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Airports and Sustainability – Potentials, Questions, Ways to the Future

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1 ABSTRACT

Air transportation as a whole has lately been ever more in the focus of increased political and public attention regarding its impact on the environment. Airports and their infrastructure present within this transportation system complex focal points with a multitude of potentially beneficial measures and actions regarding sustainability.

There are in general three major technical areas where air transport sustainability can be addressed: aircraft power plants and fleet renewal, airspace management and flight duration, and airport infrastructure, operations and capacity optimization.

Huge improvements have been made in the development of aircraft over the last 40 years. Modern aircraft have reduced fuel consumption by 70% since the early 1970s and perceived noise (per aircraft) by 90%. Now in the immediate and medium term future airports are the sector where relevant issues on sustainability can and need to be addressed without much delay.

As large airports represent the technical complexity of small cities, the methods and focal points for environmental measures are diverse and can be targeted individually or in strategic packages as appropriate.

An initial short list of sustainability potentials should contain: reduction of energy consumption needs; sustainable building design and refurbishment; regenerative energy production using buildings, roofs and other installations; further development into vehicle fleet power systems; aircraft support systems on airport to avoid APU-operations; additional noise reduction potentials; water cycle management systems; biotope development.

An incomplete short list of questions and problem areas to be addressed are: ownership issues of buildings, infrastructure, systems and vehicles; operational availability, redundancies, security of new systems; recovery of investment cost in a regulated market (airport fees); timeframe of realization, depreciation of investments existing and new.

Airports traditionally are at the forefront of technological development and of the implementation of new technologies. The general functional setup and the operational processes at airports are similar worldwide. The airport industry is already implementing steps in individual projects all over Europe. To further sustainability issues at airports however, reliable decision making criteria and metrics on the implementation and operational results of sustainable technologies at airports are needed, and currently not available.

It is therefore proposed to initiate a discussion forum on airport sustainability with the aim to create a focused research effort in this area.

2 AIRPORTS AND THE ENVIRONMENT

Airports and air transportation are in general already a very environmentally conscious community. The lately fashionable public criticism on this matter is, while not wholly unfounded, often widely out of proportion to the size of the problems addressed. While air traffic is steadily growing (in Europe by ~3% to ~6% every year) large steps to environmental sustainability have been made already. As one example the specific fuel use of the Lufthansa fleet in 2005 was 4.39l / 100 Pax km, which reflects a reduction by 70% since 1970 and by 31.9% since 1991[1].

In many countries airports are among the first companies or institutions to establish audited environmental programs and processes.

Due to the intense noise levels produced by aircraft engines, airports have long been accustomed to have a watchful environmental eye towards their airline customers. In general noise levels in the surroundings of airports have vastly improved from the early 70s, due to the efforts of the aircraft and engine manufacturers but also through proper planning of flight-paths close to the ground by airports and air traffic control agencies.

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Aircraft operations require large spaces and airports consequently possess large tracts of inaccessible open land. Often these provide valuable habitats and biotopes for a multitude of species, which in their immediate neighborhood have long been endangered or driven out by industrial agriculture and urban development.

From past experience, airports can be expected to be on the forefront of technology development and implementation.

All this bodes well for the reaction of the airport industry to new environmental challenges.

However, regarding the current issue of emissions trading and CO_2-neutral operations - and intricately linked with it the issue of energy supply, transfer, and consumption - airports have reacted rather cautiously at this time.

In part this can be blamed on the rather confused public and political discussion of the matter. The air transport industry is very often lumped together –airlines, services, manufacturers, airports, concessionaires, tenants, etc. – without due consideration of their widely varying business foci. Unlike an airline however, an airport is a conglomerate of businesses and interests arranged around the main transportation function of an airfield. Ownership and operational models of airports are diverse and widely differing on the internationally between airports.

To regard an airport as a single entity and discuss it as such is sensible only in so far as one can regard e.g. a city or township as a single entity and discuss its issues in such an overall context.

To enable the "entity airport" to react to environmental challenges in a concerted fashion there must be an understanding of who all constitutes an airport and what are the relationships of airport owners & operators with their clients (mainly airlines, passengers) and their tenants, concessionaires and supporting services (e.g. ground handlers, retailers, fuel services, support facilities, aircraft maintenance, etc.). Furthermore, as airports constitute a geographical monopoly they are in many places regulated by governments concerning their conduct and pricing of services for air transportation and their ability to diversify into unregulated support business fields (e.g. parking, retail concessions, etc.).

A successful approach to environmental measures at airports therefore needs to take into account this diverse structure of interests in such a way, that the beneficiaries of environmental evaluations (e.g. CO_2 credits) are identical to the investors in environmentally improved equipment or infrastructure.

3 POTENTIALS FOR SUSTAINABILITY AT AIRPORTS– A QUICK OVERVIEW

This paper intends to give a general overview over the adaptation of sustainable technologies onto airports. It does not address all issues in detail. As sustainability is by definition interdependent on the local environment, the following discussions are by needs somewhat overarching to provide starting points rather then to give specific solutions. The individual needs for heat, coolth, light, shade, winter or summer operation systems are what determines the locally correct technical approach to sustainability.

3.1 Where Airports Stand Today

Buildings on airports often dwarf other buildings due to their basic dimensioning requirement to conform to the aircraft size and the large number of people to be served simultaneously. Also airports require a whole variety of different types of functional buildings, many of which are very much comparable to a well diversified large commercial area.

Therefore airports sport an unusual amount of façade and roof area and uninterrupted interior volumes in comparison with other commercial buildings (e.g. shopping centers, office buildings, etc.). Depending on the building function their internal energy needs are widely different. Airports regularly require both heat and coolth at the same time, and many have centralized supply systems for both.

In their use function airport buildings however show considerable differences to comparably sized commercial buildings. Terminals have over all a relatively low population density per Volume as compared to office or retail buildings, therefore posing very different problems as to energy needs. Large aircraft hangars require sometimes precisely controlled internal environments in a huge air volume for the maintenance activities, while airport vehicle hangars often only serve as out of the weather parking with no special heating requirements.

Overall airports consume huge amounts of energy. The table below gives a few data points on energy consumption for some European airports as an indication of scale and characteristics of the situation.

Airport [1]	**Year**	**Passengers**	**Freight & Air Mail**	**Thermal**	**Thermal / User Unit**	**Electrical**	**Electrical / User Unit**	**Energy / User Unit**
Values given in *ITALIC* script are calculated, all others are taken from source material		Annual Number	Annual Tons	MWh / year	kWh / (Pax or 100kg Freight or Air Mail)	MWh / year	kWh / (Pax or 100kg Freight or Air Mail)	kWh / (Pax or 100kg Freight or Air Mail)
Brussels [2,3]	2005	16,179,733	702,819 [2]	127,272 [3]	*~5.48*	238,807[3]	*~10.29*	*~15.77*[6]
Duesseldorf [4]	2003	14,171,036	48,520 [5]	~94,000	*~6.41*	n.a.	n.a.	n.a.
Frankfurt/Main[6]	2005	52,219,412[7]	1,991,535[7]	~535,000	*~7.42*	~580,000	*~8.04*	*~15.46*[6]
Hamburg[8]	2005	10,675,127	75,152.4	105,829 [4]	*~9.26*	30,772 [5]	*~2.69*	*~11.95*[6]
Vienna[9,10]	2005	15,859,050	234,677	~116,000	*~6.37*	~110,000	*~6.04*	*~12.41*[6]
Zurich[11]	2005	17,884,652	393,890	138,872	*~6.36*	179,310	*~8.22*	*~14.58*[6]

Table 1: Energy consumption of selected European Airports

Much of an airports electricity needs comes from the various requirements for lighting fixtures. In many cases however even today airports produce a large part of their coolth in air-conditioning systems using electrical power.

In other fields the picture of attaining sustainability is not quite so bleak. Airports are often much more advanced than their surroundings when it comes to water management systems, drainage and sewage cleaning and biotope availability.

Also on the field of developing alternative fuel vehicles, airports together with public transport companies have been major drivers in the industry.

3.2 Sustainable Buildings – Passive Energy Design

Sustainable building concepts are up to now mostly absent in the design of special airport buildings. Even so the special characteristics of many types of airport buildings provide ample possibility to consider such concepts.

Special consideration is regularly given to the problems noise and radar reflections when considering façade and roof design of airport buildings. Both issues usually enforce a more technically elaborate design solution than normal on the buildings. Many of the measures so required (e.g. double facades, noise insulated roofing, uneven roof and façade structures, etc.) provide immediate synergies when regarded as a first step towards a passive solar energy building design. However, as of now there are only a very few examples of these kinds of sustainable designs being consciously pursued and implemented.

Many interior spaces in terminals and hangars are large and have a direct outside façade or roof. The issue of making use of controlled natural lighting during daytime needs poses therefore some added difficulty in the design, which needs to be addressed consciously in the architectural process to avoid unnecessary daytime internal lighting. Window areas often are large to give vistas, but unstructured as to light, shadowing and

[1] The airports listed have been chosen by process of an Internet search on energy consumption data of airports in a "pseudo-random" selection process. They are those European Airports for which, in conducting a quick research of one afternoon, usable data on energy consumption was obtainable. No airports have been filtered out, all for which I found data have been listed. If there is a slant to the values if compared to additional other airports it is not intentional.
Source Notes as referenced by letter designators in the table are given at the end of the paper.

[2] Without Air Mail

[3] Converted from GJ as given in the source material to MWh

[4] Utilized Natural Gas in Heating and Co-Generation Plant

[5] Electricity bought from the grid – it can be inferred from the source text that additional electricity is produced on airport by cogeneration, but this is only given as thermal energy gas consumption – so cannot be inferred that Hamburg needs significantly less electricity than other airports.

[6] Looking at the energy consumed per passenger, and taking into account that the average passenger is at the airport an estimated 60 minutes, these consumption levels translate to a comparative set of 12 to 16 1000W stadium flood lights or 120 to 160 100W normal light bulbs on each passenger – enough to fry the poor person so illuminated.

energy intake or loss. Passive lighting elements such as daylight piping systems, which can provide a near constant light fixture largely independent of the position of the sun in the sky, are seldom used. Especially in lighting large interior spaces such elements could be used very much like electrical lighting and reduce both daytime electricity needs and related interior heat generation.

Too often even the newest such buildings, while investing heavily in custom made hulls, end up as under lighted and without the necessary control instruments to balance hull-energy-throughput to their internal energy needs.

Overall there is a sizable, as yet underdeveloped potential for passive energy use design at airport buildings. As buildings are long-term investments consideration should be given to evaluate existing buildings regarding any possibilities to implement passive energy use design in the course of building rehabilitation or refurbishment.

3.3 Regenerative Energy Production – Active Energy Design

Airports for their operations will always require secondary energy transport media (e.g. electricity, propulsion fuels, heat, coolth, etc.). The interesting questions therefore, as regards sustainability are, which such media can be produced economically by the airport itself and which consumption process of such media can be curtailed or changed economically on the airport to produce energy savings.

In addition to the well-known technical requirements and characteristics of the different regenerative power/energy production systems (which will therefore not be here discussed), their implementation on an active airport requires some additional considerations.

Airports depend on having clear skies for flying operations, therefore cooling systems and condensers of cycle processes must be designed and placed in such a way, that no additional fog occurs on the airport. Similarly any buildings including smoke stacks or steam vents can only be of a limited height – max. 45m above the airport reference point – and need to be placed with consideration to the likely direction of plume distribution and plume effects on air traffic.

In addition to this all buildings and installations on airports are checked in size and position regarding their effect on the visibility situation of the air traffic control tower and other principal observation posts (e.g. fire fighting control room). Visibility of the tower to all aircraft movement areas must at all times be unobstructed (albeit sometimes with technical support systems like ground radar and CCTV). Also all façade and roof forms, designs and materials need to be verified regarding their radar reflection signature of the various airport radar installations.

3.3.1 Hydroelectric Power

Hydroelectric power stations are extremely situation dependent on the availability of a stream of sufficient elevation change and water flow potential. As airports are mostly in planes or large valleys the direct availability of a hydroelectric potential is highly unlikely for an individual airport power plant.

3.3.2 Wind Energy

Wind energy has an inherent functional design conflict in the environs of airports due to the height of modern large wind turbines and their characteristic as obstacles to aircraft in flight. An on airport a sizable wind energy facility can be largely ruled out.

3.3.3 Geothermal Energy

Geothermal energy is also very situation dependant similar to waterpower, however in regions with high geothermal potential it usually can be tapped at many points in the region. An airport specific application is therefore well conceivable in those regions (e.g. Iceland, New Zealand, etc.). Special consideration has to be given to the situation of the steam venting and the turbine cycle cooling systems.

A special situation of man made geothermal energy application could be large seasonal or day-cycle heat or coolth reservoirs in the ground. Depending on the geological situation airport buildings often do have deep pile foundations which in some cases can be used as heat transfer and storage medium for such reservoirs or as heat tapping devices for ambient soil heat pump systems (see below). One building using such a system in its foundation structure is the building of the Commerzbank at Frankfurt.

3.3.4 Ambient Energy – Heat Pump Systems

Utilizing a heat pump process ambient energy can be gained from air, water or soil (usually only wet/moist soils). Like geothermal systems on airport installations are easily possible. As much of ambient energy is directly related to weather and seasons, such systems can also have pronounced day/night and seasonal cycles. Heat pump systems always need a secondary technical energy source (electrical power or heat) to function.

3.3.5 Solar Energy

Solar energy is available everywhere, but very dependent in its implementation on the general weather conditions, topography, layout of buildings and has its day-night and seasonal cycles. Two main applications are possible – photovoltaic and thermal. Its application depends manly on the availability of suitable roofs and façades or other open areas suitable for collector placement.

At an airport solar systems find almost ideal conditions. Picking up one of main themes of the passive energy architecture (see chapter 3.2), the available huge façade and roof areas at airports can be viewed as assets. Especially south facing facades or roof areas (including flat roof areas) can be considered for both solar photovoltaic and solar thermal energy production.

Open airfield areas however have to be considered generally as unsuitable for such installations. Any such installations will need to be considered also in respect of their radar and visual impact on air traffic control operations.

3.3.6 Biomass Energy

Biomass energy systems function very much like fossil fuel systems. The application of biomass is largely dependent on its local availability and regenerative biomass growth potentials. On airport systems are possible but in their likelihood maybe comparable to geothermal energy systems. However some biomass is transportable, within reasonable distances and there are developing biomass supply markets, which would make such systems possible even if the biomass were not from the immediate surroundings of the airport. In relation to CO_2 emissions trading schemes, biomass systems in this sense, can also be remotely located. This is however not true for the energy consumption side of the equation. (Waste burning co-generation facilities are NOT a regenerative energy source.)

3.3.7 Overall Evaluation of the technical Implementation Potential of Active Sustainable Energy Design

In general even in higher latitude moderate climates the implementation of solar power systems and ambient energy systems should be a possibility at almost all airports. All other regenerative energy sources are very situation dependant and wind turbines can almost certainly be ruled out for large energy supply systems.

Which regenerative energy system or system combination is suitable for an individual airport can only be determined case by case. As shown above all airports need lots of electricity and usually both heating and cooling energy at the same time and year round. Many airports have airport wide heat and coolth distribution systems, which allow for larger plant dimensions and possible efficiency of scale considerations. On the other hand many of these systems currently are not equipped to handle decentralized energy production and input into these distribution systems. Such problems however are within the current state of energy transport technology and can in general be solved by application of suitable control instruments.

Also most larger airports have rather flexible supply infrastructure systems, utilizing utility tunnels, cable ducting and other systems that enable them to adapt quickly to such changes.

3.4 Reducing Current Energy Consumption

3.4.1 Electrical Lighting

Airfield Lighting is needed for safe flight and taxiing operations at night, so airports usually have several thousand such lights mounted in their pavements. Apron Flood Lighting is required to be at a minimum of 20 lux everywhere aircraft are serviced or parked at nighttimes. Terminals and all public and work spaces need to be lighted to a comfortable level as long as there are operations going on. Last but not least in respect to airport commercial income is the retail sector and its lighting needs for advertising and store operations. So any development in reducing the energy use of lighting fixtures can have a potentially high impact on the electricity needs of airports.

Especially the current developments in LED technology are of considerable interest in airfield and obstruction lighting.

3.4.2 Heat and Coolth

The savings potential for heat or coolth at an airport is much like the related such potential in any town next the airport. Much depends on the building structure and the passive (insulation, shading, etc.) and active (control systems, heating, AC, etc.) systems already in place. While there might be sizable potentials in some countries, in others, which have already stringent energy building codes for some time (e.g. Germany, Scandinavia, etc.) such potentials are limited.

However especially as it regards new or replacement construction of buildings or total renovations the principles of passive energy engineering in combination with optimized active technical energy systems do still present a potential for energy savings. It should therefore become a specification standard for such engineering and architecture works to determine these potential at the outset of every such project.

3.5 Vehicle Fleet Power Systems

Much of airport operations depend on a large array of specialized vehicles. As these vehicles also have to function inside of buildings in some cases (e.g. busses, baggage tractors) or are total special designs in others (e.g. push-back tractors, cargo loaders) already there are a large selection of vehicles with unconventional engine systems available and in use on airports.

Airports have been successful test beds for hydrogen engines, LNG- and LPG-engines and high power electrical drive systems for a long time. Availability of such vehicles on the market is in this industry already the current state of the art.

Especially in conjunction with photovoltaic electricity production energy needs for vehicles on the apron with their short travel distances and their recurrent hold-over times between serving an aircraft – allowing operational recharging windows – could be met regeneratively on a airport.

3.6 Aircraft Support Systems to avoid APU-Operations

Auxiliary Power Units (APU) of aircraft have long been identified as a nuisance as regards the additional noise level and exhaust produced on an airport apron. They are mainly needed to provide an aircraft with electricity to run its internal systems and air-conditioning while sitting on the apron.

Many airports already provide stationary electrical supply systems (400hz-Systems) and/or pre-conditioned air systems at all or some of their aircraft parking positions to enable APU shut down. Most often the drive for the installation of such systems was noise and pollution motivated.

Again both these systems can be served in a sustainable way by providing regeneratively produced electricity and coolth.

3.7 Noise Reduction Potentials

Airports suffer from the noise of the aircraft in flight, the noise of the aircraft on the ramp (unless the APU is off), the noise of the airside and landside vehicle traffic, and possibly a noisy railroad connection. By far the most obvious is the aircraft in flight problem, which manifests itself over a large area under the approach and departure paths of the airport runway system.

Once the runways have been placed the influence of an airport on this noise footprint of the flying aircraft is very limited. Meaningful measures are largely in the domain of airline operations and air traffic control entities and aircraft developers. Large strides have been taken already at this problem and the industry is aiming for further aircraft and engine noise reductions. Current aircraft engines are roughly 30dB less noisy than those of the first generation – which translates into roughly a 90% reduction of the "experienced" noise perception [Fehler! Textmarke nicht definiert.].

In their immediate neighborhood and as regards their internal working environment however airports can set measures especially as it regards the noise from all other listed sources.

3.8 Water Cycle Management Systems

3.8.1 Water Supply Needs of an Airport

Airports do have a sizable workforce in comparison to the number of passengers and other guests served. Depending on the size of an airport there are between 2.5 and 5 people working on an airport for every 10 daily passengers served. Airports therefore are very often small to midsize towns in population (up to over 50,000 employees) and have corresponding hygiene and sanitary requirements.

Water is needed also for the fire safety systems and in many places for irrigation of green areas. The later serving sometimes also the former, as irrigation of airfield areas is done mainly not for landscaping purposes but as a means to suppress the fire hazard from hot aircraft exhaust.

As the needed water quantity and the required water quality differ widely between potable water, fire fighting water, irrigation water in areas used by human beings, and irrigation of airfield areas, many airports already have rather elaborate separate water systems to avoid wasting premium potable water.

Further potential for development can be found however in many places and countries, that are not yet habitually treating water as a scarce resource

3.8.2 Water Disposal Systems

Airports contain not only large buildings, but also even larger sealed surfaces of airfield, apron and vehicle parking lots. So storm water drainage is a large issue on airports. At this usually a large part of the apron (aircraft parking area) is designated also as aircraft refueling area, which complicates the problem of storm water disposal by adding the possible necessity of water treatment of unavoidably highly diluted runoff.

The normal sanitary sewage system in size corresponding to the sanitary needs of the airport population is a standard system on airports. In addition airports create some special wastewater runoffs, which qualify as industrial sewage types. These are the industrial and restaurant kitchen sewage and in winter special deicing fluids are used to deice the ground surfaces or the aircraft. Modern such deicing fluids are biodegradable but do have rather high TOC values, so that a direct drain off into a stream is often out of the question. While these fluids are designed to not damage aircraft (made mainly from aluminum) they can exhibit other corrosive effects (some eat heavily into galvanized steel or normal reinforced concrete). In many places around the world however the deicing is still done with urea, which inevitably leads to soil contamination at deicing pads and its runoff needs to be treated as sewage.

Modern airports therefore usually have rather elaborate water collection and treatment facilities and either possess their own biological or chemical sewage treatment plant or are connected to a large one nearby. Some of the treated runoff can be used for safe secondary systems (e.g. airfield irrigation) and some of the special sewages can be treated in biological treatment fields.

Similarly to the field of vehicle technology the airport industry has been in the forefront of the development of modern wastewater treatment technology.

4 AIRPORTS AS TESTBEDS FOR TECHNOLOGY

Traditionally airports and many operators on airports have been government owned or very close to governments almost all the world over. While this has put its distinctive mark on the way airports and many companies on airports work and function to this day, there has been a decidedly positive side to this situation as it regards technology development and technology transfer.

Especially in the sector of alternative vehicle fuel development, but also in regard to security systems and logistical technology airports have served as crucial facilitators for products and technologies stepping from test bed to prototype to product. High throughput industrial kitchens as well as automated mail and baggage sorting, high power electrical vehicle drives, magnetic and explosive screening technologies all were developed and/or perfected to better serve special airport requirements.

When technologies are at the verge of emerging from prototype to product governments and industry both often use the airport as crucial stepping-stone and controllable test environment for the development and validation of usability of a technology.

While the increasing privatization of airports has somewhat changed their focus regarding procurement and technology, it has also changed the focus of the industry toward the well being of its clients. Airports still are at the forefront of technological development as we speak – however it is often no longer a government department that initiates a program, but the airport owner or some operator on airport that has a specific good economic reason or need. To facilitate the needs of the passengers, airline, security, or good neighborly relations with the surrounding townships, or… all become more and more important as the airport industry transforms from a government authority to a consumer service provider. So while the driving focus might change, the general positive attitude of the whole airport industry to technological development and change is unabated.

Never the less, airports are highly efficient entities with a main purpose of facilitating the airlines and their passengers and cargo in their need for transportation services. Whatever is used on an airport has to meet very high standards of availability, dependability, and operational safety in this consumer oriented environment. What will work on an airport will work in many other situations as well; it might just be over-engineered for them.

5 THE QUESTIONS OF IMPLEMENTATION

Implementation of technology at airports is increasingly becoming subject to the same economic and other decision criteria known the world over in business. Airports still are and will most likely remain to some part regulated entities. Always an airport is the sum of all the many different owners of facilities operators and service providers needed to provide the function of the transportation hub.

One of the best comparative analogues to airports is the township or city. Therefore implementation of technologies will proceed very much like in everyday life in fits and starts and very much dependent on the direct commercial viability of a system for the individual investor.

As airports are not the monoliths they are often made out to be in public perception, they will react very much to the same incentive structure provided by governments as everybody else. For the same reason, companies on airports might not meet certain size criteria for the implementation of a policy or law because they are smaller than given thresholds and only many of them make the "large" airport.

Airports also in their complexity sometimes do have a hard time in finding and identifying their inherent potentials and possibilities for synergies and sustainability. While certain fields like vehicles and water systems race ahead others like architecture, building energy design and energy production systems are hampered by their own size and inherent longevity in the drive to new technologies.

Often the shear size of airport installations and the commensurate diversification of tasks and responsibilities in its operating workforce prevent the detection or realization of synergies.

5.1 The Economy of System Implementation – A Sketch Outline on Three Issues

To illustrate the point of economic decision-making regarding energy supply or reduction systems three simplified outline evaluations on system economics and pricing are presented hereafter. They compare solar photovoltaic and solar thermal energy installations with their current direct competitors: grid electricity and fossil fuels and illustrate the change over costs to LED airfield lighting in relation to electricity savings.

This serves to illustrate the point that different types of renewable energy systems run into very different competitive scenarios with sometimes surprising results. It also illustrates the point that even very large installations by current standards of the regenerative energy industry make only rather small dents into the total energy needs of an airport as illustrated in chapter 3.1.

In this example the rather "expensive and high tech" photovoltaic system comes off as significantly more profitable over its lifetime than the "well tested and low tech" solar thermal system – mainly because they compete against different conventional energy supply systems. However both examples while considering large installations of 6000m² of solar panels or collectors can provide only ~0.25% to ~3% of the respective energy need of a mid sized international airport (as compared to Table 1 – Brussels, Hamburg, Duesseldorf, Zurich, Vienna).

5.1.1 Solar photovoltaic energy production – a rough estimate calculation

The power supply of solar insolation at the earth's surface is approximately 1,400 W/m^2_p [12] perpendicular to the solar light rays. In moderate climate conditions (central Europe) the average yearly solar energy delivered on a flat surface is approximately 1,100 kWh/m² [13].

Currently efficiencies of solar photovoltaic conversion range between 6% and 18% [14] depending on the type of pv-cells used. An electrical conversion efficiency of 85%Fehler! Textmarke nicht definiert. to convert pv-cell output into AC-current at 18kV also has to be taken into consideration.

On a flat roof or vertical south facing façade of a terminal or hangar of 6000m² (60m x 100m or 15m x 400m) therefore a yearly electricity output of between 336.6 MWh and 1,009.8 MWh could be achieved in an average central European location. At a price of 0.20€/kWh this would amount to 67,320€ to 201,960€ electricity sold or saved per year.

The costs of the pv-cells would thereby be between 765,000€ and 3,029,400€ to which an estimated 50,000€Fehler! Textmarke nicht definiert. of electrical installation coasts would need to be added. On average the break-even-point is therefore at between 12.1y and 15.2y. As pv-cells last at ca. 80% effectiveness for 30 years Fehler! Textmarke nicht definiert. therefore a sizable but not short-term return on investment can be expected from such an installation. Installations with a pv-cell inclination of larger than 15° are usually self-cleaning through normal rain runoff.

The overall return on investment can be estimated at 200 to 350% or higher, should electricity prices rise faster than general inflation (as can be expected). Consequently there is a developing market of investors with an interest in the lease of large roof and façade areas for such installations. As regeneratively produced electricity can be sold in many countries to the grid at much higher prices than the 0.20€/kWh profitability of such systems is currently given and in certain cases can achieve break even times of 3 to 4 years.

5.1.2 Solar thermal energy production

Solar thermal energy systems can provide efficiencies up to 80% [15] at peak and depending on the system utilized any technical temperature from below 100°C to over 1000°C (focusing systems – only for direct insolation). The efficiency of the solar collector is also very much dependent on the heat losses to the environment. Collectors that are close to or at ambient temperature have the highest efficiency because they have the least heat loss to the environment.

In western central Europe the overall yearly effectiveness of a low temperature solar thermal installation can be estimated as between 30% and 50% Fehler! Textmarke nicht definiert. in relation to the available average yearly solar energy delivered on a collector surface.

Using the previous example of available flat collector area (6,000m²) and average annual insolation (1,100 kWh/m²), and assuming a relatively low temperature system for water and building heating purposes (T_{out} ~ 100°C) the energy that can be gained could be between 1,742,400 kWh and 2,904,000 kWh thermal.

This would be roughly equivalent to 163m³ to 271m³ of light heating oil or 151,500m³ to 252,500m³ of natural gas (high gas) in a modern heating system [16].

Prices for installed solar thermal systems range between 450€/m² and 900€/m² per collector area. A 6,000m² collector system could be estimated to cost between 2,7mio€ and 5,4mio€ at installation. At an estimated price for light heating oil of 700€/m³ the yearly savings can amount to 114,100€ to 189,700€. At an estimated system lifetime of 20 years the total savings would come to between 2.28mio€ and 3.79mio€ under current conditions. As traditional heating systems need to be installed as winter backup in many places, the fuel-cost savings do have to compensate for the total investment in most cases.

At present therefore economic conditions for solar large scale thermal installations are not yet met at the market. However, the change in conditions observed over the last decades with fossil fuel prices skyrocketing might change the equation. Also in climate conditions in which sunshine is available year round and traditional backup heating are not needed economic viability can be achieved at present.

5.1.3 Replacing Light Bulb Airfield Lighting with new LED Airfield Lighting

At present the implementation of LED-lighting fixtures in the sector of airfield lighting offers the potential of reducing electricity costs by up to 80% while increasing lamp replacement intervals by a factor of 10 or more.

Airfield lighting fixtures have to withstand extreme loads, temperature ranges, weather, etc. and as high-tech elements cost about ~750€ a piece (from 500€ to 1000€; regardless of bulb- or LED technology). To this has to be added another ~500€ for the associated transformer unit and cables and ~300€ for the installation works. Should an airport want to replace 5000 airfield lights it will be faced with a bill of up to ~7,750,000€ for changing the lights plus the book value write-off from the old lights. At a power consumption change from 48W per conventional light [17] to ~10W per LED-array light [18] and electricity costs of 0.20 €/kWh this comes out to an operating time of ~200,000 h for the LED-light just to recover the replacement costs through the energy savings.

This exceeds the expected lifetime of the new LED-Lights by a factor of ~2.5, so don't hold your breath expecting a sudden changeover replacement wave for reasons of saving electricity. LED airfield lighting will slowly replace the existing lights in the future, but only in the course of normal system replacement at the end of the lifetime of the existing lights.

5.2 Setting Airport Managers, Architects and Engineers the Task

There is an unfortunate, but observable gap of understanding and communication between architecture and technical building systems engineering, which needs to be rectified. Both these technical branches are in general not used to successfully interact already at the point of architectural conception. However, as examples from the banking sector show (e.g. Bank of China HK – natural interior lighting; Commerzbank Frankfurt D – integrated foundation heat pump system – both already more than a decade old), once an building owner stipulates environmentally sound architecture and systems design, much is possible with the present state of technology, often even with unlooked for economic benefits and synergies in construction and operation of a building.

It should therefore be considered by airport owners and operators that they do have an important part to play in this process by setting economically and environmentally sound goals and parameters for their construction and design projects. Environmentally comprehensive designs require a rather larger effort on the part of all participating engineers and architects than the standard – we'll heat, cool and light whatever you design – approach. They will therefore not happen on their own, and they are almost guaranteed not to happen at all if the design services for architecture and building energy systems are contracted for separately.

5.2.1 Providing Metrics to Airport Management

With all the different possible technical systems and solutions for implementing sustainable designs and all the uncertainties of what is the right mix for the situation, there is one crucial element missing, right at the start of most airport infrastructure or building projects – a metric for the airport management to provide an initial go / no go evaluation at the outset.

Once an airport decides on an infrastructure project the related engineering tasks are mostly delegated to outside architects and engineering consultants. More often than not the task definition and deliverables for these engineer or architect lacks the specific requirements and specification of success regarding the airports optimized sustainable energy needs.

This is not necessarily an oversight or even done on purpose, more likely it is because there are no comprehensive guidelines available and no laws and regulations on sustainable technology implementation to reference to. So airport management and their support staff in their drive to come to an initial evaluation of the intended benefits and costs of the project do so without a consideration of such technologies. In the absence of a metric at this stage any sustainability system definition imposes an unevaluated economic risk on the project. So as usual economic decision-making tends to the conservative.

It follows that one item urgently needed is a metric for sustainable engineering targets at airports that can be applied with a reasonable amount of economic and technical certainty at the stage of feasibility study and project preparation.

5.2.2 Project Structure – Why Complexity like Energy Optimized Buildings doesn't Happen on its Own

Integrated Design happens in complex and medium to long duration projects – as are many airport projects – only by enforcing a decision and result oriented structure on all parties involved. Optimizing any airport project for sustainability or energy use and production is only one more level of complexity that needs to be addressed.

Traditionally the function of the architect in a building project was overarching – ensuring the consideration of all aspects of a building project. Reality however shows, that many infrastructure and building projects on airports are segmented into their technical and organizational components at the time of contracting the consultants. Reasons for this are plentiful, but results tend to have similar characteristics. Projects become slow, expensive and often rather uncoordinated. This is in no way to be considered as a conscious deficiency of the hard working people involved, but results from some simple facts of communication theory.

If the number of parties involved in a project is N then the number of interfaces in the project $I = N(N-1)/2$. If every involved party has on average P persons that handle project related outside communications (fully internally coordinated and no person-to-person channel between parties functionally doubled) the number of interfaces rises to $I_P = NP(NP-1)/2$. This holds true for any closed project group. A simple comparative example can easily demonstrate how early decisions on the structure of a project can predetermine its potential for success or failure through sheer communication overload (see Table 2).

To achieve optimized results in the complexity of the task at airport projects the general direction of the project structure needs to be actively set already at the time of preparing the procurement process for the consultants involved. It is all too often overlooked that consultants that operate under individual contracts work within their contract specifications only. It is virtually impossible to define the interfaces between technology or system discreet consultants without gap or overlap. It is absolutely impossible to achieve comprehensively concurrent, optimized, timely and economically sound concept and draft designs out of such a situation – AND THIS IS NOT THE FAULT OF THE CONSULTANTS.

A second, sometimes extremely costly and time-consuming effect of a non- or under-structured large airport project is a tendency to develop an evolving instability regarding the project aims and specifications. This effect is especially noticeable on large complex airport projects since they often have a long duration not found in other industries – between conception and completion of a terminal or hangar or runway project it is not uncommon to see the better part of a decade go by.

The following example is roughly based on an airport terminal project with both airside and landside area adaptation. It tries to consider – with some simplification – the involved parties in such a project. Parties are defined by function in the example not by internal hierarchy in an airport company.

Project A has everybody involved in one largely unstructured project group and all tasks farmed out separately to individual consultants and contractors.

Project B is at the far edge of comprehensive contracting just short of "Design-Build" and "BOT" situations and imposes a layered structure with a Core Project Group supported by several Project-Subgroups (technical task-sets farmed out for general design or construction) to focus the process.

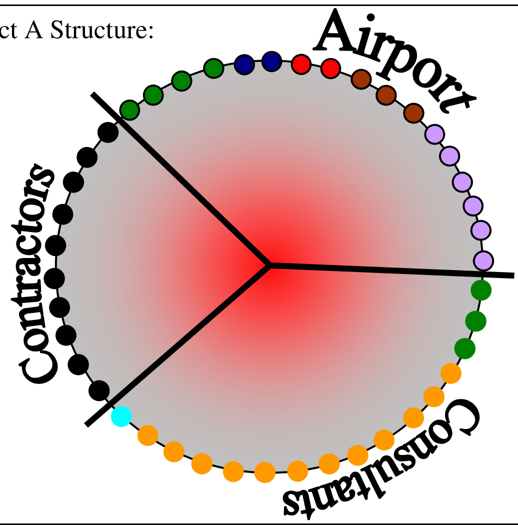
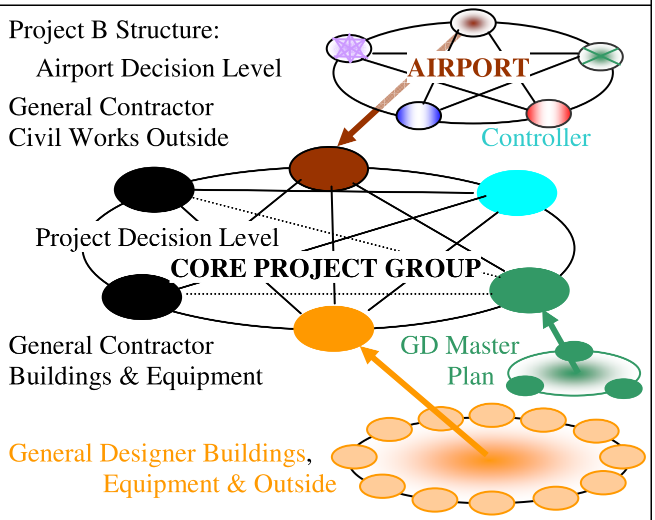
Project A: **Party to Party Direct Unstructured Communication**	**Project B:** **Decision & Result Focused, Multi-Layered Project Structure and Communication Protocol**
Individual Parties involved: (43) **Total Communication Interfaces: (43 * 42 / 2 = 903)** **Decision Active Interfaces ~40% thereof: (358)** On the assumption that every party has on average 2.5 outside communicating persons in the project (internally coordinated) that makes 108 persons that communicate along 903 p-to-p channels (none doubled) and need to: - timely inform each other, not misunderstand each other, and prepare all decisions for management => Probability of this happening = 1/903 ~ 1.1‰ ~ NIL	**Core Project Group (6)** Individual closed Project Subgroups involved: Airport Construction Management, General Designer Buildings & Outside, General Designer Master Plan and Transportation, Controller, General Contractor Building, General Contractor Outside Works Project Decision Active Interfaces between Project Subgroups: (6 * 5 / 2 = 15) **Total Communication Interfaces: (156)** **Project Decision Active Interfaces: (15)** **Airport Decision Active Interfaces (10)**
Project A Structure:  	Project B Structure: 
Result A: DECISION GRID LOCK	**Result B: TIMELY DECISIONS**
Background Assumptions on Participants and Structure Project A: Determination of the Number of Project Group Participants = Individual Parties Involved:	**Background Assumptions on Participants and Structure Project B:** Determination of Secondary Coordination Interfaces within the six closed Project Subgroups:
Airport: (17) Internal Interfaces – all active: (136) Management Terminal, Management Airfield, Management Landside, Management Concessions, Airport Operations, Handling, Security, Fire Brigade, Construction Management Building, Construction Management Outside, Construction Management Technical Systems, Technical Systems Information, Technical Systems Energy, Technical Systems Water and Sanitation, Technical Systems Building Installations, Technical Systems Maintenance Outside, Technical Systems Maintenance Buildings	Airport Construction Management (is guided by an internal process of decision finding between sub-sub-structured airport divisions): – Airport Internal Divisions (5) Airport Decision Active Interfaces (10) Airport sub-sub-structure internal interfaces: Management (4), Operations (2), Security (2), Technical & Maintenance (6), Construction Management (3) - Airport Internal Div. Interfaces: (6 + 1 + 1 + 15 + 3 = 26)
Consultants: (15) Internal Interfaces – all (105) – active: (95) master planer, transport planer airside, transport planer landside, architect, structural engineer, civil engineer landside, civil engineer airside, technical installations engineer, sustainability expert, baggage system engineer, security consultant, safety consultant, project management consultant, construction oversight engineer, controller	General Designer Buildings & Outside – Internal Parties (12) Interfaces total (66) General Designer Master Plan and Transportation – Internal Parties (3) Interfaces total (3) Controller – Internal Parties (1) Interfaces total (0)
Execution of works: (11) Internal Interfaces – all (55) – active: (27) construction civil building, civil airside, civil landside, façade & roof, internal construction, HVAC Systems, water systems, power supply, information systems, transport systems, baggage handling systems	General Contractor Building – Internal Parties (9) Interfaces total (36) General Contractor Outside – Internal Parties (1) Interfaces total (0)

Table 2 Complex Airport Project Communication Interfaces
– Comparative Project Example – Terminal + Airside + Landside Development

Without adequate project structure the proper screens and cross checks on the decision making process and its completeness through various stages are absent, and a rolling expansion and reevaluation process of specifications and expectations sets in. Design changes from “after thoughts”, intermediate technological developments, or operational reorganizations, etc. will be introduced throughout all project stages up to and through the construction. There is no fixed design and agreed overall deliverables and expectations change constantly. In the end – as any baselines to check against have been completely destroyed – there is a high potential for all parties to be dissatisfied, and maybe meet in a last unproductive step – in court.

Faulty organization and missing project structure can cost enormous sums of money and steal valuable development time and passenger satisfaction from an airport. So an effort to quantify this problem seems justified. Strictly from my personal empirical experience I tend to come to "ball park" fitting estimations (625%) for some decision metrics on this organization problem by using the following estimation approaches to quantify the effects of project organization and structure:

- The yearly organization caused cost estimate overrun of a project can be estimated as ~0.5% of the original projected cost estimation for every 10 decision active interfaces - every year cumulatively.
- The estimate of time schedule overrun (as compared to a fast track schedule) for the total project can be estimated as ~1 additional month per every decision active party above a limit number of 10 decision active parties and a project duration of more than 1 year.
- The risk of the above two event occurring can be estimated to be directly proportional to 1/10 of the number I of total number of communication interfaces with a maximum at 100%.

Applied to the above example in Table 2 this results,

for Project A in :

- an expected annual cost overrun of ~11%
  or projected on a 4 year project a cost increase between 34% and 56%.
- an expected total time overrun of 33 months
  or project on a 4-year duration a delay of between 25 and 41 months.
- a risk of an organization caused cost over run or time schedule overrun occurring of ~90%.

for Project B in :

- an expected annual cost overrun of ~0.8%
  or projected on a 4 year project a cost increase between 2.5% and 4%.
- an expected on time delivery.
- a risk of an organization caused cost over run or time schedule overrun occurring of ~15.6%.

So on Terminal-Project B with a probability of 84% the organization caused cost increase is well within the limits of standard uncertainty at the project kick-off decision stage (feasibility study) of 625% on an outline cost estimate and even within the limits of a consultants construction cost calculation of 65%, and it will deliver on time.

The Terminal-Project A however will, with a probability of 90%, go widely out of control cost and time wise and can be expected to be way outside all standard technical estimation boundary parameters that were envisioned at the time of project kick-off by the airport management.

However – all the above decision metrics on organization structure are developed purely from one person's limited experience and are accordingly to be considered so limited in their generalization at this time.

There is always the demonstrable possibility that even a complex project of low structural definition by the investing client develops its own internal structure through the leadership qualities and creative flexibility of key project personnel.

6 AIRPORTS OF THE FUTURE

Air transportation has been for the last 60 years and still currently is a booming growth industry – with on huge Achilles heel: AIRCRAFT FOSSIL FUELS. Overall airports and air transportation have been growing worldwide on an annual basis by 5% regardless of other economic cycles and turns for six decades. This stabile growth has provided especially the airport industry with the wherewithal to be at the forefront of technological development and architecture.

As the limits of availability of petroleum becomes more apparent this industry as a whole faces a very interesting future development. No other industry is currently so dependent on this one energy source (petroleum) as is the air transportation industry – at present prices the costs of jet-fuel are at roughly 30% of all flight related costs of an airline.

On the other hand all our economies worldwide are inherently dependent on the ability to transfer people and goods around half the globe within 24 hours if need be. A collapse or even a significant reduction of this transportation system would have enormous repercussions on all aspects of economic life worldwide. Whole world regions depend by now in their livelihood on the ability of millions of tourists to come and visit them each year – and many of those regions are not in a position to easily survive without this industry.

So while the challenges are great, so are the incentives to keep air transportation functioning in the future. For airports – as one of the more flexible parts of the system regarding immediate energy and environmental choices – this means that in all probability they will be asked to carry a large, possibly disproportionately larger, part of the changes to develop a sustainable air transport industry in the immediate and midterm future. At the same time airports in many ways are quite well under way on the route to sustainability. Many easy and some rather complex synergies have long been detected and developed at least in showcase examples at individual airports.

At present however these individual efforts, ideas and developments are sprinkled far and wide over the continents. While these projects usually get some exposure in the industry at the point of initial implementation the exchange of operational experience and, often more important, of decision making criteria for future implementation is more a game of chance and circumstance than industrial marketing and communication.

Especially regarding the underdeveloped field of sustainable energy use and regenerative energy production on airports, there is a dearth of comprehensively compiled information for the airport owner and operator faced with the next step of upgrading or expanding their buildings and facilities. Urgently needed decision making metrics have either not been developed yet or need to be compiled and applied to the special case of airport application.

It should therefore be considered to initiate synergetic working groups and information exchanges that bring the knowledge of modern sustainable energy systems and the state of the art passive and active building architecture into the airport community. Airport managers need instruments and reference points to prepare decisions on sustainable technology applicable to their differing scenarios and diverse locations in many countries.

A synergetic research project with the aim to combine the knowledge of energy engineering with the reality of airport infrastructure in Europe and test for economic viability of implementation under various scenarios of energy and emission pricing should be initiated. Should you agree with this idea, and feel you could bring value into such a research project please do not hesitate to contact me.

7 SOURCE NOTES

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ATG Airports - Taxiway Centerline & Stopbar Utilizing Light Emitting Diodes [18]