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# Green Airports: How to Combine Eco-Engineering Solutions, Social Responsibility and Economic Benefits

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**ABSTRACT**

Aviation produces at least 5% of global carbon and pollutant emissions. The green, sustainable, eco-friendly and silent airport concepts' implementation makes it possible to strengthen the aviation's contribution to the sustainable development agenda. **The aim** of the study is to systematize technically feasible engineering solutions for a complex object of air transport infrastructure, which lead to an increase in the project cost of construction or reconstruction, but at the same time reduce air pollution, noise, wastewater, waste, electricity and water, taking into account prolonged social and economic effects. **Methods**: a) drawing up a heat map of the appropriate solutions for airport facilities (terminal, airfield, airfield area, and hangar); b) selection and critical evaluation of engineering solutions to reduce emissions in the terminal and airfield design and construction with a forecast of economic benefits. **Findings** of the study reveal the confirmation of the advantages of implementing eco-engineering solutions for a green airport, including eco-design and data management, monitoring and forecasting energy consumption, water supply, technical parameters of airport operations to ensure flights and passenger safety in conditions of increased flight intensity, performed in the form of a critical assessment of the effects, and show the ranges as reducing the carbon footprint, as well as savings on future operating costs with objective financial constraints in the airport construction or reconstruction. **Conclusion.** The future savings effect provides an economic incentive, in addition to following responsible behavior, to build new carbon-neutral airports, combining concern for the environment, aviation safety, passenger comfort and the well-being of local residents.
***Keywords:*** green airport; innovation; project management; construction economics; sustainability management; effectiveness; airport terminal engineering; social responsibility; transport safety; eco-design

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ОРИГИНАЛЬНАЯ СТАТЬЯ

# «Зеленые» аэропорты: как совместить эко-инженерные решения, социальную ответственность и экономическую выгоду

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**АННОТАЦИЯ**

Авиаотрасль производит не менее 5% всех мировых выбросов углерода и загрязняющих веществ в атмосферу. Реализация концепций «зеленого», устойчивого, эко- и тихого аэропорта позволяет усилить вклад авиаотрасли в повестку устойчивого развития. **Целью исследования** является систематизация технически возможных к реализации инженерных решений сложного объекта авиатранспортной инфраструктуры, которые ведут к увеличению стоимости проектов строительства или реконструкции, но при этом обеспечивают снижение загрязнения воздуха, шума, сточных вод, отходов, потребления электричества и воды,

с учетом пролонгированных общественного и экономического эффектов. Исследование выполнено с использованием **методов:** а) составления тепловой карты для определения целесообразности и реализуемости инженерных решений для объектов аэропорта (терминал, аэродром, приаэродромная территория, ангар); б) отбора и критической оценки инженерных решений по снижению выбросов как при проектировании и строительстве терминалов, так и на аэродромной территории с прогнозом экономической выгоды. **Результаты исследования** включают определение преимуществ реализации эко-инженерных решений для «зеленого» аэропорта, включая экодизайн и управление данными, контроль и прогнозирование энергопотребления, водоснабжения, технических параметров деятельности аэропорта для обеспечения полетов и безопасности пассажиров в условиях повышения интенсивности авиарейсов, выполненное в форме критической оценки эффектов, и показывают диапазоны как снижения углеродного следа, так и экономии на эксплуатационных расходах в будущем при объективных финансовых ограничениях в строительстве или реконструкции аэропортов. **Вывод:** эффект будущей экономии дает экономический стимул, помимо следования ответственному устойчивому поведению, строить новые углеродно-нейтральные аэропорты, объединяя заботу об окружающей среде, безопасность авиации, комфорт пассажиров и благополучие местных жителей.

***Ключевые слова:*** «зеленый» аэропорт; инновации; управление проектами; экономика строительства; управление устойчивым развитием; эффективность; проектирование терминала аэропорта; социальная ответственность; транспортная безопасность; экодизайн

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## Introduction

The aircraft industry and air transportation represent a combination of progressive, innovative technologies, with a history spanning over a century that includes the creation of civil airliners and combat aircraft, showcasing remarkable technological achievements and the development of reliable equipment that provides people with freedom and speed of movement. These industries have become leading for the economies of countries where the largest aircraft companies are located, as well as international airports and transport hubs of global importance, each of which has a passenger traffic of 50 to 100 million people per year. All this contributes to the development of the aircraft industry, transport, and the economy as a whole and to GDP growth; enhances the image of countries as logistics and tourism centers; and can act as a tool of soft power in political matters [1].

At the same time, airplanes are not an environmentally friendly mode of transport. Moreover, aircraft engines in the sky emit tons of carbon dioxide, water vapor and other pollutants from the combustion of aviation fuel and solids from engines. The design of large airliners provides for the possibility of dumping fuel in emergency situations to avoid disasters. Thus, about 50% of emissions are carbon oxides, 46% nitrogen oxides, 3% hydrocarbons and volatile organic compounds, and about 1% solid emissions. These are the factors accelerating global warming.

At the same time, airports represent territories and facilities on earth with very unfavorable ecology [2], and terminals and airfield infrastructure facilities generate $CO_2$ and NOx emissions of at least 5% of all air transport emissions and consume huge amounts of electricity, which are comparable to the energy consumption of a small city [3], and are sources of waste. In addition to air pollution, airports are a source of increased mechanical and aerodynamic noise and vibrations, which is another significant factor affecting human health [4].

Airport compliance with sustainability principles has become a particularly acute problem in the post-pandemic period [5]. During the harsh reality of the COVID-19 pandemic, civil aviation returned to its 1999 levels, flights around the world were suspended, and passenger flights decreased significantly by 60% on average worldwide [6]. The environmental situation around airports improved, leading to a nearly 50% reduction in carbon emissions and pollutants released into the atmosphere in 2020. But as the pandemic receded and air travel gradually recovered, airports' sustainable development, which contributes to an increased carbon footprint in the atmosphere, began to rise significantly again [7]. And the issue of reducing emissions from aviation transport is becoming more important than ever due to the movement of countries and industries toward carbon neutrality.

Modern airports are not only multi-transport hubs, but they have also become mini-cities today

[8], including shopping, hotel and business complexes, industrial zones and logistics centers that consume huge amounts of electricity that increase with digitalization [9]. Airports typically reside in the suburbs, yet they maintain a connection to the vibrant rhythm of life in cities and megacities. Therefore, there should be not only a certain integration with urban planning and construction policy but also the inclusion of airports in the city's green building [10]. In this case, the airport's design or reconstruction becomes not just a new project but the implementation of an integrated systematic approach to the sustainable development of territories with the priority of an ecological element.

The implementation of the environmental aspect of sustainable development [11] has led to the formation of the green airport concept [12] as an engineering and architectural facility that reduces the negative impact on the environment in the fields of air pollution, waste production, electricity and water consumption, and noise reduction.

The positions of experts on green airports are quite interesting in their desire to combine concern for the environment, aviation safety and the well-being of users, i.e. passengers of airliners and residents in the vicinity of the airport. Thus, social justice is formed. Objectively, noise and physical restrictions lead to lower housing prices near the airport [13].

That is why it is so important to identify a green airport as an object with certified architecture. This is facilitated by the development of international and national green building certifications [14] that exist in different countries of the world and encourage the use of eco-friendly and renewable energy sources. It is important to see the relationship between urban planning, when the city is focused on green building construction, and the functioning of airports as green facilities with a high degree of environmental friendliness and minimal possible impact on nature and society.

The emergence of the sustainable airports identification [15] should be considered innovative since the recognition of the importance of sustainable development objectives is carried out in relation to facilities that are important for different spheres of society — architecture, economics, transport, science and technology, healthcare, etc. A modern sustainable airport is a large area with buildings that are managed responsibly and efficiently and do not harm the environment and people, preserving natural resources — this is what determines the airport's effectiveness [16].

In this regard, the study would be incomplete without stating that the aviation industry itself is focused on eco-friendliness. Major aircraft manufacturing companies are developing new types of aircraft engines in an effort to reduce carbon dioxide emissions in the atmosphere and generally reduce the amount of aviation fuel burned. Their efforts are also focused on the use of environmentally friendly aviation fuels (both synthetic fuels and biofuels) — sustainable aviation fuel (SAF) — in order to achieve the industry's zero emissions target by 2050 [17]. SAF is able to reduce carbon emissions into the atmosphere by up to 65% and is already present in 31 countries (mainly in Europe and South America, where government support for the aviation industry is significant). More than 100 manufacturers produce such fuel in the amount of 51 million tons. This fuel is a good contribution to improving the eco-friendliness and sustainable development in aviation and a technical and economic solution, since no changes are required to the aircraft refueling infrastructure.

In their identification, green airports emphasize an important connection with the support of nature and the use of alternative energy sources — the term "eco-airport" is also used to strengthen this position [18]. In addition to the environmental and technological components in its architecture and engineering communications, an eco-airport must also be economically optimal and comply with socio-cultural values and social responsibility [19].

According to expert estimates by the Airports Council International (ACI WORLD) and the International Civil Aviation Organization (ICAO),[1] passenger traffic has recovered by the beginning of 2025 and is now above the pre-pandemic level and will double to 19.5 billion people by 2042. It is predicted that the Asia-Pacific region (especially India, China, Indonesia) will become the fastest-growing market due to the development of air travel and the construction of a new air infrastructure. Therefore, the concept of a smart airport [20] as safe for passengers has become popular now [21].

Despite the significantly similar concepts of a green, sustainable, eco-friendly, smart and silent airport, this study will use the green airport defini-

[1] ACA — Airport Carbon Accreditation: Joint ACI WORLD-ICAO passenger traffic report, trends, and outlook. URL: https://aci.aero/2025/01/28/joint-aci-world-icao-passenger-traffic-report-trends-and-outlook (accessed on 28.06.2025).

tion as an airport that is designed, built and operated using environmentally sustainable practices aimed at minimizing negative environmental impacts through reducing greenhouse gas emissions, efficient use of resources, waste management and conservation of biodiversity for the people's well-being and benefit.

Objectively, geopolitical conflicts are becoming very noticeable and affect the organization of flights and deliveries of airliners, but forecasts of global passenger traffic growth, the success of environmentally friendly aircraft manufacturers, and increasing their profitability are becoming a driver of airport upgrades, such as new terminals and airfield areas being built and existing airports being upgraded to create new business models [22]. There is also a tendency to build multimodal transport centers, where the airport will be one of the facilities providing transfers [23]. An increase in the number of airports should be a green trend [24] and projects with excellent profit [25], because an increase in the number of flights and the number of passengers should not lead to an increase in the negative effect on nature.

Technologies that ensure energy conservation and energy efficiency for carbon-neutral airports, water and waste management, and the use of alternative energy sources are so important that everything related to aviation not only brings reliability, mobility, and speed but is also associated with a green contribution to the development of society.

Therefore, the aim of the study is to systematize technically feasible engineering solutions for a green airport, which is a complex component of sustainable air transport infrastructure. This approach may increase the project cost of construction and reconstruction while simultaneously reducing air pollution, wastewater, waste, electricity and water consumption, and noise, all while considering prolonged social and economic effects.

## Materials and methods

The analysis of regulatory requirements, standards and the current state in the airport sector in different countries of the world was carried out on the basis of open data on official Internet sites from Airports Council International (ACI WORLD), Airports Council International Europe (ACI EUROPE), ACI Asia-Pacific & Middle East (ACI APAC and MID), Airport Carbon Accreditation (ACA), CAPA Centre for Aviation, International Civil Aviation Organization (ICAO) and the special program Carbon Offset and Reduction Scheme for International Aviation (CORSIA). This approach makes it possible to significantly increase the validity and reliability of the conducted research.

The study is based on reliable open data — there are 52,128 airports of various structures, large and small, public and private, in the world at the beginning of 2025. The largest number of airports is in the USA — 15,873. This is followed by 4,919 in Brazil, 2,180 in Australia, 1,485 in Mexico, 1,425 in Canada, 1,043 in the UK, 904 in Russia, 838 in Germany, 756 in Argentina, 689 in France.[2] In 2025, 2,181 airports in 170 countries were registered in ACI WORLD. Airports are typically certified in the quality management system based on the international standard ISO 14001:2015, which creates genuine opportunities to mitigate environmental harm, lower the risks of emergencies in airport buildings and other transport infrastructure facilities, and address environmental issues, including minimizing the extent of their consequences.

International airport certification, precisely from the perspective of achieving sustainable development goals and implementing a systematic and sound integrated approach, is most developed in Europe, where the Airport Carbon Accreditation (ACA) has been operating since 2009 based on the initiative of ACI WORLD. Since 2014, after the International Civil Aviation Organization (ICAO) joined this initiative, ACA has become a global program for the active management of carbon emissions at airports based on targets on 5 continents of the world. It is important that the program be based on an independent review by experts from 36 countries, which provides an opportunity to see both best practices (for example, modernization of lighting, water supply, heating, ventilation and air conditioning systems) and challenges in the implementation of sustainable airport development. The ASA classifies airports according to seven certification levels: Mapping, Reduction, Optimization, Neutrality, Transformation, Transition and Net Zero. There are 645 ACA-accredited airports in 97 countries worldwide[3]; 286 in Europe,

[2] Airports by Country 2025. URL: https://worldpopulationreview.com/country-rankings/airports-by-country (accessed on 28.06.2025).

[3] ACA — Airport Carbon Accreditation: Accredited Airports across the world. URL: https://www.airportcarbonaccreditation.org/accredited-airports (accessed on 28.06.2025).

and 21 airports located in India, Finland, Portugal, Sweden, and the Netherlands have the highest level of Level 5.

The "Eco-friendly Airport" electronic collection developed by the International Civil Aviation Organization (ICAO)[4] is important as a methodological basis for airport infrastructure development. These are not only environmental planning and design tools, but also specific recommendations for investors in the construction of sustainable buildings in order to not only make a profit but also create value and confirm responsible decisions.

Financing for the modernization of airports to the minimum optimal level of an eco-airport is carried out within the framework of the Voluntary Airport Lower Emissions (VALE) subsidy program, which improves air quality for ozone and carbon monoxide mainly through the purchase of ground vehicles for passenger service and liners with low levels of greenhouse gas emissions and noise.

The above-mentioned materials, methods and standards are the basis for the systematization of eco-engineering solutions that are used in the context of this study to identify technologies for the construction or modernization of green airports. The information data for recording was obtained based on the analysis of reports on sustainable development and environmental impact of ACA-certified green airports.

The study was carried out using the method of critical assessment and systematization of approaches to the implementation of projects to reduce environmental impact both in the design and engineering solutions of terminals and in the organization of ground operations in the airfield area with a forecast of the range of effects achieved in terms of reducing emissions and waste. At the same time, the criterion for selecting engineering solutions that are systematized by the heat map method is the economic criterion (range of reduction of future operating costs) — initially, the cost of building a new airport or its reconstruction or modernization is a capital expenditure. But it will be compensated in the future by saving on current expenses, which is confirmed by the use of cost-benefit analysis (CBA) and life cycle assessment (LCA). This approach allowed us to identify the prolonged effect over time as an investment and the value for eco-protection as a global public and local social effect.

[4] ICAO. Eco-Airport Toolkit e-collection. URL: https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx (accessed on 28.06.2025).

## Results

### The conceptual framework of eco-protection engineering solutions for a green airport

The modern airport construction is not only always an original project with a striking architectural design, but also a technically complex project, conditionally lengthy and requiring significant investments. It is also a project that assumes compliance with green trends in modern conditions — and at least certification according to green standards gives a significant competitive advantage and a positive public image. Therefore, this study is aimed at systematizing approaches to the implementation of eco-protective engineering solutions in order to build or reconstruct airport buildings and territories in the green airport format, based on data from annual reports of certified green airports in different countries of the world and the ACA database (*Table 1*).

The importance of implementing eco-engineering solutions, however, raises the question of their expediency and application to various architectural and construction projects related to the airport. The heat map is a useful tool for presenting the types of these solutions for a green airport (*Table 2*) during new construction or reconstruction, which will be meaningfully disclosed later in the results of the study.

### Architectural solutions

Passive design architectural solutions are used for green airports, which allow for achieving energy efficiency objectives. These solutions include creating indoor spaces with maximum natural light, using natural ventilation and thermal insulation. In practice, it is possible to achieve several goals: energy efficiency, first of all, but also the creation of an open-space atmosphere and the involvement of travelers in the life of air transport. So, a project with energy-efficient glazing on building facades will provide maximum thermal insulation and, therefore, reduce operating costs later.

In existing green airports, it has already become an architectural rule to create green areas in terminals and on terminal roofs to improve air quality and water flow management. It's beautiful in design, eco-friendly, and energy-efficient.

Table 1
*ACA-certified green airports*

| Airport | Country | Level of Accreditation | Renewable energy (%) | Passenger traffic (million people per year) | Reduction of $CO_2$ (thousand tons per year) | Solar panels (MW) | Recycling of waste (%) | Water saving (%) |
|---|---|---|---|---|---|---|---|---|
| Stockholm-Arlanda Airport | Sweden | Net Zero (5) | 95 | 19.8 | 380 | 15 | 88 | 50 |
| Amsterdam Schiphol | Netherlands | Net Zero (5) | 70 | 71.7 | 680 | 25 | 87 | 40 |
| Helsinki Airport | Finland | Net Zero (5) | 85 | 20.8 | 290 | 10 | 85 | 52 |
| London Gatwick | United Kingdom | Transition (4+) | 60 | 40.9 | 410 | 18 | 83 | 48 |
| Chhatrapati Shivaji Maharaj (Mumbai International Airport) | India | Transition (4+) | 100 | 43.9 | 300 | 40 | 85 | 60 |
| San Francisco International | USA | Transformation (4) | 65 | 57.0 | 520 | 8.5 | 92 | 45 |
| Oslo Airport | Norway | Optimization (3) | 90 | 28.5 | 450 | 12 | 90 | 55 |
| Munich Airport | Germany | Optimization (3) | 75 | 47.9 | 470 | 22 | 89 | 55 |
| Singapore Changi | Singapore | Optimization (3) | 55 | 68.3 | 550 | 35 | 91 | 65 |

*Source:* Compiled by the authors based on the data: ACA. Airport Carbon Accreditation Annual Reports. 2023–2024. URL: https://www.airportcarbonaccreditation.org/media/annual-reports (accessed on 09.10.2025); Chhatrapati Shivaji Maharaj Airport paves the way for a sustainable future. International Airport Review, 18.03.2021. URL: https://www.internationalairportreview.com/news/154935/chhatrapati-shivaji-maharaj-airport-sustainable-future (accessed on 09.10.2025); Avinor's Annual and Sustainability Report 2024. URL: https://om.avinor.no/siteassets/barekraft/avinor_ars – og-barekraftsrapport_2024.pdf (accessed on 09.10.2025); Swedavia. Annual and Sustainability Report 2022. URL: https://www.swedavia.com/about-swedavia/sustainability/ (accessed on 09.10.2025); San Francisco International Airport. Reports and Documents. URL: https://sustainability.flysfo.com/reports (accessed on 09.10.2025); Amsterdam Schiphol Airport. Sustaining Your World. URL: https://www.schiphol.nl/en/sustainability/road-to-the-most-sustainable-airports (accessed on 09.10.2025); FinAvia. Air quality and emissions. Helsinki Airport is carbon neutral. URL: https://www.finavia.fi/en/about-finavia/sustainability/sustainable-air-traffic/air-quality-and-emissions (accessed on 09.10.2025); Finavian vuosikertomus 2024. URL: https://www.finavia.fi/fi/tietoa-finaviasta/taloustiedot/vuosikertomukset/2024?navref=paragraph (accessed on 09.10.2025); London Gatwick Airport. Net Zero Roadmap. Towards Net Zero (Scope 1 & 2) Emissions 2030. May 2024. URL: https://www.aci-europe.org/downloads/content/London%20Gatwick%20-%20Net%20Zero%20Roadmap.pdf (accessed on 09.10.2025); Munich Airport. Environmental Statement 2023. URL: https://www.munich-airport.com/_b/0000000000000029038172bb673df76a/environmental-statement-2023-en1.pdf (accessed on 09.10.2025); Munich Airport. Our path to a CO2-free future. URL: https://www.munich-airport.com/net-zero-19071587 (accessed on 09.10.2025); Changi Airport Group. A Sustainable Changi – connecting and conserving our world. URL: https://www.changiairport.com/en/corporate/our-sustainability-efforts/environment.html (accessed on 09.10.2025).

In the projects of new airports, it is possible to implement ideas for organizing the airport terminal area as open spaces for passengers to move. This engineering creates the potential for optimal lighting (up to automatic on/off by motion sensors) but also allows optimization of the heating and ventilation systems by organizing the flow of passengers.

The airport area design for a green airport (although this should be considered more for a sustainable airport) should be carried out with the organization of platforms for public transport — buses and express trains. Despite the fact that modern airports are located in the suburbs, the organization of communication with the city (or even the metropolis) is an important part of the work

Table 2

*Heat map of the application of eco-protection engineering solutions for various facilities of the green airport*

| Intensity of solution's application | Terminal | Airfield | Airfield territory | Ground facilities | Hangars and maintenance bases for aircraft and equipment |
|---|---|---|---|---|---|
| Architectural solutions | | | | | |
| Eco-friendly materials | | | | | |
| Energy consumption | | | | | |
| Water supply | | | | | |
| Wastewater treatment | | | | | |
| Waste management | | | | | |
| Noise reduction | | | | | |

*Designations:*

mandatory application; recommended application; conditional application

of space designers. Passengers need to be offered eco-friendly transportation options, unlike their own cars or taxis, and public transport effectively solves this problem (especially if it is, for example, electric buses or high-speed railway express trains). At the same time, an interesting alternative solution should be to organize convenient parking spaces, for example, for electric or hybrid cars. This psychological approach, combined with an architectural solution, creates the right background and supports initiatives by citizens and travelers to use environmentally friendly vehicles. Using such organizational solutions significantly reduces the environmental impact.

## The use of eco-friendly materials

The choice of eco-friendly materials and materials that require minimal maintenance (this is important for airport staff) plays a crucial role in airport terminal design, as it significantly reduces the carbon footprint from airport construction and further operation. Architects prefer materials with low energy consumption (as a rule, recycled materials). It is very important to follow a strategy of using local materials in order to support local manufacturers and take into account the traditions of the country or region of the air harbor location in the design.

A separate solution should be considered: the use of eco-friendly asphalt to cover the runway (for example, concrete with the addition of volcanic ash) — this is an innovative approach but requires very significant financing. This solution cannot be considered affordable for most airports. More comprehensive expertise is also required to ensure technical safety. But technologies are developing, and in the near future, eco-friendly materials will not only be universal for building construction but also for creating complex technical infrastructure facilities, increasing their technical properties and environmental friendliness.

## Ensuring low energy consumption

The airport requires a large amount of energy to operate, which is used for lighting areas, ventilation and air conditioning systems, maintaining security, and many other tasks. Such high energy consumption can lead to significant costs and a negative impact on the environment. This scenario means that it is necessary to design an electrical system with a sufficiently high level of energy efficiency and energy conservation.

At the same time, a large amount of the necessary energy for airport operations must be produced by energy sources — therefore, to comply with eco protection, it is crucial to use alternative energy sources such as solar energy (photovoltaic panels), wind energy (wind turbines), hydropower and even thermal water energy. Depending on the geographical location of the airport, certain renewable energy sources may be available. From an economic point of view, such initiatives can

bring a reduction in operating costs for electricity consumption. But it is also necessary to take into account the possibilities of bio-design or eco-design in modern green airports. This is not only original and aesthetically pleasing and attracts passengers temporarily staying in the terminal while waiting for a flight but also creates an eco-image of sustainability and environmental responsibility.

The terminal uses different lighting systems. Also, a huge number of energy consumption sources are located on the runway, at the airfield and in the airfield area. The various electrical and light signaling systems, radio receivers, lighting and technical support ensure the technical operation of the airport and flight safety; therefore, it must receive additional backup internal autonomous power supply to two external power sources. The sources of internal power supply can be both alternative energy sources and traditional backup diesel power plants. In the context of this study, alternative energy is a priority, but it is necessary to take into account the uninterrupted functioning of the airport's lighting and alarm systems, especially on the runway, which is provided by a traditional energy source.

An automatic control system is appropriate and economically beneficial for the airport's energy consumption as part of achieving sustainable development goals. This system includes a set of technologies and algorithms that optimize energy use and reduce costs. Automatic energy management systems can monitor and adjust the operation of lighting installations, control heating and air conditioning systems, passenger flow control systems, and monitor the energy efficiency of various systems and equipment.

Given the importance of managing operating costs, as well as taking into account the impact of power equipment and appliances on carbon emissions into the environment, such a function as flexible control of energy flows allows one to control the operation of all electrical devices in real time to reduce energy consumption based on the data analysis and enable energy-saving modes as needed, depending on the daytime, weather conditions, the presence of people on the premises, changes in flight density or changes in passenger traffic, and schedule changes.

It is especially important to note the use of microprocessor controllers, sensors and sensors for monitoring temperature, illumination and other parameters in the power supply system (lighting, air conditioning and supply and exhaust ventilation, operation of escalators, travelators and automatic doors) in various areas of the airport (waiting area, workrooms, etc.) and airfield territory, allowing you to make the airport not only green but also progressive in terms of applied technologies. At the same time, the comfort of the working conditions of the airport staff and airline representatives and the safety of passengers and crew members of airliners should not be violated in any way. A special area of responsibility is the provision of power supply to the dispatch service and the technical complex for take-off and landing of aircraft in order to prevent emergency situations.

Special attention is paid to the system of technical flight support systems at the airport. The energy supply of video surveillance systems, radars, communication and navigation systems and security systems, including biometric control and inspection areas, is a field of work that requires competent optimization. As a rule, high-tech and expensive equipment and devices are used here, which must work smoothly and ensure safety for people. Therefore, backup energy supply should be organized in parallel with alternative energy sources, however, savings in operating costs do not matter here, as opposed to the importance of eco-friendliness of energy consumption solutions.

The development of modern technologies, in particular artificial intelligence, should also find application in complementing the functionality of an automatic energy consumption system for a green airport. For example, algorithms and artificial intelligence process historical data on energy consumption, weather conditions, passenger traffic, and the number of flights, make forecasts, and optimize control of lighting, heating, air conditioning, and ventilation to adapt (minimize) energy consumption during peak periods. This is one of the main functions for a green airport — to reduce energy consumption without prejudice to its activities as a complex technical complex for passenger and airplane services, which means it will increase energy efficiency.

## Water supply organization

The airport utilizes its water resources in a continuous water supply system for various tasks: a) wa-

ter for household and technical needs, including maintenance in the terminal, aircraft maintenance and runway irrigation; b) drinking water; c) water for firefighting, the volume of which must be at least 5,000 $m^3$.

When planning the terminal building, it is necessary to provide for blocking the water supply in emergency situations based on the organization of water supply in the airport terminal areas, as well as to provide for the organization of reuse of water resources. For example, through connection to the ring water supply system of the fire extinguishing system or reuse of water for toilets in the organization of dual water supply. These responsible engineering solutions can help reduce the use of water resources.

To save energy, hot water supply may not be used or used in limited quantities only at large airports when providing services to passengers and for the needs of companies providing catering services at the airport.

An interesting solution to provide passengers with drinking water and, at the same time, an environmentally friendly solution is the organization of drinking fountains at the airport — this reduces the consumption of water in plastic packaging.

Water supply at the airport is usually characterized by constant volumes; therefore, individual eco-engineering solutions are able to contribute to the concept of a green airport, forming sources for eco-responsible behavior of airport owners.

## Wastewater treatment

The airport, using water resources, is a source of wastewater generation — as a rule, due to the use of water for technical purposes all year round when stormwater runoff is formed and the formation of toxic wastewater in winter when deicing treatment of airplanes is carried out. After accumulating pollutants on airplanes during its operation, the wastewater then contains large amounts of petroleum products, various chemicals that are difficult to clean, and metal dust.

Based on the structure of the effluents, their purification systems should be provided:

- standard cleaning for storm drains;
- multi-stage wastewater treatment in winter and spring from snowmelt;
- special cleaning for industrial effluents from deicing liquid for aircraft and reagents for the runway in the cold season.

Sewage treatment plants are designed together with the construction of the main terminal or are planned during the reconstruction of the airport — this ensures systematic activities to reduce the impact of airport wastewater pollutants. It is also necessary to provide a cleaning system and a special algorithm for actions in case of accidental spills of aviation fuel at the airport, since a very high concentration of petroleum products is formed here and rapid actions are required to prevent damage to the environment.

## Waste management

In the airport construction or reconstruction project, it is absolutely necessary to provide a waste management system, from waste collection to recycling. Of course, the aspects of waste management are most pronounced during the departing and arriving aircraft flights, but this system should be designed before the airport opens in the form of special facilities for sorting, composting and recycling waste — because it is cheaper and, above all, more rational for the realization of environmental responsibility to society.

One of the modern solutions at airports can be considered — the introduction of a strategy of a "paperless" system for selling tickets and boarding passes for passage to the screening areas and further clean areas of the airport and for boarding. This solution is primarily based on the use of digital technologies and contributes to the competitiveness and convenience of most passengers, but it is in the context of a green airport that this solution, as well as the use of biodegradable dishes for passenger meals, can contribute to the creation of a certain model of responsible behavior for aviation customers.

## Noise reduction

Noise from airplanes seriously affects the health and well-being of people living in the vicinity of the airport. No matter how positive the emotions of being able to make fast and comfortable flights are, an airplane is not only a source of emissions into the atmosphere but also a source of noise and acoustic discomfort. This phenomenon is especially true with the growth of passenger traffic and the increase in the number of flights during the day and at night. Just like the vehicles that ply the airfield and transport passengers, baggage, or

technicians, they have the same sources of negative impact.

Airports make audio announcements, which creates background white noise and increases stress and strain on the hearing aids of passengers and airport staff. To reduce the negative effect, some airports are abandoning sound announcements — these are the so-called silent airports. Unfortunately, this strategy may result in higher energy consumption due to the increased number of information monitors required for passenger convenience.

Automated electric buses and transport cars have already begun to be used at modern airports, and robots are also being used to check the condition of engineering communications and facilities and the condition of the runway. They are eco-friendly and silent, which creates a new solution to enhance the airport's environmental friendliness.

Special noise-canceling materials and fences should be used for residential areas to protect and soundproof and improve the quality of life of people near airports.

While it's not an engineering solution, a very stimulating approach can be applied in collaboration with airlines to mitigate noise pollution from airplanes. These are payments when the number of flights increases, which can be used to reduce noise and improve the acoustic environment around the airport, including for the construction and maintenance of a landscape park.

## Discussion

Green airports are becoming a new reality in order not only to provide flights and organize passengers but also to make their own significant contribution to sustainable development when the aviation industry strives to reduce hydrocarbon emissions to zero by 2050 and implements the trend towards eco-friendliness.

Since its inception, aircraft companies have been and continue to be representatives of the industry of innovation and the development of modern technologies that make it possible to technologically improve aircraft and increase their fuel efficiency. This progress enables airports, as representatives of the aviation industry, to also strive to introduce new technologies that allow them to provide services to passengers and airlines in a new capacity, with an emphasis on using alternative energy sources, reducing environmental impact and reducing emissions into the atmosphere and land, and reducing noise exposure.

A fair and objective limitation for the active dissemination of the green airport concept is the significant amount of investment required for the organization of the design of various architectural and engineering solutions, as well as the purchase of necessary equipment, devices and materials and the execution of construction work.

The use of cost-benefit analysis (CBA) in a conditionally typical green airport project, taking into account the ACA and ICAO[5] requirements and the forecast passenger traffic of 5 million people per year, shows: a) average capital expenditures on eco-engineering solutions are $35–$45 million (including solar panel installation, $15–$20 million; LED lighting and automation $6–$8 million, rainwater harvesting system $3–$5 million, waste management system $2–$3 million, LEED certification $0.5–$1 million); b) benefits per year as savings of $5–$8 million (electricity $3–$5 million, water supply $0.5 million, waste $0.5 million). Thus, the average payback period for eco-engineering solutions for a small green airport will be 9–10 years. For airports with passenger traffic of 50 million people per year and above, the CBA will be complicated by a large number of indicators to evaluate and a longer payback period — however, this circumstance expands the possibilities for green airports.

The recognition of the benefits of implementing eco-engineering solutions for a green airport, carried out in the form of an assessment of the effects (*Table 3*) and with the additional life cycle assessment (LCA) results to assess the environmental impact at all stages from construction to operation of the large green airports from *Table 1* and ACA Level 1 airports,[6] shows both a reduction in the carbon footprint and the possibility of saving on operating costs in the future. This provides an economic incentive, in addition to following responsible sustainable behavior, to build new green airports or reconstruct/modernize existing facilities.

[5] ICAO. Eco-Airport Toolkit e-collection. URL: https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx (accessed on 28.06.2025).

[6] ACA — Airport Carbon Accreditation. Accredited Airports across the world. URL: https://www.airportcarbonaccreditation.org/accredited-airports/

Table 3

*Forecast effects for different eco-protection of airport engineering solutions*

| Solution characteristics | Range of carbon footprint reduction, % | Range of reduction in energy or fuel consumption, % | Range of reduction in emissions of pollutants into the atmosphere or wastewater or waste, % | Range of savings on operating costs in the future, % |
|---|---|---|---|---|
| **Architectural solutions** | | | | |
| Passive design of the airport building / energy-efficient eco-design | 5÷20 | 5÷15 | 2÷10 | 10÷20 |
| Indoor spaces with natural light / Open spaces | 2÷4 | 3÷10 | 1÷2 | 3÷8 |
| Integration with public transport platforms | 8÷20 | 5÷12 | 4÷8 | 3÷5 |
| Using eco-friendly/recycled materials | 5÷20 | 5÷15 | 2÷10 | 10÷20 |
| Landscaping, creation of green areas (walls) and green roofs in terminals | 6÷15 | 1÷2 | 3÷7 | x |
| **Ensuring energy consumption** | | | | |
| Alternative energy sources | 3÷20 | x | 3÷10 | 5÷15 |
| Power supply of electrical and light signaling systems, electrical receivers for flight lighting (three sources) | 2÷3 | 2÷5 | x | 1÷3 |
| Implementation of an automated energy management system based on consumption data analysis and flexible control | 5÷8 | x | x | x |
| LED lighting and motion sensors | 1÷2 | 3÷5 | x | 3÷5 |
| Using microprocessor controllers, sensors, and sensors to monitor temperature, light, and other parameters | 1÷2 | 3÷5 | x | 3÷5 |
| Using artificial intelligence to predict energy consumption and situational optimization of lighting, heating, air conditioning, ventilation control | 2÷5 | x | x | 2÷5 |
| **Water supply organization** | | | | |
| Ring water supply system | 2÷5 | 3÷5 | 3÷15 | 5÷14 |
| Blocking the water supply in emergency situations | 1÷2 | x | x | x |
| Restriction of hot water supply | 3÷8 | 3÷8 | 3÷5 | 5÷10 |
| Drinking fountains for passengers | x | x | x | 1÷2 |
| Rainwater collection system | 2÷5 | x | 3÷5 | 3÷6 |
| **Wastewater treatment:** | | | | |
| Multi-stage wastewater treatment from snowmelt | 3÷5 | x | 5÷20 | x |
| Special cleaning of industrial effluents from deicing liquid for aircraft and runway reagents in the cold season | 3÷15 | x | 5÷20 | x |
| Cleaning system and special algorithm of actions in case of accidental spills of aviation fuel | 3÷10 | x | 3÷10 | x |
| **Waste management** | | | | |
| Waste recycling | 3÷8 | x | 3÷10 | 2÷3 |
| Biodegradable tableware (reducing or banning the use of plastic) | 3÷8 | x | 30÷50 | 3÷10 |
| Paperless sale of tickets and boarding passes | 3÷8 | 3÷5 | 20÷50 | 5÷15 |
| **Noise reduction** | | | | |
| The “quiet airport” concept | 8÷15 | x | x | x |
| Sound insulation structures | 3÷10 | x | 5÷8 | x |
| Silent electric transport and work | 5÷20 | 3÷8 | 5÷20 | 2÷4 |
| Landscape Park | 5÷15 | x | x | x |

*Source:* Compiled by the authors.

The effects were assessed based on an analysis of the actual engineering solutions of green airports in the ACA, ICAO,[7] IATA[8] and ACI[9] certification systems: 1) lower limit of the range fixed as the average among Level 1 airports located in Central Europe to exclude the factor of significant influence of climatic conditions, 2) upper limit of the range fixed as the average among Level 5 airports, including Stockholm-Arlanda Airport, Amsterdam Schiphol, Helsinki Airport (*Table 1*). Calculations of carbon footprint reduction ranges are performed in the ICAO Carbon Emissions Calculator,[10] which allows us to obtain reasonable estimates if we strictly follow the guidelines. The range of future savings on operating costs has been determined by experts.

The study reveals that less than 25% of ACA-registered airports possess green certification or are actively pursuing carbon reduction. This is explained both by financial budget constraints in countries with different socio-economic situations for the airport's construction or reconstruction and by access to modern eco-technologies and equipment to implement eco-engineering solutions for a green or sustainable airport.

Practice shows that each airport is a unique complex structure that takes into account the features of the terrain, the surrounding area, and connections with the nearest urban agglomerations. In order to build an airport, in addition to financing, highly qualified specialists in engineering and technology are required, which are concentrated in developed countries, and it takes time to learn and gain experience in order to implement the green airport concepts in developing countries. There are also certain difficulties with the introduction of new technologies so that they do not violate safety and flight management regulations, as well as airfield area logistics. The population sometimes disapproves of the construction of new airports due to concerns about their livelihoods. Therefore, it is important to work with the public, and the commitment to build a green airport is an important step towards compromise.

Given the difficulties of the airport construction or reconstruction process itself, it should also be noted that carbon management procedures need to be developed, including assessment, monitoring, reporting and planning to reduce the airport's carbon footprint. In fact, in addition to the construction or reconstruction plan, a strategy for the sustainable development of such a green airport should be developed in order to systematically identify key parameters for the development of eco-friendliness and the phased reduction of carbon footprint, taking into account the contribution of each architectural and construction facility of the airport and the functioning processes of all airport services. This approach will allow for step-by-step implementation of tasks in order, for example, to consistently achieve the appropriate ACA certification level.

In general, the integration of aircraft companies and airlines in terms of enhancing corporate social responsibility will be enhanced by interaction with green-certified airports, creating an image of aviation as technologically progressive and socially responsible.

## Conclusion

A green airport is an important response to the modern world with the development of technology and with unprecedented speeds and capabilities. Historically, aviation has given a lot to society — airplanes, transport mobility, travel, etc. But aviation has also significantly affected the state of the atmosphere and the environment, which is why the goal of striving for carbon neutrality by 2050 has been adopted. Upgrading aircraft engines and using environmentally friendly jet fuel alone cannot fully achieve this goal. Therefore, airports as objects of air transport infrastructure have become an important part of the realization of this goal. The use of eco-friendly engineering solutions at airports can reduce harmful emissions by 50%.

[7] ICAO Environmental Report 2025. URL: https://www.icao.int/sites/default/files/environmental-protection/Documents/EnvironmentalReports/2025/ICAO-EnvReport-2025.pdf (accessed on 09.10.2025); ICAO Doc 9829, Guidance on the Balanced Approach to Aircraft Noise Management. URL: https://www.icao.int/environmental-protection/aircraft-noise (accessed on 09.10.2025).

[8] IATA CO2 Connect. Connecting primary data from airlines to CO2 emissions calculations. URL: https://www.iata.org/en/services/data/environment-sustainability/co2-connect (accessed on 09.10.2025).

[9] ACI. ESG Global Reporting Framework and Guidance for Airports. URL: https://store.aci.aero/product/esg-global-reporting-framework-and-guidance-for-airports (accessed on 09.10.2025); ACI. 2024 Airport Key Performance Indicators. URL: https://store.aci.aero/product/2024-airport-key-performance-indicators (accessed on 09.10.2025).

[10] ICAO Carbon Emissions Calculator (ICEC). URL: https://www.icao.int/environmental-protection/environmental-tools/icec (accessed on 09.10.2025).

This study showed that in order to build or reconstruct a green airport, it is necessary to carry out a complex of work on the ergonomic eco-design, the introduction of energy consumption and water management methods, and the use of eco-friendly and alternative energy sources, as well as the use of modern information systems for data management, monitoring and forecasting the technical parameters of airport operations as a complex technical support system, passengers' safety, equipment and the surrounding area. All these decisions are based on major investments, but the effect should be to reduce the impact on the environment and foster beneficial climate change while at the same time ensuring social justice and responsible recognition of financial benefits to society for the sake of eco-friendliness.

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