work environments utilize various sensors, detectors, analytical tools, and the Internet of Things (IoT) for automation and optimization of different aspects of the work environment. These include:

- Lighting and energy conservation: in smart work environments, lighting systems are automatically adjusted depending on employee presence, natural light levels, and time of day. Additionally, systems for automatic shutdown of electrical appliances and equipment at night help reduce electricity consumption.

- Climate management: automated control systems for heating, ventilation, and air conditioning can respond to temperature changes and human presence in space, ensuring comfortable working conditions.
- Security systems: in smart work environments, video surveillance systems can use image analytics to detect suspicious activities or malfunctions [13].
- Workspace and zone reservation: Booking systems help employees find available workspaces, conference rooms, and other resources, as well as plan their workday.
- Cost management: analytical tools help track the use of resources such as electricity and water, and identify opportunities for savings.
- Health and comfort monitoring: sensors can measure air quality, humidity, and other parameters that affect employee comfort and health.
- Automatic equipment control: automation systems can provide automatic startup, shutdown, and regulation of equipment such as computers, printers, coffee makers, etc.

In addition to the above, the concept of a smart work environment can be interpreted as an intelligently constructed workspace. This means that when designing the building, it is necessary to consider the possibility of integrating all services with each other using wireless technologies. Such a high-tech system can combine all concepts into a single structure that can be conveniently managed even from a mobile phone.

Thus, a smart work environment refers to a high-technology workspace where integrated sensors, automation systems, artificial intelligence, and connectivity help provide optimal working conditions for employees, increase productivity, and reduce costs. To ensure the effective operation of a smart work environment, it is necessary to establish requirements for aspects such as lighting, ventilation, communication infrastructure, security, and privacy.

Researchers indicate that requirements for smart work environments should be flexible and adapted to the changing needs of employees.

A core tenet of the smart sustainable workspace is its commitment to sustainability. Scientific literature emphasizes resource efficiency, the reduction of carbon footprints, and the imperative to meet present needs without compromising the ability of future generations to meet their own needs [7].

The 'smart' aspects of a smart sustainable workspace are characterized by the intelligent application of technology, including artificial intelligence (AI), the Internet of Things (IoT), and data analytics, to enhance efficiency, comfort, and productivity [6]. Smart building management systems (BMS) play a pivotal role in optimizing building operations by controlling and monitoring various systems such as heating, ventilation, and air conditioning (HVAC), lighting, and security [8].

Analyzing definitions from scientific literature reveals that the smart sustainable workspace is often viewed as a constituent element within the larger framework of smart sustainable cities (SSCs) [6]. SSCs are defined as innovative urban environments that utilize information and communication technologies (ICTs) and other means to improve the quality of life, the efficiency of urban operations and services, and overall competitiveness, while ensuring that they meet the needs of present and future generations [6]. Within this context, the smart sustainable work environment can be seen as a micro-level application of the principles guiding SSCs, focusing on optimizing the workspace for both sustainability and human well-being through the integration of technology.

Synthesizing these diverse perspectives from scientific literature, a holistic definition of a “smart sustainable work space” for the future can be proposed as follows: A smart sustainable work space is an intelligent workspace that strategically integrates advanced technologies and sustainable practices within a human-centric design framework to minimize its environmental impact, optimize resource utilization, enhance the health, well-being, and productivity of its occupants, and adapt dynamically to changing environmental conditions and user needs. This definition emphasizes the interconnectedness of technology, environment, and human factors, highlighting the need for a holistic and adaptive approach to creating future-ready workspaces.

MATERIALS AND METHODS

Current state of energy conservation management in smart sustainable work environments. A distinctive feature of a “smart space” compared to conventional appliance management is that switches and remote controls are not tied to one specific device. This means that a button panel with a microcontroller can control lighting throughout all work areas. Additionally, such a panel can: regulate indoor climate; control music volume; perform other functions, depending on programming.

The functionality of buttons can be modified as needed, as it is programmatically defined. Touch panels in “Smart spaces” combine multiple functions and serve as interactive control organs. They allow complete monitoring of the space condition, for example: temperature, illumination, humidity levels, and human presence.

Smart spaces typically feature a comprehensive security, access, and video surveillance system consisting of various components to ensure high levels of protection, access control, and monitoring. The main components of these subsystems may include:

- Security system (sensors for smoke, fire and carbon monoxide, glass breakage, motion, door and window opening);
- Automatic shutdown of heating supplies that activates when a dangerous situation is detected (e.g., fire) to minimize risk;
- Access control systems (electronic locks and access cards, biometric systems, and remote access control);
- Video surveillance system (video cameras and IP cameras);
- Video data analysis systems: Used to detect suspicious actions or unusual circumstances [14].

Artificial intelligence approaches are widely used for activity recognition and employee behavior analysis in the “Smart Sustainable Production Environment” system:

- Reflection analysis. Using video surveillance to analyze employee reflections. It is possible to detect movements, gestures, postures that may indicate certain actions or employee states [15];
- Sound and speech analysis. Detection of keywords, speech, or sounds that may indicate certain activities. For example, recognition of specific dialogues that indicate work discussions;
- Sensor data analysis. Using data from motion sensors that can detect movements, positions, distances, etc. This can help recognize certain actions, such as moving around the space.

The pursuit of energy conservation and management within smart sustainable workspaces is fraught with a complex array of challenges, spanning technological, economic, and human-centric domains.

Challenges related to the implementation and operation of smart technologies:

- A significant hurdle lies in the compatibility and integration issues arising from the diverse range of IoT devices and systems that need to communicate and function cohesively [9].
- Implementing IoT for energy saving in smart work spaces can be complicated by the lack of standardized protocols, hindering seamless data exchange and unified control across different manufacturers and system types.
- Furthermore, ensuring the IoT infrastructure's scalability to handle a growing number of devices and increasing data volume presents another considerable challenge [9]. As smart workspaces become more technologically advanced with the addition of numerous sensors and interconnected devices, the underlying network capacity, data

storage, and processing power must be sufficiently robust to manage the expanding demands without creating system bottlenecks or performance degradation.

- Security concerns and data privacy are also paramount challenges in the interconnected environment of smart buildings [9]. The increased connectivity creates vulnerabilities that necessitate robust security measures to protect sensitive data from cyber threats and prevent unauthorized access to building systems.
- The effectiveness of energy management also hinges on the accuracy of the data collected by sensors. Inaccurate occupancy detection, for instance, can lead to energy wastage if lighting and HVAC systems are activated unnecessarily in empty spaces or remain off when needed.
- The sheer complexity of managing and optimizing energy usage across a multitude of interconnected systems and protocols poses a significant challenge for facility managers [9].

Economic considerations and return on investment in energy efficiency measures:

- These investment costs are often perceived as high with an uncertain or low return on investment [10]. This perception can deter organizations, particularly small and medium-sized enterprises (SMEs), from prioritizing energy efficiency projects, especially if the long-term savings and benefits are not immediately apparent.
- There can be doubts around the effectiveness of energy-saving measures, leading to a lack of confidence in the potential return on investment [10]. Demonstrating the tangible benefits through pilot projects, case studies, and transparent data on energy consumption and savings is crucial to address these doubts.
- Accessing the necessary financing can also be a significant hurdle, especially for SMEs who may face difficulties in securing loans for energy efficiency projects due to perceived risks or lack of collateral [11]. Financial incentives, such as government grants, tax breaks, or specialized financing options, may be necessary to encourage these investments.
- Organizations often face the challenge of balancing cost savings with other priorities, particularly during periods of economic uncertainty [11]. Investments in areas directly related to production or market expansion may take precedence over energy efficiency upgrades.

The complexities of integrating energy efficiency with occupant comfort and well-being:

- Aggressive energy optimization strategies can potentially compromise thermal comfort, lighting levels, or indoor air quality, leading to occupant dissatisfaction and reduced productivity. Smart workspace implementations need to carefully balance energy saving capabilities with the need to adjust ventilation, air conditioning, and lighting systems to maintain a comfortable environment [9].
- The use of workplace surveillance technologies, while potentially providing data for energy optimization through occupancy monitoring, can have negative repercussions on employee well-being [12]. The perception of being constantly monitored can lead to increased stress, anxiety, a feeling of reduced autonomy, and even privacy violations, ultimately undermining the creation of a healthy and productive work environment.
- Resistance to change and a lack of user familiarity with new technologies can impede the adoption and effective utilization of smart systems [9]. Employees may feel uncomfortable or anxious about using unfamiliar technologies, leading to reluctance and hindering the intended benefits.
- Furthermore, the effectiveness of energy-saving technologies is significantly influenced by user behavior [5]. Technological solutions alone are insufficient without the active participation of occupants in adopting energy-conscious habits.

- Finally there is the ethical concern of “function creep” in monitoring technologies [12]. Surveillance systems initially implemented for energy management purposes could potentially be used for other forms of employee monitoring without their explicit consent or knowledge, raising serious ethical and privacy concerns that need to be addressed through transparent policies and open communication.

Thus, the “smart sustainable work environment” offers a flexible and convenient approach to appliance management, making the workspace more comfortable and productive [16].

RESULTS AND DISCUSSION

Energy conservation management tools in smart sustainable work environments. Let us analyze Mi Home as an energy conservation management tool for a smart work environment. The advantages of the Mi Home system include: aesthetic design: Sensors and devices have an attractive appearance; user-friendly mobile application: The Mi Home application is easy to use and provides access to all system functions; easy automation configuration: users can easily create automated scenarios for controlling lighting, devices, and other smart work environment functions.

The disadvantages of the Mi Home system include the following characteristics: closed ecosystem: Mi Home is not compatible with devices from other brands; cloud data storage: system usage data is stored on Xiaomi cloud servers, which may raise privacy concerns; dependence on cloud servers: Mi Home system automations operate through cloud servers, therefore an Internet connection is required for their operation.

The functional capabilities of the Mi Home system include: lighting control: it is possible to turn on, turn off, adjust the brightness and contrast of lighting in the work environment; device control: various devices can be controlled, such as televisions, music players, refrigerators, air conditioners, blinds, etc.; scenario creation: automated scenarios can be created to perform certain actions, for example, turning on lighting and music when a user enters the work environment, or turning off all devices when a person leaves; Ukrainian language support: The Mi Home application and system interface support the Ukrainian language.

Technical characteristics of the Mi Home system include: operating system: Android; control type: Mixed (manual and automatic); compatibility: Devices operating from ~220V.

Executive elements of the Mi Home system: light bulbs; valves; coffee makers; laptops and tablets; printers.

Additional capabilities of the Mi Home system include: integration of Xiaomi smart devices into a common network; configuration and management of smart devices in the work environment; creation and execution of scenarios via the Internet.

Google Home represents a smart work environment management system with an effective interface and closed ecosystem. The automation operates through cloud servers, with the application supporting novel solutions that have not been reported in the domestic sector. It enables a unified “control center” for the smart work environment.

Google Nest Hub constitutes an attempt to integrate previously existing technologies into a single device [21]:

- Google Smart Speaker (capability to issue voice commands and receive responses);
- Google Chromecast (ability to stream content from smartphones);
- An implemented, albeit not yet perfected, attempt at smart work environment management.

The Google Nest Hub package includes a smart speaker capable of playing music or comprehending phrases. Responses are not only audible but also displayed on the screen. The device exhibits good sensitivity and, while lacking a camera, permits control via the display and features a physical microphone disconnect button. The smart home interface from Google is relatively modest. Google Nest Hub consumes approximately 2.5 watts from the electrical network, which is minimal, presenting no issues with keeping the device continuously powered. Numerous positive reviews regarding Google Home Hub with Apple ecosystem integration are available online [22].

Domoticz is an open-capability smart work environment management system. The principal advantages of Domoticz include:

- Open ecosystem: Domoticz is compatible with devices from various manufacturers, providing greater freedom of choice;
- Customized cloud spaces: Access to your Domoticz server is available from any location via internet connection;
- User-friendly Blockly automation language: Blockly employs visual blocks for creating automations, making it accessible even for beginners.

Significant disadvantages of Domoticz include:

- Implementation complexity of certain elements: Some Domoticz functions may be difficult to configure, particularly for inexperienced users;
- Outdated documentation: Domoticz documentation is not always updated promptly, potentially causing difficulties in information retrieval.

Domoticz supports a broad spectrum of Xiaomi devices, including:

- Xiaomi Gateway: Domoticz can manage the Xiaomi Gateway and all connected devices;
- Xiaomi buttons and sensors: Domoticz can control buttons, opening and movement sensors, ZigBee sockets, and Aqara switches;
- Yeelight illumination devices: Domoticz can manage RGBW and White Yeelight lamps, as well as CeilingLight ceiling fixtures;
- MiFlora Bluetooth sensors: Domoticz can operate with MiFlora Bluetooth sensors.

Domoticz offers flexible scenario configuration capabilities, enabling automation of various tasks in the smart work environment. Domoticz scenarios operate independently of Chinese servers and internet connectivity, rendering them more reliable and secure. Domoticz can extend Xiaomi device functionality by adding new actions such as “free fall" or “alert" for speakers, or “LongClickRelease” for buttons. Connecting Xiaomi to Domoticz is straightforward and does not affect the basic functionality of utilized devices.

A wide range of researchers employ the MIND method (Method for analysis of INDustrial energy systems) for modeling management influences on energy conservation in smart work environments. This method facilitates the identification of economically effective approaches to optimizing energy consumption in work environments of any scale.

It is important to note that the greatest interest in applying the MIND method or its variations lies in the possibility of making informed decisions regarding the selection of energy-saving measures. Among the methods aimed at addressing these challenges, the following should be highlighted:

- Methods for formulating various energy conservation policy variants and energy conservation management programs in smart work environments using program-target planning methodology;
- Classification of economically effective measures for improving energy efficiency;
- Methodology for planning production activities to ensure efficient energy consumption.

Ensuring resilience and sustainability in the management of a smart work environment. Currently, the primary management objective of energy conservation in a smart manufacturing setting is the selection of the most economically effective energy-saving measures [18]. Among the most widely used, the following should be noted:

- Replacing the traditional lighting with energy-efficient LED systems.
- Using the occupancy sensors, predictive algorithms, and real-time data to adjust heating, cooling, and ventilation systems based on actual demand.

- Integrating IoT sensors and advanced analytics to monitor energy use across lighting, HVAC, and equipment, then automatically adjust settings for optimal efficiency.

Overall, the most broadly implemented and economically effective solutions are smart EMS combined with efficient HVAC and LED lighting systems.

It is worth mentioning that such an approach is not always justified, as decision-making must consider not only economic efficiency but also environmental consequences, reputational effects, production reliability requirements, achievement of strategic goals through innovative development paths, and other factors.

Energy conservation in smart work environments using fuzzy logic does not require complex mathematical models for system management and can rely on users' practical experience. However, this method has a disadvantage related to the complexity of determining optimal rules and membership functions for such systems. An alternative approach to creating energy conservation systems in smart work spaces is artificial neural networks (ANN), which are widely used for modeling and predicting energy consumption in the work environment. Artificial neural networks have the ability to model nonlinear processes, continuously adapt to new data, and learn from them to solve complex tasks [19].

In addition to traditional energy management methods, hybrid approaches combining the advantages of fuzzy logic and artificial neural networks are gaining popularity in smart work environments. The advantages of hybrid approaches include:

- Human-like logic: fuzzy logic allows systems to make decisions similar to human ones, considering fuzzy and uncertain factors;
- Learning capability: artificial neural networks can learn from data and independently optimize their operation.

The adaptive neuro-fuzzy systems (ANF) combine neural network learning algorithms with fuzzy logic membership functions. This allows systems to dynamically adapt to changing conditions and improve their efficiency.

Agent-based energy management systems utilize virtual or physical modules (agents) that interact with the environment through artificial intelligence.

The advantages of agent systems are:

- Compromise finding: agent systems can find an optimal balance between energy consumption, costs, and comfort;
- Measurement and interaction with the environment: agents can collect data about the environment and use it for decision-making;
- System control: agents can control heating, ventilation, air conditioning systems, and electrical appliances;
- Multi-agent systems: multi-agent systems consisting of several agents are capable of solving complex problems and responding to changes in real-time.

Hybrid approaches to energy management that combine fuzzy logic, artificial neural networks, and agent systems offer a flexible and effective way to optimize energy consumption in smart work environments. These approaches can consider complex factors, dynamically adapt to changing conditions, and find optimal solutions for energy savings and comfort provision.

The Adaptive-Smart Energy Management Tool (A-SEM) is an intelligent system that dynamically regulates energy consumption in a smart work environment. A-SEM ensures a balance between user comfort and efficient use of energy resources [21].

The A-SEM system uses an adaptive energy restriction algorithm based on analyzing data about the average daily energy consumption over the past 30 days. This data takes into account seasonal fluctuations, weekends, and other factors affecting energy consumption.

The A-SEM system also considers user behavior, as it plays a significant role in energy consumption. For this purpose, the system uses various sensors that collect information about user activity and the state of IT equipment.

A-SEM monitors and controls energy consumption in real-time. The system uses various indicators, evaluated at the testing stage, to adapt energy restrictions to current conditions.

The energy consumption limit for each user is calculated using the formula:

$$E_{\mathrm{lim}} = E_{\mathrm{bud}} \cdot \frac{P_{\mathrm{avg}}}{P_{\mathrm{tot}}} \cdot \frac{T_{\mathrm{cur}}}{T_{\mathrm{avg}}}, \tag{1}$$

where E_{lim} is energy consumption limit for the user (kWh);
E_{bud} is the monthly energy consumption budget set by the user (kWh);
P_{avg} is average daily energy consumption over the past 30 days (kWh);
P_{tot} is total energy consumption in the work environment over the past 30 days (kWh);
T_{cur} is the current time (hours);
T_{avg} is the average daily operating time of IT equipment (hours).

Significant advantages of A-SEM include:

- Balanced energy consumption: A-SEM provides an optimal ratio between user comfort and energy efficiency;
- Dynamic adaptation: the system dynamically adapts to changing conditions, considering seasonal fluctuations, weekends, and user behavior;
- Energy savings: A-SEM contributes to significant reductions in energy consumption without compromising user comfort.

Thus, A-SEM is a promising tool for adaptive-intelligent energy conservation management in smart work spaces. The system provides an optimal ratio between user comfort and energy efficiency, dynamically adapting to changing conditions. A-SEM contributes to significant reductions in energy consumption and decreases negative environmental impact.

The growing need for energy efficiency and environmentally friendly technologies contributes to the development of intelligent energy management systems in smart work environments [20]. This work proposes an integrated system that combines IoT devices into a single system to optimize energy consumption and ensure user comfort.

The system consists of three intelligent models functioning as IoT platform services:

- Intelligence Awareness Target (IAT):
  - Collects data from IoT device sensors
  - Uses machine learning to understand the situational significance of data
- Intelligence Energy Efficiency (IE2S):
  - Based on the open-source Mobius platform and TensorFlow
  - Processes data collected by IAT and analyzes energy consumption patterns
  - Automatically provides recommendations for optimizing energy consumption
- Intelligent Service TAS (IST):
  - Controls and manages energy consumption at the user service stage
  - Implements IE2S recommendations

To achieve better energy efficiency, a hybrid intelligent system using fog computing is proposed. The system architecture combines:

- Response intelligence: provides rapid adaptation to changing environmental conditions;
- Deliberative intelligence: conducts comprehensive learning and system optimization.
- Significant advantages of this system include:

- Reduction of network overload: optimization of tasks and energy use by patterns;
- Energy savings: significant reduction in energy consumption;
- Adaptability: real-time response to environmental events;
- Personalization: meeting user needs and preferences.

Experimental studies confirm that the proposed system provides significant energy savings in managing smart work environments.

Thus, the proposed integrated energy management system is an effective solution for optimizing energy consumption in smart work environments. The system combines intelligent models and fog computing to achieve adaptability, personalization, and energy savings.

Disadvantages of existing energy management systems include:

- Unsuitability for multi-user scenarios: existing systems cannot effectively manage energy consumption in scenarios with many users, as they do not account for interactions between their scenarios;
- Contradictions of individual needs: systems cannot always balance the needs and preferences of different users, which can lead to conflicts;
- Complexity of configuration: fuzzy controllers used in some systems require significant amounts of data for configuration, complicating their practical application.

A comprehensive approach to energy management includes:

- Mixed-integer quadratic programming model: the proposed model combines discrete and continuous variables, allowing consideration of various aspects of energy consumption, such as temperature, lighting, computer equipment operation, and printers;
- Forecasting: the model uses forecasting of disturbances, work environment functions, and individual user weights for dynamic adaptation to changing conditions;
- Consideration of thermal and electrical components: the model accounts for both thermal and electrical energy, providing a more comprehensive approach to energy conservation.

Application of statistical modeling methods reveals:

- Wiener and generalized Wiener processes: these methods are used for modeling stochastic processes, allowing consideration of uncertainty and randomness in energy conservation systems;
- Computational mathematics: statistical modeling methods are used to solve complex computational mathematics problems related to energy consumption optimization;
- Hausdorff dimension estimation: these methods are used to estimate the complexity and fractal structure of data, which can be useful for analyzing energy consumption in smart work environments.

The proposed comprehensive approach, which combines mixed-integer quadratic programming modeling, forecasting, and statistical modeling methods, allows overcoming the disadvantages of existing energy management systems and provides more efficient and adaptive management of energy consumption in smart work environments.

One method for improving energy conservation in smart work environments is the use of alternative energy sources. Thus, increasing the efficiency of solar panels will allow more effective conversion of solar energy into electrical energy, making them more profitable and accessible. To achieve this, scientists are working on developing new methods and improving existing devices. The goal is to maximize the efficiency of solar panels, ensuring optimal conversion of solar energy into electrical energy [18].

The main ways to increase the efficiency of solar panels include:

- Using solar radiation concentration systems: these systems collect sunlight from a larger area and focus it on a smaller area of the photovoltaic module, increasing its efficiency;
- Applying sun-tracking systems: These systems automatically rotate solar panels throughout the day so they are always directed at the sun, maximizing the amount of sunlight they receive;
- Using MPPT controllers: These controllers regulate the voltage and current supplied to photovoltaic modules so they always operate at the maximum power point (MPP), increasing their overall efficiency;
- Developing new technologies for manufacturing photovoltaic modules: This may include using new materials such as perovskites or organic compounds, or new module designs that increase their efficiency and reduce their degradation period.

It is important to note that all these methods have their advantages and disadvantages. Since the output power of solar modules depends on factors such as solar radiation and the temperature of solar cells, the measurement of solar modules is conducted under standard conditions (STC). These standard conditions are defined as follows: atmospheric quality AM1.5, light intensity of 1000 W/m², and a temperature of 25 °C.

It is well known that solar cells convert only a portion of solar energy into electricity, while the remaining energy is dissipated as heat. This occurs because an increase in temperature near the solar panel reduces the semiconductor's band gap width, leading to an increase in saturation current due to the lower energy required for electron-hole pair generation.

However, while the short-circuit current slightly increases, the open-circuit voltage decreases, thereby reducing the panel's output power. The effect of temperature on the output power of a solar panel can be expressed by the equation:

$$P_S = P_0\,(1 + \beta \cdot \Delta t), \tag{2}$$

where P_S is the power of the solar panel (W);
P_0 is the power of the solar panel at 25 °C (W);
β is the power temperature coefficient (°C), and
Δt is the temperature change (°C).

The temperature coefficient affects output power within the range of –0.2% to –0.5% per 1 °C temperature increase. The power temperature coefficient for monocrystalline silicon is –0.4% per °C. This indicates that the output power decreases by 0.4% for each degree of temperature rise beyond the operating range of the solar panel.

There are three primary mechanisms for heat dissipation from a heated object: convection, conduction, and radiation. Thermal conduction is utilized when there is a temperature gradient between the object, such as a solar panel, and another medium, including the surrounding air. The ability of a solar panel to transfer heat to another object is characterized by the thermal resistance of the materials comprising the panel.

Heat dissipation from the solar panel can be achieved via thermal conduction, specifically through Peltier elements placed on the cooler side of the panel's rear surface.

As mentioned earlier, the implementation of intelligent energy-saving management systems in smart workspaces is a key factor in optimizing energy consumption and reducing environmental impact. One promising approach is the development of systems based on the Arduino microprocessor. The system includes a central control module composed of the following components:

- Arduino microprocessor: ensures centralized system management, processes data, and transmits commands to other modules;

- nRF24L01+ wired communication module: establishes a wireless network at a frequency of 2.4 GHz, enabling the integration of additional sensors and actuators;
- DS1302 real-time module: manages the precise activation and deactivation of connected devices according to a predefined schedule;
- 4x4 matrix keypad: allows users to input commands for system control;
- HCM1205X piezoelectric emitter: generates sound signals to notify users of system events;
- Dual-channel relay module: controls two high-current devices;
- I2C PCF8574 module: expands the number of available Arduino outputs for display connection;
- LCD display module: displays system status and other essential messages.
- Functional Blocks of the Main Module:
- DM1 – Arduino microprocessor: executes computational and control functions;
- DM2 – HCM1205X piezoelectric emitter: generates sound notifications;
- DM3 – nRF24L01+ communication module: provides wireless connectivity with other modules;
- DM4 – Android communication module: allows system control via a mobile application;
- DM5 – DS1302 real-time module: manages device scheduling;
- DM6 – Relay1 module: controls the first device;
- DM7 – Relay2 module: controls the second device;
- KM1 – 4x4 matrix keypad: accepts user commands;
- DD1 – I2C PCF8574 module: expands Arduino output capabilities;
- HG1 – LCD display module: visualizes system information.

The proposed Arduino-based energy-saving management system (see Fig. 1) represents a promising solution for optimizing energy consumption in smart workspaces. The system offers extensive functionality, ease of implementation, and the ability to be easily adapted to various needs. By integrating advanced microprocessor-based control, wireless communication, and real-time management, this system contributes to more efficient energy utilization and reduces the environmental impact of modern work environments.

The implementation of intelligent energy management systems (HEMS) in smart work environments is becoming increasingly relevant. The HEMS-IoT system, which integrates the principles of the Internet of Things (IoT) and machine learning, has demonstrated significant potential for optimizing energy consumption while ensuring user comfort and safety [22]. The HEMS-IoT system employs the J48 machine learning algorithm and the Weka API to analyze large datasets related to user behavior and energy consumption patterns. This enables the system to:

- Classify work environments based on energy consumption levels: this facilitates the development of more targeted and effective energy-saving strategies;
- Identify anomalous consumption patterns: this can help detect potential issues related to energy waste or inefficient resource utilization.

Based on the analysis results, the HEMS-IoT system utilizes RuleML and Apache Mahout to generate personalized energy-saving recommendations, which take user preferences into account, ensuring comfort and security in the smart work environment.

The implementation of the HEMS-IoT system in a company has demonstrated significant positive outcomes:

- Reduction in energy consumption: the HEMS-IoT system has significantly reduced energy consumption in the work environment, leading to cost savings and a lower environmental impact;
- Enhanced user comfort: personalized energy-saving recommendations do not compromise user comfort but instead improve it through more efficient resource utilization;

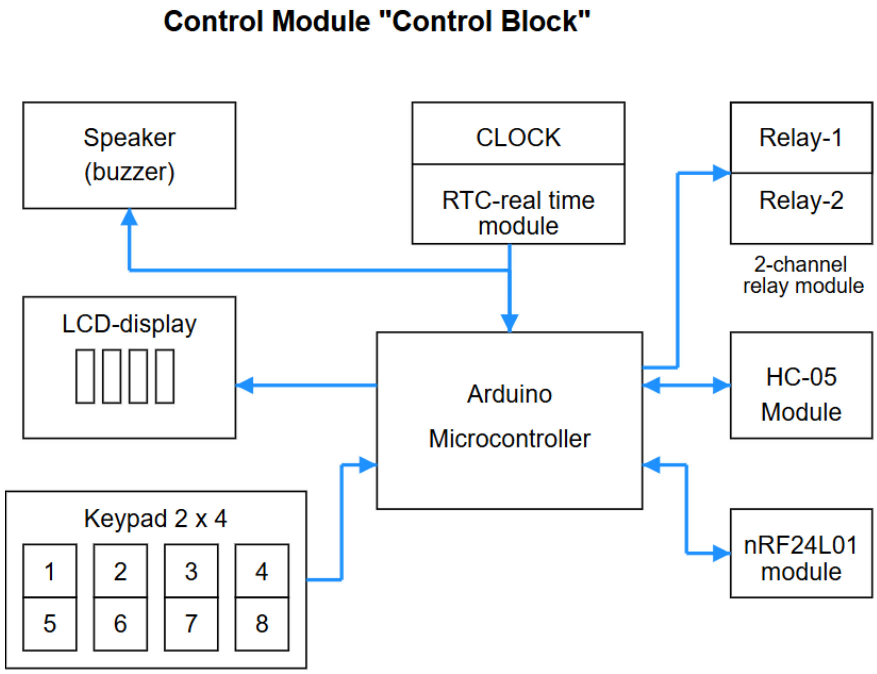

Fig. 1. Structural diagram of the "Control Block" module in the energy management system for a smart sustainable work environment.

- Increased safety: the HEMS-IoT system can help detect potential safety issues, such as electrical overloads or equipment malfunctions.

Thus, the HEMS-IoT system, leveraging big data and machine learning, serves as an effective tool for managing energy efficiency in a smart work environment. The system not only facilitates energy savings but also enhances user comfort and security.

CONCLUSION

The evolution of smart work environments represents a significant advancement in workplace design and management. By integrating IoT technologies, sensors, and automated systems, these environments offer enhanced energy efficiency, improved comfort, and increased productivity. The flexibility of smart systems allows for adaptation to varying work patterns and individual preferences, creating spaces that respond dynamically to users' needs. As organizations continue to prioritize sustainability and employee well-being, smart work environments will likely become standard practice in the design and operation of modern workspaces. Future developments in this field should focus on further integration of systems, improved data analytics for decision-making, and maintaining a balance between technological advancement and human-centered design principles.

The concept of a "smart sustainable work environment" has been analyzed. A description of the most common energy management systems in smart work environments has been provided. The Mi Home system offers a convenient and functional way to manage lighting, devices, and automation in a smart workspace. However, before selecting this system, it is important to consider its advantages, disadvantages, and individual user needs and preferences.

It has been stated that the Domoticz system is a powerful and flexible platform for managing a smart work environment, offering extensive customization and integration options for Xiaomi devices. Domoticz may be particularly appealing to users seeking an open ecosystem with cloud-based configurations and a user-friendly automation scripting language. From a mathematical modeling perspective, the statistical modeling method of fractional Brownian motion has been analyzed for simulating the operation of key energy management tools in a smart IT work environment.

Taking into account other components of a smart sustainable working space management system, we can conclude that modern information technologies and data analytics are becoming powerful tools for optimizing energy consumption and enhancing comfort and productivity in working spaces.

REFERENCES

[1] MINOLI, Daniel; SOHRABY, Kazem; OCCHIOGROSSO, Benedict. IoT considerations, requirements, and architectures for smart buildings—Energy optimization and next-generation building management systems. IEEE Internet of Things Journal, 2017, 4.1: 269-283.

[2] SAPNA, R., et al. Smart Workspace Automation: Harnessing IoT and AI for Sustainable Urban Development and Improved Quality of Life. In: IoT and Machine Learning for Smart Applications. Chapman and Hall/CRC, 2025. p. 163-177.

[3] ALGUNAIBET, Ibrahim M., et al. Powering sustainable development within planetary boundaries. Energy & environmental science, 2019, 12.6: 1890-1900.

[4] Tohid Kamali Rousta. From a Traditional Workplace to a sustainable smart office. Rel. Anna Osello, Francesca Maria Ugliotti. Politecnico di Torino, Corso di laurea magistrale in Architettura Per Il Progetto Sostenibile, 2023

[5] Hnin, Su Wutyi et al. “Workplace sustainability: energy-saving behaviors in office environments of Thailand”. Frontiers in psychology vol. 16 1400410. 4 Mar. 2025, https://doi.org/10.3389/fpsyg.2025.1400410

[6] Ramli, H.; Azizi, Z.M.; Thurairajah, N. Sustainable Smart City Technologies and Their Impact on Users’ Energy Consumption Behaviour. Energies 2024, 17, 771. https://doi.org/10.3390/en17040771

[7] Ozarslan Dogan, B. (2024), “The role of smart cities in sustainable development: empirical evidence from Türkiye", EconomiA, Vol. 25 No. 3, pp. 422-438. https://doi.org/10.1108/ECON-07-2023-0108

[8] Ali, D.M.T.E.; Motuzienė, V.; Džiugaitė-Tumėnienė, R. AI-Driven Innovations in Building Energy Management Systems: A Review of Potential Applications and Energy Savings. Energies 2024, 17, 4277. https://doi.org/10.3390/en17174277

[9] Wang, Z., Zhao, Y., Long, Y., Shi, X., Chen, X., & Dilnutt, R. Integrating IoT Technologies for Smart Office Energy Management: A TOGAF® ADM-Guided Approach. October 20, 2024.

[10] CORDERO, A. Cobaleda, et al. Smart and Sustainable Offices (SSO): Showcasing a holistic approach to realise the next generation offices. Informes de la Construcción, 2017, 69.548: e221.

[11] Gennitsaris, S.; Oliveira, M.C.; Vris, G.; Bofilios, A.; Ntinou, T.; Frutuoso, A.R.; Queiroga, C.; Giannatsis, J.; Sofianopoulou, S.; Dedoussis, V. Energy Efficiency Management in Small and Medium-Sized Enterprises: Current Situation, Case Studies and Best Practices. Sustainability 2023, 15, 3727. https://doi.org/10.3390/su15043727

[12] Ball, K. (2010). Workplace surveillance: an overview. Labor History, 51(1), 87–106. https://doi.org/10.1080/00236561003654776

[13] Огірко І. В., ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ ТА КІБЕРБЕЗПЕКА . Інформаційні технології в освіті та практиці : матеріали Науково-практичної конференції (Львів) . – Львів : ЛьвДУВС, 2023.С. 51- 52

[14] Parubochyi V. O. Performance Evaluation of Self-Quotient Image Methods / V. O. Parubochyi, R. Y. Shuvar // Ukrainian Journal of Information Technologies, 2020. – Volume 2. – Number 1. P. 8–14. https://doi.org/10.23939/ujit2020.02.008

[15] Kaskun O. Face emotion recognition with convolutional neural network / O. Kaskun, R. Shuvar, A. Prodyvus // Electronics and information technologies. – 2020. – Issue 13. – P. 38–49. https://doi.org/10.30970/eli.13.4

[16] Аршан Є. В. Система адаптивного контролю освітлення [Електронний ресурс] / Аршан Є. В. // Сучасні виклики і актуальні проблеми науки, освіти та виробництва. Київ: матеріали конференції. 2020. С. 554–563.

[17] Котунова Д. Г. Огляд DIY елементів для систем «Smart Home» / Д. Г. Котунова, О. М. Павловський // Погляд у майбутнє приладобудування. Київ: КПІ ім. Ігоря Сікорського, 2020. С. 35–38.

[18] Кирисов І. Г., Михайлов Б. К., Лосенко Є. В. Вплив затінення та пошкоджень сонячних батарей на їх параметри. Вчені записки ТНУ імені В. І. Вернадського. Серія: Технічні науки. 2023. Том 34 (73). № 1. С. 180–185. https://doi.org/10.32782/2663-5941/2023.1/27

[19] Felius, L. C. Retrofitting towards energy-efficient homes in European cold climates: a review / L. C. Felius, F. Dessen, B. D. Hrynyszyn // Energy Efficiency. – 2020. – Vol. 13, Issue 1. – pp. 101-125.

[20] Paredes-Valverde, M. A. IntelliHome: An internet of things-based system for electrical energy saving in smart home environment / M. A. Paredes-Valverde, G. Alor-Hernandez, J. L. Garcia-Alcaraz, M. D. P. Salas-Zarate, L. O. Colombo-Mendoza, J. L. Sanchez-Cervantes // Computational Intelligence. – 2020. – Vol. 36, Issue 1. – pp. 203-224.

[21] Isnen, M. A-SEM: An adaptive smart energy management testbed for shiftable loads optimisation in the smart home / M. Isnen, S. Kurniawan, E. Garcia-Palacios // Measurement. 2020. Vol. 152, 107285.

[22] Machorro-Cano, I. HEMS-IoT: A Big Data and Machine Learning-Based Smart Home System for Energy Saving / I. MachorroCano, G. Alor-Hernández, M. A. Paredes-Valverde, L. Rodríguez-Mazahua, J. L. Sánchez-Cervantes, J. O. Olmedo-Aguirre // Energies. 2020. Vol. 13, Issue 5. pp. 1097.

ЕНЕРГОЗБЕРЕЖЕННЯ ЯК ОДНА ІЗ СКЛАДОВИХ СИСТЕМИ КЕРУВАННЯ РОЗУМНИМИ СТІЙКИМИ РОБОЧИМИ ПРИМІЩЕННЯМИ

Максим Якубович, Василь Ляшкевич, Роман Шувар

Кафедра системного проектування,
Львівський національний університет імені Івана Франка,
вул. Драгоманова, 50, м.Львів, 79005, Україна

АНОТАЦІЯ

Вступ. «Розумні технології» стрімко розвиваються завдяки передовим досягненням у сфері штучного інтелекту (AI) та Інтернету речей (IoT). Великі компанії зацікавлені в концепціях «розумних приміщень» або «розумних робочих місць», оскільки ці технології дозволяють їм зменшити витрати на утримання робочих просторів і зосередитися на стійкому виробництві без надмірних витрат ресурсів.

Енергозбереження є надзвичайно важливим елементом системи керування розумними стійкими робочими місцями, тому воно було проаналізоване в цій роботі.

Враховуючи особливості розумних робочих приміщень, ми відзначили, що цей підхід забезпечує гнучкий і зручний спосіб підвищення комфорту та продуктивності на робочому місці завдяки більш точній стратегії керування пристроями.

Матеріали та методи. Для досягнення поставлених цілей було досліджено задачі, пов’язані з моделями та методологіями керування споживанням енергії на основі доступних технічних ресурсів і стандартів. Зокрема, використовувався системний підхід до відбору матеріалів, методи індуктивного та логічного аналізу, спостереження тощо. Також було розглянуто відповідні датчики та пристрої для керування енергоспоживанням у розумних робочих місцях.

Результати. Основну увагу приділено пристроям, які були доступні для дослідження, зокрема Google Home, Mi Home і Domoticz, та їхнім попередньо визначеним функціональним характеристикам. Серед моделей управління енергоспоживанням були розглянуті найбільш поширені. Зокрема, зазначено, що керування енергоспоживанням у розумних робочих місцях на основі нечіткої логіки не потребує складної математичної моделі для керування системою і може безпосередньо спиратися на досвід якісних користувачів.

Висновки. Беручи до уваги інші компоненти системи управління розумним сталим робочим простором, можемо зробити висновок, що сучасні інформаційні технології та аналітика даних стають потужними інструментами для оптимізації енергоспоживання й підвищення комфорту та продуктивності в робочих приміщеннях.

Ключові слова: розумне стійке робоче місце, система керування розумним стійким робочим місцем, споживання енергії, енергозбереження, адаптивно-інтелектуальне керування.

Received / Одержано	Revised / Доопрацьовано	Accepted / Прийнято	Published / Опубліковано
19 August, 2024	20 February, 2025	01 March, 2025	29 March, 2025