Airport buildings: A key opportunity for sustainability in aviation

Received (in revised form): 17th January, 2020

GRAY BENDER
Senior Consultant, Energy & Sustainability, Arup San Francisco, USA

Gray Bender is a senior consultant and project manager in Arup's San Francisco office, where he works on the Energy & Sustainability team. His work spans across the scale of the built environment, developing energy and sustainability approaches for cities, master plans, and major infrastructure and building projects. This includes a combination of developing city-scale sustainability frameworks and strategic planning, as well as high-performance building design and energy analysis.

Arup, 506 Mission Street, Suite 700, San Francisco, CA 94105, USA
Tel: (415) 946-0748; E-mail: Gray.bender@arup.com

RAPHAEL SPERRY
Associate, Energy & Sustainability, Arup San Francisco, USA

Raphael Sperry is a sustainability consultant for buildings and helps lead the San Francisco Energy & Sustainability team. He has facilitated the design of low-energy buildings and applied the LEED rating system to numerous commercial and institutional building owners. He has also pioneered sustainability applications in transportation projects, especially airports. He helps lead Arup's effort to support the United Nations (UN) Sustainable Development Goals in partnership with its clients.

Arup, 506 Mission Street, Suite 700, San Francisco, CA 94105, USA
Tel: (415) 946-0227; E-mail: Raphael.Sperry@arup.com

Abstract

The aviation industry is under increasing pressure to reduce its greenhouse gas (GHG) emissions, and advancing sustainable airport facilities is an important and highly visible way to demonstrate progress. Citizen groups and scientific reports have both highlighted the increasing share of global GHG emissions due to aviation and have called for everything from policy changes to constrain aviation emissions growth, to a movement for passengers to abstain from flying. With the social licence to operate being called into question, the aviation industry must demonstrate that it takes concerns around sustainability seriously and that it is addressing them in order to maintain public support. A common misconception exists that because aircraft emissions are so significant, sustainability efforts at airports are negligible. Airport GHG emissions are, however, substantial, stemming from energy use in buildings, ground service equipment and specialised equipment. San Francisco International Airport (SFO), to take an example, where the authors have consulted on sustainability, uses as much energy as its three neighbouring towns combined. Nor do airport environmental impacts stop at GHG emissions — airport development and operations can lead to substantial land-use changes, health impacts on millions of passengers and airport workers and noise impacts on neighbouring communities. The secondary impacts of the enormous quantity of materials used in construction of airfields and buildings can all be felt on the local, regional and global scales. Airports can best demonstrate their commitment to sustainability through reference to the United Nations Sustainable Development Goals (SDGs): a global plan of action to protect the environment while promoting the economic growth needed to lift people out of poverty and reduce inequalities between and within countries.

The SDGs have received commitments of support from civil society non-governmental organisations, national, state, and local governments and private companies around the world following the most extensive public outreach process ever undertaken, involving over 3 million people. This paper explores how sustainability fits within the SDGs across four categories — energy, water, construction materials and indoor environmental quality — and presents real-world case studies where strategies addressing these topics have been incorporated.

Keywords
airport sustainability, SDGs, Sustainable Development Goals, energy, water, construction, materials, indoor environmental quality, Mexico City Airport, San Francisco International Airport (SFO), John Wayne Airport (SNA), Brisbane Airport (BNE)

THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

Since their promulgation in 2015, the United Nations Sustainable Development Goals (SDGs) have become a common global definition of sustainability. The SDGs refine the long-held characterisation of sustainability as a 'triple bottom line' proposition, presenting social, environmental and economic goals for 'meeting the needs of the present generations without compromising the ability of future generations to meet their own needs'.[1] The SDGs flesh out these overarching goals with specific policy-level targets and indicators around reducing poverty and hunger, improving global health and education, providing access to clean energy and water, reducing discrimination and promoting infrastructure and development while combatting climate change (among others). The 17 goals are considered an indivisible programme — no goals can be sacrificed for the benefit of others (Figure 1).

Within the aviation sector, participants, such as airlines,[2] airport operators[3] and international organisations,[4] are aligning their practices with these goals. Goals such as contributing to regional economic development by promoting trade, serving as a model major employment centre and safeguarding community health are all strongly aligned with the SDGs. Increased access to air travel that is sustainable and resilient is part of the vision: SDG 9 is to 'build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation', including a target for 'regional and transborder infrastructure, to support economic development and human wellbeing, with a focus on affordable and equitable access for all'. The comprehensive nature of the SDGs and their broad social support can guide airports' current operations and future development by providing a context to identify desirable triple bottom-line benefits that an airport can provide while ensuring that the airport will not negatively impact social, environmental or economic progress.

ENERGY AND GREENHOUSE GAS EMISSIONS

Reducing GHG emissions and incorporating clean, renewable energy span several of the United Nations SDGs. SDG 7: Affordable and Clean Energy calls for an increase in the share of renewable energy in the global energy mix and a doubling in the rate of improvement in energy efficiency by 2030. Airports have

Figure 1 The 17 Sustainable Development Goals outlined by the United Nations

significant opportunities to advance SDG 7's targets by investing in energy efficiency, replacing fossil fuel use with a clean electric grid or funding large-scale renewable projects (on and/or offsite) to offset emissions. SDG 13: Climate Action includes a target that calls for integrating climate change measures into national policies and planning. Airports lagging in adopting such measures may see them enforced top-down by the cities and government agencies that oversee them. Airports can stay ahead of that trend by undertaking studies to better understand their energy consumption, initiating a plan for reducing energy use and incorporating renewable energy and executing on a near-term timeline. While the SDG programme is much broader than just reducing GHG emissions, the focus on aviation carbon emissions centres around the question of energy use and GHGs in any discussion of airport sustainability. Accordingly, airports must make energy-use reductions a central part of their sustainability efforts to maintain public acceptance, taking responsibility for their own energy-use GHG emissions and working with airlines to reduce in-flight emissions as well.

At airports, energy use and associated GHG emissions occur in building operations, from ground service equipment and in other systems such as airfield lighting and storm water pumping. Energy use includes both on-site fossil fuel burning for end uses such as vehicle engines, building heating and commercial cooking, known as Scope 1 emissions, as well as emissions from the generation of electricity purchased from the local energy grid, known as Scope 2 (Figure 2). While electrical grids in many places around the world are incrementally getting cleaner as they incorporate more renewable energy, reducing Scope 2 emissions over time, Scope 1 fossil fuel emissions are unaffected by this progress. Therefore, a three-pronged approach is

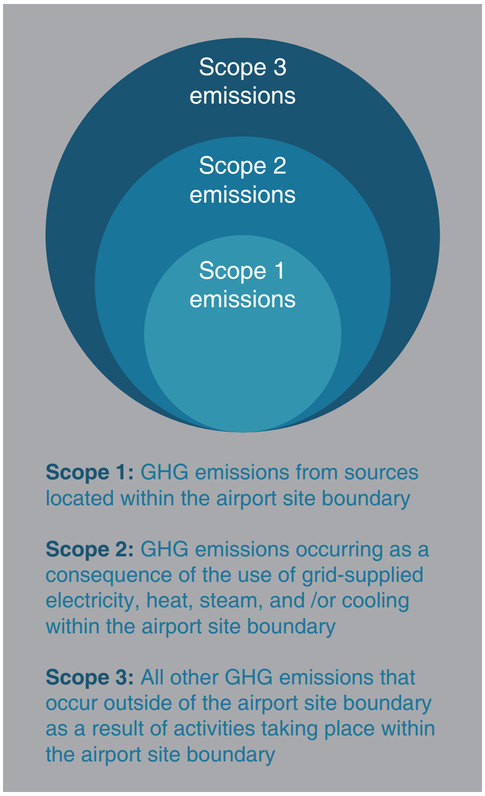

Figure 2 Defining emission scopes for airports (© Arup)
Note: GHG, greenhouse gas.

required to achieve progress towards sustainability:

1. Reduce overall energy use through energy-efficiency strategies.
2. Generate renewable electricity on-site (generally with solar power or small-scale wind).
3. Electrify end uses (ie switch from fossil fuels to electricity) if the local utility grid is in the process of becoming cleaner.

San Francisco International Airport (SFO) is employing this strategy to achieve its ambitious goal of zero net energy — a goal derived from the overall City and County of San Francisco Climate Action Plan (SFO is a department of the local government). In 2017, SFO committed to four sustainability goals under its strategic plan: achieving zero net energy, zero waste, zero carbon and a 50 per cent reduction in GHG emissions from a 1990 baseline by 2021. To achieve the energy goal, SFO is working with an Arup-led team on an energy-benchmarking initiative that includes a review of its design specifications and capital plans for opportunities to incorporate energy-efficiency targets and strategies, wherever possible. It is also undertaking a detailed analysis of current building energy use across its site to identify readily available opportunities for eliminating energy waste and inefficiency, as well as to identify campus-wide opportunities for energy-efficiency investments. SFO is also planning for steadily increasing deployment of electric vehicles and on-site electricity generation and storage. By taking the time to understand the current state of the airport's energy use, SFO leaders are making informed decisions to meet their goals in the near term.

While existing airports can incorporate energy efficiency into their ongoing operations in various ways, designing and building a completely new airport presents a tremendous opportunity for incorporating sustainable design strategies from the earliest stages of the project. From the onset of conceptual design of the new airport in Mexico City (which due to national policy changes has been cancelled for the time being[5]), energy efficiency was a key concern for the airport authority and project design team: a joint venture between architects Foster + Partners and Fernando Romero Enterprise, engineers Arup and planners Netherlands Airport Consultants (NACO). The structure of the terminal

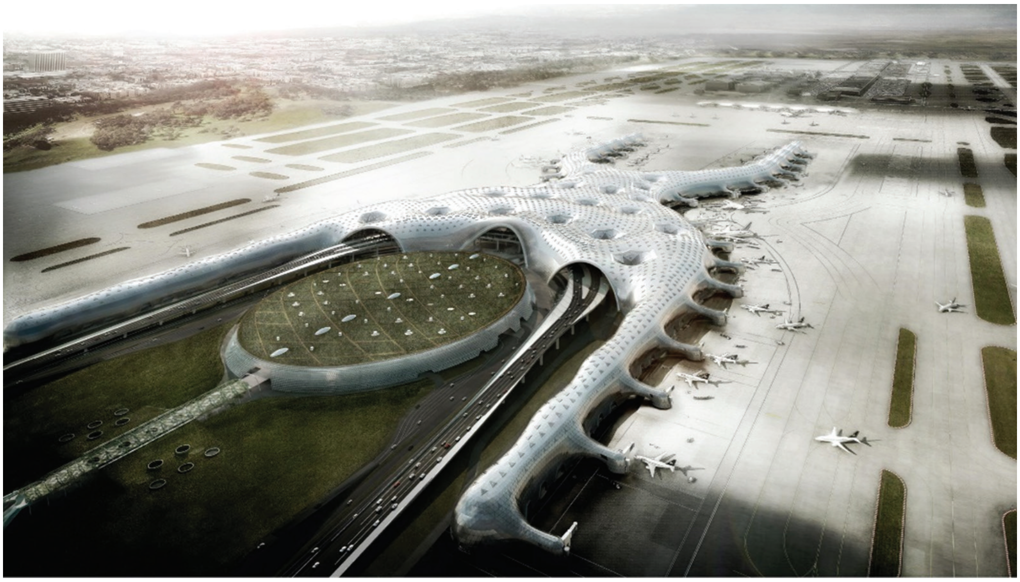

Figure 3 Design rendering for the new international airport in Mexico City (FP-FREE)

was designed around a series of voids within the building's foundation system that stretched the length of the building, to allow for a much more efficient displacement air system to be used in the terminal, and to obtain the passive cooling effects of running outdoor air along the colder concrete thermal mass. The façade of the terminal was overlaid with hundreds of carefully placed skylights and 21 glazed structural funnels that maximised daylight penetration into the building (Figure 3). This design enabled interior lighting levels to be drastically reduced automatically with the help of daylight sensors in a building type where a deep floor plate often provides no daylight at all to interior spaces.

A central utility plant was also designed for the airport, taking advantage of the increased efficiency of larger cooling systems, while heating of any kind was eliminated by a façade tuned to the benign winter conditions of Mexico City. In total, energy use by building services (heating, ventilation, air-conditioning, lighting, plumbing, vertical and horizontal transport etc) was reduced by 26 per cent from a code-compliant baseline. To meet the airport authority's goal of a 50 per cent energy-use reduction, a 40 MW on-site solar photovoltaic (PV) array was planned: the largest ever for an airport at the time. In addition to providing clean energy to the airport, such an array was also valuable from a resilience standpoint; adding the ability to have electricity during the day even if the local grid went down.

Operational resilience is central to SDG 9 (referenced earlier) and is vital to every airport in the world. Energy efficiency and renewable energy-generation strategies can often be combined to create the synergies between sustainability and resilience envisioned by the SDGs. One such strategy is microgrids: localised electricity grids that incorporate independent energy generation (ideally clean renewable power), energy storage and an islanding capability to operate completely independent of the regional

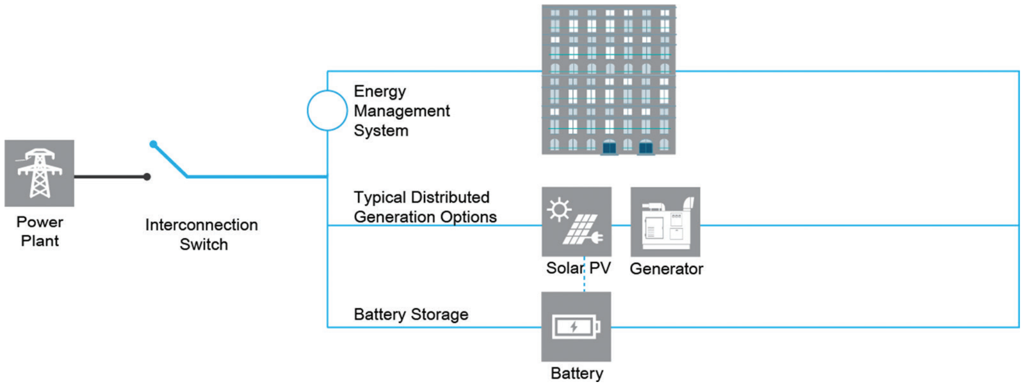

Figure 4 Microgrid Line Diagram showing Island Mode not connected to the utility grid (© Arup)
Note: PV, photovoltaic.

power grid. Arup's 2018 study for the Airport Cooperative Research Program 'Microgrids and Their Application for Airports and Public Transit' describes the benefits, challenges, costs, revenue streams and ownership structures relevant to airports.[6]

To take a specific example, a recent project at John Wayne Airport (SNA) in Orange County, California, sought to incorporate a microgrid to improve resilience. For this project, Arup undertook a study to compare the microgrid option incorporating a 1.95 MW on-site solar PV array coupled with an 8.8 MWh/2.2 MW battery against a baseline case, with SNA purchasing all its electricity from the local energy utility provider. The resulting microgrid design showed a 33 per cent reduction in Scope 1 and 2 emissions from energy use compared with purchasing all energy from the local utility. In addition, by incorporating the on-site solar PV array, the airport was able to directly offset 13 per cent of its emissions. The PV array coupled with battery storage provided energy resilience to critical airport systems to continue operating in the event of a grid failure, ensuring safety, and operational systems were kept online for the duration of the outage (Figure 4).

WATER

Water conservation in places with existing water stress, as well as those that will soon be prone to water stress as the climate continues to change more rapidly, is a critical consideration for enabling resilient and enduring population centres in developing and developed countries alike. SDG 6: Clean Water and Sanitation, calls for universal and equitable access to safe drinking water, an increase in water-use efficiency and minimising the release of hazardous chemicals. As major consumers of water resources and as sites handling large volumes of hazardous chemicals, airports are positioned to make meaningful contributions to reducing water stress and pollution while providing a high level of comfort and service to their passengers, employees and neighbours.

Airports consume water for uses such as hand washing and toilet flushing, commercial kitchen and cleaning uses, process systems such as cooling towers, car and equipment washing and landscape irrigation. In addition, airports handle large volumes of rainwater from airfields and potential contaminant concerns from deicing, fuelling and other activities. Many often operate their own wastewater-treatment plants. From an operational perspective, it is important to consider which end uses require potable water sourced from utility water treatment plants and which uses can employ treated non-potable water. Developing on-site sources of non-potable water, for instance by capturing rainwater or reclaiming water at a treatment plant, is a key strategy to handle water more sustainably.

In Mexico City, water scarcity is a historic issue that is only becoming more prevalent. Water stress in 2017 rose to 139 per cent, requiring the city to increase its already unsustainable pumping of the underground aquifer — an action that is literally sinking the city.[7] Accordingly, water-use reduction was a key consideration for the design team of the new airport in Mexico City, leading to the incorporation of an on-site water treatment facility with the capacity to serve 100 per cent of the non-potable water demand on-site. Greywater and blackwater from airport restrooms were fed to the plant for treatment to meet the high standards required even for non-potable water use. This design feature, combined with the use of low-flow fixtures and fittings for domestic water use, would have accounted for 118 million gallons of potable water saved per year, equivalent to the annual water consumption of over 3,400 Mexico City residents.[8]

Opportunities for water conservation at existing airports also exist, whether as a specific building upgrade activity or as part of a larger building retrofit, and are called for by SDG Target 6.4 to 'substantially increase water-use efficiency across all sectors'. Arup is significantly involved in the design of the domestic terminal expansion at the Brisbane (Australia) Airport providing services across a broad range of disciplines. As part of this broader project, Arup undertook the design of the purified recycled water (PRW) supply scheme and rainwater-harvesting systems (a strategy that was restricted by the local water authority in Mexico City but encouraged in Brisbane). The approach aims to reduce potable water consumption by utilising PRW for use in cooling towers, urinals and toilet flushing, landscape irrigation and car washing. Rainwater is also captured from the multi-level car park and used for irrigation, toilet flushing and wash down. The project undertook a storm water quality management assessment (SQMA) to quantify the pollutant-removal performance of the proposed water-quality devices.

CONSTRUCTION AND MATERIALS

In any community, an airport is likely to be one of the biggest buildings present, whether it is a collection of hangars in a small town or a campus of millions of square feet serving a major metropolitan region. Procuring construction materials has impacts all along the supply chain, including energy use, land-use impacts and environmental pollution associated with the extraction, manufacturing and transportation of building products. Given the scale and material intensity of airport building projects, whether existing building retrofits or ground-up new construction, the choices made during the design and procurement process have substantial environmental impacts.

SDG 12: Responsible Consumption and Production aims to achieve sustainable management and efficient use of natural resources, substantial reduction in waste generation including construction and demolition waste, and to promote sustainable procurement practices. SDG 14: Life below Water and SDG 15: Life on Land both call for material extraction, manufacturing and distribution practices to eliminate pollution and promote sustainable management of the ecosystems that our natural resources are drawn from. Recently developed management tools such as whole building life cycle assessments, environmental product declarations (EPDs), health product declarations (HPDs) and global reporting standards, such as REACH and Cradle-to-Cradle, mean that for the first time, the impacts of products can be quantified and compared to inform design and procurement decisions.

During design and through the beginning of construction of the new airport in Mexico City, strict material reporting standards were required in line with the US Green Building Council's LEED™ material credits. The requirements mandated that contractors procuring materials meet a minimum number of EPDs, HPDs and general emission evaluations. In Mexico at the time, very few of the manufacturers preparing to supply products to the project were familiar with these tools and the associated processes for collecting and publishing information on their products' environmental impacts. With the motivation of potentially millions to tens of millions of US dollars' worth of product purchases, however, manufacturers readily submitted their products to testing and disclosure reporting. At the time construction halted, 85 EPDs and 36 HPDs had been undertaken specifically for the project, yielding a trove of environmental management information now available to the entire regional building industry.

Another two dozen manufacturers had engaged with UL or other providers to undertake or queue their products for volatile organic compound testing in accordance with the California Department of Public Health's strict standard method[9] (also cited in LEED). While many of the products were being sourced globally (giving this project a vast reach in improving sustainable-material markets around the world), the majority were being sourced locally in Mexico, thanks to a requirement influenced by LEED targets to source a certain percentage of materials locally. The reduction in hazardous emissions from building materials supports achievement of SDG 3: Good Health and Wellbeing, which targets ambient and household air pollution.

In addition to reporting standards, building design itself can play a significant role in reducing material use and the associated embodied carbon emitted. As part of the joint venture team of Foster + Partners and FR-EE, Arup led the innovative structural engineering design of the Mexico City Airport, using automated calculations to optimise every individual structural element in the 8.1 million square-foot building roof. The team designed a space-frame with spans exceeding 100 metres in length: greater than three times the span length of a conventional airport. A life cycle assessment of the design showed the space frame of the proposed building to be more than twice as efficient, on a weight basis, as typical airport space-frame roofs. This meant that less than half of the material used in a typical design was required, in line with SDG 12's targeting of material consumption as a key indicator of sustainable natural resource management.

Already made lighter with the optimised space frame on top, the concrete foundation of the terminal building (a 1.6-kilometre-long concrete 'raft') then used alternative cementitious materials to replace up to 25 per cent of the cement needed, one of the most GHG-intensive construction materials (cement production is responsible for an estimated 6–8

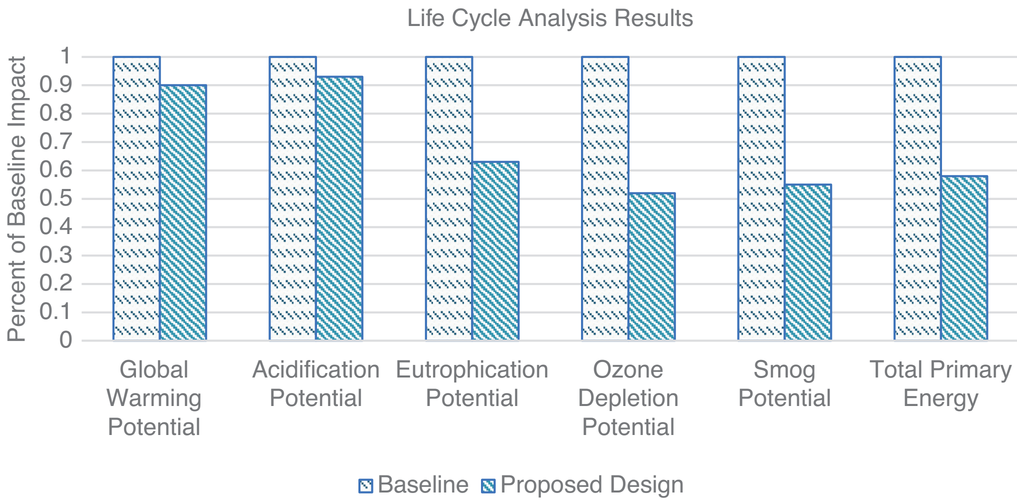

Figure 5 Reduced climate and environmental impacts of the design for the new airport in Mexico City (© Arup)

per cent of total GHG emissions; more than the entire aviation sector). This change to the foundation alone gave an overall 10 per cent reduction in global warming potential of the entire building (measured in $kgCO_2e$). Similar or greater reductions were found across all other life cycle assessment categories as shown in Figure 5, including acidification, eutrophication, ozone depletion and smog potential, as well as embodied primary energy use.

INDOOR ENVIRONMENTAL QUALITY

Because sustainability is about people as much as it is about the planet, the impact of indoor environments on human comfort and wellbeing is as much a sustainability element as the impact of human activity on natural environments. SDG 3: Good Health and Wellbeing seeks to reduce the number of deaths and illnesses from hazardous chemicals and contamination (as noted earlier), of concern to both airport passengers and workers. In addition, creating a better workplace aligns with SDG 8: Decent Work and Economic Growth, and its target of providing a safe and secure working environment for all workers.

The building industry uses the term Indoor Environmental Quality (IEQ) to refer to a series of factors defining human comfort and wellbeing including lighting, thermal comfort, air quality and acoustics. As the science of human wellbeing has become more robust in recent years, links between measurable indoor environmental metrics and holistic human health are becoming clearer.[10] IEQ can now be linked directly to worker productivity, absenteeism and retention of employees, and anxiety or satisfaction among visitors. For airports, IEQ has a different impact on two distinct occupant groups: for passengers, IEQ colours the travel experience and the first or last impression of a destination city or nation and impacts SDG 3; while for hundreds or even thousands of direct and tenant employees, IEQ shapes health and wellbeing at work, impacting both SDGs 3 and 8. Strategies for creating and maintaining sustainable human environments can have a positive impact on both user groups.

When it comes to passengers, airports can be an unfortunately stressful place for people inexperienced with air travel or rushing to catch their planes. Security screening creates lines and an experience of vulnerability that reinforces these stressful moments. Fortunately, human-centred terminal design can help assuage these anxieties, not only creating a less negative experience but switching the narrative to make the airport a positive part of the traveling experience. New studies are exploring ways to track the impact of various environmental factors on passengers in real-time and at precise locations, allowing for operational and design responses to improve the passenger experience. Embracing the smart building approach, a recent Arup-authored study introduced an 'emotional mapping' initiative, which was offered as a voluntary programme for passengers with reduced mobility at a major international airport.[11] The programme uses wearable sensors to measure biometric data related to the cardiovascular, respiratory and muscular systems. This data is processed through artificial intelligence programmes into a real-time emotional status for the wearer, providing the airport with precise time and location data on the passenger experience. 'While pedestrian flow simulations and conventional surveys have some understanding of a citizen's behavioral patterns . . . they ignore the complex nature of environmental experience', explains Arup aviation planning designer, Ali Jabbari, with the emotional mapping initiative. Gaining a precise understanding of the passenger experience empowers airports to respond to immediate problems with customer service in the short term and to identify retrofit and capital project opportunities for improving the passenger experience in the long term.

For airport workers, the environment in terminal buildings can be structured for employee health, wellness and productivity. Strategies such as incorporating indoor vegetation (an example of nature-inspired design known as biophilia),[12] reducing volatile organic compound levels,[13] human-centred lighting design and acoustical control all have effects on a person's cognitive function and overall health. When it comes to the workforce, these are important considerations for employers — they map directly to increasing productivity and reducing absenteeism, as well as helping achieve the SDG 8 target of safe and secure working environments for all workers.

For the SFO Terminal 1 redevelopment projects, whose first phase opened in mid-2019, promoting improved indoor air quality for the health and wellbeing of the passengers and airport employees was a key priority. Terminal 1 is located near to a major freeway and adjacent to the airport taxiways and runways. Lawrence Berkeley National Laboratory performed outdoor air-quality testing to identify the potential key volatile organic compounds and formaldehyde pollutants in the outdoor air that may have human health impacts, while also identifying compounds that might impact odour from the jet fuel. The mechanical engineering design-build teams (including Arup and Southland Industries) were provided with this data in the form of an outdoor air-quality report, and were requested to select an outdoor air filtration system that would remove unwanted chemicals of concern prior to distribution indoors. All of SFO's future design-build teams are being requested to select filtration systems to address these chemicals of concern for improved human health and to reduce jet and vehicular fuel odour within the airport buildings.

CONCLUSION

Within the broad sphere of sustainability as defined by the United Nations SDGs, this paper has focused on energy, water, construction materials and IEQ impacts as central considerations in the design and operation of airports. The examples presented across these four categories hopefully will encourage airports around the world to not only advance individual issues but also to look for synergies wherever possible: strategies that provide multiple sustainability benefits with a single investment. For example, recycling water onsite can lead to cost savings on purchased water, reduction or elimination of pollutant releases to surface waters and GHG emission reductions through a reduction in energy used for pumping and treating water offsite. Requiring disclosures around the environmental and human health impacts of construction materials can inform procurement practices to improve both. Providing daylight and using displacement ventilation can create a better indoor environment for passengers and employees while also reducing energy use in a terminal building. These are just a few examples of how incorporating sustainability strategies can span impact categories.

The authors also acknowledge that sustainability extends beyond just the environmental impact of airports to include vitally important social and economic goals. Airports are key nodes in regional, national and international networks of the exchange of goods and people, and hence also of knowledge and ideas. There are ample opportunities and contemporary examples of airports providing leadership in regional development and increasing equality in line with the social and economic SDGs; the discussion of which warrants an entire paper in and of itself, building upon the environmental sustainability discussion presented here.

The environmental impact of the aviation sector is significant and growing, and airports have a singular opportunity to make substantial reductions in the industry's environmental footprint — reductions increasingly demanded by the public and policy-makers. Airports are generally large facilities (with respect to the communities they serve) and are uniquely positioned with a single organisational structure, whether public or private, that enables rapid and large-scale progress. As hubs of globalisation, airports can demonstrate the achievement of global SDGs through strategies that benefit travellers, workers and their host communities. Sustainable airport design and operations are well under way. Continuing to build on this momentum will position the industry at the forefront of environmental leadership as the world works to deliver the promise of sustainable development for all.

References and Notes

(1) This is the widely cited definition of sustainability developed by the World Commission on Environment and Development in a publication titled *Our Common Future*. World Commission on Environment and Development (1987) 'Our Common Future', Oxford University Press, Oxford, available at: http://www.un-documents.net/our-common-future.pdf (accessed 14th September, 2019).

(2) Delta Airlines (Delta Airlines [2018] '2018 corporate sustainability report: Connecting global communities in the air and on the ground', available at: http://www.corporatereport.com/delta/2018/crr/Delta_2018_CRR.pdf) and Lufthansa Group (Lufthansa Group [n.d.] 'Sustainable development goals', available at: https://www.lufthansagroup.com/en/responsibility/corporate-responsibility/sustainable-development-goals.html [accessed 16th

September, 2019]), among others, have recently committed to supporting the SDGs.
(3) San Francisco International Airport is among many others who have aligned their sustainability goals with the SDGs (San Francisco International Airport [2018] 'Sustainability plan', San Francisco International Airport, San Francisco, available at: https://www.sfoconnect.com/sites/default/files/Sustainability%20Plan%20Executive%20Summary%20F4.pdf [accessed 16th September, 2019]).
(4) The International Civil Aviation Organization (ICAO) has committed to work closely towards supporting the SDGs (International Civil Aviation Organization [ICAO] [n.d.] 'ICAO and the United Nations sustainable development goals', available at: https://www.icao.int/about-icao/aviation-development/Pages/SDG.aspx [accessed 1st November, 2019]).
(5) Due to national administrative and policy changes in the Mexican federal government, the new airport project in Mexico City has been cancelled until further notice. This paper discusses the design elements that were finalised and the project under construction up until the cancellation.
(6) Heard, R. and Mannarino, E. (2018) 'Microgrids and their application for airports and public transit', Airport Cooperative Research Program, available at: http://www.trb.org/Main/Blurbs/177928.aspx (accessed 1st November, 2019).
(7) Conagua Mexico (2017) 'Statistics on water in Mexico, 2017 Edition', Ministry of Environment and Natural Resources, available at: http://sina.conagua.gob.mx/publicaciones/EAM_i_2017.pdf (accessed 14th September, 2019).
(8) Based on an average annual consumption of 131.4 m^3/capita/yr (US Organization for Economic Cooperation and Development [2015] 'Water governance in cities', Mexico City, Mexico, OECD Water Governance Programme, available at: http://www.oecd.org/cfe/regional-policy/water-governance-in-cities-mexico-city.pdf [accessed 16th September, 2019]).
(9) California Department of Public Health (2017) 'Standard method for testing and evaluation of volatile organic chemical emissions from indoors sources using environmental chambers version 1.2', CA.gov, January, available at: https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/EHLB/IAQ/Pages/VOC.aspx#material%20for%20the%20correct%20reference (accessed 16th September, 2019).
(10) International WELL Building Institute (2017) 'WELL building standard', available at: https://a.storyblok.com/f/52232/x/a45787692a/wellbrochure_020317-cb.pdf (accessed 15th November, 2019).
(11) Jahromi, A., Oram, M.-Y., Santhanam, V. and Trevan, J. (2019) 'Citizens as real-time emotional sensors in smart cities', International Conference on Smart Infrastructure and Construction 2019 (ICSIC), available at: https://www.icevirtuallibrary.com/doi/10.1680/icsic.64669.571 (accessed 15th November, 2019).
(12) Service Futures (2019) Biophilic design: The best kept secret of a great workplace', 5th September, available at: https://www.servicefutures.com/biophilic-design-the-best-kept-secret-of-a-great-workplace (accessed 1st November, 2019).
(13) Allen, J., MacNaughton, P., Satish, U., Santanam, S., Vallarino, J. and Spengler, J. (2016) 'Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments', *Environmental Health Perspectives*, Vol. 124, No. 6, available at: https://ehp.niehs.nih.gov/doi/10.1289/ehp.1510037 (accessed 16th September, 2019).