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# An Analysis of Local Climate Effects: A Case Study of the Lviv International Airport

**Abstract.** The effect of aircraft emissions on the global climate is a serious long-term environmental issue faced by the aviation industry. As the number of passengers grows, so does the use of jet fuel and the emission of greenhouse gases (GHG). This may destabilize the world's climatic systems, which will consequently lead to global, regional and local environmental, economic and social damage. The Intergovernmental Panel on Climate Change (IPCC) estimates that aircrafts are currently responsible for 3.5 % of the total anthropogenic greenhouse effect. To avoid the negative consequences of climate change, it is necessary to fully understand factors affecting this problem locally and develop methods of mitigating airport climate effects. This article describes and analyses calculations of radiative forcing of aircraft emissions and the radiative impact of clouds in the surrounding area of the Lviv airport. The calculated values were verified against temperature data for the city and at the airport provided by meteorological authorities.

**Keywords:** airport, aircraft emissions, microclimate, greenhouse effect, radiative forcing, climate change

## 1. Introduction

Within the sources and activities across the global economy that produce greenhouse gas emissions, the transportation sector is the third largest emitter of GHGs (the first is power generation and the second is industry), accounting for

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about 13% GHG emissions at a global level and, in particular, about 20% carbon dioxide emissions [Herzog 2009]. Aviation is one mode of transportation that, in turn, is one of many GHG emitting sectors, generating at a global level, over 730 million tons of carbon dioxide per year with an increase of 45% compared to 1990 [Lepore 2009].

The climatic impacts of aviation emissions include: direct climate effects from carbon dioxide ($CO_2$) and water vapor emissions; indirect forcing on climate resulting from changes in distributions and concentrations of ozone and methane as a consequence of aircraft nitrogen oxide (NOx) emissions; direct effects (and indirect effects on clouds) from emitted aerosols and aerosol precursors; and climate effects associated with contrails and cirrus clouds formation [Workshop on the Impacts of Aviation on Climate Change 2006]. In attempting to aggregate and quantify the total climate impact of aircraft emissions the IPCC has estimated that aviation's total climate impact is some 2-4 times over its direct $CO_2$ emissions alone (excluding the potential impact of cirrus cloud enhancement). This is measured as radiative forcing. Globally in 2005, aviation contributed "possibly as much as 4.9% of radiative forcing" [Owen, Lee & Lim 2010].

The IPCC has estimated that aviation is responsible for around 3.5% of anthropogenic climate change, which includes both $CO_2$ and non-$CO_2$ induced effects. The IPCC has produced scenarios estimating, what this figure could be in 2050. The central case estimate is that aviation's contribution could grow to 5% the total contribution by 2050, if actions are not taken to limit these emissions, the highest scenario will be 15% [Lepore 2009]. Moreover, if other industries achieve significant cuts in their own greenhouse gas emissions, aviation's share will definitely stay the same or, which is more likely, will grow.

In Europe, $CO_2$ emissions from aviation have grown by 90% from 1990 to 2005 [Herzog 2009]. If the current trend continue, the growth in emissions from air transport could compromise the achievement of the reductions by the European Union according to the Kyoto Protocol. Moreover, the presence of very busy airport activity has very negative effect on global climate and the environment. For example, in Italy, the European country with highly developed infrastructural facilities, aviation is responsible for 12 million tons of $CO_2$ (8% total emissions from transport) and 68,000 tons of NOx, equivalent to 9% total emitted by the transport sector [Lepore 2009].

Except being the sources of emissions that affect climate, emissions generated by activities occurring inside and outside the airport perimeter associated with the operation and use of an airport, create significant health hazard for people living near airports. In this view, GHGs inventory can become the benchmark, against which the achievement of quantitative targets set at the political level in the fight against climate change and human health hazards are measured [van Begin & van Staden 2011].

The issues of local thermal mode effects of airports are not that well studied as global impact of aviation. To feel this gap this study on the example of the Lviv Danylo Halytskyi International Airport was initiated. The aim of the research is to define the effects of aircrafts' emissions on the temperature mode at the territory of the airport and compare the results with the corresponding situation at the municipal area out of the airport impact zone to validate the contribution of air transportation activity in the formation of local climate parameters values.

## 2. The sources of greenhouse emissions at airports

The composition of emissions at the airport is defined by the activity of power generating facilities, boiling plants, special transport and aircrafts (Table 1).

The aircraft emissions contribution to an airport $CO_2$ inventory typically ranges from 50% to 80% and these are from 2% to 4% of the total global GHG inventory. Based on airport emission inventories prepared to date, emissions from non-aircraft airport-related operations represent an additional 0.1% to 0.3% of the global total [van Begin & van Staden 2011]. In practice, airports use a variety of definitions to determine the aircraft emissions contribution: they can be based entirely on the fuel dispensed at the airport, count the emissions from aircraft only while their wheels are on the ground or include the whole landing and take-off cycle down from and up to an altitude of 900 meters [van Begin & van Staden 2011; Kim, Bassarab, Vigilante & Waitz 2009]. As for our opinion, an airport $CO_2$ inventory must include the landing and take-off cycle, taxiing, and auxiliary power units use.

Other major sources of $CO_2$ at airports are fuel combustion in ground service equipment (GSE) and airside and landside motor vehicles. Airside vehicles include passenger transfer buses and service vehicles, while landside vehicles include passenger and staff transport to and from the airport. Utility plants at airports that burn fossil fuels to produce electricity, heating and cooling can also be large sources of GHG emissions. In Europe, some airports have power generation stations that are already subject to restrictions and emissions trading under the EU's Emissions Trading Scheme. Aviation's overall contribution to the global GHG emissions inventory is dominated by aircraft in flight and these emissions are beyond the control and influence of airports. Discussion here is limited to actions airports can take to address GHG sources within their control and influence.

While the airport contribution can be relatively small, many improvements can still be made. The best approach for addressing aviation's climate change

Table 1. Airport sources of GHG emissions

| Source category | Specific source |
|---|---|
| Aircraft emissions | Aircraft engine emissions before approach above 900 m approach and landing, take-off and initial climb (ground to 900 m), taxiing and queuing (ground). |
| APU | The on-board engine supporting the aircraft while parks on the ground. |
| Ground access vehicles | Include all vehicles traveling to and from, as well as within the airport public roadway system (excluding GSE). On-road and highway vehicles include: vehicles transporting passengers and vehicles using airport parking, vehicles transporting airport employees, including vehicles in employee parking lots, vehicles transporting cargo, airport-owned vehicles. |
| Stationary Sources (Facility Power) | Power/electricity consumption, airport facility boilers, heaters, and generators, aircraft engine testing, maintenance activities (surface coating/painting, degreasing), fuels used by food concessions, etc. |
| Ground support equipment (GSE) | A variety of ground equipment services for commercial aircraft used to unload and to load passengers and to freight at an airport. GSE consist of vehicles that do not leave the airfield: aircraft tugs, air start units, loaders, tractors, air-conditioning units, ground power units, cargo-moving equipment, service vehicles, etc. Off-road vehicles and vehicles that maintain airport facilities are also included. |
| Airport construction activities | Vehicles consuming fuels during the construction process: runway extension or development, terminal building and gate area expansion, new taxiways, etc. |
| Training fires | Fuel usage for planned training activities. Emissions are mostly due to combustion from the burning of the fuel, as well as emissions associated from the use of fire extinguishers or other equipment. |
| Waste management activities | Activities reflect any processes or use of equipment specifically geared toward waste management: sorting of waste, shipping to waste management facilities, recycling, and incineration. |
| Other | All other sources such as local airport companies with industrial processes, farming activities, etc. |

Source: Kim et al. 2009.

emissions, including those from airports, is a long-term strategy that identifies and implements environmentally effective, economically efficient, and politically viable measures for each category of emissions.

## 3. The potential impacts of aviation on ground layers of the atmosphere

Air pollution due to continuous and increasing combustion of fossil fuels for energy has gradually led to the increase of greenhouse gases content in the atmosphere, thus raising the natural greenhouse effect with anthropogenic component. GHGs, naturally occurring and man-made, include, but are not limited to, water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), ozone ($O_3$) and halocarbon compounds containing fluorine (PFCs), chlorine (CFCs, HCFCs) and bromine (halons or sulfur $SF_6$) [Forster et al. 2007]. GHGs in the atmosphere contribute to the greenhouse effect directly when they absorb radiation; on the contrary, indirect effects occur both when greenhouse gases are produced by chemical transformations, and when the atmospheric lifetimes of a gas is influenced by another gas, as well as when a gas affects cloud formations and, more in general, atmospheric processes that alter the radiative balance of the earth.

Most modern jet aircrafts cruise within the altitude range (9-13 km) that include parts of the upper troposphere (UT) and lower stratosphere (LS). Because these two atmospheric regions are characterized with different dynamics and photochemistry, the introduction of aircraft emissions into these regions must be considered when evaluating the impact of emissions on atmosphere structure [Hoinka, Reinhardt & Metz 1993].

Carbon dioxide ($CO_2$) and water vapor ($H_2O$) are the most abundant products of jet fuel combustion (emission indices for $CO_2$ and $H_2O$ are 3.15 kg/kg fuel burned and 1.26 kg/kg fuel, respectively). However, both substances have significant natural background levels in the UT and the LS [Schumann 1994]. Neither current aircraft emission rates nor likely future subsonic emission rates will affect the ambient levels by more than a few percent. Future supersonic aviation, on the other hand (which would emit at higher altitudes), could perturb ambient $H_2O$ levels significantly at cruise altitudes. Regardless of the magnitude of the aircraft emission source, $CO_2$ does not participate directly in ozone photochemistry, because of its thermodynamic and photochemical stability. It may participate indirectly by affecting stratospheric cooling, which can in turn lead to changes in atmospheric thermal stratification, increased polar stratospheric clouds formation, and reduced ozone concentrations.

Aircraft water vapor generation, although relatively small in the troposphere, lead to the atmospheric phenomenon of contrail formation. Depending on the exact composition of contrail particles, which is largely determined by the specific processes occurring in the aircraft plume and by the ambient atmosphere composition and temperature – the particles may act as surfaces for a variety of heterogeneous reactions.

NOx represents the next most abundant engine emission (emission indices range from 5 to 25 g of $NO_2$ per kg of fuel burned) [Report by the IPCC 1999]. With respect to ozone photochemistry, NOx is the most important and most studied component; its aircraft emission rates are sufficient to affect background levels in the UT and LS. Moreover, its active role in ozone photochemistry in the UT and LS has been well recognized.

Aircraft carbon monoxide (CO) emissions are of the same order of magnitude as NOx emissions (i.e., 1-2 g/kg for supersonic and 1-10 g/kg for subsonic aircraft) [Hoinka et al. 1993]. Like NOx, CO is a key participant in tropospheric ozone production. However, natural and non-aircraft anthropogenic sources of CO are substantially larger than analogous NOx sources, thereby reducing the role of aircraft CO emissions in ozone photochemistry to a level far below that of aircraft NOx emissions.

Emissions of sulfur dioxide ($SO_2$) and hydrocarbons from aircraft, at less than 1 g/kg fuel, are significantly less than the more studied emission components discussed above [Report by the IPCC 2004]. Their primary potential impacts are related to formation of sulfate and carbonaceous aerosols that may serve as sites for heterogeneous chemistry. Non-methane hydrocarbon (NMHC) emissions may also contribute to autocatalytic production of NOx, provided that the reactivity of the NHMCs is sufficiently large relative to that of $CH_4$ to overcome their numerical inferiority [Schumann 1994]. However, model studies have indicated that volatile organic emissions from aircraft have an insignificant impact on atmospheric ozone at cruise altitudes [Hoinka et al. 1993].

The climate impacts of the gases and particles emitted and formed as a result of aviation are more difficult to quantify than the emissions; however, they can be compared to each other and to climate effects from other sectors by using the concept of radiative forcing. Because carbon dioxide has a long atmospheric residence time (≈100 years) and so becomes well mixed throughout the atmosphere, the effects of its emissions from aircraft are indistinguishable from the same quantity of carbon dioxide emitted by any other source [Owen et al. 2010].

The other gases (e.g., NOx, SOx, water vapour) and particles have shorter atmospheric residence times and remain concentrated near flight routes, mainly in the northern mid-latitudes. These emissions can lead to radiative forcing that is regionally located near the flight routes for some components (e.g., ozone and contrails) in contrast to emissions that are globally mixed (e.g., carbon dioxide and methane) [Forster et al. 2007].

The global mean climate change is reasonably well represented by the global average radiative forcing, for example, when evaluating the contributions of aviation to the rise in globally averaged temperature or sea level. However, because some of aviation's key contributions to radiative forcing are located mainly in the northern mid-latitudes, the regional climate response may differ from that derived from a global mean radiative forcing. The impact of aircraft on regional and local climate could be important, but has not been assessed.

## 4. The methodology of aircraft emissions thermal impacts calculation

The most useful assessment of the aircrafts impact on climate would be a comprehensive prediction of changes to the climate system, including temperature, sea level, frequency of severe weather phenomena, and so forth. Such assessment is difficult to achieve given the current state of climate models and inability to separate the influence of aviation sector from the global forcing of climate. So, radiative forcing (RF) has been chosen as the one, which is calculated directly from changes in greenhouse gases, aerosols, and clouds, and which provides ready comparison of the climate impact of different aviation scenarios.

For a greenhouse gas, such as carbon dioxide, radiative transfer codes that examine each spectral line of atmospheric conditions can be used to calculate the change $\Delta F$, W/m$^2$, as a function of changing concentration [Chung & Soden 2015]. These calculations can often be simplified into an algebraic formulation that is specific to that gas. For instance, the simplified first-order approximation expression for carbon dioxide is:

$$\Delta F = 5.35 \times \mathrm{lh}\,\frac{\mathrm{C}}{\mathrm{C}_0}$$

where C is the $CO_2$ concentration in parts per million by volume and $C_0$ is the reference concentration. The relationship between carbon dioxide and radiative forcing is logarithmic, and thus increased concentrations have a progressively smaller warming effect [Chung & Soden 2015; Gregory et al. 2004].

The calculation procedure, developed by the authors, includes calculation of total $CO_2$ emissions, produced by aircrafts flying at an airport taking into account their forcing fuel consumption. Then, the final concentration of carbon dioxide in the air of the airport was calculated, supposing that 20-33% of the gas is blown away from the territory of airport and the calculated air volume is limited with the borders of airport to the height of 900 m, or the boundary layer [Kim et al. 2009].

The algorithm of defining temperature increase over the airport territory, conditioned by concentration of $CO_2$, was offered to include the following steps:

1) Defining the mass of fuel spent by each type of aircraft.

2) Calculation of the amount of $CO_2$ produced by aircrafts per day, supposing that per each kg of jet fuel, consumed by aircraft, 3.157 kg of $CO_2$ are formed.

3) Defining total mass of carbon dioxide produced per day at airport ($C_{CO_2}$), mg/m$^3$, accounting the area of an airport and the height of the boundary layer, forming together the study volume.

4) Recalculation of the resulted value into ppm – parts of $CO_2$ per 1000000 parts of atmospheric air:

5) Accounting background concentration of $CO_2$ (which makes 380 ppm) after recalculation of $CO_2$ concentration into ppm, this is done by adding it to the obtained value.

6) Defining the factor of "radiative forcing," which is formed as a result of air traffic at the airport, using the above mentioned formula [Chung & Soden 2015].

7) Definition of the resulted temperature increase over the airport territory, conditioned by this concentration of $CO_2$ [Gregory et al. 2004]:

$$\Delta T_S = \lambda \times \Delta F$$

where $\lambda$ – is a climate sensitivity, which is established to be $\lambda = 0{,}8$ K/(W × m$^2$).

## 5. The characteristics of the studied object

Lviv Danylo Halytskyi International Airport is an international airport in Ukraine with passenger overflow near 600 thousands people per year. It has direct con-

Table 2. The number of flights for the 2015

| Month | Number of flights | International flights | Domestic flights | Peak month |
|---|---|---|---|---|
| January | 645 | 454 | 191 | Peak |
| February | 555 | 379 | 176 | – |
| March | 589 | 400 | 189 | Peak |
| April | 577 | 382 | 195 | – |
| May | 581 | 455 | 126 | – |
| June | 706 | 539 | 167 | – |
| July | 803 | 615 | 188 | – |
| August | 845 | 663 | 182 | Peak |
| September | 743 | 565 | 178 | Peak |
| October | 594 | 438 | 156 | – |
| November | 530 | 376 | 154 | – |
| December | 540 | 371 | 169 | – |

Source: Official website of the Lviv Danylo Halytskyi International Airport, 2015.

nection with the cities all over the world such as: Munich, Dortmund, Vienna, Warsaw, Krakow and Wroclaw, Moscow and Surgut, Naples, Venice and Milan, Prague, Hurghada, Istanbul, Kyiv and others.

The perspectives of transportation volumes growth in the upcoming years raises the question about climate effects of increased traffic [IATA 2014]. The prognosis of air transportation growth up to 2035 year supposes that volume of transportation will double. With increasing number of flights the environmental situation at airport will be getting worse.

Lviv Danylo Halytskyi International Airport carries out both international and domestic flights. To analyze the potential climate effects of air flights in the airport intensity of air transportation was studied during one year (Table 2).

## 6. The results of the Lviv airport temperature mode changes under the influence of air traffic

Based on the technique, presented above, the gross emissions of aircrafts at the territory of Lviv airport by days were calculated. As it could be seen from the table the busiest months and correspondingly the most intensively polluting the ground layer atmosphere are July and August, followed by June and September.

The resulted total radiative forcing of aircrafts emissions by days shows that the maximal values are typical for July and August. Due to radiative forcing the increase of temperature at the airport vicinity is observed (Table 3). This number reaches 1.34 degree at the busiest August days. In average the increase of temperature is 0.8–1.2 degree at days with high flight intensity and 0.6–0.8 at not busy days.

The activity of air transportation processes affect on thermal mode as we try to prove with our calculations, so there is need to analyze the weather regime at the territory of Lviv Danylo Halytskyi International Airport as compared to Lviv municipal area. Having analyzed the information about the temperature levels in Lviv Danylo Halytskyi International Airport and Lviv municipal area, we have established, that there is noticeable difference between them: the average temperatures ranges from 0.61°C in September to 1.7°C in July.

The radiation strengthening due to clouds (which is 1.1) have to be added to the value of temperature increase over the airport territory, conditioned by this concentration of $CO_2$ in cloudy days. As a result the radiative forcing rises to the range 1.2–2.3°C.

Table 3. Total radiative forcing of aircrafts ($\Delta T$)

| Days | April | May | June | July | August | September | October |
|---|---|---|---|---|---|---|---|
| 1 | 0.978 | 0.890 | 1.129 | 1.109 | 0.835 | 1.275 | 0.945 |
| 2 | 1.009 | 0.516 | 1.117 | 1.368 | 1.515 | 1.109 | 1.277 |
| 3 | 0.972 | 0.930 | 1.109 | 1.277 | 1.547 | 1.505 | 0.405 |
| 4 | 0.763 | 0.991 | 1.213 | 0.835 | 1.275 | 1.277 | 1.224 |
| 5 | 1.003 | 1.117 | 1.119 | 1.515 | 1.109 | 0.835 | 1.229 |
| 6 | 0.972 | 0.803 | 0.505 | 1.453 | 1.410 | 1.515 | 1.117 |
| 7 | 1.041 | 0.777 | 1.364 | 1.275 | 1.277 | 1.453 | 1.109 |
| 8 | 0.966 | 0.981 | 1.129 | 1.109 | 0.835 | 1.275 | 0.945 |
| 9 | 0.872 | 0.566 | 1.275 | 1.408 | 1.515 | 1.109 | 1.119 |
| 10 | 0.972 | 0.930 | 1.109 | 1.277 | 1.678 | 1.408 | 0.405 |
| 11 | 0.665 | 0.991 | 1.213 | 0.835 | 1.275 | 1.277 | 1.224 |
| 12 | 1.089 | 1.117 | 1.119 | 1.515 | 1.109 | 0.835 | 1.129 |
| 13 | 0.972 | 0.803 | 0.663 | 1.547 | 1.410 | 1.515 | 1.117 |
| 14 | 1.041 | 0.945 | 1.364 | 1.275 | 1.277 | 1.547 | 1.109 |
| 15 | 0.966 | 0.981 | 1.300 | 1.109 | 0.835 | 1.117 | 0.945 |
| 16 | 0.872 | 0.516 | 1.275 | 1.410 | 1.515 | 1.109 | 1.119 |
| 17 | 0.972 | 1.089 | 1.109 | 1.277 | 1.453 | 0.945 | 0.405 |
| 18 | 0.665 | 0.991 | 1.254 | 0.835 | 1.275 | 1.277 | 1.070 |
| 19 | 1.089 | 1.117 | 1.277 | 1.515 | 1.109 | 0.663 | 1.129 |
| 20 | 0.809 | 0.970 | 0.663 | 1.586 | 1.543 | 1.515 | 1.117 |
| 21 | 0.881 | 0.945 | 1.515 | 1.275 | 1.358 | 1.586 | 0.777 |
| 22 | 0.803 | 0.981 | 1.397 | 1.109 | 0.835 | 1.117 | 0.777 |
| 23 | 0.706 | 0.566 | 1.275 | 1.505 | 1.515 | 1.109 | 1.119 |
| 24 | 0.809 | 1.044 | 1.109 | 1.277 | 1.547 | 1.049 | 0.405 |
| 25 | 0.492 | 0.991 | 1.271 | 0.835 | 1.275 | 1.277 | 1.089 |
| 26 | 0.930 | 1.117 | 1.277 | 1.515 | 1.109 | 0.663 | 0.809 |
| 27 | 0.991 | 0.970 | 0.835 | 1.453 | 1.410 | 1.224 | 0.881 |
| 28 | 1.050 | 0.945 | 1.515 | 1.275 | 1.358 | 1.287 | 0.803 |
| 29 | 0.803 | 0.981 | 1.586 | 1.109 | 0.835 | 1.117 | 0.706 |
| 30 | 0.706 | 0.505 | 1.275 | 1.543 | 1.515 | 1.109 | 1.109 |
| 31 | – | 1.089 | – | 1.277 | 1.586 | – | – |

Source: authors development.

## 7. The potential climate effects of airports and their environmental consequrences

There are several environmental effects due to airport activity, among them are:

– Increasing of frequency and intensity of climate anomalies and extreme weather phenomena.

– Droughts that genetically peculiar to a climate of Ukraine are becoming more frequent and more intense.

– Further spread of new types of diseases of crops, pests and weed.

– Worsening of problems with water supply of southern and south-eastern regions of Ukraine.

– The increase in morbidity and mortality due to changes in temperature.

– Forest productivity reducing.

– Irreversible changes in ecosystems [Shevchenko 2014].

These effects are valid at national and regional levels, but they could be also displayed at local levels in the vicinity of major airport.

The damage from climate effects might be assessed directly or indirectly in monetary value. The direct assessment is possible accounting the price of carbon unit, which is a ton of $CO_2$ and cost 13.75 USD as for the prices of 2010, 21.35 USD in 2015, and by 2020 it will be 32 USD [Shevchenko 2014]. Thus, the cost of monthly $CO_2$ emissions represents the environmental losses, which could be deducted from airport incomes make up from 80184.2 in April 2015 to 11370.1 in September. The estimation of cost of generated carbon units shows that there are 703 thousand UAH for the period of 2015 year from April to October could be dedicated from airport incomes. This money could be spent on greening of the airport territory for catching some part of $CO_2$ emissions or for other environmental purposes.

## 8. The approaches to mitigation of airport environmental effects

The adoption of measures to prevent, minimize or mitigate adverse impact of aviation on climate is the main target of airport stakeholders; today more than ever they are called upon to assess the local air quality at and around the airport. Assessment should be based on air quality regulation or standards to determine if the current or planned airport activities are expected to comply with the applicable regulations for each pollutant species. There are three main types of actions:

1. Measurements of the concentrations of specific pollutants of concern;
2. Development of inventories of emission sources to quantify the airport and airport-related sources for each pollutant;
3. Assessment of the expected pollutant concentrations at receptor locations by dispersion modeling [Berry, Gillhespy & Rogers 2008].

Mitigation of local air quality pollution is best achieved by reducing emissions at source. To reduce emissions the following measures are offered to be done:

– regulate the amount of emissions by setting emissions standards on sources or prescribing restrictions on operations (regulatory measures);
– reduce emissions through the implementation of technical solutions (technical measures);
– influence the emission levels through reducing fuel consumption or changing operating times of emissions sources or procedures (operational measures);
– create economic incentives to change activities or equipment with lower emissions (economic or market-based measures), including local emission charges and global or regional emission trading schemes.

These can be also implemented as a combination of several categories of measures. For emissions reduction opportunities, or where reductions in the adverse impact of aviation on climate change can be achieved, it is therefore important to distinguish between aircraft emissions and those emissions directly associated with airports. Moreover, particularly in the development of greenhouse gas emissions inventories, responsibility or ownership and location (on and off airport) have to be clearly demarked. Then, an airport has to develop goals and action plans to achieve the ultimate target of being carbon neutral [Berry et al. 2008].

Airport Council International Policies and Recommended Practices Handbook identify approaches to minimize or mitigate the adverse impacts of aviation on climate change:

1. Airports should develop inventory of airport and airport-related GHG emissions.
2. Goals and action plans should be developed with the ultimate target of becoming carbon neutral.
3. Reductions in aircraft taxiing, queuing and APU usage reduce GHG emissions.
4. Airports should review GSE and ground vehicles (airside) as well as ground vehicles (landside) and land transport for GHG emissions reduction opportunities.
5. New buildings should employ best practice energy efficiency and GHG technology:

– underground thermal sinks can be used to enhance heating and cooling efficiencies.

– combined cooling, heat, and power systems use waste heat from electricity generation to heat the terminal in winter. In summer, absorption cycle refrigeration systems can use the same heat source to generate chilled water to cool the building.

– smart building technologies can be used to reduce lighting and heating or cooling in unoccupied spaces. Unoccupied escalators can be slowed or paused until people need to use them.

– for large interior spaces in hot climates, thermal stratification can be used to cool occupied areas at floor level while allowing unoccupied space near the ceiling to remain hot.

– in cold climates, new steam plume-suppressing technologies can be used to allow heating plants to be located close to terminal and control tower structures without affecting visibility. This can substantially reduce piping losses and inefficiencies.

6. New and existing buildings should have best practical thermal insulation and glazing:

– installation of shading or light-filtering films on windows to reduce solar load.

– modifying and modernizing heating, ventilation and air-conditioning systems, such as installing variable speed electric motors to reduce air flows when occupancy is low or temperatures are mild.

– installation of more efficient and long-life light bulbs for both interior and exterior lighting.

7. Operational procedures can also be used to improve energy efficiency:

– maintenance hangar door opening and closing procedures can be improved to reduce heat loss in winter or heat gain in summer.

– lighting procedures can be improved to minimize lighting in unoccupied areas or during low occupancy.

8. Renewable energy should be used, where practicable, to reduce fossil fuel consumption.

## 9. Conclusions and discussions

Airports are sources of emissions that affect climate. Having analyzed the information about the temperature levels in Lviv airport and Lviv municipal area, it was established, that there is noticeable difference between them – temperature difference reach 1-3°C.

Radiative forcing formed as a result of air traffic of the airport depends on the number of flights. The value of forcing reaches 1.34 degree at the busiest August days. On average the increase of temperature is by 0.8–1.2 degree during the days with high flight intensity and 0.6–0.8 during not busy days.

The prognosis of air transportation development at Lviv airport that based on information from 2004 to 2015 years, shows that passenger overflow will double by 2025 [Polyarush & Tarasova 2010]. With increasing of number of flights the environmental situation at airport will getting worse.

The estimation of cost of monthly $CO_2$ emissions shows that over 703 thousand UAH for the period of 2015 year from April to October could be deducted from airport incomes. This money could be spent on greening the airport territory, catching some part of $CO_2$ emissions or for other environmental purposes.

There is a range of policy options being considered at governmental level and instruments such as ICAO engine emission standards to help in reducing aircraft fuel consumption and greenhouse gas emissions. However, because the science on the relative climate effects of altitude, contrails and NOx is not yet fully understood, the evaluation of potential policy solutions with the certainty of a positive result is incomplete. Moreover, the observed and assessed thermal effects were considered for a limited period of time, which does give possibility to make final conclusions about the continuous effects of air traffic on local climate. The further investigations will be aimed at defining regularities of thermal mode fluctuations at airport territory on the annual basis. Nevertheless there is a lot that can be done to reduce fuel consumption, which reduces climate change effects of air transportation:

– making routes more direct;
– aiming for a fuel optimised flight profile;
– increasing load factor and capacity (and use) of more fuel optimised routes;
– operating more fuel efficient aircraft;
– avoid holding and queuing aircraft with engines running (in the air and on the ground);
– avoid restrictions and procedures that do not achieve sufficient benefits compared to the other environmental disadvantages;
– using effective fuel optimised speeds when circumstances change.

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## Wpływ funkcjonowania lotniska na zmiany klimatu na przykładzie Portu Lotniczego Lwów

**Streszczenie.** Wpływ emisji spalin z silników samolotów na klimat Ziemi to poważny problem dla przemysłu lotniczego. Wraz ze wzrostem liczby pasażerów rośnie zużycie paliwa lotniczego oraz emisja gazów cieplarnianych (GHG). Może to destabilizować światowe stosunki klimatyczne, a w konsekwencji powodować szkody środowiskowe, ekonomiczne i społeczne na skalę globalną, regionalną i lokalną. Według szacunków Międzyrządowego Zespołu ds. Zmian Klimatu (IPCC) samoloty są odpowiedzialne za 3,5% antropogenicznego efektu cieplarnianego. Aby zapobiec negatywnym skutkom zmian klimatycznych, konieczne jest poznanie czynników wpływających na to zjawisko na poziomie lokalnym oraz opracowanie metody zmniejszania skutków klimatycznych związanych z działalnością lotnisk. W artykule przedstawiono obliczenia i analizę wartości wymuszania promieniowania związanego z emisjami samolotowymi oraz wpływu promieniowania chmur na obszarze Portu Lotniczego Lwów. Obliczone wartości zostały zweryfikowane przez porównanie z danymi meteorologicznymi dotyczącymi temperatury w mieście i na terenie lotniska.

**Słowa kluczowe:** lotnisko, emisje samolotowe, mikroklimat, efekt cieplarniany, wymuszanie promieniowania, zmiany klimatyczne