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IMPROVEMENT OF AIRPORTS ENERGY EFFICIENCY, CASE STUDY OF AIRPORT SARAJEVO

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Abstract
The aviation sector generates approximately 2,5 % of the world's carbon dioxide emissions. Waste majority of it is associated to air traffic and 5% to airports. With the expected increase of number of airports worldwide and intensity of air traffic, it is foreseen that carbon footprint of aviation sector will increase. Modern airports strive to rationalize the resources and energy consumption per passenger served, to increase its competitiveness and reduce energy consumption and carbon dioxide emissions. The paper presents an analysis of the energy efficiency of the selected regional airport, performed using benchmarking and energy audit methods. Historical data of energy consumption are used to calculate the company's carbon footprint and energy key performance indicators. Several improvement measures are analysed to reduce energy consumption of heating, ventilation and air conditioning and lighting system, improve energy management system and to implement systems based on renewable energy. Implementation of selected measures should result in reduction of all relevant indicators as follows; reduction of specific carbon dioxide emissions for 43%, and reduction of specific energy consumption for 28%. Strengthening of airport energy management system should ensure continuous evaluation and modification of airport resource and energy efficiency, which also contributes to facility energy savings.

Keywords: Airport; Energy efficiency; Carbon footprint; Performance indicators.

1. Introduction

In terms of impact on climate change, the aviation sector, including passenger, cargo and military transport, accounts for 1.9% of global greenhouse gas emissions (including all greenhouse gases, not just carbon dioxide), and 2.5% of global carbon dioxide (CO_2) emissions [1]. Greenhouse gas (GHG) emissions from airports are caused by the consumption of fuel (gasoline and diesel) for airport vehicles and ground support equipment, the consumption of fossil fuels for the production of electricity and heat, and the consumption of kerosene for auxiliary power units that power airplanes from airports gates and other sources [2].According to Statista 2020 [3], in 2019, Dubai and London Heathrow airports were among international airports the largest emitters of CO_2 globally, with over 30 million metric tons of CO_2 emissions.

According to Airport Carbon Accreditation Annual Report 2010-2011, out of the total 2.5% of CO_2 emissions from air transport, 5% goes to airports [4], i.e. 0.1% of global carbon emissions. Airports, as like many other resources consuming economic activity, needs to fulfil international obligations to combat climate change but also to reduce their own operational costs. Modern airports committed to rationalize the resources and energy consumption per passenger served, to increase its competitiveness and reduce energy consumption, carbon dioxide emissions and waste. In line with the commitments given, some airports made a significant improvements and reported reduction of airport CO_2 emissions to 2%-3% of the aviation industry's total CO_2 emissions (equivalent to 15-20 million tonnes of CO_2 per year), suggesting that there are opportunities for further reductions [5]. This reduction is certainly a consequence of the developed methods and accreditation programs [6] for improving resource efficiency at airports as well as the development and implementation of more resource efficient technologies and technologies based on renewable energy sources. Both methods and programs imply measuring the environmental sustainability of the airport using indicators and the application of benchmarking methods [7], [8]. The benchmarking method allows airports to perform self-measurement (internal) to monitor progress in achieving set goals and/or to do peer-benchmark (external) where they compare their performance with other airports. In [7], 3 sets of resource related indicators are introduced, namely: i) Static power consumption- Fossil-fuelled electricity consumption, kWh (monthly, yearly), Fossil-fuelled gas consumption (kWh monthly, yearly) Wind, solar or bio-generated electricity consumption, (kWh monthly, yearly), ii) Water consumption- Monthly volume consumed (m^3), iii) Waste generation- Monthly volume arising (kg), Monthly volume recycled or re-used (not incinerated/sent to incineration). In [9], authors proposed 77 indicators, organized in the ten performance dimensions, including resource efficiency related indicators: water, waste and energy consumption reduction. Resource consumption at the airports is related to either to surface area of terminals (heating and cooling, lighting) and other buildings or to number of passengers. In [10] and [8], normalized indicators expressed per reference unit are introduced (m^2 or passenger), i) energy per square meter of terminal, ii) water consumption per passenger.

According to the Greenhouse Gas Protocol initiative [11] the calculation method for the CO_2 footprint depends on scope of organizational and operational boundaries. In terms of organizational boundaries, airport sites contain variety of ground operations among which some are not related to flights serviced. In [7], authors underlines that airports vary in terms of their area occupied, transport access modalities, presence of commercial tenants, and more. Airport Carbon Accreditation Guidance Document [12], suggest application of a so-called control approach, saying that a company accounts for 100 percent of the GHG emissions from operations over which it has control. In terms of operational boundaries, calculation may vary from taking int account direct and indirect emissions that are related to direct airport operations but can also take into account all other indirect emissions which are a consequence of the activities of the airport but occur from sources not owned and/or controlled by the company (e.g., aircraft movements, vehicles and equipment operated by third parties, off-site waste management, etc.) [12]. When benchmarking, it is very important to take a sample with similar scope of organizational and operational boundaries, so that one do not draw wrong conclusions.

European airports are very active in the Airport Carbon Accreditation. According to data from 2022 [13], those registered in the program covers 73.1% of the total air passenger traffic in Europe. 76 airports mapped their carbon footprints, 45 airports actively reduced their CO_2 emissions, 22 airports reduced their CO_2 emissions & engaged others to do so, 39 are carbon neutral airports, 10 airports aligned their CO_2 management with global climate goals, 19 airports achieved transformation and further compensated for residual emissions. Only four airports from Western Balkan countries are included in the program, namely: Belgrade (Serbia), Pristina (Kosovo), Skopje (North Macedonia) and Tirana (Albania). Bosnia and Herzegovina (B&H) have 4 active airports, but none of them are included in any carbon reduction program. Also, according to [14], [15] B&H industry sector possess a large potential for energy savings and carbon reduction, therefore authors were motivated to conduct this research and to apply airport's energy performance evaluation methods along with identification of opportunities for improvement. Authors selected an airport that does not have any previous practice of data monitoring and performance analysis. Airport of Sarajevo, which is the largest airport in B&H, voluntarily accepted to participate in authors research study. Study results enables detail insight into a total and normalized values of energy consumption, energy breakdown and carbon footprint and allow their benchmarking and analysis of impact of various energy saving measures on the airport carbon footprint. It is expected that study data will be of great usage for the Airport of Sarajevo to strengthen airport energy management system and to reduce its carbon footprint.

2. Methods

Standard methodology for conducting energy audits is applied [16], [17] starting with introductory meeting with top management and core engineering team, followed by identification of major energy consumers and consumption level, energy related challenges, discussion of potential for energy efficiency improvement. The second phase included measurements and detailed engineering analyses of proposed measures. Both phases imply the full participation of airport employees, both in the phase of data collection and in the phase of identification of improvement measures.

The organizational boundaries included the terminal buildings (terminals A and B), administrative buildings, cargo warehouse, fire station building, two-story hangar, control tower, runway, and parking lot. Airport Sarajevo has no other services or commercial tenants. The operational boundaries included direct and indirect emissions for which the airport is directly responsible (heating and cooling, lighting, electrical consumers located in the buildings including the electrical vehicles, and fuel consumption for internal transport). This correspond to the Scope 1 and the Scope 2 of the CO_2 emission calculation as presented in the Airport Carbon Accreditation Guidance Document [12].

Data of monthly consumption of electric energy and fuel consumption for a period of 2017-2019 years are provided. Energy supplied by fuel is calculated by multiplying fuel consumed and lower heating value of fuel. Total CO_2 emission from fuel and electrical energy is calculated by multiplying the values of energy supplied by fuel (or electric energy) and related fuel (or electric energy) conversion factor, regulated at national level [18]. CO_2 emission from internal transport (mobile sources within the Scope 1) is calculated by considering vehicle type, its average annual distance travelled, and CO_2 emission coefficient [12].

No energy metering is enabled towards particular energy users or airport buildings. Therefore, energy consumption breakdown was made using the indirect method. For each category of electric energy user annual electricity consumption has been calculated by considering installed power and working hours. There are no heating meters installed in substations, therefore approximate values of buildings energy consumption for heating are derived based on installed power, and working hours of system. During the audit, thermovision imaging of subsystems and facilities was also performed, as well as measurement of boiler combustion efficiency, using the indirect method.

For the benchmarking purposes authors selected 4 airports from Western Balkan region that belongs to a same climatic area and with similarity in a scope of organisation boundaries, as well as in their respective national CO_2 calculation factors: Zagreb, Ljubljana, Priština and Belgrade. Airport Edinburgh represents large airports with more than 10 million passengers per year, while Inverness Airport is included due to similar annual number of passengers. Data on CO_2 footprint for the sample airports were taken from their annual carbon footprint reports covering the same period of 2017-2019 [19], [20]. The benchmarking exercise included total carbon footprint (tCO_2/ann.), normalised carbon footprint (tCO_2/passenger), as well as annual number of passengers.

These methods enable identification of systems with excessive energy consumption and weakness of energy management system, aiming to determine and select adequate improvement measures. Evaluation of proposed energy savings measures included: i) investment's costs, ii) energy and iii) CO_2 saving potentials, as well as effects of potential measures expressed through the iv) simple payback period (SPP) and v) reduction of the baseline value of the indicator in absolute value and in percentage.

3. Audit and benchmarking results

3.1 Energy consumption and carbon footprint indicators

The airport uses natural gas and fuel oil, for the production of energy for heating. Electricity is supplied from the public distribution network, and diesel fuel is used for the production of electricity in case of an interruption of the supply of electricity, and for vehicles. Facility does not use any renewable energy sources in energy supply system. Total annual energy consumption of facility amount to 6.285 GWh/ann. Natural gas has highest share in total energy consumption (51%), followed by electrical energy (46 %) (Figure 1). Diesel and fuel oil have negligible percentage. Annual facility CO_2 emission is 2.845 t/ann. Due to the high conversion factor related to electrical energy (0,744 kgCO2/kWh), CO_2 emission resulting from consumption of electrical energy is dominant, with 76 % of total facility CO_2 emissions (Figure 1).

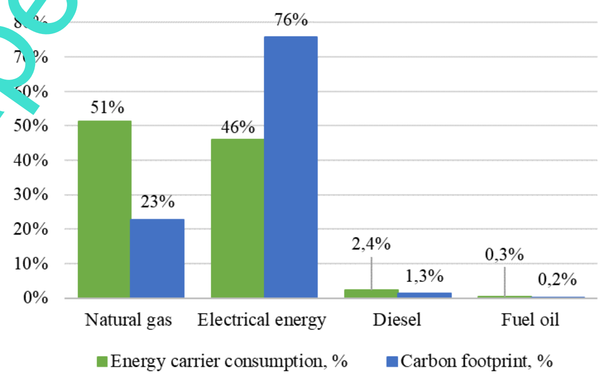

Fig. 1. Percentage of energy sources in total facility energy consumption and share of CO_2 for 2017-2019

3.2 Energy consumption breakdown

Energy for heating is supplied to the facility via two boilers with nominal power of 2.900 kW each. Boilers efficiency is 94,4 and 93,8 %, and they work alternately every other day. Hot water from boiler is supplied to seven heating substations, with total nominal heating power of 2.743 kW. Breakdown of buildings energy consumption for heating is shown on Figure 2., where it is visible that terminal B have highest share in energy consumption for heating (Figure 2.).

Electrical energy consumers can be classified into the following categories: heating, cooling, ventilation (HVAC), lighting, office equipment, kitchen equipment, equipment for workshops and other consumers. Categories with highest share in total electrical energy consumption are HVAC, lighting, and office equipment (Figure 5.), so an analyses of an energy savings measures is focused on these systems.

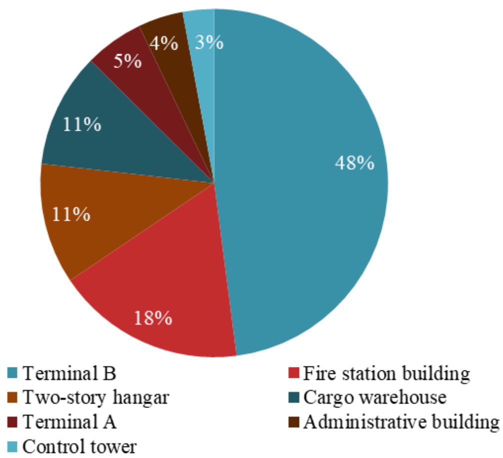

Fig. 2. Buildings energy consumption for heating

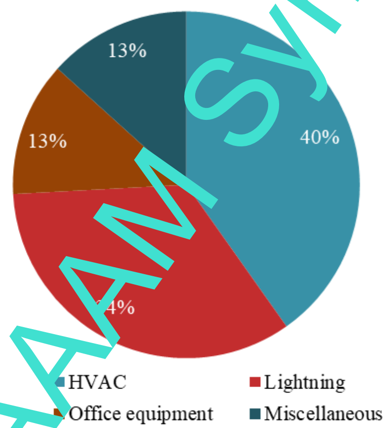

Fig. 3. Breakdown of electricity consumption by user category

Terminal B (Figure 4.) serves as passenger terminal with nett surface area of 9.233 m^2. Considering that it is in use during the whole year, with complex HVAC system installed for heating and cooling, terminal B represents building with highest share in facility heat (48 %) and electrical energy consumption (52 %), as well. This is common in airport facilities worldwide [17].

Fig. 4. Terminal B exterior

Fig. 5. Thermal image of terminal B

Central cooling system is installed in terminal B and administrative building, and other building uses local split systems. Cooling system in terminal B accounts in approximately 11,7 % of facility electrical energy consumption. One of the major issue regarding the building envelope are large transparent surfaces that does not meet regulations regarding the heat transfer coefficient [18], and with glazing with large Solar Heat Gain Coefficient (SHGC), (Figure 5.). Conditioned spaces, including terminal B, are overheated in winter with temperatures set up to approx. 24 °C, that is much higher than designed temperatures [21]. This is common problem for other similar facilities worldwide [22], and results in excess energy consumption.

3.3 Benchmarking of energy and carbon footprint indicators

Using a monthly data of energy consumption and a monthly data of passengers served, energy related indicators and carbon footprint indicators are calculated (Figure 6.). Average values of indicators are noted, with average specific energy consumption of 5,99 kWh/pass, and substantial seasonal variation of the indicator (lowest value of indicator is 1,8 kWh/pass and highest 19,9 kWh/pass). This is a result of increase of energy consumption in the winter period (70,8 % of total energy consumption is related to the winter period), with decrease in number of passengers (36,3 % of the total number of passengers). Similar trend is noticed regarding the carbon footprint indicator (Figure 7.), where the average value of the indicator is 2,71 kgCO_2/pass., the lowest value is 1,3 kgCO_2/pass., and the highest value is 7,0 kgCO_2/pass.

Compared to the selected regional airports Zagreb and Ljubljana, the Sarajevo airport has the lower total annual CO_2 emission, but its average carbon footprint per passenger (2,71 kgCO_2/pass) is higher due to the lower number of passengers (Zagreb 1,57 and Ljubljana 1,85 kgCO_2/pass). The same can been seen in Edinburgh were annual number of passengers over 14 million significantly decrease normalised carbon footprint per passengers. But comparison with the Belgrade airport, which is much larger and with higher number passengers and has both indicators lower than Sarajevo, and also with the airport in Inverness (Scotland) which is of similar size and number of passengers but with the 26% lower carbon footprint per passenger, indicates that Sarajevo have potential to improve its energy efficiency performance. Airport at Priština has the worst energy efficiency performance.

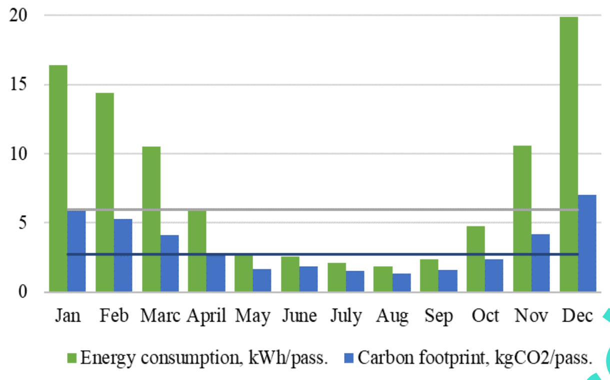

Fig. 6. Average monthly specific energy consumption and carbon footprint indicators for 2017-2019

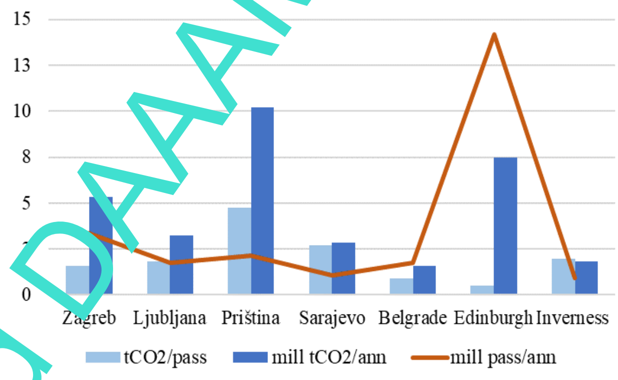

Fig. 7. Benchmarking of carbon footprint for selected airports

4. Key observations and proposal for improvement of energy efficiency

Considering facility energy consumption, characteristics of installed equipment and its operating regimes, most important conclusions related to excessive energy consumption are summarized and given in Table 1.

User category	Conclusion
HVAC system	Sarajevo Airport does not use any renewable energy sources in energy supply system. Conditioned space is overheated during winter. Heating substation of terminal B is equipped with circulation pumps with large number of annual working hours. Pumps do not have frequency regulation. Transparent building envelope of terminal B is a source of excessive heat losses during the winter and heat gains during summer.
Lighting system	The lighting bulbs in terminal B are outdated, mostly based on fluorescent tubes with a magnetic starter, high power, low efficiency and manually controlled. In the parking lot in front of terminal B, 40 reflectors with a power of 150W and low efficiency are installed for the advertisement purpose. The lighting on the advertisement panels is outdated and consumes 30% more electricity than the new LED technology for the same illuminance.
Office equipment	In the administration building, there is one installed printer for each employee (total number of printers is 58). Laser printers remain on during the night and on non-working days. Many of installed computer equipment is not actively used during working hours. The largest number of installed telephones is found in terminal B and the administration building (261 units).

Table 1. Observations related to energy and water consumer categories

Based on a detailed analysis of collected data and observations, large number of energy saving measures are listed and shown in Table 2.

Measure	Description
Integration of renewable energy sources in energy supply system	
M1. Installation of photovoltaic solar panels in the parking lot to produce electrical energy. Parking lot has surface area of 9.036 m^2.	Covering the parking area would provide protection from the sun in the summer and snow in the winter, and base for setting the photovoltaic solar panels. Number of panels is 3.780, nominal installed power is 1,3 MW, electricity produced approx. is 1.290,9 MWh/ann.
M2. Installation of a water-to-water heat pump for the heating and cooling needs of the administration building. Current system is connected to heating substation and central cooling system.	Building envelope thermal properties are in line with current regulation, and specific energy need of building is low. Heat pump characteristics are, SCOP – 5,17 and SEER – 4,95, which is higher than SEER of current system.
M3. Installation of a thin film of photovoltaic cells on the glazed surfaces of terminal B to produce electrical energy Total surface area of windows is 2.966,93 m^2, with glazing surface of 2.520,00 m^2	Installation of a thin film of photovoltaic cells, amorphous silicon thin film with low opacity, will enable production of electrical energy [23] and reduction of heat gains in the summer period. Nominal installed power is 112 kW, generated electrical energy is 84,14 MWh/ann., and reduction of electricity consumption for system cooling is up to 10 %.
HVAC system	
M4. Replacement of 18 pumps with variable frequency regulated pumps in heat substation of terminal B. Heating substation is equipped with circulation pumps, with no frequency regulation, and with nominal power of 0,55, 1,1 and 2 kW, with large number of annual working hours.	By replacing 18 pumps in the terminal B substation with frequency-regulated pumps, the consumption of electrical energy will be reduced, and overall heating system efficiency will be increased. Electrical energy savings of more than 30 % can be achieved [24], depending on the number, size and working hours of pumps.
M5. Placing of low-E window film on to all transparent surfaces of terminal B. Total glazing surface is 2.520,00 m^2, double glazed 8/16/8 mm, Low-E filled with argon, metal framed with non-insulated thermal bridges.	Thermal insulating UV films are placing on the inner surface of the windows. Implementation of this measure results in reduction of inner temperature by 1 °C during the summer, and can result in reduction of cooling load and energy consumption for cooling up to 10 % [25].
M6. Night cooling during the summer period. Operating regime of cooling system is completely related to the daily regime, and benefits of night cooling regime are not exploited.	Mechanical ventilation system can be used to automatically ventilate the building at night to cool the building's thermal mass and reduce the need for compressor cooling the next day. It is shown that energy consumption for cooling can be reduced up to 15 % [26].
M7. Hydraulic balancing and regulation of water supply temperature for terminal B. Installation of heat meters in each thermal substation.	Adjustment of flow rate, water temperature and pressure drop for terminal B, will result in decrease of energy consumption up to 9 % [27]. Installing the heat meters in heat substations, will provide detail insight in energy consumption of each building and provide base for implementing energy management system.
Lighting system	
M8. Replacement of lighting bulbs in terminal B. A total of 781 standard fluorescent tubes (T12) with a power of 36 W is installed in terminal B. Annual working hour of lighting system is substantial.	The energy consumption of the lighting system accounts for 34% of the facility energy consumption, which is in line with the share of consumption of other similar plants [28]. Replacement of lighting bulbs in terminal B with LED lightings, will result in reduction of electrical energy consumption of lighting system up to 25 % [28].
M9. Installation of occupancy detection sensors and occupancy-driven lighting control.	Installing sensors for occupancy detection and occupancy driven lighting control in administration building, terminal A, terminal B and fire station building, it is possible to save up to 25 % of electricity [29] .
M10. Replacement of reflectors from advertisements panels in the parking lot. Panels are outdated, with power of 150 W (40 psc.) with large number of annual working hours and poor characteristics such as illuminance, efficiency etc.	By replacing 40 old reflectors with a power of 150W each, with low-voltage tungsten halogen bulbs or with metal halogen HID bulbs, it is expected that energy savings for this uses category, will be up to 50 %.

Measure	Description
M11. Replacing the neon tubes from the advertisement panel in parking lot.	Replacement of 40 pcs. of 54W neon tubes from the one advertisement panel, with fluo-tubes of 36W. Energy savings will be 33 %.
Office equipment	
M12. Centralization of 58 printers in the administrative building. The power of the printer during operation is 650W, and the power of the printer in stand-by mode is 8.5W.	Replacement of 58 local printers with 4 centralized printers. This will ensure reduction of electrical energy consumption and cartridge consumption.
M13. Shutting down all laser printers at night and on weekends. The laser printer consumes 20W in stand-by mode, and 1W when turned off.	A total of 200 printers with a power of 350W are installed in the facility. By turning off laser printers during the night and on weekends, electricity consumption will be reduced by up to 75% on an annual basis.
M14. Setting computer equipment in energy saving mode. In total 407 computer units with monitors are installed in the facility.	Set computer equipment to the "hibernate" energy saving option (computer operation mode), thereby saving up to 90 % of electrical energy consumption annually.
M15. Reduction in the number of telephones.	Total number of telephones can be reduced up to 50 %. As a result, electrical energy consumption will decrease.

Table 2. Energy and water saving measures

By implementing all the measures, the facility annual consumption of electricity and natural gas will be reduced, and the carbon footprint of the company, as well. Financial and energy related indicators for all analysed measures are presented in Table 3. Energy savings are estimated as very conservative with smaller percentage than found in literature, as noted in Table 2, for particular measures, to make sure that indicators are correctly calculated and not overestimated. Implementation of all selected measures should result in reduction of CO_2 emission. Only for measure M2 (installation of heat pump in administrative building), electrical energy consumption will increase after implementation of measure, since it will be in use during the winter and summer, opposite the current system (heating from boiler room and cooling from central system with low SEER).

No.	Investment	Electrical energy saving	Natural gas saving	Savings	SPP	CO_2 reduction	
	[Eur]	[kWh/ann.]	[kWh/ann.]	[Eur/ann.]	[-]	[t/ann.]	[%.]
Integration of renewable energy sources in energy supply system							
M1.	1.119.652	1.290.900	0	99.993	11,2	961	33,79
M2.	101.400	-20.726	128.832	7.145	14,2	10	0,37
M3.	152.265	104.572	0	8.100	18,8	78	2,74
HVAC system							
M4.	16.112	22.083	0	1.711	9,4	16	0,58
M5.	87.937	23.834	0	1.846	47,6	18	0,62
M6.	0	17.024	0	1.319	0,0	13	0,45
M7.	18.247	0	60.873	4.135	4,4	12	0,43
Lighting system							
M8.	3.594	50.016	0	3.874	0,9	37	1,31
M9.	6.519	37.512	0	2.906	2,2	28	0,98
M10.	5.113	8.760	0	679	7,5	7	0,23
M11.	123	2.628	0	204	0,6	2	0,07
Office equipment							
M12.	4.090	10.456	0	4.900	0,8	8	0,27
M13.	0	9.850	0	763	0,0	7	0,26
M14.	0	6.417	0	497	0,0	5	0,17
M15.	0	20.577	0	1.594	0,0	15	0,54
Total	**1.515.052**	**1.583.901**	**189.704**	**139.665**	**10,8**	**1.217**	**42,80**

Table 3. Evaluation of energy and CO_2 saving measures

5. Discussion

Large number of energy-saving measures are analysed; ranging from organisational measures, measures for reduction of electrical energy consumption for lightings, HVAC system and integration of renewable energy sources into a facility energy supply system. It is shown that all measures result in reduction of facility carbon footprint and, when combined they can result in reduction of facility carbon footprint by 43 % and energy consumption by 28 %, with favourable SPP. Reduction of specific carbon footprint will ensure that Airport of Sarajevo is in line with the best ranked airports in region. Energy supply system of Airport of Sarajevo is based on fossil fuels, with resulting high CO_2 emission, in absolute value and normalized by a number of passengers, as well, so there is a necessity for reduction of facility carbon footprint.

Several improvement measures are analysed to reduce energy consumption of HVAC and lighting system, improve energy management system and to implement systems based on renewable energy sources. Implementation of all measures will result in substantial energy and energy cost reduction, with average SPP period of 10,8 years. Also, reduction of all relevant indicators will be achieved as follows; reduction of specific carbon dioxide emissions for 43% and reduction of specific energy consumption for 28% with substantial amount of energy provided from renewable energy sources.

Parameter	Current	With measures	Reduction
Electrical energy, kWh/ann.	2.893.253	1.309.352	55%
Fossil fuels, kWh/ann.	3.391.452	3.201.748	6%
Renewable energy, kWh/ann.	0	1.374.745	-
Total energy consumption, kWh/ann.	6.284.705	4.511.100	28%
Total carbon footprint, tCO_2/ann.	2.845	1.627	43%
Specific energy consumption, kWh/pass.	5,99	4,30	28%
Specific carbon footprint, $kgCO_2$/pass.	2,71	1,55	43%

Table 4. Effect of energy and CO_2 saving measures

6. Conclusion

The paper presents application of airport's energy performance evaluation methods along with identification of opportunities for improvement to an airport that does not have any previous practice of data monitoring and performance analysis. Authors combined performance benchmarking method and energy audit method. Due to the fact that the airport does not have a practice of measuring, collecting and analysing data, certain parameters were obtained indirectly, such as breakdown of energy consumption. Using the monthly data of energy consumption and monthly data of passengers served, energy related indicators and carbon footprint indicators are calculated.

The study showed that benchmarking the normalized value of the carbon footprint per passenger can lead to the conclusion that the airport environmental impact is small, which would not be the case if one analysed only the total annual carbon footprint. Namely, Sarajevo airport has a significantly lower total annual CO_2 emission than, for example, the airport in Zagreb, but its average carbon footprint per passenger (2.71 $kgCO_2$/pass) is higher due to the smaller number of passengers (Zagreb 1.57 $kgCO_2$/pass). The Edinburgh Airport has larger CO_2 emission and negative impact to the environment than airports in Sarajevo and Zagreb, due to its high value of the carbon footprint, while its normalized value is the lowest among the analysed airports due to the large number of passengers (14 million).

In order to get a complete picture of the overall environmental impact and the company's performance, it is necessary to perform an analysis of both the total energy consumption and the carbon footprint and their normalized values. Analysis of normalized values only can also lead to a wrong conclusion about the overall impact of an airport operation on the environment and climate change, because due to the large number of passengers, the normalized value becomes significantly lower than in airports with lower annual CO_2 emissions and a small number of passengers.

Carbon footprint benchmarking should be combined with the benchmarking of the total annual energy consumption, and the analysis of the monthly consumption, as well as consumption by energy sources. The share of renewable energy sources reduces the carbon footprint, but not the total energy consumption, so it can be wrongly concluded that the airport does not need to improve its energy efficiency. Seasonal fluctuations in monthly consumption may indicate the impact of heating and cooling on the overall result and the need to work on potential improvements in their energy efficiency.

The combined application of the performance benchmarking methods and energy audit method proved to be successful as the airport identified places of energy inefficiency that can be improved with the implementation of a several improvement measures aiming to decrease the total and the specific carbon dioxide emissions for 43%, and reduction of the total and the specific energy consumption for 28%.

Further research into the efficiency and sustainability of airports should, in addition to analyses of water efficiency and further development of on-site renewable energy technologies, include a waste flow analyses and technology solutions for the application of circular economy at airports.

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