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Sustainable Airport Water Management: The Case of Hong Kong International Airport

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Abstract— *Utilizing an in-depth longitudinal case study research design, this study has examined Hong Kong International Airport's water management and the annual trends in the airport's water consumption for the study period of 2011 to 2020. Since its inception of operations in 1998, the airport has used a "triple water system", that has been designed to improve the efficiency of its three major water sources: freshwater, seawater and treated wastewater. The largest water source used by the airport is seawater. In the early years of the study (2011 to 2013), there was a general upward trend in the airport's annual municipal supplied water consumption. However, from 2014 to 2020, there was an overall downward trend in the airports municipal water consumption at the airport. The municipal supplied water consumption per enplaned passenger or per workload unit (WLU) largely displayed a general downward trend, which is very favorable given the strong growth in enplaned passengers recorded during the study period. The airport's annual seawater consumption, annual recycled/re-used water consumption and the annual discharged waters oscillated over the study period reflecting differing water consumption patterns.*

Keywords— ***Airport water management; Case study; Hong Kong International Airport; Water consumption, Water recycling/re-use***

I. INTRODUCTION

Airports are one of the critical actors in the global air transport value chain, as they provide the necessary ground-based and airfield-related infrastructure that facilitates the movement of passengers and air cargo between the air and surface transport modes. However, in delivering air transportation services, the key actors in the global air transport value chain require water, which is used in the provision of their services and for maintaining their infrastructure and equipment. To facilitate the provision of these aviation-related services, airports require and use very substantial amounts of water (Fossi & Esposito, 2015). Airports principally source waters from municipal authorities. Other sources of water are from rainwater harvesting (Somerville et al., 2015), and from seawater. Hong Kong International Airport, the case airport in this study, uses seawater as one of its key water sources. In addition, airports can produce very significant volumes of storm or waste waters (Baxter, 2022). These waters need to be handled in an environmentally sustainable way to mitigate their potential adverse impact on the environment. Thus, stormwater runoff at airports is a significant issue for airport operators (Shi et al., 2017).

Sustainable water management has increasingly become a very important element in airport's sustainability policies and, as a result, airports are increasingly focusing on ways to mitigate their water consumption. This is because airports consume large amounts of water. Airports are also focusing on the safe and environmentally friendly management of waste waters (Baxter, 2022; Pitt et al., 2002).

One such airport that has sustainably managed its water requirements throughout its inception of operations in 1998 is Hong Kong International Airport. Hong Kong International Airport is one of the world's major global passenger and air cargo hubs (Govada et al., 2017). In addition, Hong Kong International Airport (HKIA) is one of the principal gateways to Mainland China and is the major aviation hub in Asia (Tsui et al., 2014; Yuen et al., 2020). The mainland China market is Hong Kong International Airport's (HKIA's) largest air travel market (Centre for Aviation, 2019).

The objective of this study is to empirically examine how Hong Kong International Airport sustainably manages its water consumption and the discharge of its wastewaters. Hong Kong International Airport was selected as the case airport due to its long held sustainable water management practices. A second objective of the study was to examine how the increases in passenger traffic recorded at the airport have influenced the airport's water consumption during the study period. Hong Kong International Airport was selected as the case airport as it is a hub airport that is served by both full-service network carriers (FSNCs), low-cost carriers (LCCs), regional airlines, and dedicated air cargo carrying airlines. The availability of a comprehensive data set covering the period 2011 to 2020, was a further factor in selecting Hong Kong International Airport as the study's selected case airport.

The remainder of the paper is organized as follows: The literature review that sets the context of the case study is presented in Section 2. The research method that underpinned the case study is presented in Section 3. The Hong Kong International Airport case study is presented in Section 4. Section 5 presents the findings of the study.

II. BACKGROUND

2.1. Airport Water Management

The water consumption of airports is very substantial, as airports and their key stakeholders require large amounts of water to maintain their infrastructure and to support and facilitate their operational activities (de Castro Carvalho et al., 2013). Airports are also the source of run-off waters (Baxter et al., 2018b; Sulej et al., 2011; Sulej-Suchomska et al., 2016). Due to the significant impact that the high-water consumption and the runoff waters have on the environment, airports are now placing a very high focus on sustainable water management (Somerville et al, 2015). Indeed, sustainable water management is now a key element in many airports environmental and sustainability policies and practices (Baxter, 2021).

2.2. Airport Stakeholders Water Requirements and Usage

As previously noted, airports consume substantial volumes of water to maintain both their infrastructure, and thus, sustain their aircraft and ground-based operations (Baxter et al., 2018a; de Castro Carvalho et al., 2013, Neto et al., 2012). Airport operators, airlines, air traffic management agencies, ground handling agents, aircraft, and ground service equipment (GSE) maintenance organizations, airport concessionaires, and passengers and staff require water for drinking, catering, retail, cleaning, flushing toilets, and system maintenance. Water is also used to maintain an airport grounds and during the landscaping of gardens and parks that are located within the airport precinct (Thomas & Hooper, 2013).

2.3. Airport Water Sources

Historically, airports were designed to make use of ground water or water supplied from municipal authorities that satisfy appropriate quality standards. Where this water has only been used for non-industrial purposes (for example, washing, cleaning, and laundry), wastewater can be collected by the airport, treated, and reused for activities including toilet flushing, washing, and in some instances irrigation of plants. Such practices may require the airport to introduce a dual drainage system as well as water-purification facilities (Thomas & Hooper, 2013).

A further source of water comes from harvesting (collecting) and storing rainwater (Abdulla et al., 2021; Somerville et al., 2015; Yannopoulis et al., 2019). If implemented at an airport, then rainwater harvesting can substantially reduce the volume of water sourced from conventional supplies and acts as a reservoir to guard against water shortages. The most sustainable approach to water management is for airports seeking to become self-sufficient in their water supply by optimizing opportunities for water harvesting, recycling, and reducing consumption (Thomas & Hooper, 2013).

2.4. Airport Runoff Waters

In an airport's operational area, run-off waters can have a very serious environmental threat. These waters could have a negative impact on both soil and groundwater since they contain a relatively high concentration of contaminants (Vanker et al., 2013). Wastes associated with aircraft refueling, aircraft operations, aircraft, and ground service equipment (GSE) maintenance and equipment and facilities cleaning can potentially enter lakes and streams located nearby to the airport via the airport's storm water drainage system. Major aircraft overhauls that use toxic chemicals to remove paint can also pose a significant environmental threat should these toxic chemicals enter the water system (Culberson, 2011). Other contaminants originating from other airport operations or activities include detergent formulations, solids, oils, greases, residues, solvent residues, and heavy metals (Grantham, 1996). The discharge of fire-fighting foam during an aircraft emergency (Fawell, 2014) together with the production of in-flight meals, and meals served at restaurants and staff canteens also contribute grease and detergents to the wastewater generated at an airport (Baxter et al., 2018b).

2.5. Airport Water Processing Plants

Rainwater from the paved areas, particularly from the airport's apron areas, can be cleaned using a special treatment plant located at the airport. This facility will separate oil products from the waters. Alternatively, a collector can be connected to the local municipal treatment plant. Fuel storage, and aircraft hangars and aircraft and ground service equipment (GSE) maintenance facilities, should be equipped with traps to catch any waste oil products. These facilities should be inspected regularly (Kazda et al., 2015).

2.6. Airport Water Conservation Measures

Because of the increasing pressure to reduce water consumption and conserve available water resources, airports can implement a range of measures that will enable them to reduce their water consumption. To achieve their environmental-related and sustainability goals, many airports around the world have implemented a range of water conservation measures (Dimitriou & Voskaki, 2011). These water conservation measures include the overall reduction in water consumption at the airport (Baxter et al., 2018a, 2018b; Rossi & Cancelliere, 2013), re-using water from the treatment of waters at wastewater and sewage treatment plants in toilet facilities and for irrigation purposes (Baxter et al., 2018b; Chen et al., 2012), using rainwater for the flushing of the toilets in airport buildings and facilities (Baxter et al., 2018a; Yu et al., 2013), protecting groundwater from pollution (Gupta & Onta, 1997), the overall monitoring of water consumption at the airport (Boyle et al., 2013), and monitoring the surface and ground water quality (Bartram & Balance, 1996; Baxter et al., 2018b; Thomas & Hooper, 2013). Airports also need to protect surface and ground water resources (Thomas & Hooper, 2013).

III. RESEARCH METHODOLOGY

3.1 Research Method

The study's qualitative analysis was underpinned by a longitudinal case study research design (Derrington, 2019; Hassett & Paavilainen-Mäntymäki, 2013; Neale, 2019). The primary advantage of a qualitative longitudinal research design is that it reveals change and growth in an outcome over time (Kalaian & Kasim, 2008). A case study allows for the in-depth examination of complex phenomena (Cua & Garrett, 2009; Remenyi et al., 2010; Yin 2018). Case studies also permit researchers to gather and analyze rich, explanatory information (Ang, 2014; Mentzer & Flint, 1997). A further advantage of case studies is that they enable researchers to build theory and connect with practice (McCutchen & Meredith, 1993).

3.2 Data Collection

The qualitative data was sourced from the Airport Authority of Hong Kong annual sustainability reports. Thus, in this study secondary data was used to investigate the research objectives. The three guiding principles of data collection in case study research as recommended by Yin (2018) were followed in this study: the use of multiple sources of case evidence, creation of a database on the subject, and the establishment of a chain of evidence.

3.3 Data Analysis

The data collected for the case studies was examined using document analysis. Document analysis is often used in case studies and focuses on the information and data from formal documents and company records (Ramon Gil-Garcia, 2012). Existing documents provide a vital source of qualitative data (Woods & Graber, 2017). Furthermore, documents are one of the principal forms of data sources for the interpretation and analysis in case study research (Olson, 2010). The documents collected for the present study were examined according to four criteria: authenticity, credibility, representativeness, and meaning (Fitzgerald, 2012; Scott, 2004, 2014).

The key words used in the database searches included "Airport Authority of Hong Kong environmental management policy", "Hong Kong International Airport's principal water sources", "Hong Kong International Airport's total annual water consumption", "Hong Kong International Airport's total annual municipal supplied water consumption"; "Hong Kong International Airport's total annual seawater consumption"; "Hong Kong International Airport's total annual water consumption per passenger", "Hong Kong International Airport's total annual recycled/reused waters", and "Hong Kong International Airport's total annual discharged waters".

The study's document analysis was conducted in six distinct phases. The first phase involved planning the types and required documentation and ascertaining their availability for the study. In the second phase, the data collection involved sourcing the documents from Fraport AG and developing and implementing a scheme for managing the gathered documents. The collected documents were examined to assess their authenticity, credibility and to identify any potential bias in the third phase of the document analysis process. In the fourth phase, the content of the collected documents was carefully examined, and the key themes and issues were identified and recorded. The fifth phase involved the deliberation and refinement to identify any difficulties associated with the documents, reviewing sources, as well as exploring the documents content. In the sixth and final phase, the analysis of the data was completed (O'Leary 2004).

In this study, all the gathered documents were downloaded and stored in a case study database (Yin 2018). The documents were all in English. Each document was carefully read, and key themes were coded and recorded (Baxter, 2022).

IV. RESULTS

4.1. An Overview of Hong Kong International Airport

The Hong Kong Government announced their intention to construct a new international airport at Chek Lap Kok with the new airport replacing the country's Kai Tak Airport, which was capacity restrained. Chek Lap Kok Airport is located off the north coast of Lantau Island which is itself located off the west coast of the Kowloon peninsula and to the northwest of Hong Kong Island (Staddon & Fan, 1994).

Hong Kong's Chek Lap Kok International Airport was constructed through the reclamation of two small islands, namely Chek Lap Kok and Lam Chau. These islands are located 25 kilometres west of Hong Kong Island, and this served as the base for the new 1,255-hectare airport site (Chow et al., 2004). The construction of the new airport involved land reclamation from the surrounding water (Wu et al., 2020). The new Hong Kong Airport at Chek Lap Kok was constructed on a 1,248-hectare offshore reclamation platform (Covil & James, 1997; Pickles & Tosen, 1998; Plant, 1997), whilst a total area of 928 hectares was from reclaimed land (Berner, 1998; Endicott & Fraser, 2001). Hong Kong's airport relocated from Kai Tak to Chek Lap Kok Airport (Hong Kong International Airport) in 1998 (Kwong & Miscevic, 2002; Li & Loo, 2016; Zheng et al., 2020). In addition to the construction of a brand-new airport that had the capacity to handle up to 87 million passengers and 9 million tonnes of air cargo a year (Tsang, 1998). The airport occupies a site of 1,255 hectares (Airport Authority of Hong Kong, 2021b).

Air services are provided from Hong Kong International Airport to more than 190 cities around the world, including 50 Mainland China destinations (Choi, 2019). Hong Kong International Airport is the home base for Air Hong Kong, Cathay Pacific Airways and Hong Kong Airlines. As noted earlier, the airport is served by full-service network airlines (FSNCs), low-cost carriers (LCCs), dedicated all cargo airlines, and the integrated carriers, for example, FedEx and United Parcel Service (UPS). Hong Kong International Airport is ranked as being one of the world's largest air cargo hubs (Graham & Ison, 2014; Rodrigue, 2020; Sales, 2017).

Founded in 1995, Airport Authority Hong Kong (AAHK) is a statutory body wholly owned by the Government of the Hong Kong Special Administrative Region (HKSAR) and the airport authority is governed by the *Airport Authority Ordinance* (Chapter 483, The Laws of Hong Kong). Guided by the Ordinance and the objective of maintaining Hong Kong's competitiveness as a global and regional aviation hub, the airport authority is responsible for the provision, operation, development, and maintenance of Hong Kong International Airport (HKIA), and the provision of facilities, amenities, or industry at or from any place on the airport island, and other airport-related activities as permitted by the *Airport Authority (Permitted Airport-related Activities) Order* (Cap. 483E) (Airport Authority of Hong Kong, 2021b).

Hong Kong International Airport opened its third runway on 8 July 2022 (Ganesh, 2022; Lee, 2022; Wenzel, 2022). The airport can accommodate International Civil Aviation Organization (ICAO) Code F designated aircraft. The Airbus A380 is an ICAO Code F designated aircraft (Simons, 2014).

Figure 1 presents the annual enplaned passengers handled at Hong Kong International Airport together with the year-on-year change from 2011 to 2020. One passenger enplanement measures the embarkation of a revenue passenger, whether originating, stop-over, connecting or returning (Holloway, 2016). As can be observed in Figure 1, there was considerable growth in Hong Kong International Airport's passenger traffic from 2011 to 2019. Hong Kong International Airport's annual enplaned passengers decreased by 4.13% in 2019 and by 87.63% in 2020 (Figure 1). In 2019, world airline passenger traffic slow downed compared to 2018 (International Air Transport Association, 2020). The global aviation industry has also been adversely affected by the COVID-19 pandemic (Heiets & Xie, 2021; Khan et al., 2022; Lie et al., 2022; Yu & Chen, 2021). The COVID-19 pandemic caused a very substantial reduction in airline passenger traffic (Barczak et al., 2022), and the pandemic had a very disruptive effect on the world air travel market supply and demand chain (Dube et al., 2021). Hong Kong's government implemented a multipronged COVID-19 pandemic response approach, which included border controls, social distancing, quarantine, testing, screening, and surveillance (Wong et al, 2020). Figure 1 shows that there was a very significant decline in Hong Kong International Airport's passenger traffic in 2020, which could be attributed to adverse impact of the Covid-19 pandemic on passenger demand and the related government and airline COVID-19 pandemic response measures.

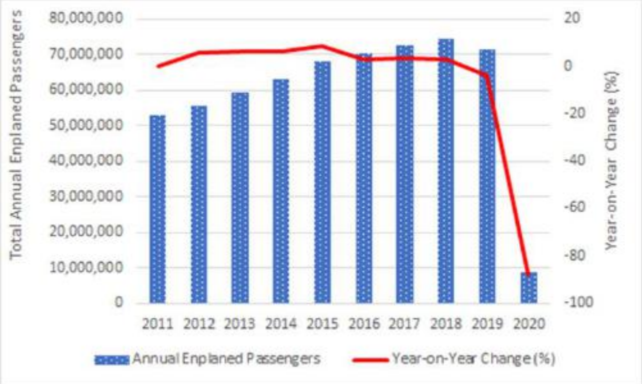

Fig.1: Hong Kong International Airport annual enplaned passengers and year-on-year change (%): 2011 to 2020. Source: data derived from Hong Kong Civil Aviation Department (2022).

Figure 2 presents the annual aircraft movements at Hong Kong International Airport and the year-on-year change (%) from 2011 to 2020. Figure 2 shows that there was an overall upward trend in the number of aircraft movements during the period 2011 to 2018. However, the airport's annual aircraft movements decreased on a year-on-year basis in 2019 (-1.86%) and 2020 (-61.72%), respectively (Figure 2). The small decrease in 2019 reflected airlines lower aircraft deployment patterns. The significant decrease in 2020 could be attributed to the COVID-19 pandemic impact on air passenger demand as well as the government and airline related response measures to the pandemic. These measures impacted airline aircraft fleet deployment patterns.

Fig.2: Hong Kong International Airport annual aircraft movements and year-on-year change (%): 2011 to 2020. Source: data derived from Hong Kong Civil Aviation Department (2022).

4.2. Hong Kong International Airport Environmental Policy

In October 2011, the Airport Authority of Hong Kong (AAHK) established its first Three-Year Environmental Plan. This plan serves as a principal tool for fulfilling the airport's Corporate Environmental Policy and driving airport-wide environmental improvement. The rolling Plan is updated on an annual basis and covers AAHK's own environmental targets and initiatives as well as efforts with the airport's business partners to reduce the airport's environmental footprint (Airport Authority of Hong Kong, 2014).

In 2012, Hong Kong International Airport made a pledge that the airport would be the world's greenest airport (Airport Authority of Hong Kong, 2015a). A "green airport" is defined as an airport which has a minimal impact on the environment and is an airport that endeavors to become a carbon neutral facility in terms of carbon emissions, with the aim to ultimately produce zero greenhouse gas emissions (González-Ruiz et al., 2017). The concept underlying a "green airport" is for the airport to create a centre of sustainable practices (Sumathi et al., 2018). This goal to be the world's greenest airport serves as a goal and a driver for the airport to continuously improve its environmental performance (Airport Authority of Hong Kong, 2015a).

In 2015, the Airport Authority of Hong Kong defined and implemented a comprehensive corporate environmental policy. In accordance with this policy, the Airport Authority Hong Kong has committed to the long-term sustainable growth of Hong Kong International Airport (HKIA) and is supporting the sustainable development of Hong Kong (Airport Authority of Hong Kong, 2015a). To achieve these goals, the Authority works to minimize the environmental footprint associated with the development and operation of Hong Kong International Airport (HKIA) through:

(1) ensuring compliance with all applicable local and international environmental and related legislation.

(2) optimizing energy and natural resource use efficiencies.

(3) prevention and minimization of both waste and pollution of the land, atmosphere, and surrounding waters of the airport.

(4) implementing an Environmental Management System (EMS) that enables the Authority to manage the company's risks around regulatory compliance, operational resilience, and corporate

reputation, and to create a framework for continual improvement by:

a) identifying and prioritizing key environmental aspects that must include climate change/carbon reduction, air quality, waste management, water usage, ecology & biodiversity, and noise.

b) setting, monitoring, and reporting against clearly defined targets; and

c) assigning appropriate management responsibility for oversight, review, and revision of the Environmental Management System (EMS).

5) providing training to employees and collaborating with business partners to instil a culture of sustainability and extend the most effective measures implemented by the Authority across the whole airport community; and

6) communicating and consulting with employees, relevant airport, government, and community stakeholders to ensure a high level of transparency and that relevant social and economic considerations are considered (Airport Authority of Hong Kong, 2015a).

The Airport Authority is also committed to achieving high standards of environmental performance in pursuit of its pledge to make Hong Kong International Airport the world's greenest airport (Airport Authority of Hong Kong, 2015a).

The Airport Authority of Hong Kong (AA) received its ISO 14001 Environmental Management System (EMS) certification from the British Standards Institution (BSI) on 22 June 2018. This certification formed a key part of Hong Kong International Airport (HKIA) achieving its Greenest Airport Pledge (Airport Authority of Hong Kong, 2018a). The ISO 14001 Environmental Management System (EMS) applies to the environmental aspects of a firm's operations, products, and services that the firm sets and for which it can control and or influence (International Organization for Standardization, 2021; Shehabi, 2016).

On 9 December 2021, Airport Authority of Hong Kong released its target and strategy to achieve Net Zero Carbon by 2050, with a midpoint target of 55% reduction of absolute emissions by 2035 from a 2018 baseline (Airport Authority of Hong Kong, 2021a; Airport World, 2021). Furthermore, the Airport Authority of Hong Kong (AAHK) will work with Technology Working Groups to improve the collaboration between AAHK and business associates (Airport Technology, 2021; International Airport Review, 2021).

The Airport Authority of Hong Kong's sustainability vision is to strengthen the airport's ability to operate and grow profitably in a changing and challenging economic, ecological, technological, and social environment, whilst at the same time developing a robust culture of sustainability throughout the organization (Airport Authority of Hong Kong, 2021b.

4.3. Hong Kong International Airport Water Management System

Hong Kong International Airport (HKIA) uses a "triple water system", that has been designed to improve the efficiency of its three major water sources: freshwater, seawater and treated wastewater. The Airport Authority of Hong's "triple water system" has served the airport since its opening in 1998. A very important benefit of this "triple water system" is that it enables the airport to reduce its freshwater demand by over 50% each year (Airport Authority of Hong Kong, 2022).

Since the airport opened in 1998, Hong Kong International Airport has used seawater for its toilets and air-cooling systems as a standalone component of the airport's triple water system (TWS). The airport's triple water system (TWS) uses potable water for drinking, catering and aircraft washing, and reclaimed water for landscape irrigation. The use of seawater for sanitation and cooling provides substantial cost, energy, and carbon savings over the use of the more traditional "dual water systems", which generally use potable water for these purposes (Airport Authority of Hong Kong, 2013). Potable water is used at the airport in several critical aircraft and airport operations processes, one of which includes aircraft washing (International Civil Aviation Organization, 2020).

As previously noted, at Hong Kong International Airport, seawater is used for toilet flushing and as the cooling medium in the air-conditioning systems of major airport buildings. This significantly reduces the use of freshwater by the airport. Wastewater that is produced from terminal building kitchens, washroom sinks, and aircraft catering and cleaning activities is collected and processed in an on-site wastewater treatment plant. These processed waters are subsequently reused for landscape irrigation (Airport Authority of Hong Kong, 2022).

The Airport Authority of Hong Kong has implemented various measures to manage sewage and storm water discharges at the airport. These measures include:

- Deploying extensive petrol/ oil interceptors in areas where a pollution risk exists, including airport apron areas and airport carparks (Airport Authority of Hong Kong, 2022). The airport apron comprises the individual aircraft stands that interface with the airport terminal building(s) and where aircraft are ground handled in between flights (Budd & Ison, 2017).

- The installation of spill traps at storm water outfalls.
- Discharging storm water away from the potentially sensitive southern sea channel (Hong Kong International Airport, 2022).

The Airport Authority of Hong Kong regularly monitors the airport's impact on the marine environment caused by sewage, storm water discharge and construction activities. The results of this monitoring have indicated that cooling water and storm drain discharges from the airport do not have an adverse impact on local water quality (Airport Authority of Hong Kong, 2022).

4.4 Hong Kong International Airport Annual Water Consumption

Hong Kong International Airport annual water consumption (all sources) and year-on-year change (%) from 2011 to 2020 is presented in Figure 3. Figure 3 shows that the airport's annual water consumption exhibited a downward trend over the period 2011 to 2013, when it decreased from 83,474,000.00 cubic metres in 2019 to 79,697,000.00 cubic metres in 2013. Following this there was a general upward trend from 2014 to 2016, when it increased from 86,444,000.00 cubic metres in 2014 to a high of 92,116,000.00 cubic metres in 2016 (Figure 3). During the latter years of the study, that is, 2017 to 2020, there was an overall downward trend in the airport's annual water consumption. This latter trend was very favorable given the growth in the airport's passenger traffic from 2017 to 2019. The most significant annual increase in water consumption occurred in 2014, at which time it increased by 8.46% on the 2013 levels (Figure 3). There were five years during the study period where the airport's annual water consumption decreased on a year-on-year basis. These annual decreases were recorded in 2012 (-4.43%), 2013 (-0.09%), 2017 (-11.96%), 2018 (-2.74%), and 2020 (-24.18%), respectively (Figure 3). These decreases were favorable as the airport increased its passenger traffic (and aircraft movements) in 2012, 2013, 2017, and 2018, whilst at the same time reducing its municipal water consumption. The significant decrease in 2020 could be attributed to the lower levels of airport operations because of the COVID-19 pandemic and the related government and airline measures that were implemented in response to the pandemic.

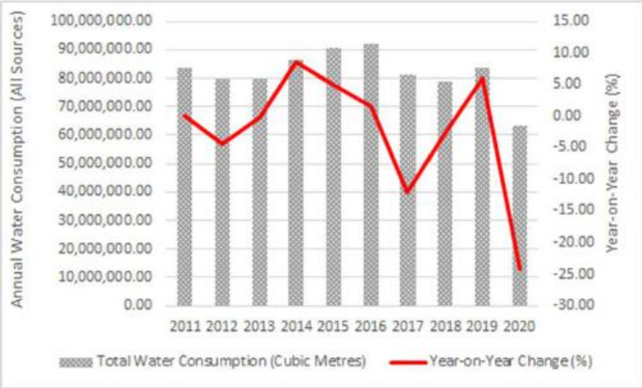

Fig.3: Hong Kong International Airport annual water consumption (all sources) and year-on-year change (%): 2011 to 2020.

Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

4.5. Hong Kong International Airport Annual Municipal Supplied Water Consumption

Hong Kong International Airport's annual municipal supplied water consumption and the year-on-year change for the period 2011 to 2020 is presented in Figure 4. As can be observed in Figure 4, there were two discernible trends in the airport's annual municipal supplied water consumption during the study period. There was a general upward trend in this metric from 2011 to 2013, at which time it increased from 424,000.0 cubic metres in 2011 to a high of 709,000.0 cubic metres in 2013. There was a pronounced spike in this metric in 2013, when it increased by 61.87% on the 2012 levels. This was the highest single annual increase in this metric during the study period. In 2013, the airport recorded growth in its annual enplaned passengers and aircraft movements, and this translated to additional water requirements. The increase could also be attributed to the airport's stakeholders higher water demand in 2013. Figure 4 shows that there was an overall downward trend in the airport's annual municipal supplied water consumption over the period 2014 to 2020. This is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, all bar value is below the line. In 2017, Hong Kong International Airport's annual municipal supplied water increased by 1.59% on the 2016 levels. This increase was slightly less than the 2016 annual passenger traffic growth rate of 2.97%. Figure 4 shows that there was a significant annual decrease in the airport's municipal supplied water in 2016, at which time it decreased by 38.19% on the 2015 levels. This was also a very favorable outcome as the airport handled higher passenger volumes in 2016, and also handled an increased number of inbound and outbound flights. Figure 4 also shows that the airport's annual municipal supplied water consumption decreased quite significantly in 2014 (-7.47%), 2015 (-7.01%), and 2019 (-7.1%), respectively. Both passenger traffic and aircraft movements increased in 2014, 2015, and 2019 and the airport was able to handle this air traffic growth whilst at the same time lowering its annual municipal supplied water consumption. The lowest annual municipal supplied water consumption was recorded in 2020 (340,000.0 cubic metres) (Figure 4). As previously noted, there was a very pronounced decrease in passenger traffic and aircraft movements in 2020 due to the CORONA-19 virus pandemic and the related government and airline-related response measures.

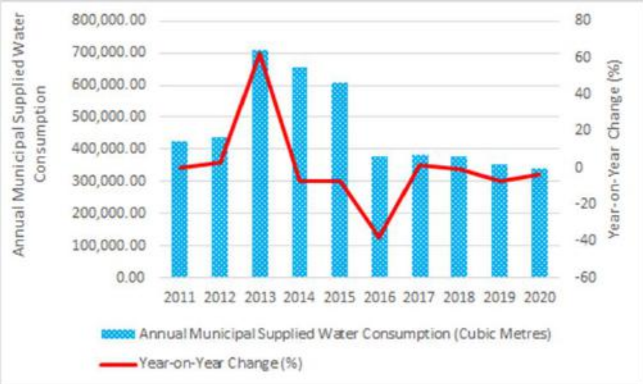

Fig.4: Hong Kong International Airport annual municipal supplied water consumption and year-on-year change (%): 2011 to 2020.
Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

An important environmental related efficiency metric used by airports is the annual water consumption per enplaned passenger (Baxter, 2022; Graham, 2005) or per workload unit (WLU). One workload (WLU) or traffic unit is equivalent to one passenger, or 100 kilograms of air cargo handled (Doganis, 2005; Graham, 2005; Teodorović & Janić, 2017). Figure 5 presents Hong Kong International Airport's annual water consumption per workload unit (WLU) and the year-on-year change for the period 2011 to 2020. As can be observed in Figure 5, there were four discernible trends in this metric during the study period. In 2012, the annual water consumption per workload unit (WLU) decreased by 2.11% on the 2011 levels (Figure 5). In 2012, the airport's enplaned passengers increased by 5.5%, whilst the annual municipal supplied water consumption increased by 3.3%. Thus, the airport was able to accommodate the higher passenger traffic growth without increasing its water consumption at the same rate of passenger traffic growth. This was a very favorable outcome. Figure 5 shows that there was a pronounced spike in this metric in 2013, at which time it increased by 51.96% on the 2012 levels. This was the second highest annual increase in this metric during the study period. Figure 5 shows that there was a downward trend in this metric during the period 2014 to 2019. This is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, all values are below the line. The annual municipal supplied water consumption per workload (WLU) declined significantly in 2014 (-12.79%), 2015 (-14.09%), and 2016 (-40.29%), respectively (Figure 5). In each of these years, the airport was able to accommodate and process higher levels of passenger traffic, whilst at the same time reducing the amount of municipal supplied water consumed. This was another very favorable outcome for the airport and demonstrated a high level of water consumption efficiency. As can be observed in Figure 5, there was a very pronounced spike in this metric in 2020, when it increased by 678.94% on the 2019 levels. In 2020, the airport reduced its annual municipal supplied water consumption by 3.68%. However, in 2020, the airport's annual passenger throughput decreased by 87.63%, and, as a result, there were fewer passengers to spread the water consumption over. This translated into the significant spike in this metric in 2020.

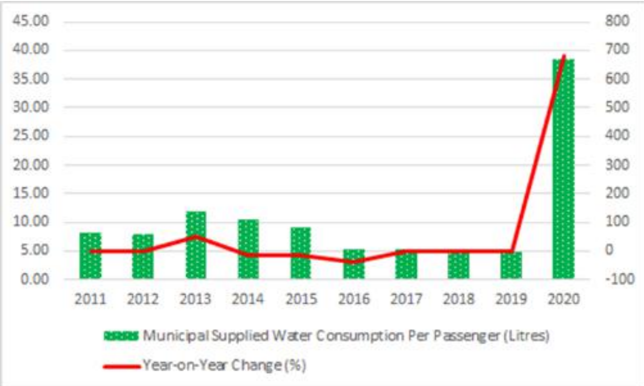

Fig.5: Hong Kong International Airport annual municipal supplied water consumption per workload unit (WLU) and year-on-year change (%): 2011 to 2020.
Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

Hong Kong International Airport's annual municipal supplied water consumption as a portion of the airport's total annual water consumption and the year-on-year change from 2011 to 2020 is presented in Figure 6. As can be observed in Figure 6, Hong Kong International Airport's annual municipal supplied water as a portion of the airport's total annual water consumption has oscillated throughout the study period. From 2011 to 2013, there was a general upward trend in this metric, when it increased from 0.51% in 2011 to a high of 0.89% in 2013 (Figure 6).

The most significant annual increase in this metric was recorded during this period. In 2013, the metric increased by 61.81% on the 2012 levels. As previously noted, Hong Kong International Airport's annual municipal supplied water increased very significantly in 2013 (+61.87%), and this in turn resulted in municipality supplied waters accounting for a greater share of total water consumption in 2013. Figure 6 shows that this metric decreased quite significantly in 2014 (-14.60%), 2015 (-11.84%), and 2016 (-38.80%), respectively. These decreases could be attributed to the airport's lower annual municipality supplied water consumption in these respective years. Figure 6 also shows that there were two quite significant annual increases in this metric during the study period. These increases occurred in 2017 (+14.63%), and 2020 (+28.57%) (Figure 6). The increase in 2017 could be attributed to the higher municipal supplied water consumption at the airport during 2017. In 2020, the annual municipal supplied water consumption decreased by 3.68%, whilst the annual seawater consumption, a key water source, decreased by 24.27% in 2020. As a result, municipal supplied water consumption as a share of total water consumption increased in both 2017 and 2020, reflecting the differing water sources consumption patterns in 2020.

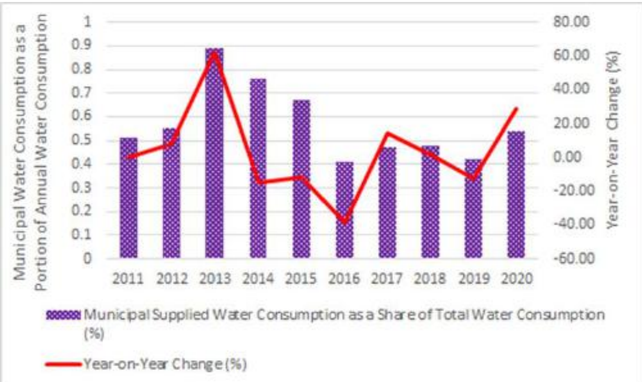

Fig.6: Municipal supplied water as a share of total annual water consumption and year-on-year change (%): 2011 to 2020.

Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

4.6. Hong Kong International Airport Annual Seawater Consumption

Hong Kong International Airport's annual seawater consumption and the year-on-year change from 2011 to 2020 is depicted in Figure 7. Figure 7 shows that there were three discernible trends in the airport's annual seawater consumption. There was a general downward trend during the early years of the study, that is, 2011 to 2014, at which time the airport's annual seawater consumption decreased from 83,050,000 cubic metres in 2011 to 78,988,000 cubic metres in 2013. In these early years of the study period, the most significant annual decrease was recorded in 2012, when it decreased by 4.47% on the 2011 levels, reflecting a lower usage requirement in 2012. From 2014 to 2016, there was a general upward trend in the airport's annual seawater consumption, with the two most significant annual increases being recorded in 2014 (+8.6%), and 2015 (+5.11%), respectively (Figure 7). Hong Kong International Airport recorded strong growth in its annual passenger traffic (and aircraft movements) in both 2014 and 2015, and this growth in passenger traffic and aircraft movements would have required greater amounts of water to sustain the airport's operations. From 2017 to 2020, there was an overall downward trend in the airport's annual seawater consumption, when it decreased from a high of 91,739,000 cubic metres in 2016 to a low of 63,069,000 cubic metres in 2020. Figure 7 shows that there was one exception to this downward trend, when the airport's annual seawater consumption increased by 6.11% in 2019, reflecting higher consumption patterns. In 2020, the airport's annual seawater consumption decreased by 24.27% on the 2019 levels, reflecting the lower passenger volumes and aircraft movements in 2020 handled at the airport due to the CORONA-19 virus pandemic.

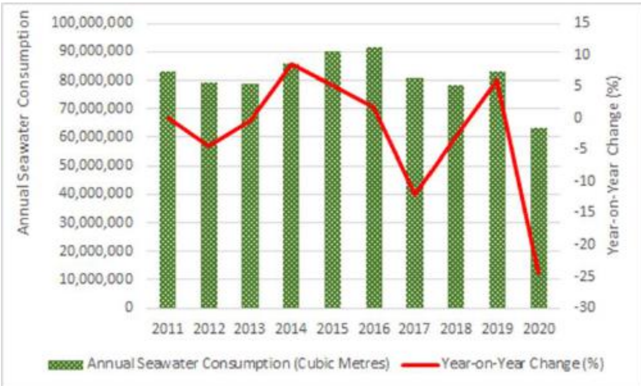

Fig.7: Hong Kong International Airport annual seawater consumption and year-on-year change (%): 2011 to 2020.

Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

Hong Kong International Airport's annual seawater consumption as a portion of the airport's total annual water consumption and the year-on-year change from 2011 to 2020 is presented in Figure 8. Figure 8 shows that this metric has fluctuated over the study period reflecting differing consumption patterns. During the study period, there were four years where the airport's annual seawater consumption as a share of total water consumption increased slightly on a year-on-year basis. These annual increases occurred in 2014 (+0.13%), 2015 (+0.09%), 2016 (+0.26%), and 2019 (+0.06%), respectively (Figure 8). In 2014, the airport's annual municipal supplied water consumption decreased on a year-on-year basis whereas the airport's seawater consumption increased in the same year, and thus, this resulted in the seawater's higher share of total water consumption in 2014. A similar situation occurred in 2015, when once again the airport's municipal supplied water consumption declined on a year-on-year basis, whilst at the same time the annual seawater consumption in that year, and once again, this resulted in the airport's seawater consumption accounting for a higher share of the airport's total annual water consumption in 2015. The same trend occurred in 2016, when once again the airport's municipal supplied water consumption decreased on an annualized basis, whilst the airport's seawater consumption increased on an annualized basis. Hence, in 2016, the airport's annual seawater consumption once again accounted for the higher share of the airport's total annual water consumption in that year. In 2019, there was a significant decrease in the airport's municipal supplied water and a 6.11% increase in the annual seawater consumption. This translated into the growth in the seawater consumption as a share of the airport's total annual water consumption in 2019. Figure 8 shows that there were five years in the study period where the airport's annual seawater consumption as a share of total water consumption decreased on a year-on-year basis. These annual decreases occurred in 2012 (-0.04%), 2013 (-0.34%), 2017 (-0.06%), 2018 (-0.01%), and 2020 (-0.12%), respectively (Figure 8). In 2012 and 2013, the airport's annual seawater consumption declined on a year-on-year basis whereas the airport's annual municipal supplied water increased in both years. This resulted in an increase in the municipal supplied share of total water consumption and a decrease in the seawaters share of total water consumption in both years. A similar trend occurred in 2017, at which time the airport's aannual municipal supplied water consumption increased on a year-on-year basis, whilst at the same time the annual seawater consumption decreased by -12.02%. Consequently, the seawater share of the airport's total annual water consumption declined whilst the municipal supplied water consumption as a share of total water increased in 2017. In 2018, the airport consumed increased volumes of municipal supplied water but consumed less seawater. Once again, this meant that there was a decrease in the seawater consumption as a share of total water consumption in 2018. In 2020, the airport's annual municipal supplied water and seawater consumption both decreased on an annualized basis due to the impact of the CORONA-19 virus pandemic and the related government and airline related pandemic response measures. However, in 2020, the decrease in the airport's annual seawater consumption was lower than the decrease in the airport's municipal supplied water consumption, and hence, the seawater consumption as a share of total water consumption was influenced by the differences in the two water sources annual consumption pattern.

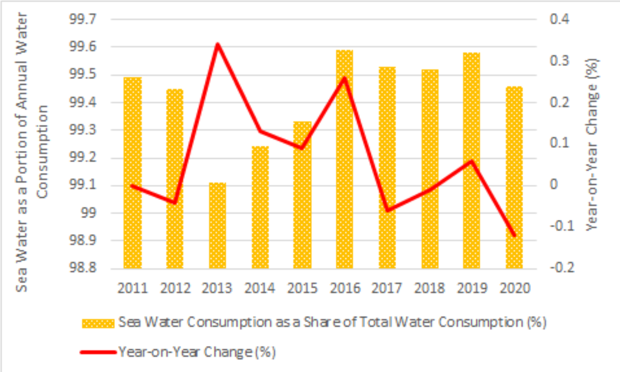

Fig.8: Sea water as a share of total annual water consumption and year-on-year change (%): 2011 to 2020. Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

4.7. Hong Kong International Airport Annual Recycled/Re-Used Water Consumption

As noted earlier, Hong Kong International Airport re-uses and recycles wastewaters, which once processed the re-processed waters are used for irrigation purposes. It is important to note that the re-use of water produces substantial environmental benefits, arising from reductions in water diversions, and reductions in the impacts of wastewater discharges on environmental water quality (Anderson, 2003). The re-use of wastewater also prevents environmental pollution (Nair, 2008; Ofori et al., 2021). Hong Kong International Airport's annual recycled/re-used waters and the year-on-year change from 2011 to 2020 is presented in Figure 9. As can be observed in Figure 9, Hong Kong International Airport's annual recycled/re-used waters have oscillated over the study period. Figure 9 shows that there were two quite pronounced annual decreases in this metric, with these decreases occurring in 2013 (-26.66%) and 2018 (-16.41%), respectively. These decreases were due to smaller volumes of water that were available to be recycled/re-used in both 2013 and 2016. Figure 9 shows that were was a spike in this metric in 2014, at which time the annual waters recycled/re-used increased by 16.23% on the 2013 levels. There were four smaller annual increases in this metric during the study period, with these smaller annual increases occurring in 2012 (+5.52%), 2014 (+3.24%), 2016 (+8.1%), and 2019

(+6.13%), respectively (Figure 9). This was a very favorable outcome for the airport and showed that it was able to make very good use of its waters in these respective years. Figure 9 also shows that the annual recycled/re-used waters decreased in 2020 by 2.89% in 2020, reflecting the lower water requirements at the airport due to the CORONA-19 pandemic government and airline response measures. During the study period, the smallest annual volume of recycled/re-used waters was recorded in 2013, at which time the airport recycled/reused 154,000 cubic metres of water (Figure 9). The highest annual volume of recycled/re-used waters was recorded in 2012, at which time the airport recycled/reused 210,000 cubic metres of water (Figure 9).

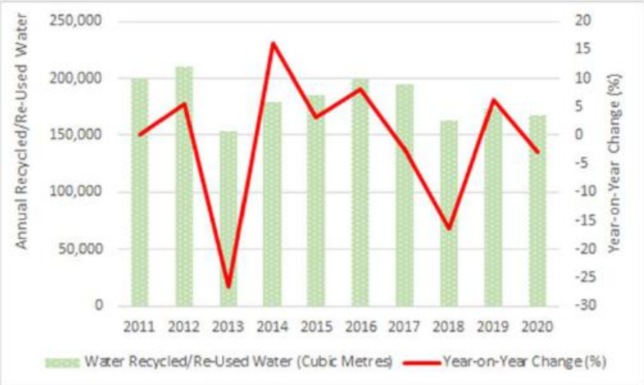

Fig.9: Hong Kong International Airport annual recycled/re-used waters and year-on-year change (%): 2011 to 2020.
Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b.

4.8. Hong Kong International Airport Annual Discharged Waters

Prior to examining Hong Kong International Airport's annual discharged wastewaters, it is important to note that very significant volumes of wastewater can be produced at airports (Baxter et al., 2018a; Pitt et al., 2002). Allenby and Park (2013, p. 462) have observed that wastewater is "water that carries wastes from homes, businesses, and industries and usually contains dissolved solids and/or suspended solids". Hong Kong International Airport's annual discharged wastewaters and the year-on-year change for the period 2011 to 2020 is presented in Figure 10. Figure 10 shows that the airport's annual discharged wastewaters fluctuated over the study period. There was a very pronounced spike in the airport's annual discharged wastewaters in 2013, at which time they increased by 143.42% on the 2012 levels. In 2013, the airport discharged a total of 555,000 cubic metres of wastewaters. This was the highest annual discharge of wastewaters by the airport during the study period. The smallest annual volume of discharged waters was recorded in 2020, at which time the airport discharged 172,000 cubic metres of wastewaters (Figure 10). Figure 10 also shows that there were three years during the study period where smaller annual increases were recorded in the annual wastewaters discharged by the airport. These increases were recorded in 2012 (+1.33%), 2017 (+6.21%), and 2018 (+15.42%) and reflected a greater requirement by the airport to discharge waters in these respective years (Figure 10). Figure 10 also reveals that there were five years during the study period where the annual volume of wastewaters discharged decreased on a year-on-year basis. These annual decreases occurred in 2014 (-14.05%), 2015 (-10.9%), 2016 (-58.35%), 2019 (-17.05%), and 2020 (-4.44%), respectively (Figure 10). These annual decreases are another very favorable trend and in these years the airport was able to mitigate the potential level of environmental harm from its annual wastewater discharges. An airport's annual wastewaters can fluctuate (Baxter, 2021; Baxter et al., 2018a, 2018b) and Hong Kong International Airport's annual wastewaters have displayed such a trend.

The volume of wastewater discharge at Hong Kong International Airport is estimated by subtracting the volume of wastewater recycled from the airport's municipal water consumption. Under the *Water Pollution Control Ordinance* (Chapter 358, The Laws of Hong Kong), the Airport Authority of Hong Kong AAHK holds a number of licenses which require the monitoring of water quality using the following parameters: flow rate (m^3/day), total residue chlorine, amines, temperature, antifoulant, suspended solids, chemical oxygen demand, oil and grease, surfactants (total), biochemical oxygen demand, total phosphorus and formaldehyde (Airport Authority of Hong Kong, 2021b).

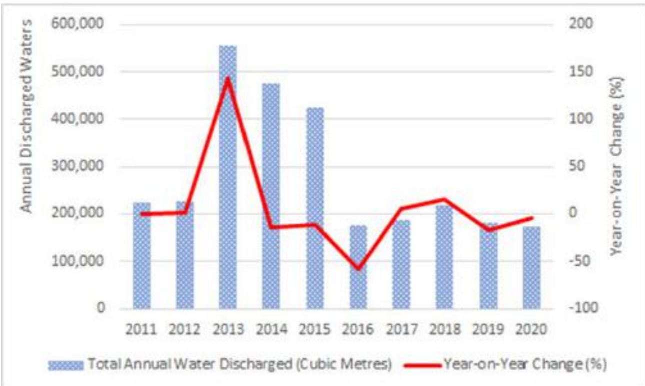

Fig.10: Hong Kong International Airport annual discharged wastewaters and year-on-year change (%): 2011 to 2020.
Source: data derived from Airport Authority of Hong Kong (2013, 2014, 2015b, 2018b, 2019, 2020, 2021b).

4.9. Dry Aircraft washing at Hong Kong International Airport

In June 2019, the Airport Authority of Hong Kong granted approval for Hong Kong Aircraft Engineering Company Limited (HAECO) to perform the dry washing of aircraft at the airport (International Civil Aviation Organization, 2020). Aircraft dry washing involves applying cleaning agents to the aircraft surface, then removing with mops or wipes. This practice uses considerably less water and can be carried out in any location (Hayward, 2022). The cleaning product used in the dry washing of aircraft is more effective at removing insects, oil stains and other dirt from the aircraft's exterior. Following washing, a fine protective film is formed on the aircraft enabling it to retain a longer shine. Importantly, the aircraft dry wash technique uses 90% less water than conventional wet washing methods that use highly pressurized water, while the biodegradable, non-toxic cleaning product produces fewer chemical effluents (Airport Authority of Hong Kong, 2020b).

Traditionally, aircraft washing at Hong Kong International Airport was allowed only in 10 designated aircraft parking bays that were equipped with drainage to collect effluent for treatment. Prior to approving the dry washing of aircraft for a further 29 predesignated aircraft parking bays, which reduces the distance of aircraft towing by relaxing the requirements to use parking bays for cleaning, the airport authority reviewed the physical and chemical properties of the products, assessed the environmental risks, and provided advice on the Dry Wash Procedures. The benefits of dry wash are significant in various aspects. Compared with the traditional wet washing of aircraft, HAECO anticipates an aircraft dry wash to use 90% less water. This new practice saves more than 860,000 liters of water a year and produces less effluent. An additional environmental related benefit is that by reducing the aircraft towing requirement, this helps reduce the traffic on the apron and fuel consumption by aircraft and ground services equipment (GSE), hence this reduces the airport-wide greenhouse gas emissions (International Civil Aviation Organization, 2020). In 2020, the Airport Authority of Hong Kong approved another aircraft maintenance service provider, China Aircraft Services Limited (CASL), to conduct aircraft dry wash on the maintenance apron at the airport (Airport Authority of Hong Kong, 2020a; International Civil Aviation Organization, 2020).

4.10. Hong Kong International Airport Water Saving Efficiency Measures in the Midfield Concourse (MFC)

Hong Kong International Airport has installed a range of water saving efficiency measures in its new Midfield Concourse (MFC). A sustainable water strategy has been adopted for the MFC which covers demand reduction, grey water recycling, and condensate water harvesting. The airport's goal is to reduce potable water consumption by 30% compared to typical Hong Kong consumption. The water demand reduction is principally supported using sea water for toilet flushing and other water-conserving sanitary fittings. Treated grey water and condensate water is to be reused in the cooling system of the MFC to further reduce potable water consumption. The airport's Midfield Concourse (MFC) water strategy aims to eliminate water leakage, reduce water consumption, use non-potable water for the flushing of toilets, and harvest and recycle water where possible (Airport Authority of Hong Kong, 2015). In addition, the airport is using condensate water from air-conditioning systems as well as reclaimed water to cool the chiller systems in the concourse, and these measures will thereby reduce the use of potable water (Airport Authority of Hong Kong, 2014).

V. CONCLUSION

Utilizing an in-depth longitudinal case study research design, this study has examined Hong Kong International Airport's water management and the annual trends in the airport's water consumption for the study period of 2011 to 2020. The qualitative data used in the study was examined by document analysis.

The case study revealed that the two principal sources of water used by the airport are municipal supplied water and seawater. The airport also recycles water for use in the irrigation of the airport's grounds. The airport uses a "triple water system", that has been designed to improve the efficiency of its three major water sources: freshwater, seawater and treated wastewater.

The airport's total annual water consumption decreased from 83,474,000.0 cubic metres in 2011 to a low of 63,409,000.0 cubic metres in 2020. The highest annual water consumption was recorded in 2016, when the airport consumed 92,116,000.00 cubic metres of water.

The case study found that the airport's use of municipal supplied water displayed an upward trend from 2011 to 2013 and an overall downward trend from 2014 to 2020. This latter trend was very favorable as the airport's annual enplaned passengers and aircraft movements grew very strongly over the study period. The municipal supplied water consumption per enplaned passenger or per workload unit (WLU) largely displayed a general downward trend. The lowest annual municipal supplied water consumption per enplaned passenger or per workload unit (WLU) was recorded in 2019 (4.94 litres/WLU), whilst the highest was recorded in 2020 (38.48 litres/WLU). The airport was adversely impacted by the CORONA-19 virus pandemic and the related government response measures, and thus, there were fewer passengers handled at the airport and this led to the very large increase in 2020.

The airport's annual seawater consumption oscillated over the study period, reflecting differing consumption patterns. The lowest annual seawater consumption was recorded in 2020, at which time the airport consumed 63,069,000 cubic metres of seawater. The highest annual seawater consumption was recorded in 2016, at which time the airport consumed 91,739,000 cubic metres of seawater. Sea waters are the primary water source used by the airport, averaging around 99.43% of the airport's total annual water consumption during the study period.

The case study also found that Hong Kong International Airport's annual recycled/re-used water consumption fluctuated over the study period. The lowest annual recycled/reused waters consumption was recorded in 2013, at which time the airport consumed 154,000 cubic metres of recycled/re-used waters. The highest annual recycled/re-used water consumption was recorded in 2012, at which time the airport consumed 210,000 cubic metres of recycled/re-used waters.

Hong Kong International Airport's annual discharged wastewaters also fluctuated over the study period. The lowest annual level of discharged waters was recorded in 2020, at which time the airport consumed 172,000 cubic metres of discharged waters. The highest annual release of discharged waters was recorded in 2013, at which time 555,000 cubic metres of wastewaters were discharged from the airport.

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