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Smart Solutions for Building Energy Performance: The Role of Artificial Intelligence

Soluții inteligente pentru performanța energetică a clădirilor: rolul inteligenței artificiale

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Abstract. *The increasing need for energy-efficient buildings has led to the development of smart solutions that integrate cutting-edge technologies, such as artificial intelligence (AI), into building services systems. This paper explores the role of AI in improving building energy performance, highlighting the benefits and challenges of integrating AI into building systems. The paper presents a review of relevant literature on AI-based building energy management systems and provides a case study of some AI-based solutions for building services systems management in an administrative building. The results show that AI can significantly improve building energy performance. However, successful implementation of AI-based solutions requires careful consideration of various factors, such as data quality, system complexity, and user acceptance.*

Key words: *energy-efficient buildings, AI-based solutions for building services, energy management*

Rezumat. *Nevoia tot mai mare de clădiri eficiente din punct de vedere energetic a condus la dezvoltarea de soluții inteligente care integrează tehnologii de ultimă oră, cum ar fi inteligența artificială (IA), în sistemele de instalații pentru clădiri. Această lucrare explorează rolul IA în îmbunătățirea performanței energetice a clădirilor, subliniind beneficiile și provocările integrării IA în sistemele unei clădiri. Lucrarea prezintă o trecere în revistă a literaturii relevante despre sistemele de management energetic al clădirilor bazate pe IA și oferă un studiu de caz al unor soluții bazate pe IA pentru managementul sistemelor de instalații într-o clădire administrativă. Rezultatele arată că IA poate îmbunătăți semnificativ performanța energetică a unei clădiri. Cu toate acestea, implementarea cu succes a soluțiilor bazate pe inteligență artificială necesită o analiză atentă a diferiților factori, cum ar fi calitatea datelor, complexitatea sistemului și acceptarea de către utilizatori.*

Cuvinte cheie: clădiri eficiente din punct de vedere energetic, soluții bazate pe inteligență artificială pentru instalații în clădiri, managementul energiei

1. Introduction

In an international context, in industrialized countries, the construction sector represents nearly 40% of the total consumption of non-renewable energy, 40% of greenhouse gas emissions, and 70% of electricity consumption [1].

At the national level, according to current regulations, new buildings, for which acceptance at the end of works is carried out based on the building permit issued starting from December 31, 2020, will be buildings whose energy consumption is nearly zero [2]. Thus, the necessity of innovative solutions to reduce carbon emissions and energy consumption is emerging.

One potential solution to this challenge could be the use of Artificial Intelligence (AI) for various analyses, predictions, or control strategies of systems that ensure indoor comfort conditions in buildings.

In recent years, the field of AI has seen a significant improvement in various domains, including civil engineering and maintenance of existing buildings. The capability of AI to process massive amounts of data, recognize patterns, and build large-scale statistical models is a key facilitator of the construction sector [3] towards a future with reduced emissions and nearly zero-energy buildings.

The literature in the field of AI [4] presents an approach that utilizes human-computer interactions for the improvement of energy consumption with a focus on energy efficiency. Existing solutions attempting to explore the concept of consumer-oriented energy efficiency models based on AI are, however, heavily customized for utilities administrative users rather than ordinary energy consumers. [5]

This study proposes the integration of AI-based solutions into the analysis and planning of energy efficiency strategies for end consumers, namely buildings that are to be rehabilitated or modernized to increase energy efficiency.

2. Materials and methods

The analyzed building is an existing administrative building, most of the interior rooms being used as offices. Its location is in Cluj-Napoca Municipality. The interior spaces are spread over three levels, namely basement, ground floor and first floor. The heated area of the building is 6593 m^2.

The outer envelope of the building consists of solid brick walls 60 cm wide, without thermal insulation. The windows have a PVC frame and two sheets of glass. The slab on the ground is made of reinforced concrete with a thickness of 15 cm over which a leveling screed with a thickness of 5 cm is poured. The floor above the last level is also made of reinforced concrete with a thickness of 10 cm, above it there is also a thermal insulation layer of expanded slag 80 cm thick.

The building is heated by means of a thermal plant, which is located to the basement, and which is composed of two boilers operating on methane gas, each of the boilers having a nominal power of 350 kW. The indoor heating system consists of cast iron radiant heaters with elements.

In the building proposed for optimization from the point of view of energy efficiency, measurements were made regarding the provision of comfortable indoor temperatures in the rooms for a period of two months, from 14.02.2022 to 14.04.2022, being measured permanently, every 15 minutes, the indoor temperatures of two spaces located on opposite sides of the building, respectively one space being located on the eastern side and the other on the western side of the building. Figure 1 shows an overview of the building.

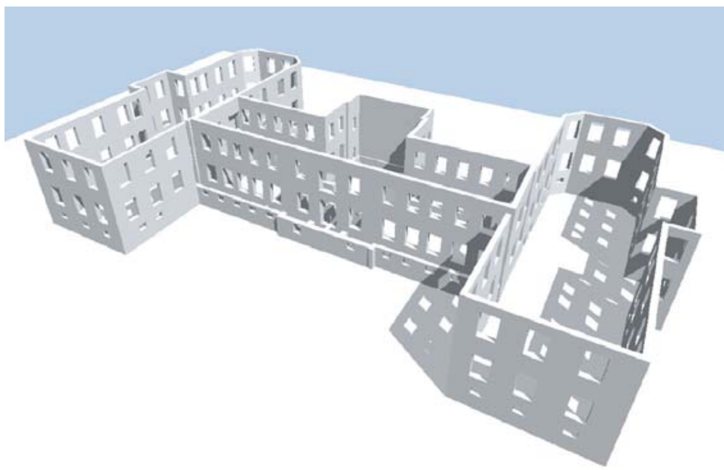

Fig. 1. Overview of the building - view on the north side

The measurements were made with two electronic measuring devices of the RC-5 Data Logger type, calibrated by the manufacturer, with an accuracy of ±0.5ºC for a temperature range from -20ºC to +40ºC.

For the first space, located on the ground floor, on the eastern side, a minimum temperature of 14.7ºC and a maximum temperature of 31ºC were recorded. The average indoor temperatures recorded during the considered period was 25.4ºC, the results being presented in figure 2.

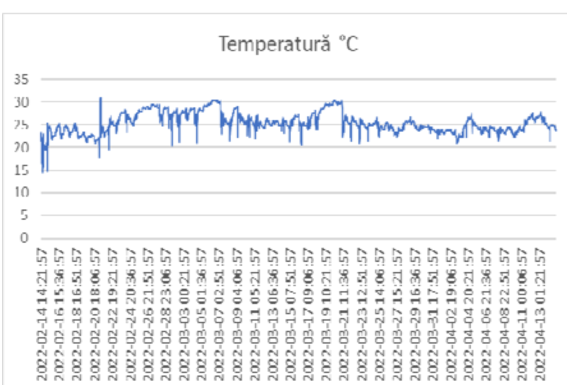

Fig. 2. Recorded temperatures
in the space on the east side

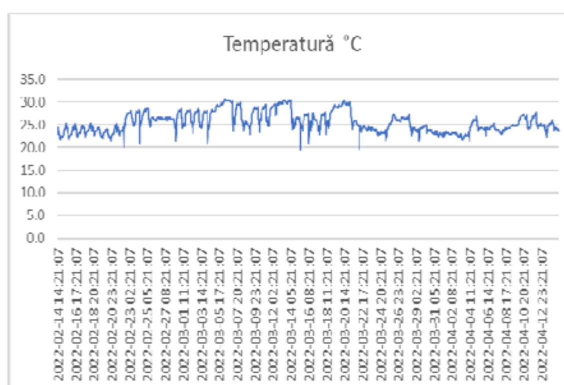

Fig. 3. Recorded temperatures
in the space on the west side

For the second space, also located on the ground floor, on the western side, a minimum temperature of 19.4ºC and a maximum temperature of 30.6ºC were recorded. The average indoor temperatures recorded during the considered period was 25.6ºC, the results being presented in figure 3.

From the images presented, it can be easily observed that the interior spaces are overheated, the interior temperatures obtained being above 25ºC in most of the analysis period.

In accordance with the national technical regulations [6], the indoor comfort temperatures in the heating season for buildings whose function is administrative type are in the range of 20÷24ºC, considering an ambience category II. It should be considered that these temperatures are recommended to be ensured permanently for the entire period of occupation of the building.

To optimize from the energy point of view, the thermal loads for heating the building were calculated [7] for several internal temperatures, respectively for 20ºC, 22ºC, 24ºC, 25.4ºC and 25.6ºC.

Thus, for an average indoor temperature of 20ºC, a heating thermal load of 666.27 kW was obtained, and for an average indoor temperature of 25.6ºC, a heating thermal load of 768.17 kW was obtained, the intermediate results being presented in table 1.

Table 1

Heating loads depending on average indoor temperatures

Building level	$T_{i\ med.}$ [ºC]	Heating load [kW]
S+P+E	20	666.27
S+P+E	22	702.63
S+P+E	24	739.11
S+P+E	25.4	764.57
S+P+E	25.6	768.17

Considering the values obtained, it can be observed that the thermal load for heating the building at an average indoor temperature of 25.6ºC is higher by 15.29% compared to the thermal load required to ensure an average indoor temperature of 20ºC.

This foreshadows a possibility of optimizing the internal heating systems so that the energy efficiency of the building can be improved.

The Role of Artificial Intelligence [8]

Artificial Intelligence (AI) can play an important role in improving the energy performance of buildings by providing intelligent control solutions for heating systems.

Specifically, by analyzing data collected by temperature and humidity sensors in the building, AI can help optimize the performance of heating systems, quickly identify, fix technical problems, and predict future energy consumption.

To be able to offer intelligent solutions to improve the energy performance of the building, a detailed analysis of the data collected through measurements should be carried out, with the help of analysis and machine learning algorithms.

First, the temperature patterns and trends recorded in the two rooms should be identified to determine when the temperatures are highest or lowest and what factors might influence these fluctuations.

After that, the efficiency of the existing heating system should be determined, checking if it is working optimally or if there are areas where heat losses are higher. For this, it would be useful to carry out an analysis of the level of thermal insulation of the building and the efficiency of heating equipment, such as existing boilers and radiators.

After analyzing the data and identifying the factors that affect the indoor temperature, intelligent solutions can be proposed to improve energy performance, such as:

1. Implementation of automated temperature control systems (through presence sensors coupled with thermostat valves) in each room, which adjust the heat level according to the comfort needs of the occupants and the outside weather conditions.
2. Improving the thermal insulation of the building, by installing thermally insulating windows and doors, as well as by insulating the external walls and the roof.
3. Replacing the existing heating system with a more energy-efficient one, such as a heat pump or cogeneration system, which can produce electricity and heat simultaneously.
4. Implementation of an electricity consumption monitoring and control system that provides the building owner with real-time information on energy consumption and associated costs to make better informed decisions about energy savings.
5. Development of a program of education and awareness of building occupants regarding the importance of energy saving and efficient use of the heating system and other electrical equipment in the building.

AI Predictions [8]

The optimum indoor temperature may vary depending on local conditions and occupant preferences. In general, an indoor temperature between 20-22 degrees Celsius is recommended for office buildings.

If the average indoor temperature is reduced to 22 degrees Celsius, the heating load will decrease to approximately 697.22 kW. This would represent an energy saving of approximately 71.95 kW, i.e., approximately 10.8% of the building's heating load.

By thermally insulating the building, heat loss can be reduced by approximately 20%, which can lead to an annual thermal energy saving of approximately 131.86 MWh and a reduction in heating costs of approximately 17688.69 euros.

The installation of energy-efficient windows can reduce heat loss through glazed surfaces by approximately 40%, which can lead to an annual thermal energy saving of approximately 263.72 MWh and a reduction in heating costs of approximately 35954.8 euros.

By implementing an intelligent indoor temperature control system, the electricity consumption for heating can be reduced by about 30%, which can lead to an annual electricity saving of about 36.56 MWh and a reduction in heating costs of about 2479.34 euro.

3. Conclusion

AI could be described as a key technology that can help improve the energy performance of buildings, by providing intelligent control solutions for heating systems and real-time data analysis.

In addition, AI can also be used to help the building owner or manager make more informed decisions about heating equipment investments by providing analysis and predictions on maintenance costs, energy savings and operating costs investment.

Of course, this technology is still in its infancy, being in an early stage of development, the algorithm used for predictions being only in the 4th generation. Because of this, it is necessary to analyze, verify and interpret the results and suggestions provided, by an HVAC specialist.

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