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ECOTECHNOLOGICAL IMPERATIVE OF INTERNATIONAL AIRPORT DEVELOPMENT

ABSTRACT

Introduction. The ideology of the ecotechnological imperative generally refers to an ideology or concept that emphasizes the need to develop and use environmentally sustainable technologies and innovations to achieve environmental sustainability and reduce negative environmental impacts. This is particularly relevant for airport complexes, which have a significant impact on the environment. This approach to the use of saving technologies and their minimization of environmental impact requires the search for alternative, efficient and environmentally friendly solutions. The use of innovative technologies minimizes the use of natural resources, pollutant emissions and other negative impacts.

Purpose. Research of conceptual and theoretical issues of implementation of the ecotechnological imperative of the world's airports development, the impact of the latest ecotechnologies in the field of sustainable airport development, digital technologies of environmental safety management to minimize the reduction of negative impact on the environment.

Method (methodology). The theoretical and research-methodological basis of the study was the provisions of the concept of ecotechnology, based on the idea of using advanced scientific and technical developments to solve environmental problems and achieve sustainable development.

In the process of the research such methods and approaches were used as: the method of system analysis – consideration of ecotechnologies as part of system interactions of the airport ecosystem; logical generalization and synthesis – formation of the main conclusions and proposals of the research; graphic – visualization of the results of identification of the main advantages of using energy technologies in airports to improve energy efficiency and reduce the negative impact on the environment.

Results. The article identifies that the introduction of energy technologies at airports can lead to outcomes such as reduced energy consumption, lower operating costs, reduced greenhouse gas emissions, improved public image, and increased environmental awareness and development of the country's energy sector as a whole.

Conducted analysis has led to the conclusions that the introduction of energy technologies at airports has the potential not only to reduce energy consumption and operational costs, but also to contribute to more environmentally sustainable and efficient airport operations. Proposed advantages of using energy technologies in airports lead to increased energy efficiency and reduced negative impact on the environment. The given classification of implemented ecotechnologies for the airport with the indication of advantages and disadvantages of each of them can become a dynamic and strategic tool for forecasting and implementing future projects in the development of airport infrastructure.

Keywords: alternative energy sources; airport; environment; ecotechnologies; airport energy efficiency.

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Introduction

A modern approach to airport operations typically includes a commitment to sustainable consumption and production, energy efficiency, renewable energy, development of environmentally friendly materials and production processes, improved waste management systems and other measures to conserve resources and protect nature. The ecotechnological imperative is considered essential to combat climate change, conserve biodiversity and ensure the sustainable development of the planet. It emphasizes not only the environmental significance of such technologies, but also their potential for economic and social development, job creation and improving people's quality of life.

Analyzing both the regulatory framework and the activities of various research universities with staff of researchers engaged in research in the field of airport energy technology. Thus, the International Air Transport Association (IATA) is a regulatory area: IATA is actively engaged in research and development of sustainable solutions for aviation [3]. They focus on various aspects including alternative energy sources, greenhouse gas emission reduction and energy efficiency. Also, the International Civil Aviation Organization (ICAO): ICAO also conducts research and development in the field of ecotechnology in aviation [4]. They work to develop international standards and guidelines to reduce the environmental impact of aviation, including energy aspects.

Aircraft manufacturers such as Airbus and Boeing, as well as manufacturers of technical equipment for airports, are actively engaged in energy technology research. They are developing more efficient engines, energy saving systems and other innovative solutions to reduce the environmental impact of aviation [1].

Many governments and non-profit organizations are also involved in ecotechnology research at airports. They fund and support projects to develop and implement sustainable aviation solutions.

Several universities and research centers have shown that they are actively conducting research into ecotechnology at airports. Here are some of them:

Massachusetts Institute of Technology (MIT) – the MIT Laboratory for Aviation and the Environment conducts research on reducing greenhouse gas emissions, noise and energy consumption in aviation. They develop new technologies and strategies for sustainable air transport [13].

University of Cambridge, Centre for Sustainable Development of Aviation – researches the development and implementation of ecotechnologies in aviation. They study energy efficiency, alternative fuels and reducing greenhouse gas emissions [12].

Delft University of Technology, Department of Energy Technology – conducts research on ecotechnology in aviation, including alternative energy sources, emission reduction and energy efficiency [10].

University of Texas at Austin, Centre for Sustainable Energy and Environmental Engineering – engages in research on environmental sustainability in aviation. Their research includes developing new technologies to reduce emissions and energy consumption at airports [20].

University of California, Berkeley, Center for Sustainable Energy and Environmental Engineering – conducts research in environmental technology in aviation, including alternative energy sources, emissions reduction and sustainable airport management [11].

Technical University of Darmstadt, Centre for Aviation Systems – engaged in research to improve energy efficiency and reduce emissions in aviation, including airport infrastructure and operational processes [19].

These are just some examples of universities and research centers that are conducting research on ecotechnologies in airports."

Of note is research in 2019 by authors Milner M., Rice S., Rice K. "Supporting green airports by political affiliation and social identity", where they examined the relationship of public-private partnerships in airport Ecotec development [5].

Xiang Y. (2021) [9], together with other authors presented techno-economic design of energy systems for airport electrification: Hydrogen-solar-battery integrated microgrid solution.

Greer F., Rakas J., Horvath A. (2020) published their comprehensive review on airports and

environmental sustainability. This review synthesizes the current state of environmental sustainability metrics and methods (e.g., life-cycle assessment, Scope GHG emissions) for airports [2].

All these research [2, 5-9] aim to develop and implement new technologies and methods that will help airports become more sustainable and reduce their negative environmental impact. Through the joint efforts of industry and academia, airports will be able to implement more efficient solutions, reduce emissions, reduce energy consumption and mitigate the negative environmental impacts of aviation.

Purpose and objectives of the article

The purpose of the article is to analyze the conceptual and theoretical issues of implementation of the ecotechnological imperative of the world's airports development, the impact of the latest ecotechnologies in the field of sustainable airport development, digital technologies of environmental safety management to minimize the reduction of negative impact on the environment.

The theoretical and research-methodological basis of the study was the provisions of the concept of ecotechnology, based on the idea of using advanced scientific and technical developments to solve environmental problems and achieve sustainable development.

In the process of the research such methods and approaches were used as: the method of system analysis – consideration of ecotechnologies as part of system interactions of the airport ecosystem; logical generalization and synthesis – formation of the main conclusions and proposals of the research; graphic – visualization of the results of identification of the main advantages of using energy technologies in airports to improve energy efficiency and reduce the negative impact on the environment.

The main material of the research

Most countries in the world consider energy efficiency improvement in any sector of the economy as a strategy to reduce energy consumption and minimize the negative impact on the environment. Let’s consider the main strategies that can be applied to improve energy efficiency in various sectors of the economy [1; 3; 4]:

1. Energy audits and monitoring. Energy audits and systematic monitoring of energy consumption can identify areas with the highest energy losses and identify opportunities for efficiency improvements.

2. Energy saving technologies. The introduction of modern energy-saving technologies such as LED lighting, high-efficiency heating and air conditioning systems, improved insulation materials and high-efficiency equipment can significantly reduce energy consumption.

3. Optimization of production processes. Production processes can be optimized to reduce energy costs. This may include improving control systems, optimizing production process parameters, introducing automation, and using energy-saving methods and technologies.

4. Cogeneration and waste utilization. Cogeneration, or the co-production of electricity and heat, allows the utilization of waste heat that would normally be lost in the production process. It is also possible to use waste and biogas to generate energy.

5. Training and awareness raising. Training employees and industry workers on energy efficiency and involving them in the efficiency improvement process can promote energy saving practices and raise awareness.

6. Utilization of renewable energy sources. Adoption of renewable energy sources such as solar and wind energy can reduce dependence on fossil fuels and reduce greenhouse gas emissions.

7. Legislative measures and incentives. The introduction of energy-saving regulations and standards, financial incentives, tax breaks and other government incentives can promote energy efficiency in various industries.

The strategies described can be adapted depending on the specific industry and its characteristics, but the overall goal is to use energy efficiently and reduce consumption without compromising productivity or product quality.

The use of ecotechnologies at airports can significantly reduce environmental impact and operating costs. For example, installing solar panels on the roofs of airport buildings or on the ground can provide part of the airport's energy needs. Solar energy can be used to power lighting,

heating, and air conditioning systems, and to charge electric vehicles. In turn, replacing traditional lamps with energy-efficient light-emitting diode (LED) lighting fixtures can significantly reduce energy consumption for airport lighting. Lighting control technologies such as motion sensors and automatic dimming can also be applied to optimize energy use. The use of highly efficient air conditioning systems and heat recovery technologies helps to reduce energy consumption associated with ensuring comfortable conditions in buildings and passenger areas.

Implementation of Building Energy Management Systems (BEMS) enables the monitoring and optimization of energy use in airport buildings. BEMS monitors and adjusts lighting, heating, air conditioning and other systems to minimize energy consumption when not in use or optimize their operation according to activity in the building.

Airports can also take measures to improve the energy efficiency of internal transport such as buses, electric traction equipment on runways and aircraft maintenance equipment. Replacing traditional vehicles with electric or hybrid vehicles can reduce emissions and fuel consumption.

The introduction of runway energy management systems can optimize lighting and signaling systems and manage the energy consumption of other equipment that is essential for the safe operation of the airport.

It should be noted that the actual selection and implementation of technologies may depend on the specific conditions and requirements of a particular airport.

Let us consider a few examples of airports that have already implemented various energy technologies to improve energy efficiency:

1) Chhatrapati Shivaji Maharaj Airport (Mumbai, India) [18]. This airport has installed a large solar panel system on the roof of the Terminal 2 building. The solar panels generate up to 2.6 MW of electricity, reducing carbon dioxide emissions by 3,000 tons annually.

2) Incheon Airport (Seoul, South Korea) [14]. Incheon Airport has implemented energy management systems that control lighting and air conditioning in buildings. Solar panels have also been installed on the roofs of buildings to provide additional energy supply.

3) Hamad International Airport (Doha, Qatar) [17]. Hamad Airport utilizes energy efficient lighting using LED lamps and a lighting control system. The airport has also introduced energy efficient air conditioning and heat recovery systems to optimize energy consumption.

4) Schiphol Airport (Amsterdam, Netherlands) [16]. Schiphol Airport has introduced various energy efficient technologies, including energy efficient lighting and energy management systems. The airport is also developing plans to introduce alternative energy sources such as geothermal energy.

5) San Francisco Airport (California, USA) [15]. San Francisco Airport is installing solar panels on building roofs and on the ground to generate its own electricity. It also uses energy efficient lighting systems and energy management systems to reduce energy consumption.

Many other airports around the world are also actively working to implement energy efficient practices and technologies to reduce energy consumption and environmental impact. Thus, various energy technologies can be introduced at airports to improve energy efficiency and reduce the negative environmental impact.

Fig. 1 presents the Advantages of using energy technologies at airports to improve energy efficiency and reduce the negative impact on the environment.

It is important to note that these technologies can be used in combination with each other, depending on the specific conditions and needs of each airport. A combined approach to energy technologies can lead to the most significant results in energy efficiency and reduced environmental impact at airports.

Next, consider the advantages and disadvantages of each of the energy technologies mentioned before (table 1).

It should also be noted that the introduction of ecotechnologies in airports may face several obstacles, such as high implementation costs. Some ecotechnologies, such as the installation of solar panels or wind turbines, may require significant capital investment. This can be a major obstacle for airports with limited financial resources or limited access to financing. There are also technical limitations and challenges. For example, some airports may face technical limitations and difficulties in implementing

ecotechnologies. For example, some airports may have limited space to install solar panels or restrictions on the use of wind turbines due to airspace or local legal regulations.

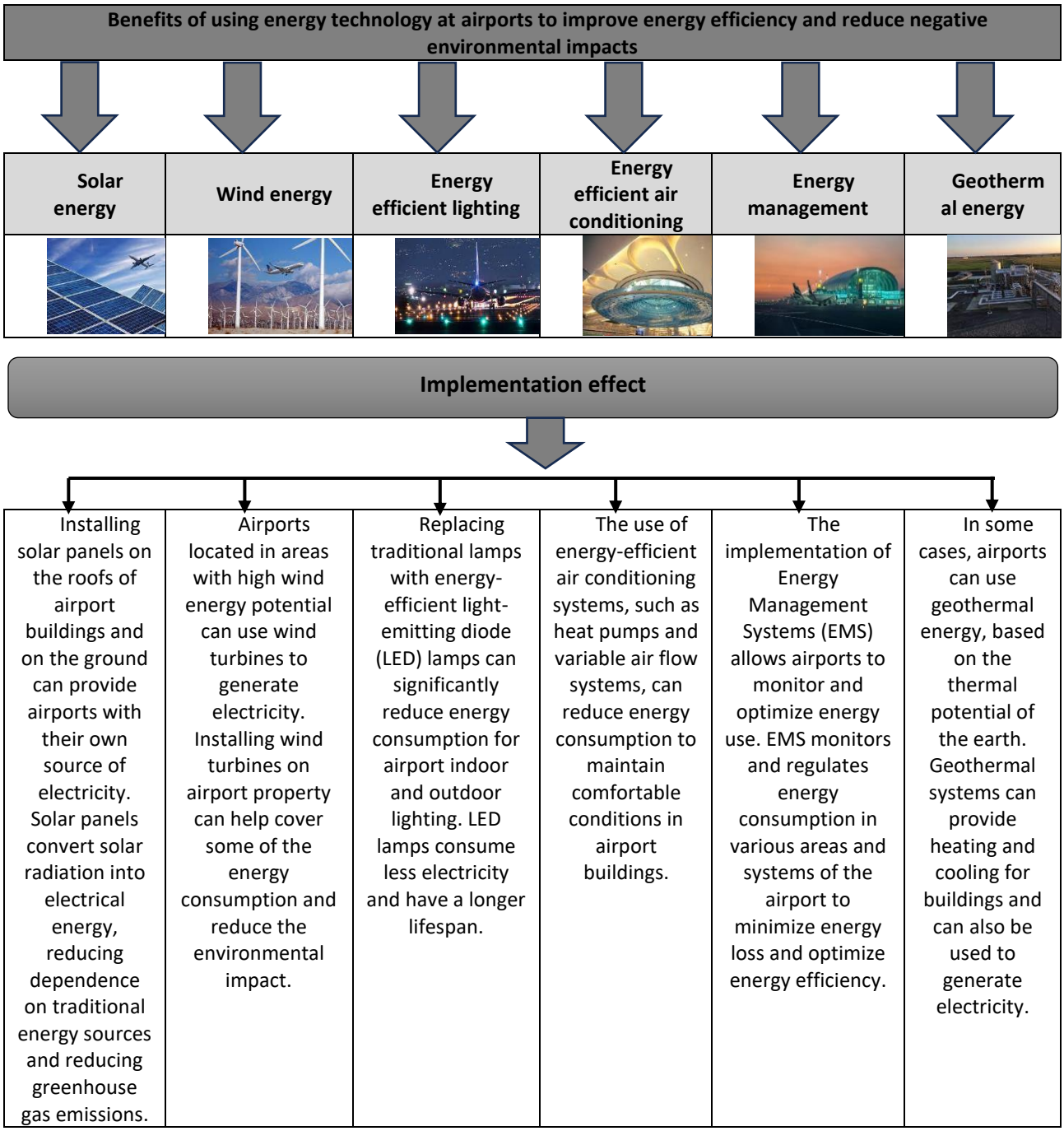

Fig. 1. Benefits of using energy technology at airports to improve energy efficiency and reduce negative environmental impacts

Source: compiled by author.

Table 1. Advantages and disadvantages of implemented airport energy technologies

Type of energy technology at airports	Advantages	Disadvantages
Solar energy	- Free energy source: Solar energy is free and inexhaustible. - Environmentally friendly: Generating electricity from solar panels does not emit greenhouse gases or other pollutants. - Grid-independent: An airport can reduce its dependence on traditional energy sources by having its own solar energy system.	- Dependence on weather conditions: Electricity production from solar panels depends on the availability of solar radiation, so it can be unpredictable in some regions. - High upfront costs: Installing solar panels requires a significant investment, although the cost of solar technology decreases over time.
Wind energy	- Environmentally clean: Generating electricity with wind turbines does not produce greenhouse gases or other emissions. - Renewable energy source: Wind is a renewable resource that is available in many regions. - Potential for self-sufficiency: Airports can use wind to generate their own electricity, reducing dependence on external suppliers.	- Wind Dependency: Electricity generation from wind turbines is dependent on the availability of sufficient wind speeds and their performance may be intermittent. - Visual impact: Wind turbines can be tall and occupy a significant amount of space, which can cause problems with the visual aspect of the surrounding area.
Energy efficient lighting	- Energy savings: LED lamps consume less energy than traditional lamps and have a long lifespan, resulting in energy savings and cost savings. - Great upgrade potential: Replacing old lamps with LED lamps is a relatively easy and affordable upgrade.	- Initial costs: LED lamps can be more expensive to purchase than traditional lamps, although their prices decrease over time. - Limited choice: Some LED lamps may have a limited choice of colors or color temperatures, which can be a limiting factor when creating a particular lighting atmosphere.
Energy efficient air conditioning	- Energy savings: Energy-efficient air conditioning systems can reduce energy consumption and the cost of heating and cooling buildings. - Improved comfort: More precise control of airflow and more efficient distribution of heat and cooling can create a more comfortable environment for occupants and staff.	- High initial costs: Energy efficient air conditioning systems can be more expensive to install and require additional investment. - Regular maintenance required: Regular maintenance and inspection is required to ensure optimum system performance.
Management of energy consumption	- Energy optimization: Energy management systems enable real-time monitoring and regulation of energy consumption, allowing inefficiencies to be identified and energy use to be optimized. - Energy savings and cost savings: More efficient use of energy can lead to lower energy consumption and lower operating costs.	- Initial costs: Installing an energy management system can require a significant investment. - Implementation complexity: Implementing and customizing an energy management system can be challenging, especially for older buildings or systems.
Geothermal energy	- Low operating costs: Geothermal systems typically have low operating costs and require less maintenance than other heating and cooling systems. - Environmentally friendly: Geothermal energy produces no greenhouse gas emissions or other pollution. - Weather Independence: Geothermal systems have little dependence on external factors such as solar activity or wind speed.	- High initial costs: Installing a geothermal system can be more expensive, especially if well drilling or piping is required. - Limited availability: Geothermal systems may not be available in all regions and may require certain geological conditions.

Source: compiled by author.

The introduction of some ecotechnologies may require changes to the existing airport infrastructure. For example, the installation of charging systems for electric vehicles may require the installation of additional electric stations or modifications to car parks. These changes can be complex and require significant investment and time. There may also be limitations on the part of the authorities, for example some countries or regions may have specific rules and regulations that make it difficult or slow the introduction of new technologies or require special authorizations and certifications.

However, despite these barriers, many airports continue to successfully adopt ecotechnologies, recognizing their long-term sustainability and energy efficiency benefits. Overcoming these barriers requires collaboration between stakeholders, including airports, government organizations, technology companies and environmental groups, as well as the development of innovation and financial support from governments and investors.

Conclusions and prospects for further research

Based on the research conducted, the following conclusions can be drawn:

1.The utilization of renewable energy sources, such as solar and wind power, allows airports to reduce their dependence on fossil fuel-based energy sources. This helps to diversify the energy portfolio and reduce risks associated with price fluctuations and fuel availability.

2- Ecotechnologies at airports contribute to the reduction of greenhouse gas emissions such as carbon dioxide (CO2). The use of renewable energy sources and improvements in energy efficiency help to minimize negative impacts on the climate and the environment.

3. The introduction of ecotechnologies enables airports to reduce energy consumption and operating costs. For example, the use of energy-efficient lighting, air conditioning and improved energy management systems can reduce energy costs and improve resource efficiency.

4. The adoption of ecotechnology in airports stimulates innovation and technological advancement. Airports are important sites for testing and applying new solutions such as solar panels, wind turbines, fuel cells and energy management systems. This promotes the development of sustainable technologies and can lead to their wider use in other areas.

5. Airports that successfully implement ecotechnologies act as leaders in sustainability and serve as examples for other airports and organizations. Their experience and best practices can inspire other sectors to adopt similar measures to reduce their environmental impact.

Overall, the adoption of ecotechnology in airports is an important step towards a more sustainable aviation industry. It helps to reduce greenhouse gas emissions, improve energy efficiency, and stimulate the development of innovative solutions. These measures help to balance the needs of aviation with environmental protection and contribute to a more sustainable development.

Further research on ecotechnology at airports aims to investigate the challenge of introducing electric transport on the aerodrome, including electric buses, lorries and technical equipment, which will look at the potential of electric transport to reduce emissions and improve air quality on the aerodrome.

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ЕКОТЕХНОЛОГІЧНИЙ ІМПЕРАТИВ РОЗВИТКУ МІЖНАРОДНИХ АЕРОПОРТІВ

Анотація

Вступ. Ідеологія екотехнологічного імперативу зазвичай відноситься до ідеології або концепції, що акцентує на необхідності розвитку та використанні екологічно стійких технологій та інновацій для досягнення екологічної стійкості та зниження негативного впливу на довкілля. Особливо актуальним це є для аеропортових комплексів, які значно впливають на навколишнє середовище. Такий підхід до використання ощадних технологій і їхня мінімізація впливу на навколишнє середовище вимагає пошуку альтернативних, ефективних і екологічно безпечних рішень. Застосовування інноваційних технологій максимально знижують використання природних ресурсів, викиди забруднювальних речовин та інші негативні впливи.

Мета. Дослідження концептуальних та теоретичних питань реалізації екотехнологічного імперативу розвитку аеропортів світу, вплив новітніх екотехнологій у сфері забезпечення сталого розвитку аеропорту, цифрових технологій керування екологічною безпекою, з метою мінімізації зменшення негативного впливу на оточуюче середовище.

Метод (методологія). Теоретичною та науково-методологічною основою дослідження стали положення концепції екотехнологій, що ґрунтуються на ідеї використання передових наукових та технічних розробок для вирішення екологічних проблем та досягнення сталого розвитку.

У процесі дослідження використано такі методи та підходи як: метод системного аналізу – розгляду екотехнологій як частини системних взаємодій екосистеми аеропорту; логічного узагальнення і синтезу – формування основних висновків і пропозицій дослідження; графічний – візуалізації результатів ідентифікації основних переваг використання енергетичних технологій в аеропортах для підвищення енергоефективності та зменшення негативного впливу на навколишнє середовище.

Результати.

У статті визначено, що впровадження енерготехнологій в аеропортах може призвести до таких результатів як скорочення енергоспоживання, зниження операційних витрат, зниження викидів парникових газів, покращення суспільного іміджу, а також зростання екологічної обізнаності та розвитку енергетичного сектору країни загалом. Поведений аналіз дозволив дійти висновків, що впровадження енерготехнологій в аеропортах має потенціал не лише скоротити енергоспоживання та операційні витрати, а й сприяти більш екологічно стійкій та ефективній роботі аеропортів. Представлені переваги використання енергетичних технологій в аеропортах призводять до підвищення енергоефективності та зменшення негативного впливу на навколишнє середовище. Представлена класифікація впроваджуваних екотехнологій для аеропорту із зазначенням переваг та недоліків кожної з них, може стати динамічним і стратегічним інструментарієм прогнозування та впровадження майбутніх проектів у розвиток інфраструктури аеропорту.

Ключові слова: альтернативні джерела енергії; аеропорт; навколишнє середовище; екотехнології; енергоефективність аеропорту.

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