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CONTROL, INFORMATICS AND ROBOTICS

Smart parameterization for energy-efficient public buildings

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Abstract. The main goal of the research is effective BMS parameterization based on automatic evaluation systems, both manual and data-based decisions generated by a central automation system. Building management systems, accelerating historical data, may be used as crucial tools to achieve high energy efficiency in a building of high heterogeneity with low cost. The study aims to test innovative mechanisms for automatic group changes in temperature parameters and control of air conditioning and ventilation systems without the involvement of large human resources. This is possible thanks to the use of HMI operator panels and freely programmable controllers, whose control can be changed by modifying comfort parameters (lowering the set temperature in the room, increasing the inertia of the system – hysteresis setting, distinguishing between seasons and weather-based control, reducing the operation of HVAC systems according to a schedule based on building occupancy). Centralized control allows application of parameters with a single click, ensuring stability and speed of the applied settings. The tested public utility building with a heterogeneous purpose consists of many groups of rooms: approximately 700 office rooms, server rooms, conference rooms, meeting rooms including a director's room, archives, underground parking, VIP rooms, restaurants, technical rooms (heat nodes, gray water tanks, internal patio, monitored elevators, kitchens – two on each floor). Due to their geographical location and the system of opening and closing window frames with reed switches, office rooms are the most complex in terms of thermal comfort control. This is an effect of diverse user needs and different heating and cooling requirements resulting from additional solar heat gain in some offices. Research on such a diverse building ensures that the solutions developed can be applied to other buildings. This article will examine the possibility of zero-cost BMS parameterization using the example of a building with high functionality and safety requirements. The aim is to demonstrate that the parameterization of the building management system, based on historical data and analysis of a 13-storey building (even after 11 years of use, it shows certain design limitations), increases the comfort and energy efficiency of the building and it is the first step to connect buildings in smart cities. Increasing the level of building smartness by integrating all installations creates the highest potential to reduce the carbon footprint over the entire life cycle of a building in cities. Prediction of energy consumption, for each building based on historical data accumulated by BMS, is the first step to conduct cloud-based building integration into an energy cooperative of buildings, within the framework of a smart city.

Keywords: BMS system; fan coil control; primary energy; smart building; building management system; energy efficiency; sustainability; energy monitoring; optimization; decarbonization of the building.

1. INTRODUCTION

BMS automation systems are influencing the digital transformation of urban infrastructure. Their structure facilitates integration into digital city management networks, such as Smart City dashboards. IoT devices used within BMS can transmit information to central analysis systems. In addition, remote building control enables communication with the emergency management center. Automatic adaptation of ventilation systems based on changing weather conditions and usage, using machine learning, is also possible, especially in buildings equipped with central automation management systems (air conditioning, ventilation, lighting, heating, cooling, irrigation, and others) at every stage of the life cycle of a building. If environmental certification is required, building systems are a tool for obtaining certificates such as LEED, BREEAM, and WELL, which impact the value and quality of the building. The research conducted in a highly heterogeneous building equipped with a BMS system since 2014 introduces a new approach to cost-free parameterization. This approach is based not only on the automation of control parameters and algorithm settings but also on the continuity of building operation, without creating financial and operational burdens for the personnel responsible for its management. Smart buildings have been gaining in importance since the 1970s, because of the development of civilization and industry and the first energy crises, which inspired the development of regulation and automation systems optimizing energy consumption and increasing the level of building intelligence. The term "intelligent building" was first coined in the 1980s by the Intelligent Building Institute in Washington, D.C. Since the first intelligent building, The City Place Building (1983) in Hartford (USA), building management systems have gained in importance not only in industrial applications, but also in commercial and public ones. Over the past 55 years, diverse market needs have stimulated the supply of numerous system variants, both open and closed, but regardless of the system provider, the implementation of the

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BMS (Building Management System) does not guarantee energy savings. Parametrization of such a system, which is key to increasing the intelligence of the building and thus increasing operational and economic possibilities, is BMS parameterization, based on the specifics of the building operation, the usage and functional plan, the correctness of the designed installations and the geometry of the building, as well as the possibility of implementing control algorithms enabling optimal control already at the low-level PLC layer. It is also important to be able to expand the functionality that was not previously demanded by the market, due to the specific nature of the building or group of buildings, while maintaining the hardware layer (PLC, control boxes, device buses, topology) to achieve the least possible impact on the environment. The parameterization of the BMS system is crucial for maintaining user comfort and achieving long-term and repeatable utility savings throughout the building life cycle. Due to Poland's location and moderate climate, BMS systems can increase operational and economic capabilities in various weather conditions, even in such a wide range of temperatures as between the lowest temperatures in winter and the highest (−35.0°C) in summer (40.5°C). Even in cases when there are barriers due to design mistakes, optimization is difficult but still possible with an individual approach. In the case of the office building in the critical sector of the Local Government Unit, which was the subject of the analysis, due to the method of financing, complex functionality, changing regulations regarding air conditioning and ventilation conditions, energy efficiency, and continuous operation of the building, correct parameterization is more demanding but achievable. The zero-cost parameterization proposals can also be transferred to other types of buildings, provided that the building's operating cycle, BMS system, and functional-utility program are understood.

The European Union's Climate Law, which is based on the Paris Agreement [1], continues to require member states to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. The goal is to achieve a higher level of net carbon dioxide absorption by 2030. At the same time, as many as 75% of buildings in the EU are energy inefficient and therefore require shallow and deep thermal modernization. From the point of view of the possibility of replacing advanced building insulation elements, replacing window and door frames, modernizing the heating system, using renewable energy sources, and implementing a building management system (BMS), it seems to be the least invasive factor that significantly improves the energy efficiency of buildings. Importantly, recently, due to the need for effective process and building management under the Paris Agreement [1], it is necessary not only to monitor but also to optimally control technical systems to increase control both over greenhouse gas emissions and the costs of maintaining comfort in buildings. The complexity of public-use building installations required to manage the climate is beyond the competence of a single person who lacks the right tools. Given over 700 offices, meeting rooms, a session room, a footbridge system, an open patio, a restaurant, an underground car park, lifts, and numerous glass partitions, maintaining adequate thermal comfort in the building constitutes a considerable challenge. Office spaces are equipped with fan coil units communicating with the central building management system, to which suitably purified and humidified air is distributed from an air conditioning and ventilation unit serving the entire vertical from floor I to XI. The air temperature in each of the office rooms is monitored at a height of approximately 1.40 m, based on a temperature sensor placed in a wall-mounted HMI panel, which can help the user to adjust the temperature.

In the literature [2], there are a lot of theses that implementing robust monitoring systems and demand management strategies can lead to electricity consumption reductions of up to 15%. Minor modifications to the temperature settings in HVAC systems can bring measurable benefits in terms of both energy savings and comfort [3] for commercial building users, without diminishing the comfort of its use. Various examples in the literature prove that combining current air conditioning technologies can effectively conserve energy while maintaining thermal comfort [4, 5]. A holistic approach, integrating various technologies and strategies, is essential for achieving substantial energy savings in HVAC systems without compromising indoor air quality and occupant comfort. The analyzed case of a multistorey building with a public function is an example of an application of such changes, mechanisms, and grouping of rooms to achieve electricity savings. The alterations consist of low-cost changes in the agora, the user panel, where the temperature is adjusted, and the functional capabilities of the BMS systems. The article aims to examine the following theses: The implementation of building management systems (BMS) is a universal tool for reducing energy consumption in a long-term approach to the life cycle of a building. Optimal air-conditioning and ventilation management systems within the BMS not only improve user comfort but also increase the energy efficiency of buildings, resulting in lower costs.

The main goal to achieve is to prepare, test, and implement a method to decrease energy consumption by parametrization of HVAC automation equipment (based on the administration suggestion), using calendar scenarios (BMS) and HMI operator panel temperature and gear limitations, simultaneously maintaining thermal comfort. The planned research stays in line with an innovative approach to the increasing intelligence of buildings and cities by using a central automation system to manage and implement tools to increase the SRI (Smart Readiness Indicator) index of the building and reduce environmental impact. The method of low-cost parametrization of BMS may be used for the building under research, and other types of buildings; therefore, it is highly universal and applicable for different types of fan coils automation, different producers, and a plethora of configurations already present in the building. The mentioned approach may be a great tool to increase the SRI score of a building, which is a great measure of the intelligence of a building since it also covers comfort, health, and security aspects of the building and its users.

2. JUSTIFICATION OF THE RESEARCH

The main objective of research based on data harvested by the building management system (Fig. 1) and an interview with the administrators managing and responsible for the well-being and safety in the building is to implement and evaluate improvements suggested in the analysis of needs and inconveniences reported by the users. The improvements should consider the economic factor, i.e., the reduction in electricity consumption. Not all data collected by the system can be included in this study, but all decisions related to its expansion and modernization, including zero-cost ones, are based on decisions made based on data, electricity bills, and user feedback. Another significant issue is the fact that the building has numerous limitations, both financial and resulting from errors in the design and orientation of the air conditioning and ventilation units. They are not oriented according to the exposure to surplus solar energy, which significantly hinders collective regulation at the level of air conditioning and ventilation units in groups, without the involvement of a master system. In this case, automation based on the control of solenoid valves cannot be conducted in architect-designed groups, because a single air handling unit is responsible for both overheated rooms and those that are not exposed to excessive sunlight.

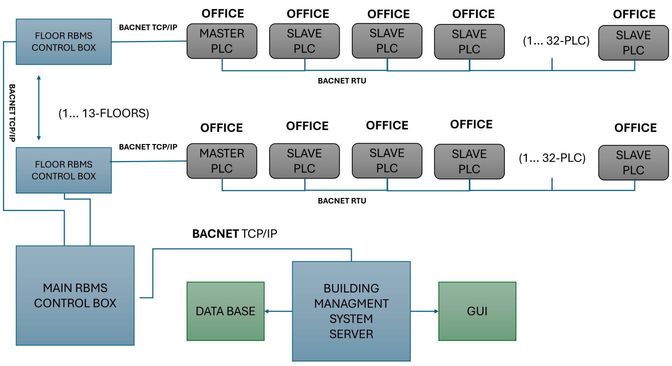


Fig. 1. Floor plan visualizing air-conditioning and ventilation topology, controlled by sensor readings in a particular office. Each controller representing an office is also equipped with a fully manageable HMI control panel, which performs information functions (alarms, alerts, temperature levels) as well as control and monitoring functions (air temperature setting, air changes, fan coil operation mode). The individual floors differ in terms of the layout and office space organization and in terms of the intended use due to different competences of the officials

When it comes to heating and cooling requirements, offices have complex characteristics dictated by their location (sunny side, shady side, with or without tilt windows). To achieve acceptable air parameters assumed by the users and standardized by the supervisors, the office rooms had to be grouped based on geographical location and sunlight exposure. To enable multiple, collective, and error-free setting of air parameters at a given time, it was necessary to develop a functionality that would be a tool for this task. If such parameters must be set manually, there is a high probability of errors or irregularities due to the monotony of such settings. Dividing the rooms into 12 groups according to their purpose, functionality, location, and energy characteristics also enabled greater control over the so-called night/weekend stops, resulting from the guarantee of restoring comfortable conditions before the arrival of employees or guests. Night/weekend shutdowns must be strictly based on the tightness and thermal capacity of a building, as stated in the building energy performance certificate.

The system should be equipped with a communication module that facilitates sending notifications about the status of the building to its administrators, even if there are no petitioners in the building or it is under closure for public holidays or other days off. The system is also equipped with electricity analyzers that enable continuous monitoring of the quality of electricity, including not only the main parameters, but also the secondary ones that also affect the price of electricity.

Increasing the interoperability of a building with a superior building management system is the cheapest solution for an investor. It transfers the burden of translating signals, operating instructions for many actuators, which are integrated on the integrator, whose functions the investor must fully understand to control them so that the BMS system displays to the operator the location of the signal on the plan of the building, installation, and location in a given technical room (no need to read electrical, hydraulic, or other diagrams). As a result, the BMS operator does not need to ensure interoperability between automation systems from different manufacturers, since alarm messages and parameter readings are expressed in specific units, and alarms are defined in the native language along with the date and the manufacturer's ID. Ultimately, this allows for more efficient building operations, maintenance of safety levels, and full information. The messages and levels of importance of alerts and alarms that appear in the system are also crucial. In the case of life-threatening, critical, and urgent alarms, on-duty users should receive telephone or e-mail notifications of the hazard or critical level of the fault. Early detection of system anomalies that are not redundant can affect the behavior of the organization and the functioning of the building in the following days of use.

The main objective of the study is to demonstrate that appropriate parameterization of the master control system, which is implemented by the building management system, can generate savings in the energy consumption of an office building in a cost-effective way (Fig. 2). Optimization is based on low-level

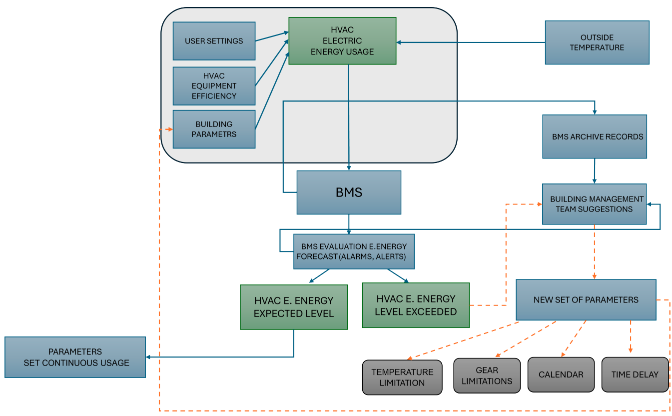


Fig. 2. Schema of method used to evaluate and apply parameter changes (temperature, gears, calendar events) based on real-time data, accumulated by BMS system database, which is an alert tool controlling and implementing parameter sets suggested by users to attaining building decarbonization and maintain comfort

optimization, i.e., the introduction of temperatures, gears and thresholds below which the user cannot adjust the systems, the synchronization of control systems according to a time schedule developed by the administration department, as well as temporary shutdowns of the systems.

Offices have complex characteristics when it comes to heating and cooling requirements, which is dictated by their location (sunny side, shady side, with or without tilt windows). To achieve acceptable air parameters assumed by the users and standardized by the supervisors, the office rooms had to be grouped based on geographical location and sunlight exposure. Based on the experience of other researchers [6] and suggestions from building administrators, restrictions on temperature parameters and the control of air conditioning and ventilation equipment in the office were implemented (Fig. 3). Office users working in the building can adjust the parameters of the air conditioning and ventilation system within a range limited by the administrators, which is different in summer and winter. In the autumn and winter, access to heat was reduced (by about 2°C) and the intensity of fan control was reduced, while in summer and spring, access to cooling was optimized (also by about 2°C) to improve energy efficiency and maintain the comfort of the building.

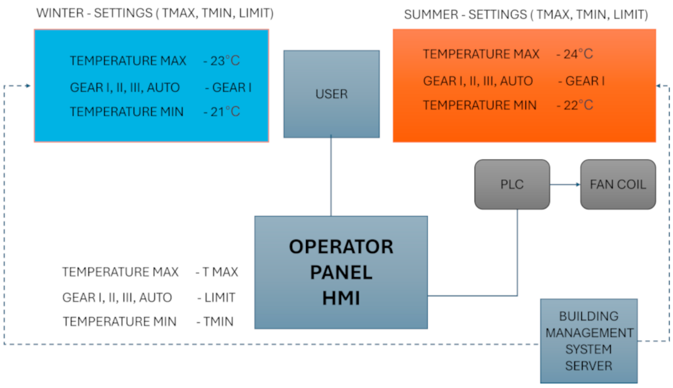


Fig. 3. A simplified schematic diagram of the modified fan coil control algorithm, which allows for the modification of settings in the PLC responsible for controlling the device in a single office. In winter, the restrictions are aimed at minimizing heat consumption and cooling in summer. In addition, the hysteresis step is also defined, i.e., the degree of the system inertia, which also affects electricity consumption. The user also has a limited possibility of setting the operating speeds of the air-conditioning and ventilation unit in order to maintain high energy efficiency while maintaining thermal comfort

3. MATERIAL AND METHOD

To enable multiple, collective, and error-free setting of air parameters at a given time, it was necessary to develop a functionality that would be a tool for this task. If such parameters must be set manually, there is a high probability of errors or irregularities due to the monotony of such settings. The rooms were divided into 12 groups (Fig. 4) according to purpose, functionality, location, and energy characteristics of the room, which enabled greater control over the so-called night/weekend stops, resulting from the guarantee of restoring comfortable conditions before the arrival of employees or guests. Night/weekend shutdowns must be strictly based on the building tightness and thermal capacity, as stated in the energy performance certificate of the building.

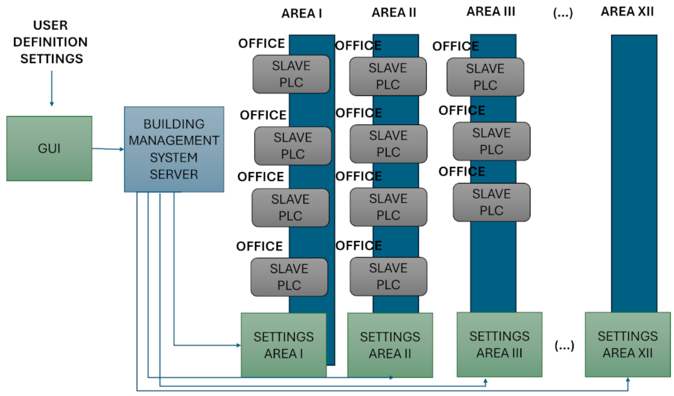


Fig. 4. Simplified scheme for grouping office rooms based on sunlight to compensate for solar heat and better control groups of offices with similar characteristics. All Area names are editable – to ensure better user understanding

Data stored on servers, ranging from personal data to office automation systems, as well as building security systems (CCTV, access control, BMS), must have stable temperature and humidity conditions to minimize flooding, overheating, and other processes that can have a detrimental effect on the infrastructure inside the server room. In the analyzed building (Table 1), data centers on each floor are monitored by additional flood and temperature sensors to eliminate risk of data damage.

Table 1

Server rooms – air conditioning. Temperature and control overview for rooms with high heat gain, such as data centers, where additional flood sensors and temperature sensors are installed to control the air conditioners in these rooms. Server rooms are excluded from interruptions in air conditioning and ventilation due to the need to maintain a temperature below 23°C

Server room Floor	Work status	Leading temperature [°C]	Actual temperature [°C]	Alarm temperature [°C]	Desired temperature [°C]
+02	Cooling ON	18.5	19.7	23.0	20.0
+03		17.0	17.4	23.0	20.0
+04		20.0	18.7	23.0	20.0
+05		15.5	17.9	23.0	20.0
+06		17.0	20.2	23.0	20.0
+07		20.0	20.4	23.0	20.0
+08		18.5	19.8	23.0	20.0
+09		19.0	19.2	23.0	20.0
+10		16.0	19.3	23.0	20.0
+11		19.5	18.3	23.0	20.0

In addition to the use of a thermal imaging camera, a good additional measure used to monitor the temperature of the control and power rack is the use of an additional, monitored sensor inside which, in the event of large temperature spikes or if the critical temperature is exceeded, will trigger an immediate alert of a high fire risk in the specific location.

Over time, wires become oxidized, and all sorts of processes occur, which can affect not only the communication of the automation with the management server or the main BMS cabinet but also increase the risk of a fire if the control cabinets are not thoroughly inspected and serviced. In the case of the building in question, the rooms have not only VRFs but also additional air conditioners running at different capacities based on the set temperature. In the event of insufficient cooling (due to the thermal energy generated by the servers), an alert is issued to intervene in the room and ensure that no critical or urgent fault has occurred. The location of the temperature sensor to be installed is also not without merit. If the sensor is located too close to a door, window opening, or other objects, there are large air fluctuations that affect the instantaneous readings.

3.1. Monitoring the humidity and temperature levels in archives

Concerning standards and recommendations for the storage environment of archival materials, according to recommendations [7] of the Supreme Directorate of State Archives of the Republic of Poland, paper stored at a constant low temperature (below 10°C) and relative humidity (30–40%) will retain its chemical stability and physical appearance for a very long time. No fixed value of environmental conditions would be recommended for all types of stored materials; it is more important to maintain a constant and unchanging temperature and air humidity. "For every 10°C increase in temperature, the rate of chemical decomposition reaction occurring in traditional archival materials doubles. In contrast, every 10°C drop in temperature slows the rate of reaction by half." [7] Heat combined with low relative humidity causes certain materials to dry out and disintegrate leather, parchment, paper, adhesives, adhesive tapes, self-adhesive labels on audio and video cassettes, etc. Heat and high relative humidity stimulate the growth of microorganisms and create favorable conditions for insects and rodents. Cold weather (below 10°C) combined with high relative humidity and poor air circulation leads to dampness and, as a result, the growth of microorganisms.

As large and rapid changes in temperature and relative humidity cause more damage to archive materials than frequent use, it is particularly important to manage the climate in the archive premises skillfully to minimize, by degrees, the natural ageing processes of archive materials. International standards [8] confirm the necessity of maintaining stable, recommended air condition in archive rooms to minimize the ageing of stored materials of various types.

3.2. Automated sun visors

High electricity consumption in the office space occurs during the summer, due to the high occupancy and use of PCs and sunlight. The demand for electricity, cooling and air-conditioning, including ventilation, is a result of many aspects of the building, such as the geometry, the geographical location of the building, the thermal insulation of glass partitions, thermal bridges, the color of the façade, the amount of greenery around the building and the design of the air-conditioning and ventilation systems and the parameterization of the auxiliary equipment and the central automation system. To consider the aspect of high electricity consumption generated by the need for cooling, it is reasonable to use movable sunscreens [9], especially in offices facing south, south-west, and placed on the west wall. The control of the automation of such shades, from the level of the BMS system, depending on weather parameters, can significantly reduce the amount of cooling needed to be generated during the summer period, especially from June to August in a temperate warm transitional climate (Poland).

3.3. VOC air quality monitoring

Air quality monitoring in office premises, at the time of writing, is not legally required in Poland, because Polish regulations on working conditions do not specify specific allowable concentrations of volatile organic compounds (VOCs) in office premises. However, according to § 32(1) of the Ordinance of the Minister of Labor and Social Policy of 26 September 1997 on general regulations of safety and hygiene at work (Journal of Laws 2003, No. 169, item 1650), air exchange should be ensured in work rooms, taking into account the needs of use, the heat and humidity balance and the presence of solid and gaseous pollutants [10]. VOC monitoring, according to WHO recommendations, is a recommended and recommended activity, but not required. The use of VOC sensors in office spaces would entail increasing air exchanges in specific rooms, without averaging these values, to minimize the carbon footprint of the building. A solution to this type of problem would be decentralized air filters like PRO-VENT CLEAN R efficiencies, installed in existing air handling units or ionization/filtration units located directly in the office spaces. According to the producer, filtration efficiency for particles, VOCs, pathogens, and others is based on particle size at an efficiency level of 99.95%. The use of technology is based on the electrostatic exclusion of hazardous particles from the indoor air through their biological deactivation and removal from the building internal circulation improves indoor air quality in offices and improves the working comfort and health wellbeing of building occupants. Source: PROVENT Sp. z o.o.

3.4. Energy evaluation framework

Referring to other authors [6], they analyzed energy savings produced by better parametrization of HVAC equipment to gain day-by-day savings (1)

$$\text{EnergySavings}\ (\%) = \sum_{d=1}^{365} \frac{E_{\text{without BMS}} - E_{\text{with BMS}}}{E_{\text{without BMS}}} \times 100, \quad (1)$$

where $E_{\text{without BMS}}$ – energy usage without BMS (kWh/year), $E_{\text{with BMS}}$ – energy usage with BMS (kWh/year), d – daily energy.

For instance, for building using a total energy 14 000 [MWh] per year, w_p – primary energy factor (conversion coefficient depending on energy source, 3 for electric energy)

$$E_p = \left(\frac{14000\ \text{MWh/year}}{70000\ ,\text{m}^2} \cdot 3\right) = 600\ [\text{kWh/year}],$$

$$\begin{aligned}&\text{EnergySavings}\ (\%)\\ &= \frac{14000\ [\text{MWh/year}] - 12000\ [\text{MWh/year}]}{14000\ [\text{MWh/year}]} \times 100\\ &= 14.28\%.\end{aligned}$$

There is potential to save 14.28% of energy when using the BMS system in comparison to the same building without automated building management.

To examine the potential for the savings that can be achieved, it is important to estimate which industry (HVAC, lighting, DHW, IT equipment, heating, cooling) generates the highest consumption. In the case of the office building under study, it was assumed that the share of individual installations in electricity costs (2) and (3) are as follows

$$\begin{aligned}&\text{Exploitation cost}_{\text{with BMS}}\\ &= \frac{\begin{pmatrix}0.3 \cdot E_{\text{HVAC}} + 0.25 \cdot E_{\text{LIGHTING}}\\ +0.2 \cdot E_{\text{DHW}} + 0.15 \cdot E_{\text{IT POWER}}\\ +0.1 \cdot E_{\text{SYSTEM LOSES}}\end{pmatrix} \cdot E_{\text{PRICE}}}{V}\\ &\quad + \frac{\text{CT}_{\text{BMS}}}{V},\end{aligned} \tag{2}$$

$$\begin{aligned}&\text{Exploitation cost}_{\text{without BMS}}\\ &= \frac{\begin{pmatrix}0.3 \cdot E_{\text{HVAC}} + 0.25 \cdot E_{\text{LIGHTING}}\\ +0.2 \cdot E_{\text{DHW}} + 0.15 \cdot E_{\text{IT POWER}}\\ +0.1 \cdot E_{\text{SYSTEM LOSES}}\end{pmatrix} \cdot E_{\text{PRICE}}}{V},\end{aligned} \tag{3}$$

where E_{HVAC} – estimated energy usage for HVAC, E_{LIGHTING} – energy usage for lighting, E_{DHW} – energy usage for DHW, $E_{\text{IT POWER}}$ – energy usage for PC, servers, $E_{\text{SYSTEM LOSES}}$ – energy usage for system losses, CT_{BMS} – cost of BMS implementation and usage license (EUR), V – real or estimated building volume in cubic meters [m^3].

For instance, for buildings using 14 000 [MWh/year], where 30% of electric energy is consumed by HVAC system, 25% of energy is consumed by lighting equipment, 20% by DHW circuit, 15% by office equipment and servers and 10% by additional devices necessary to building stable operations. BMS implementation of additional mechanisms costs EUR 260 000 and the system has been running for 11 years, and the average E_PRICE is EUR 145.95. To research estimated average floor height (gross): ~ 3.6 m (typical range is 3.3–4.0 m, including floor slabs and technical space for a floor area of 70 000 square meters is

$$V = 70000\ \text{m}^2 \times 3.6\ \text{m} = 252000\ \text{m}^3.$$

The price level is assumed at the level of EUR 145.95 per 1 kWh.

$$\begin{aligned}&\text{Exploitation cost}_{\text{with BMS}} = \big(0.3 \cdot 12000\ [\text{MWh/year}]\\ &\qquad + 0.25 \cdot 12000\ [\text{MWh/year}] + 0.2 \cdot 12000\ [\text{MWh/year}]\\ &\qquad + 0.15 \cdot 12000\ [\text{MWh/year}] + 0.1 \cdot 12000\ [\text{MWh/year}]\big)\\ &\qquad \cdot 145.95\ € + (260000\ €/252000\ \text{m}^3)\\ &\quad = 12000\ [\text{MWh/year}] \cdot 145.95\ € + 1.0317\ €/\text{m}^3\\ &\quad = €\ 7.98/\text{m}^3,\end{aligned}$$

$$\begin{aligned}&\text{Exploatation cost}_{\text{without BMS}} = \big(0.3 \cdot 14000\ [\text{MWh/year}]\\ &\qquad + 0.25 \cdot 14000\ [\text{MWh/year}] + 0.2 \cdot 12000\ [\text{MWh/year}]\\ &\qquad + 0.15 \cdot 14000\ [\text{MWh/year}] + 0.1 \cdot 12000\ [\text{MWh/year}]\big)\\ &\qquad \cdot 145.95\ € + (260000\ €/252000\ \text{m}^3)\\ &\quad = 12000\ [\text{MWh/year}] \cdot 145.95\ € = €\ 8.11/\text{m}^3.‘\end{aligned}$$

Considering that the implementation of a building management system is a financial investment, the system-generated energy savings do not exceed the operational and financial gains. The larger the building volume, the faster the return on investment and the energy baseline that can be optimized in subsequent, low-cost stages of parameterization and development of the BMS automation system. It is worth noting that the model does not consider the gains associated with lower depreciation of equipment (inverters, actuators, motors, fans, and others) and less frequent service visits due to remote alarm handling.

Energy savings must be adjusted by the costs of the BMS itself (implementation in the central system, including license costs).

This approach guarantees that the costs of modernization and integration will include the costs of BMS. The examination of calendar mechanisms and setting temperature limitations in the 13-floor building guarantees low costs of implementation and changes in implementations in the long run, since the mechanism is automated by a set of buttons.

4. RESULTS AND DISCUSSION

4.1. Reactive/active energy – night interruptions

The BMS system in the Local Government Unit office building has implemented schedules related to lowering the temperature in the office premises outside of official working hours to reduce the amount of air exchange and heat in winter and cold in summer (Fig. 5). The implemented mechanisms do not adversely affect the thermal comfort of users, because during night hours, with a few hours' notice, the system returns to the standard temperature of 21°C, so that the temperature in the room is comfortable for the user at the start of work. As a result of night-time reductions between 5 p.m. and 8 p.m. (Fig. 6) in separate groups of rooms (divided into sunny and less sunny areas), active and reactive energy consumption is lower. According to the literature [11], research shows that reducing or increasing the temperature settings in HVAC systems by 2 or 3°C can significantly affect energy consumption without compromising comfort. Especially in moderate and hot climates [6]. These changes can

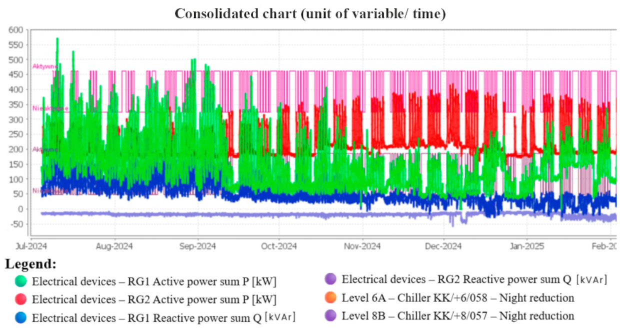


Fig. 5. Consolidated pre-study diagram of recorded air conditioning and ventilation intervals in the afternoons and nights to improve the energy efficiency of the building, while maintaining occupant comfort during the operation of a public building from 01.02.2024 to 01.02.2025. Active energy is used most in July because of the highest need for cooling during that period. Due to the reduction of HVAC system usage during nighttime hours and weekends, the building energy consumption is significantly lower than without this mechanism.

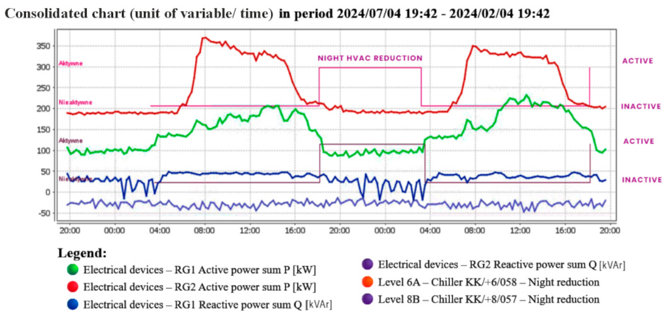


Fig. 6. The diagram represents all consolidated monitored signals for 24 hours (reactive energy – navy, active energy – green and light – violet, fan coil energy reduction – magenta and violet, active energy – red). Calendar mechanism controls fan coils to decrease energy use and turn on reducing algorithms. The daily summary of the sum of active and reactive power consumption remains in close relation to the 24-hour life cycle of the building. From 18:00 to 04:00 the active and reactive power consumption is lower. During the other hours from 06:00 to 18:00, the consumption is higher, and the fastest increase is seen between 06:00 and 08:00, i.e., the hours when the office work starts (PCs are switched on, lifts start running, etc.)

be made without additional investment in infrastructure, making them a near-zero-cost solution. The authors note that the optimal temperature settings vary depending on the climate of the building [12]. In warmer climates, the cooling temperature can be increased, and in colder climates, the heating temperature can be lowered, which will reduce energy consumption. It may be applied to weather seasons in Poland (winter/summer approach). In addition, slight temperature changes, such as lowering the cooling setting or increasing the heating [13, 14] are still within the comfort limits of users, as confirmed by survey results. By changing the temperature settings, buildings can save a significant amount of energy, which contributes to a reduction in operating costs and a lower environmental impact, especially in cities with high energy consumption (Fig. 7).

The semi-annual summary of the sum of active power, reactive power and the on and off states of night-time temperature

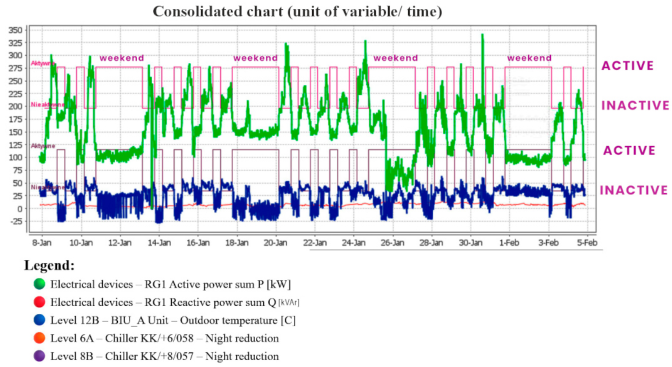
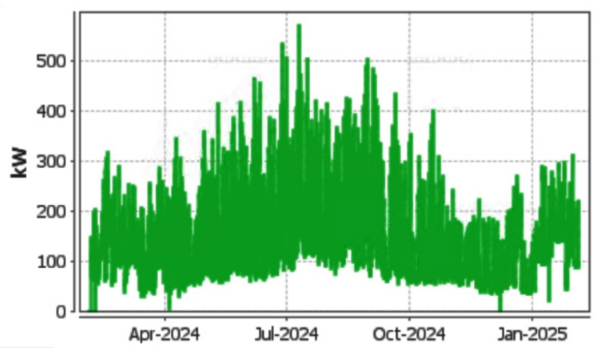


Fig. 7. Consolidated pre-study diagram of recorded air conditioning and ventilation intervals in the afternoons and nights to improve the energy efficiency of the building while maintaining occupant comfort during the operation of a public building from 8.01.2025 to 05.02.2025. At weekends, active power and reactive power levels decreased because of the night and weekend HVAC reductions

reductions and air changes shows that active and reactive power consumption is highest in the summer due to the high demand for cooling (Fig. 8). In winter, despite the need to heat the offices, the consumption is much lower (Fig. 8).

Electrical devices – consumption overview – sum of active energy
(average: 151.31 kW)



Electrical devices – consumption overview – sum of reactive energy
(average: 60.71 kvar)

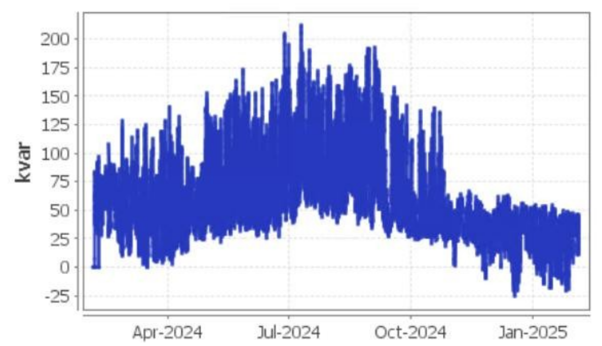


Fig. 8. Monitoring energy consumption, analyzing needs and dividing public buildings into sector systems, and data acquisition enable dynamic inspections and statistics as well as energy audits [2, 15–17]. The gained knowledge about the needs and running costs of specific public buildings is crucial for data-based decisionmaking

4.2. Monitoring of chillers – supplying cooling to two risers in the building

Monitoring and controlling the basic parameters in a building responsible for the generation and distribution of cooling is an important aspect of building decarbonization (Fig. 9). One source of cooling, apart from the obvious chillers, can be the use of the temperature outdoors when it is lower than the temperature indoors at night to lower the building temperature by a few degrees. This can be attained by opening physical air exchanges between the air handling units and the outside environment (so-called free cooling). Ground exchangers can also be subjected to this type of exchange, which can take advantage of the lower air temperature around the exchanger.

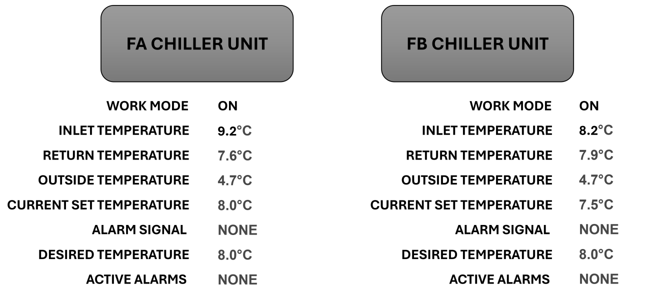


Fig. 9. Diagrams representing set of parameters, which are monitored and controlled by BMS system

The energy consumed by the building is related to its functional and utility plan. From the moment work begins in the offices (Fig. 6), lighting is switched on in common areas, and air conditioning and ventilation systems are activated at night to prepare the rooms for work. The highest active energy consumption occurs around 8:00 a.m., with the largest drop in active energy consumption occurring around 3:00- 3:30 p.m. Optimization consists of limiting the temperature settings of the air conditioning and ventilation systems and introducing fixed schedules for reducing the operation of air conditioning and ventilation systems outside building hours (reducing cooling and heating consumption) (Fig. 10)

4.3. Humidifying the air in office spaces – problems and facilities

When it comes to the level of humidity in office spaces, there are several problems, including high running costs when using steam solutions without water treatment for the humidifier. Such solutions are based on measuring the humidity in the ductwork of the air handling unit, which is responsible for supplying humidity to almost 300 offices. Consequently, the measurement of humidity is unjustifiably averaged, which can frequently result in a high amount of humidity in parts of the rooms and can also be responsible for too much humidity in other rooms, without ensuring the right parameters in the entire sector of the building

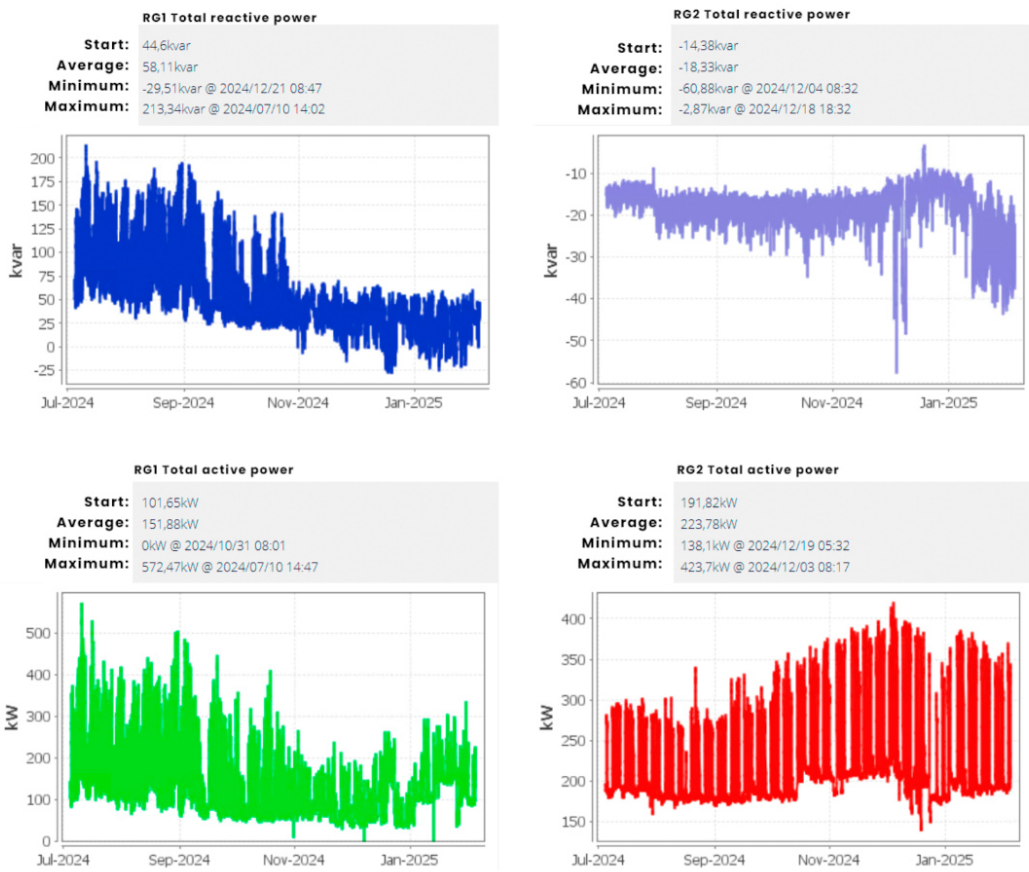


Fig. 10. Diagrams represent all divided monitored energy signals (reactive energy – navy, active energy green, fan coil energy reduction – magenta and violet). Calendar mechanism, which controls fan coils, provides energy savings, especially during summertime by saving cold

to which the humidity should be distributed. In addition, dehumidification is also necessary to manage humidity correctly and effectively. Only then can we speak of active humidity control in the room.

4.4. Description of measuring devices

ELP11R32L BACNET IP PLC controllers with HMI Touch 4.3″ (Fig. 11) operator panels equipped with PT1000 temperature sensors were used to measure the temperature in the rooms. The operator panels measure the air temperature at a height of 1.40 m, allow the set temperature and operating mode of the air handling unit to be changed, display the current temperature in the rooms, and send the reading to the industrial controller via the HMI input, which then transmits the data to the BMS. Measurement frequency – 2.5 msec-Measurement range – −50 … 170°C, measurement accuracy – ±0.2°C-Resolution: 8 bit/°C.

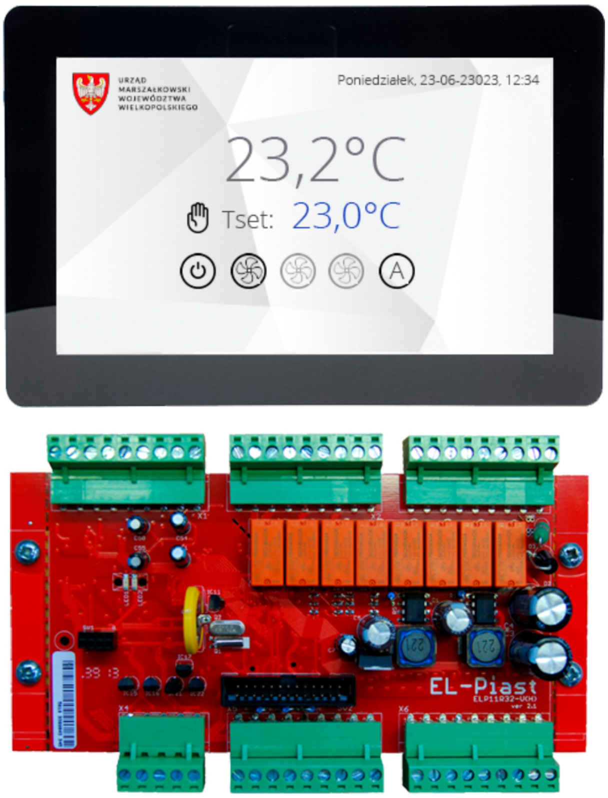


Fig. 11. A set of room automation devices designed for measuring, setting the temperature and regulating the operation of the air handling unit. The PLC controller is located in the power supply and control cabinet together with other automation components necessary for the operation of air conditioning and ventilation. The operator panel is located on the wall of the rooms

Implemented functional management systems (BMS) allow for the control and monitoring of energy consumption, which leads to the reduction of greenhouse gas emissions, which is a global environmental protection objective. Optimizing air conditioning and ventilation systems within the BMS not only increases user comfort but also contributes to lower consumption costs for buildings, which ensures more economical and sustainable operation. It stays consistent with UE [13] and Polish [14] long-term building decarbonization regulations and reduces human environmental impact. For public buildings, which have even higher energy efficiency requirements than other buildings (multi-family, factories, single-family, etc.), i.e., healthcare buildings: 190 kWh/(m^2yr), other public buildings: 45 kWh/(m^2yr) it is necessary to be aware of the passive elements of the JST building [17, 18] (geometry, geo-location, windows, glass screens, building materials of which the building was constructed together with possible design errors) that may hinder or prevent in the future the effective, i.e., noticeable EP energy management of such a building without the necessary upgrades. Apart from the introduction of optimization in the control of air conditioning and ventilation systems, lighting, night and weekend shutdowns, the analyzed building has great potential for the introduction of further energy efficiency optimizations through the installation of sunshades integrated and automated in the BMS system, based on solar radiation conditions and weather stations. This adds alternative energy sources, which will compensate for the cooling expenditure that accounts for the highest electricity consumption. Another aspect is the possibility of controlling the parameters of the heat node, which, in the current shape of the system, due to the limitations of production automation from the BMS level, cannot change the parameters, but only monitor. The modernization of the heat interface unit into an automatic unit, which also provides variables for setting values, will have a positive effect [19, 20] on the potential for saving electricity consumed by this system. Only the awareness of the limitations, advantages, and the passive elements of the building management system, builds awareness and determines the direction in which the modernization or retrofitting of the building should go, so that in the most energy inefficient elements (branch systems, e.g., in the heat substation), the control algorithm, settings or actuators are replaced. Building management systems must be used skillfully and cannot be based only on the knowledge and operation of stand-alone systems such as air conditioning and ventilation, domestic hot water, lighting, cooling, and others, but they must achieve the intended effect and compensate for design errors. They should also be based on knowledge from in-post and ex-post energy audits. This type of procedure allows for continuous evaluation of the proposed and building-adapted system, which learns from accumulated data, but the decision-making remains with the analysts who create, develop, and direct the system based on personal and professional experience and interviews with the administrators, users, and decision-makers of such a building. Transferring decision-making to a building management system without the oversight of a quantitative data analyst generates security, cyber-security, and control risks unacceptable from a critical infrastructure level. Researchers Talami, Dawoodjee, and Ghahramani (2023) in [6] show that optimizing HVAC temperature settings has a real impact on improving the energy efficiency of a building, especially in moderate and hot climates. The simulation in the article indicates that even small adjustments reduce energy consumption while maintaining the comfort of building users. In conclusion, the literature [11, 21] emphasizes that small, zero-cost modifications to the temperature settings in HVAC systems can bring measurable benefits in terms of both energy savings and comfort for commercial building users. Enhancing real-time data monitoring is crucial for improving energy management in public buildings [2]. The construction industry has enormous potential for reducing its carbon footprint because residential and commercial buildings account for 20–40% of total energy consumption [22], more than transportation. HVAC systems account for 50% of the energy consumption in buildings in the USA [22] and have a 20% share in the national energy demand, thus having a huge optimization potential. Therefore, a good understanding of how building systems work and skillful optimization, as well as solutions and mechanisms that allow for the expansion of the system with new functionalities that increase the energy efficiency of a building based on detailed and long-term data collected in the system, prove to be crucial.

Building management systems, in terms of infrastructure transformation and increasing the intelligence of cities, are key tools that allow for full control, monitoring, and management of building maintenance in a condition necessary for public utilities without the need to expand administrative departments. BMS and EMS (Energy Management Systems) can dynamically manage loads and work with DSR (Demand Side Response) aggregators. In this context, buildings equipped with EMS and BMS systems (with the possibility of accumulating heat, cooling, hot water, and using ion-lithium storage) become a guarantee of stability or relief for the power grid. In addition, in the case of long-term monitoring of electricity consumption in a building, it is possible to predict consumption in subsequent years of the building use. The energy transition of cities requires energy sharing between buildings that can be connected to a single energy network and flexible switching between electricity sources within a single building. As part of an energy cooperative, buildings use or return energy from AZE installations, among other things, ensure reactive power compensation, and provide full monitoring of individual prosumers who are members of the cooperative. The integration of many types of buildings, photovoltaic and wind farms, multi-family and single-family buildings, commercial facilities, hospitals, educational buildings, and research units is inexpensive and easy to implement using BMS and EMS systems installed in each building and connected into a single master system.

5. CONCLUSIONS

The BMS system has been optimized according to user needs and the reactive power limits set by the administration with the electricity operator. Despite the integration of air conditioning, ventilation, heating, cooling, irrigation, and humidity systems, the building still has many opportunities to optimize its consumption of electricity and other utilities. Due to the largely glazed façade, it is necessary to use automatic sunshades to reduce heat accumulation from the sun and protect the coolness accumulated in the building. Another issue to be modernized is the possibility of controlling the heat node in the building, as at the time of the study, it was only possible to monitor its parameters. Models used in the optimization and energy savings estimation referring to building volume instead of building floor area must be revised and enriched by additional parameters that may be used to reflect the full impact of the automation system on the full building cycle of life and footprint. Additionally, the following stages should be considered to support the system with a machine learning mechanism, which will predict and suggest settings according to historical data and weather forecast [23].

Despite considering parameters related to air conditioning and ventilation in the building, the research method used also has numerous limitations and imperfections. The first of these is the need to analyze and determine the projected electricity consumption of control systems. This is possible in the absence of an energy performance certificate for the building but only based on a good knowledge of the building energy consumption and the need to separate the circuits responsible for these systems. If it is not possible to separate consumption into air conditioning and ventilation, lighting, auxiliary equipment, and other items, it is difficult to evaluate the results and assess the set of configuration parameters used. Another limitation is the variability of external conditions, including the external temperature, which, despite repetitive seasons, varies from year to year. On this basis, it is difficult to estimate the predicted HVAC consumption by comparing it to the same day in the previous year. A solution worth considering is the integration of a weather station that provides information on the forecast weather to demonstrate the proactivity of the system. Another shortcoming of the adopted model is the need to integrate and measure all systems responsible for air conditioning and ventilation to collect complete information on energy consumption by the control systems responsible for HVAC. In modernized buildings where not all devices are integrated, for example, Klima convectors, due to the lack of communication, it is not possible to apply many changes to the settings of air conditioning and ventilation systems in a cost-effective manner. In addition, the BMS system does not consider the energy gain associated with the presence of users in the rooms. Consider making the ventilation system dependent on the number of users in the rooms, for example, by installing and integrating carbon dioxide or air quality sensors that would collect data in the BMS and modify the dynamics of the air conditioning and ventilation system on this basis.

Despite its limitations, the developed method can be applied in a low-cost manner to any building that has HVAC systems integrated into a master BMS system. The system will keep pace with the changing use of individual rooms and premises (in the event of a change in the purpose and use of a room during the life cycle of a building). This does not generate additional costs and, more importantly, does not have a negative environmental impact, as there is no need to replace the control automation, only to reparametrize it. The greater the scale of HVAC integration, the greater the potential for improving energy efficiency, as human error is eliminated. The developed methodology requires expansion with additional parameters and additional measuring devices that provide information on sunlight and wind, which could also enable the integration of automated sun blinds.

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