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Inteligentni sistemi za klimatizaciju, grejanje i hlađenje zasnovani na savremenim metodama mašinstva

Intelligent systems for air conditioning, heating, and cooling based on modern mechanical engineering methods

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Ključne reči:
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U radu se razmatraju razvoj i primena inteligentnih sistema za klimatizaciju, grejanje i hlađenje (KGH), zasnovanih na savremenim metodama mašinstva. Poseban akcenat stavljen je na optimizaciju rada kroz inženjersko modeliranje, obradu rezanjem i primenu laserske tehnologije pri izradi preciznih komponenti. Metodologija istraživanja obuhvatila je analitičke i eksperimentalne postupke, uključujući 3D modeliranje ključnih elemenata sistema i ispitivanje njihovih performansi u realnim uslovima. Dobijeni rezultati pokazuju smanjenje potrošnje energije za gotovo 30%, poboljšanje termičke ugodnosti i povećanu pouzdanost sistema. Zaključeno je da primena digitalnih alata i integrisanih proizvodnih metoda predstavlja ključni pravac daljeg razvoja inteligentnih rešenja za KGH, sa značajnim potencijalom za širu primenu u praksi i doprinos održivoj energetskoj efikasnosti.

Key words:
AHC systems; energy efficiency; 3D modeling; production technologies; laser processing

The paper examines the development and application of intelligent systems for air conditioning, heating, and cooling (AHC) based on modern mechanical engineering methods. Special emphasis is placed on optimizing system performance through engineering modeling, machining, and the use of laser technology for the fabrication of precise components. The research methodology included both analytical and experimental approaches, incorporating 3D modeling of key system elements and evaluating their performance under real operating conditions. The results demonstrate an energy consumption reduction of nearly 30%, improved thermal comfort, and increased system reliability. It is concluded that the application of digital tools and integrated manufacturing methods represents a crucial direction for the further development of intelligent AHC solutions, with significant potential for wider practical implementation and contribution to sustainable energy efficiency.

1. Introduction

Air conditioning, heating, and cooling (AHC) systems occupy a central role in modern life as they provide stable microclimatic conditions essential both for user comfort and for the uninterrupted operation of industrial processes. Their importance is further increasing in the context of rising global energy consumption, growing urban populations, and increasingly strict environmental regulations. Traditional AHC systems, based on conventional mechanical components and simple control principles, are increasingly unable to meet the demands for energy efficiency, sustainability, and smart management.

In recent decades, thanks to advances in production engineering and the application of new mechanical engineering methods, the AHC sector has undergone significant transformation. Advanced manufacturing technologies-such as precision machining, additive manufacturing (3D printing), and laser processing-have enabled the production of sophisticated components with high accuracy and durability. At the same time, process digitalization and the integration of software solutions, particularly in 3D modeling, have created opportunities for predictive design and detailed simulations that enhance system performance even before physical implementation.

A particular challenge today is balancing energy efficiency and sustainability. Modern AHC systems are increasingly becoming part of the broader concept of smart buildings, where adaptive algorithms, the Internet of Things (IoT), and predictive control are applied. This not only achieves energy savings but also reduces the ecological footprint by lowering greenhouse gas emissions. This paper focuses specifically on the engineering methods and technologies underlying the development of intelligent AHC systems and their role in transforming traditional solutions into high-tech, sustainable systems of the future.

2. Development and application of smart AHC systems

Smart AHC systems represent an advanced generation of climate, heating, and cooling solutions that integrate sensors, digital control platforms, and optimized components developed through modern production technologies. Their primary objective is to ensure higher levels of energy efficiency, adaptability, and operational reliability compared to conventional systems.

– Production technologies: Modern manufacturing techniques such as machining and laser processing are key ena-

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blers of improved system performance. Machining enables the fabrication of highly precise components, including fans, compressor housings, and valve elements, which are essential for maintaining system durability under intensive operating conditions. Laser processing, on the other hand, ensures fine shaping of openings, micro-channels, and surface finishes with high accuracy, thereby reducing aerodynamic resistance and energy losses during operation. The use of additive technologies is also emerging, providing opportunities for lightweight and custom-designed components.

– 3D modeling and simulation: The application of CAD/CAE tools allows the development of components and subsystems with optimized geometry that improves fluid flow, minimizes turbulence, and reduces heat transfer inefficiencies. Through 3D modeling, it becomes possible to simulate a wide range of operating conditions before physical implementation, which significantly shortens the development cycle, lowers prototyping costs, and provides accurate predictions of energy performance.
– Practical integration and intelligent control: In real-world applications, smart AHC systems integrate heating, cooling, and ventilation functions within a unified platform. Advanced control algorithms, supported by real-time sensor data, enable adaptive operation in response to changing external and internal conditions. This not only reduces energy consumption by up to 30% compared to conventional systems but also enhances user comfort and equipment lifespan. Furthermore, the inclusion of IoT-based monitoring and predictive maintenance capabilities ensures early detection of malfunctions, minimizing downtime and improving system reliability.

In summary, the development and application of smart AHC systems highlight the synergy between modern production methods, digital modeling, and intelligent operational strategies. These systems are paving the way toward sustainable, energy-efficient, and adaptive climate technologies designed for both residential and industrial environments.

3. Methodology

The research was conducted through the following steps:

1. Analysis of conventional AHC systems and identification of areas with the highest energy losses.
2. Design of improved components using CAD/3D software.
3. Prototype fabrication through machining and laser processing technologies.
4. Performance monitoring under experimental conditions (measuring temperature, flow, and energy consumption).
5. Comparison of results with standard systems and efficiency analysis.

4. Results

The presented results provide a quantitative insight into the energy efficiency of standard and smart AHC systems. The comparisons allow for the assessment of the effects of advanced manufacturing technologies, 3D modeling, and intelligent control on reducing energy consumption. Table 1 clearly illustrates the extent to which the smart AHC system contributes to operational optimization and energy savings under real conditions.

The table clearly shows the difference in energy consumption between the standard and smart AHC systems. The standard system records a consumption of 125.4 kWh per day, while the smart system consumes 87.9 kWh, representing a saving of nearly 30%. These results confirm that the application of modern manufacturing technologies and intelligent control significantly enhances energy efficiency.

Table 1. Comparison of energy consumption in AHC systems

System type	Energy consumption [kWh/day]	Savings compared to standard [%]
Standard AHC	125.4	–
Smart AHC	87.9	29.9

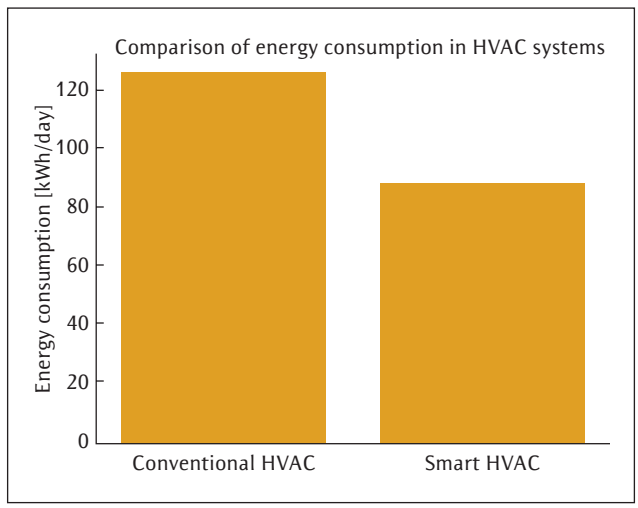

Figure 1. Comparison of daily energy consumption of standard and smart AHC systems

The diagram shows the energy consumption of standard and smart AHC systems. The bars in the chart clearly illustrate the differences in energy usage. The standard system consumes 125.4 kWh/day, while the smart system consumes 87.9 kWh/day, representing a saving of 29.9%. This visual representation allows for a quick analysis and comparison of results, confirming that the application of intelligent control and optimized manufacturing technologies significantly contributes to energy consumption reduction.

5. Discussion

The analyzed results indicate that intelligent AHC systems, developed with the support of modern mechanical engineering methods, can be considered a technological advancement toward sustainable solutions. Energy savings of nearly 30% confirm that improvements in component design and manufacturing are directly linked to better operational performance. This clearly demonstrates that production engineering, through machining and laser technology, contributes not only to precision and reliability but also to overall process optimization.

A particularly significant contribution comes from the application of 3D modeling, which has proven to be a key tool in designing new generations of systems. Thanks to the ability to simulate various operating scenarios, 3D modeling significantly reduces the need for time-consuming experimental testing, accelerates development, and enables accurate prediction of energy performance. This directly impacts development cost reduction and shortens the time required to implement new solutions on the market.

Compared to conventional systems, smart AHC systems also provide a broader range of functionalities-from automatic adaptation to external conditions to predictive maintenance-substantially reducing unplanned downtime and extending equipment lifespan. The introduction of IoT sensors and digital platforms further increases the level of automation and enables integration with renewable energy sources, creating a synergy between production technologies and sustainable development.

It should be emphasized that, although experimental results indicate clear advantages of smart AHC systems, it is necessary to conduct a more detailed analysis of the long-term reliability of these solutions in different types of buildings-from industrial facilities to residential complexes. Beyond the technical dimension, key challenges also relate to economic feasibility and payback periods, which will be critical for broader practical adoption.

Finally, the combination of new manufacturing technologies and digital planning opens the way for the development of the next generation of AHC systems—intelligent, adaptive, and self-sustaining solutions that will significantly contribute to global efforts in reducing energy consumption and preserving the environment.

6. Conclusion

The conducted analysis demonstrates that the application of modern manufacturing technologies and digital tools significantly improves the performance of air conditioning, heating, and cooling (AHC) systems. In particular, the contribution of precision machining and laser technology in the production of reliable and durable components is highlighted, while 3D modeling enables simulation and system optimization before implementation in real buildings.

The research results clearly confirm that smart AHC systems contribute to energy consumption reduction of nearly 30%, while simultaneously achieving better indoor climate control and extending equipment lifespan. This provides not only technical benefits but also economic advantages through reduced operating and maintenance costs.

The integration of intelligent functionalities and digital solutions opens opportunities for the application of adaptive control algorithms, which adjust system operation to real environmental conditions. In this way, AHC systems transform from passive energy consumers into active elements of energy-efficient and sustainable buildings.

Although the results indicate clear advantages, further research should focus on the long-term reliability of smart systems, their economic feasibility in different types of buildings, and the potential for integration with renewable energy sources. By combining advanced manufacturing technologies with digital planning, mechanical engineering can play a key role in the transition to sustainable and intelligent AHC solutions for the future.

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