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Smart Parameterisation for Energy-Efficient Public Buildings

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Abstract. Main goal of the research is effective BMS parameterization based on automatic evaluation systems, both manual and data-based decision generated by a central automation system. Building management systems accelerating historical data may be used as crucial tools to achieving 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 parameters to be applied 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 with a director's room, archives, underground parking, VIP rooms, restaurants, technical rooms (heat nodes, gray water tanks, internal patio, monitored elevators, kitchens – 2 on each floor). Due to their geographical location and the system of opening (with reed switches) and non-opening window frames, the office rooms are the most complex in terms of thermal comfort control. This is due to the diverse needs of users and different heating and cooling requirements due to additional solar heat gain in some offices. Conducting 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 first step to connect buildings in smart cities Increasing smartness of the building by integration of all installations, causes highest potential to reduce carbon footprint over the entire life cycle of a building an 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 to energy cooperative of buildings, within the framework of a smart city.

Key words: 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 enables 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 building's life cycle. If environmental certification is required, building systems are a tool for obtaining certificates such as LEED, BREEAM, and WELL, which affect the value and quality of the building. The research conducted in a highly heterogeneous building, which has been equipped with a BMS system since 2014, presents a new approach to cost-free parameterization based on the automation of settings not only of control parameters and algorithms, but also of the continuity of building operation and without financial and operational burden on the personnel responsible for building. Smart buildings have been gaining in importance since the 1970s, as a consequence of the development of civilization and industry and the first energy crises, which became the basis for the development of

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regulation and automation systems optimizing energy consumption and increasing the intelligence of the building. 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. The diverse needs of the market over the past 55 years have ensured the supply of many system variants, both open and closed, but regardless of the system provider, the implementation of a 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 the parameterization of BMS, based on the specifics of the building's 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 functionality that was not previously needed on 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) in order 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's 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 where there are barriers due to design mistakes, optimization is difficult but 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 all the 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. 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, 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 in accordance with the Paris Agreement [1], it is necessary not only to monitor but also to optimally control technical systems to increase control not only over greenhouse gas emissions but also over the costs of maintaining comfort in buildings. The complexity of a public-use building's installations needed to manage the climate is beyond the competence of a single person - without the right tools to manage it. The building, which has over 700 offices, meeting rooms, a session room, a footbridge system, an open patio, a restaurant, an underground car park, lifts and many glass partitions, presents many difficulties in maintaining adequate thermal comfort. Office spaces, 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 mounted in a wall mounted HMI panel on which the user can set the temperature. In 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 affecting the comfort of use. Various literature proves that combining current air conditioning technologies can effectively conserve energy while maintaining thermal comfort [4][5]. 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 analysed case of a multistorey building with a public function is an example of the application of such changes, mechanisms and grouping of rooms to achieve electricity savings consisting of low-cost changes in the agora, the user panel - where the temperature is set - and the functional capabilities of the BMS systems. The aim of the article is 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 (based administration suggestion) method to decrease energy consumption by parametrization of HVAC automation equipment - using calendar scenarios (BMS) and HMI operator panel temperature and gear limitations simultaneously saving temperature comfort. The planned research stays in line with an innovative approach to the increasing intelligence of the buildings and cities by using central automation system to manage and implement tools to increase SRI (Smart Readiness Indicator) index of the building and reduce environmental impact. Method low-cost parametrization of BMS may be used for research building may be used for other types of building, therefore it is highly universal - for different types of fan coils automation - different producers and many configurations which are already present in building. Mentioned approach may be great tool to increase SRI score of building, which is great measure of intelligence of building - since it covers also comfort, health and security aspects of building and users.

2. JUSTIFICATION OF THE RESEARCH

The main objective of research based on data aggregated by the building management system (Fig.1.) and an interview with the administration managing and responsible for the well-being and safety in the building is to implement and evaluate improvements resulting from the analysis of needs and inconveniences reported by users, taking into account the economic factor - reducing 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 on the basis of data, electricity bills and feedback from building users. It is not without significance that the building has numerous limitations, both financial and also errors resulting from 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 carried out 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.
Offices have complex characteristics when it comes to heating and cooling requirements, which is dictated by their location (sunny side, shady side, with tilt windows, without tilt windows). In order to achieve the 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. In order to enable multiple, collective

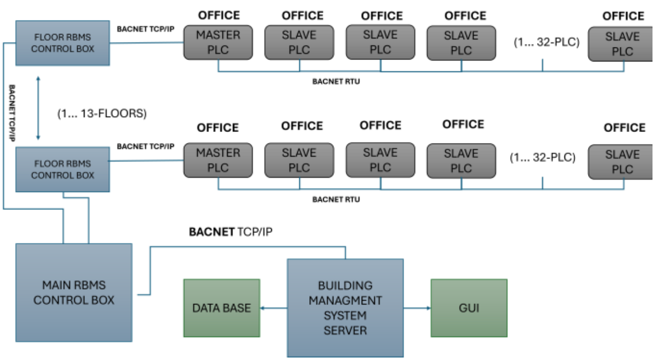

Fig.1. Floor plan visualising air-conditioning and ventilation topology, controlled by sensor readings in a particular office. Each controller represents an office is also equipped with a fully manageable HMI control panel, which performs information functions (alarms, alerts, temperature levels) as 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 organisation of the office space and differ in terms of the intended use due to the different competences of the officials.

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 have to be set manually, there is a high probability of errors or irregularities due to the monotony of such settings. The creation of 12 groups of rooms, allowing for division according to purpose, functionality, location and energy characteristics of the room, also enabled greater control over the so-called night/weekend stops, resulting from the guarantee of a return to comfortable conditions before the arrival of employees or guests. Night/weekend shutdowns must be strictly based on the building's tightness and thermal capacity, as stated in the building's energy performance certificate.
The system should be equipped with a communication module that allows notifications to be sent to building administrators about the status of the building, even if there are no petitioners in the building or it is in the process of being closed for public holidays or other days off. The system is also equipped with electricity analysers that enable continuous monitoring of the quality of electricity - not only the main parameters, but also the secondary parameters that also affect the price of electricity.

Increasing the interoperability of a building through the use of a superior building management system is the cheapest solution for the investor, because it transfers the burden of translating signals, operating instructions for many actuators - which are integrated on the integrator - which he must fully understand how they function and control - so that the BMS system displays to the operator not only the location of the signal on the plan of the building, installation, location in a given technical room (no need to read electrical, hydraulic, or other diagrams). As a result, the BMS operator does not have to require interoperability of individual manufacturers' automation systems, because alarm messages and the levels of read parameters are expressed in specific units, and alarms are defined in the native language along with the date and manufacturer's ID. Ultimately, this allows for more efficient building operation, maintenance of safety levels and full information. The messages and levels of importance of alerts and alarms that appear in the system are also important. 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 anomalies in systems that are not redundant can affect the behaviour 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 optimization, i.e. the introduction of temperatures, gears and thresholds below which the user cannot regulate the systems, the synchronization of control systems according to a

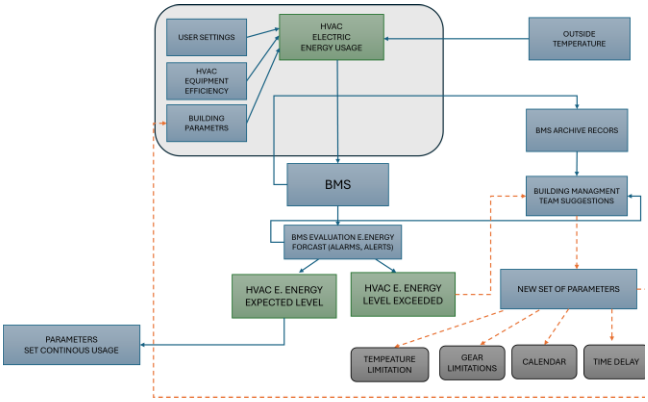

Fig.2. Schema of method used to evaluate and apply parameters changes (temperature, gears, calendar events) based on real time data, accumulated by BMS system database, which is a tool to alert, control and to implement suggested by user parameters sets to reach building decarbonisation and save comfort.

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 tilt windows, without tilt windows). In order to achieve the 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

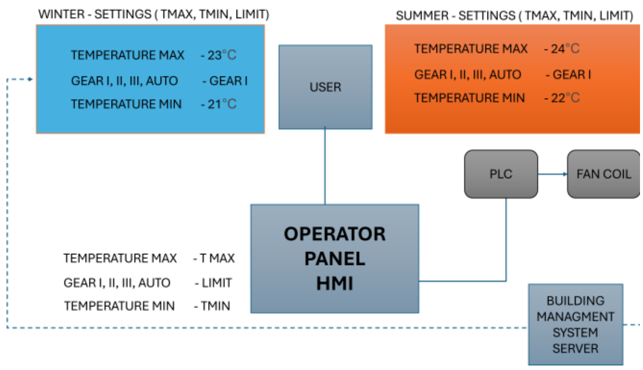

Fig.3. A simplified schematic diagram of the modified fan coil control algorithm, which allows for the modification of settings in the PLC responsible for controlling the device in a single office. In winter, the restrictions are aimed at minimizing heat consumption, and in summer, cooling. In addition, the hysteresis step is also defined, i.e. the degree of inertia of the system, 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.

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 degrees Celsius) and the intensity of fan control was reduced, while in the summer and spring, access to cooling was optimized (also by about 2 degrees Celsius) to improve energy efficiency and maintain the comfort of the building.

3. MATHERIAL AND METHOD

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

In order 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 have to be set manually, there is a high probability of errors or irregularities due to the monotony of such settings. The creation of 12 groups (Fig.4.) of rooms, allowing for division according to purpose, functionality, location and energy characteristics of the room, also enabled greater control over the so-called night/weekend stops, resulting from the guarantee of a return to comfortable conditions before the arrival of employees or guests. Night/weekend shutdowns must be strictly based on the building's tightness and thermal capacity, as stated in the building's energy performance

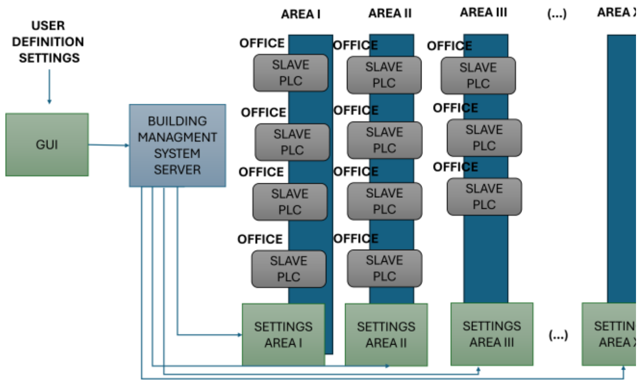

Fig.4. Simplified scheme for grouping office rooms based on sunlight to compensate for solar heat and better control groups of offices with similar characteristics. All of Area names are editable – to increase better user understanding.

certificate.

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 in order to minimise flooding, overheating and other processes that can have a detrimental effect on the infrastructure inside the server room. In analysed building (Table.1.) data centre, on each floor are monitored by additional flood and temperature sensors to eliminate risk of data damage. 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

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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.

TABLE 1. Server rooms - air conditioning. Temperature and control overview for rooms with high heat gain such as data centres, 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 degrees Celsius.

Server room Floor	Work Status	Leading temperature [°C]	Actual temp.[°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

Over time, wires become oxidised, 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 a fire risk occurs - 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 which are run 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 - there are large air fluctuations that affect the instantaneous readings.

3.1. Monitoring of humidity and temperature levels in archives.

With regard to 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. There is no fixed value of environmental conditions that 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 micro-organisms and create favourable 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 skilfully - in order to minimise, by degrees, the natural ageing processes of archive materials. International standards [8] confirm the necessity of maintaining stable, recommended air conditions in archive rooms in order to minimize the aging 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 the glass partitions, thermal bridges, the colour of the façade, the amount of greenery around the building and the design of the air-conditioning and ventilation systems and the parameterisation of the auxiliary equipment and the central automation system, if any. In order to take into account, 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 in 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 Labour 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 minimise the carbon footprint of the building. A solution to this type of problem would be decentralised air filters like PRO-VENT CLEAN R efficiencies, installed in existing air handling units or ionisation/filtration units located directly in the office spaces. According to the producer, filtration efficiency for particles, VOCs, pathogens, and others based on particle size at an efficiency level of 99.95%. The use of technology based on the electrostatic exclusion of hazardous particles from the indoor air - through their biological deactivation and removal from the building's 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 analysed energy savings, produced by better parametrization of HVAC equipment to gain, day by day savings (Equ.1.).

$$Energy\ Savings(\%) = \sum_{d=1}^{365} \frac{E_{without\ BMS} - E_{with\ BMS}}{E_{without\ BMS}} x\ 100 \quad (1)$$

where:

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

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

$$E_p = (\frac{14\ 000\ MWh/year}{70000\ m^2} \cdot 3) = 600\ \text{[kWh/year]}$$

$$Energy\ Savings(\%) = \frac{14\ 000\ \text{[MWh/year]} - 12\ 000\ \text{[MWh/year]}}{14\ 000\ \text{[MWh/year]}} x\ 100 = 14{,}28\%$$

There is potential to save 14,28% of energy savings by using BMS system in comparison to the same building without automated building management.

In order 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 (Equ.2.) and (Equ.3.) is as follows.

$$Exploatation\ cost_{with\ BMS} = \frac{\begin{pmatrix} 0.3 \cdot E_{HVAC} + 0.25 \cdot E_{LIGHTING} + 0.2 \cdot E_{DHW} + \\ 0.15 \cdot E_{IT\ POWER} + 0.1 \cdot E_{SYSTEM\ LOSES} \end{pmatrix} \cdot E_{PRICE}}{V} + \frac{CT_{BMS}}{V} \quad (2)$$

$$Exploatation\ cost_{\ without\ BMS} = \frac{0.3 \cdot E_{HVAC} + 0.25 \cdot E_{LIGHTING} + 0.2 \cdot E_{DHW} + 0.15 \cdot E_{IT\ POWER} + 0.1 \cdot E_{SYSTEM\ LOSES}) \cdot E_{PRICE}}{V} \quad (3)$$

where:

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

For instance, for building 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 which are necessary to building stable work, BMS implementation of additional mechanisms is 260 000 € and system is running 11 years and average E_PRICE is 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 floor area 70 000m2 is

$$V = 70\ 000\ m2 \times 3.6\ m = 252\ 000\ m^3$$

Price level is assumed at the level of 145.95€ per 1kWh.

$$Exploatation\ cost_{with\ BMS} = (0.3 \cdot 12\ 000\ \text{[MWh/year]} + 0.25 \cdot 12\ 000\ \text{[MWh/year]} + 0.2 \cdot 12\ 000\ \text{[MWh/year]} + 0.15 \cdot 12\ 000\ \text{[MWh/year]} + 0.1 \cdot 12\ 000\ \text{[MWh/year]}) \cdot 145.95€, + (260\ 000€/252\ 000\ m^3) = 12\ 000\text{[MWh/year]}\ \cdot 145.95€ + 1.0317\ €/m^3 = €\ 7.98/m^3$$

$$Exploatation\ cost_{without\ BMS} = (0.3 \cdot 14\ 000\ \text{[MWh/year]} + 0.25 \cdot 14\ 000\ \text{[MWh/year]} + 0.2 \cdot 12\ 000\ \text{[MWh/year]} + 0.15 \cdot 14\ 000\ \text{[MWh/year]} + 0.1 \cdot 12\ 000\ \text{[MWh/year]}) \cdot 145.95€, + (260\ 000€/252\ 000\ m^3) = 12\ 000\text{[MWh/year]}\ \cdot 145.95€ + = \ €\ 8{,}11\ /m^3`$$

Considering that the implementation of a building management system is a financial investment, the energy savings generated by the system do not exceed the operational and financial gains. The larger the building's 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 saving must be adjusted by costs of BMS itself (implementation in central system, including license costs).
This approach guarantees, that costs of modernisation and integration will include costs of BMS. Examinate calendar mechanisms, and setting temperature limitations, in 13th floor building, guarantees low costs of implementation and changes in implementations in long-term period – since mechanism is automated by 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 officials' 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 the night hours, with a few hours' notice, the system returns to the standard temperature - 21 degrees Celsius, so that the user

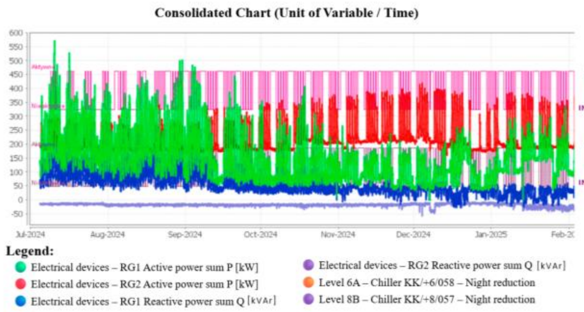

Fig.5. Consolidated pre-study diagram of recorded air conditioning and ventilation intervals in the afternoons and nights - to improve the energy efficiency of the building - while maintaining occupant comfort during the operation of a public building during 01.02.2024 – 01.02.2025 period. Active energy is used in most July – because of highest need for cool during that period. Since night and weekends HVAC usage reduction power usage is significantly lower that without this mechanism.

has temperature comfort in the room at the start of work. According to 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) reduce active and reactive energy consumption. According to literature [11] research shows that reducing or

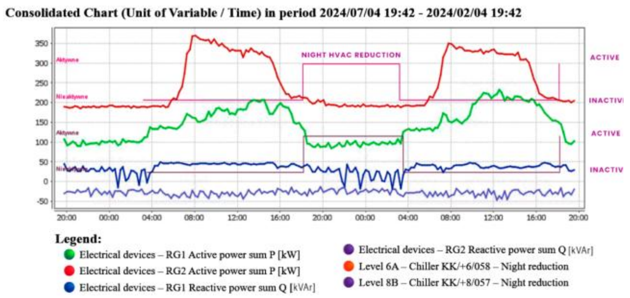

Fig.6. Diagram represents consolidated all monitored signals for 24 hours (Reactive energy – Navy, Active Energy Green and Light Violet, Fan Coil Energy reduction – Magenta and Violet, Red – Active Energy). Calendar mechanism which controls fan coils – to decrease use of energy and turn on reducing algorithms. Calendar mechanism which controls fan coils – to decrease use of energy 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 - 04:00 the active and reactive power consumption is lower. During the other hours from 06:00 - 18:00 the consumptions are higher, and the fastest increase is between 06:00 and 08:00 - the hours when the office work starts (PC are switched on, lifts start running and the like).

increasing the temperature settings in HVAC systems by 2/3 degrees can significantly affect energy consumption without compromising comfort. Especially in in moderate and hot climates [6]. These changes can be made without additional investment in infrastructure, making them a near zero-cost solution. The authors [12] note that the optimal temperature settings vary depending on the climate of the building. 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 changes in temperature, 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.).

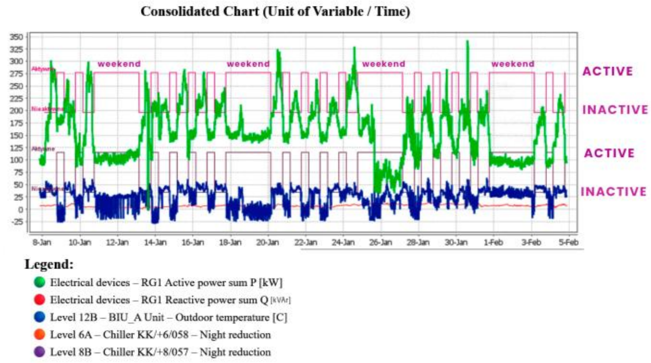

Fig.7. Consolidated pre-study diagram of recorded air conditioning and ventilation intervals in the afternoons and nights - to improve the energy efficiency of the building - while maintaining occupant comfort during the operation of a public building during 8.01.2025 – 05.02.2025 period. During weekends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

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

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 decarbonisation (Fig.9.). One source of cooling, apart from the obvious chillers, can be the use of the outside temperature - lower than the building temperature - during the night period to lower the building temperature by a few degrees - 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.

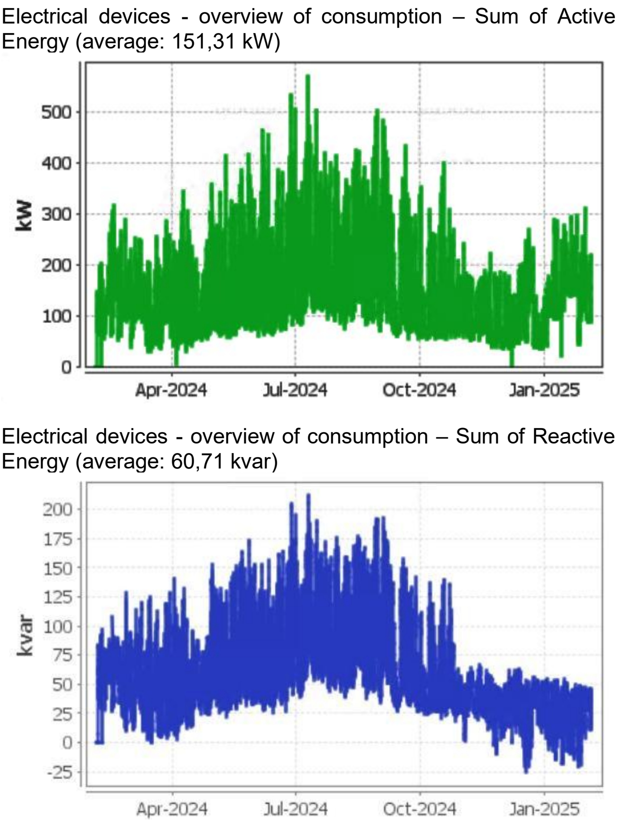

Fig.8. Monitoring energy consumption, analysing needs and dividing public buildings into sector systems, and data acquisition enable dynamic inspections and statistics as well as energy audits [2][15][16][17]. The knowledge gained about the needs and running costs of specific public buildings is crucial for data-based decision-making.

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

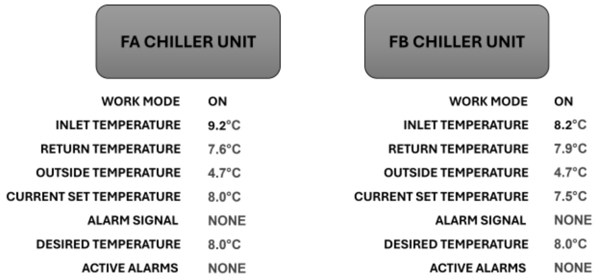

Fig.9. Diagrams represent set of parameters which are monitored and controlled by BMS system.

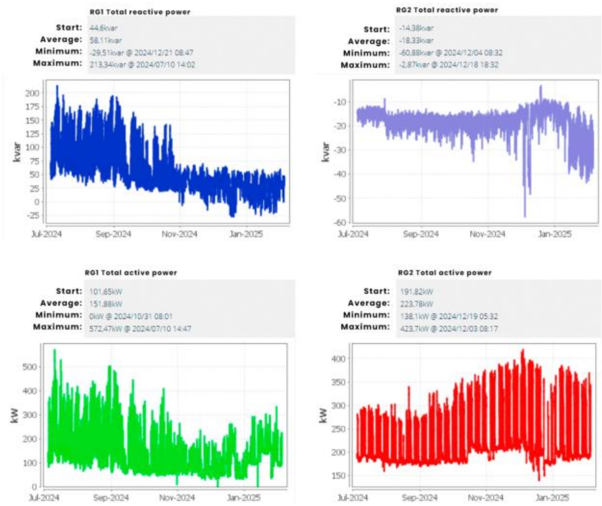

Fig.10. Diagrams represent divided on all monitored energy signals (Reactive energy – Navy, Active Energy Green, Fan Coil Energy reduction – Magenta and Violet). Calendar mechanism which controls fan coils provides energy savings especially during summertime by saving cold.

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 a number of problems, consisting of 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 result in a high amount of humidity in parts of the rooms, which is often the case - and can also be responsible for too much humidity in other rooms - without guaranteeing the right parameters in the entire sector of the building 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

Implemented functional management systems (BMS) allow for the control and monitoring of energy consumption, which leads to the reduction of greenhouse gas emissions, a global environmental protection goal. 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 decarbonation regulations and reduce human environment 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/(m²-yr), other public buildings: 45 kWh/(m²year) it is necessary to be aware of the passive elements of the JST building [17][18] (geometry, geo-localisation, 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. The analysed building, apart from the introduction of optimization in the control of air conditioning and ventilation systems, lighting, night and weekend shutdowns, 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, adding 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 - only monitoring. 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 and advantages, of the passive elements of the building management system, builds awareness and determines the direction in which the modernisation 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 skilfully - not only based on the knowledge and operation of stand-alone systems such as air conditioning and ventilation, domestic hot water, lighting, cooling and others, but to achieve the intended effect and compensate for design errors, it 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 this 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.

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 office rooms.

Researchers Talami, Dawoodjee, and Ghahramani (2023) in article [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] emphasises 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 skilful optimization, as well as solutions and mechanisms that allow for the expansion of the system with new functionalities that increase the building's energy efficiency based on detailed and long-term data collected in the system, turn out to be crucial.

Building management systems, in terms of infrastructure transformation and increasing the intelligence of cities, are a key tool that allows for full control, monitoring, and management of building maintenance in a condition necessary for public utility 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's 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, among other sources, AZE installations, 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, which are 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 – at the time of the study, it was only possible to monitor its parameters. Models used in optimisation and energy savings estimation referring to building volume instead of building floor area must be revised and enriched by additional parameters which may be used in reflect full impact of automation system on full building cycle of life and footprint. Additionally in next stages should be considered to support system by machine learning mechanism, which will predict and suggest settings according to historical data and weather forecast [23].

Despite taking into account 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 analyse 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 on the basis of a good knowledge of the building's 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 the 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 in order to collect complete information on energy consumption by the control systems responsible for HVAC. In modernised 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 take into account 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 building's life cycle). This does not generate additional costs and, more importantly, does not have a negative impact on the environment, as there is no need to replace the control automation, only to re-parameterise 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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