Seawater as Renewable Energy in Air Conditioning and Plumbing Systems for Coastal Development

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Abstract

Seawater is deemed as renewable energy and supplemental water source in coastal development. Utilizing seawater resources in air conditioning and plumbing system involves implementation of innovative technology such as seawater air conditioning (SWAC), seawater heat pump (SWHP), landscape irrigation system, potable water and greywater recycling. The research aims to demonstrate seawater usage as water efficiency option to reduce energy consumption, save freshwater and environment. The research had adopted systematic literature review (SLR) method to analyze the application of seawater building air conditioning and plumbing system on current publications and papers, and conclude with summary of benefits and challenges.

Keywords: seawater renewable energy; air conditioning and plumbing system; innovative technology; water efficiency

1. Introduction

Over the last decade, guidelines such as American Society of Heating, Refrigeration and Air Conditioning Engineer (ASHRAE), Green Building Index (GBI) and various government agencies have strived to improve the energy efficiency in architectural and engineering design in a building. Application of renewable energy has been further studied by National Renewable Energy Laboratory (NREL) with the implementation of renewable energy such as photovoltaic system, solar system, wind turbines and so on. As cooling and heating system serves many multi-use buildings, it can contribute to a significant energy load to the country, especially in economically growing countries. Hence, utilization of renewable energy in air conditioning and plumbing system is indispensable to take advantages of abundance resources of seawater at coastal area.

The ocean and sea are the blue energy which is still untapped as renewable resources, said Kristian

Dubrawski, a postdoctoral scholar in civil and environmental engineering at Stanford University. (Jordan, 2019) From the perspective of environmental friendly and energy efficiency, seawater air conditioning (SWAC) and seawater heat pump (SWHP) are one of the preferably approaches to develop ocean thermal energy, which allows the seawater for heating and cooling of certain spaces in a building. It is widely used in coastal development, since then, many studies have been conducted to improve the system performance. (Wu, You, Zhang, & Zheng, 2020) As we all know that three quarters of the megacities in the world are situated next to the shoreline, the implementation of seawater air conditioning is commonly in used in Hong Kong, Singapore, Denmark, Sweden and more. Moreover, utilizing seawater air conditioning in commercial complex is proven to be more efficient and lesser CO^2 emission than traditional air chillers. (Chang, Madani, Liu, Wang, & Palm, 2020) The innovative seawater cooling and heating system offers different design for greater flexibility, where the seawater can flow in either open-loop or closed-loop system. (Sustainable Water & Energy Solutions Network, 2020) An open-loop system pumps the seawater through a heat exchanger and returns to the sea with only slight increase in temperature, while the closed-loop system allows the seawater to recirculated and reused continuously for a certain period of time.

Freshwater takes up only 2.5% of the earth's water resources, while seawater takes up 97.5% of all water resources. (Gong, Wang, Zhu, Bai, & Wang, 2019) Therefore, to respond with the lack of freshwater resources in the world, seawater desalination has been introduced to harness the unlimited treasure in the sea, to become another source to produce freshwater for the people and to meet the demand of the world. (Balaban, 2009) Desalinating seawater does not only remove its salinity, it also eliminates harmful bacteria and chemical. Therefore, the treated seawater can be even cleaner and healthier than fresh water where it offers potable water for human consumption and landscape irrigation system. (Pure Aqua, 2018) Meanwhile, by adopting seawater desalination, seawater for toilet flushing (SWTF) allows greywater recycling for the building to minimize water wastage. For instance, the practice has been developed to tackle the water shortage problems in places such as Hong Kong. Hong Kong has practiced SWTF system since 1958, now, it serves 80% of the citizen in Hong Kong, facilitating the city to reduce the freshwater consumption and increase the water efficiency annually. (Liu, et al., 2016) According to David A. Reckhow, an environmental engineer at University of Massachusetts, the SWFT system could affect the ecosystems by keeping marine life away from the high concentration of freshwater near the outlet areas. (Yang, Liu, Zhang, & Richardson, 2015)

2. Problem Statement

How much water is needed to operate a building? Water supply in some places in the world are not as sufficient and abundant as many might think. Thus, creating our future with a more sustainable water supply is very much needed to tackle the problems as such:

1. Renewable Energy Act 2011 in Malaysia

Government has targeted to achieve energy mix with 20% renewable energy by the year of 2025. (Abdullah , Osman, Ab Kadir, & Verayiah, 2019) Malaysia has abundance renewable resources on biomass, hydro and solar. (Shamsuddin, 2012) A large natural hydro resource has potential to be utilized as another main renewable energy like solar energy in Malaysia, to perform more efficiently than wind power.

2. Energy inefficiency of building systems and technologies

The demand for cooling is increasing steadily in hot tropical climate, the total energy consumed by air conditioning and ventilation can exceed 50% of total energy consumption in a building. (Hunt, Byers, & Sanchez, 2018) Building system that relies on fossil fuels has caused more greenhouse gases (GHG) emission, urban heat island (UHI) phenomenon locally and global warming in world. (Santillán-Soto, García-Cueto, Lambert-Arista, Ojeda-Benítez, & Cruz-Sotelo, 2019)

3. Freshwater wastage

As freshwater resources do not get replenished with speed at the ever-increasing in human population and demand of water usage, the over-exploitation of limited freshwater resources has to be halted in no time. (Ezugbe & Rathilal, 2020) While many places in the world are still using freshwater for potable water, toilet flushing and landscape irrigation, millions gallons of freshwater are flushed as wastewater every day. (Berning, 2014)

2.1 Research Question

1. How is the application of seawater in air conditioning and plumbing system in a building?
2. What are the benefits and challenges of seawater in air conditioning and plumbing in a building?

2.1 Research Objective

The objective of the research aims to:

1. To identify on the application of seawater in air conditioning and plumbing system in a building
2. To investigate the benefits and challenges of seawater in air conditioning and plumbing system in a building

3. Methodology

A comprehensive study was done by using qualitative and exploratory research method, where the author used keywords and phraseology to search for relevant topics on search engine such as Research Gate, Science Direct, Google Scholar as well as reliable websites relating to the subject matter. Only current and up-to-date literature reviews were analysed and compiled from relevant international journal papers, proceedings, reports and conference paper.

The process refined the research questions as the exploration of the study grows further with sufficient reading and material on the subject matter. Studies and research papers which had been chosen were selected and appraised thoughtfully, then data and results obtained were extracted and contextualized to be interpreted in the compiled literature review list.

4. Literature Review

Reviews from related topic papers has been compiled, to study on the application of different type of seawater building system, the benefits and challenges of executing the seawater technologies.

Table 1. Summary of Benefits and Challenges
on Seawater Air Conditioning and Plumbing System

Author / Title	Application	Methodology	Benefits	Challenges
(Chang, Madani, Liu, Wang, & Palm, 2020) / Seawater heat pumps in China, a spatial analysis	Seawater heat pump (SWHP)	Systematic method is used to build evaluation model to analyse spatial data in seawater source, building and energy system.	1.Compared to coal boiler heating system, SWHP heating save up 19% fossil fuel primary energy use. 2.Compared to split-type air-conditioners, SWHP save up 43% primary energy use.	Retrofitting thermal infrastructure requires high costs.
(Yan, et al., 2020) / Comparative study on the cooling performance of evaporative cooling systems using seawater and freshwater	Seawater evaporative cooler	Field test and mathematical model is conducted with seawater and wet media.	Feasible to use in coastal area for saving freshwater.	The cooling effectiveness of seawater is at least 2.8%, slightly lower than freshwater.
(Schibuola & Tambani, 2020) / Performance assessment of seawater cooled chillers to mitigate urban heat island	Seawater air conditioning (SWAC)	Case study in Jesolo, a seaside resort town, on monitoring stimulation of meteorological data, urban area modelling, UWG code application, chiller and SWAC model data.	1. SWAC has reduced the UHI effect with 57% at night. 2.Cooling demand has decreased of 58%, achieving 23.5% of energy saving.	1. Two heat exchangers have to operate alternatively for maintenance of fouling. 2. Self-cleaning filter is adopted to decrease percentage of fouling.
(Gong, Wang, Zhu, Bai, & Wang, 2019) / Comprehensive Utilization of Seawater in China: A Description of	Seawater heat pump (SWHP), seawater irrigation, potable water, seawater flushing toilet.	Data and information analysis on utilization of seawater in China.	Circulating seawater cooling system reduces 95% of pollution compared to once-through seawater cooling system.	1. Low localization rate of technologies and equipment. 2. High cost of desalination. 3. Incomplete law

the Present Situation, Restrictive Factors and Potential Counter-measures				and policy supports.
(Arias-Gaviria, Adoption of sea water air conditioning (SWAC) in the Caribbean: Individual vs regional effects, 2019) / Adoption of sea water air conditioning (SWAC) in the Caribbean: Individual vs regional effects	Seawater air conditioning (SWAC)	Diffusion models to study the effect on SWAC adoption rates, comparing the effectiveness of country and regional level incentives.	Energy supply: SWAC provides thermal energy for air conditioning. Energy demand: SWAC increases the cooling efficiency and removes the electricity consumption.	1. High investment costs. 2. Limited adoption of SWAC. 3. Lack of knowledge. 4. Uncertain about ocean environmental impact.
(Hernandez-Romero, et al., 2019) / Multi-scenario model for optimal design of seawater air-conditioning systems under demand uncertainty	Seawater air conditioning (SWAC)	Mathematical programing formulation to obtain the operation policy and design of the SWAC at tourist zone in Mexico.	Compare to conventional AC: 1. Reduce the energy by 75-90%. 2. Life cycle cost around 50% lower. 3. Contributing less greenhouse gas (GHG).	Seasonal energy demand uncertainty leads to uncertainties for seawater extracted for cooling.
(Inayat & Raza, 2019) / District cooling system via renewable energy sources: A review	Seawater air conditioning (SWAC)	Study on technical and economic analysis of SWAC.	1. Saving of 80% as compared to the conventional cooling systems. 2. Economical and not sophisticated.	Strategic location with sufficient cold water supply from deep sea.

(Hunt, Byers, & Sanchez, 2018) / Technical potential and cost estimates for seawater air conditioning	Seawater air conditioning (SWAC)	Data inputs methods to develop SWAC world potential model framework and analyse the data.	1. Reduction of around 80% in electricity consumption. 2. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and water consumption. 3. Cost and energy savings for base load cooling process.	1. High capital costs for district cooling and building retrofitting. 2. Require detailed knowledge on system requirements. 3. Risk of high nutrient loading and thermal shock in seawater outlet.
(Hezi, et al., 2018) / Optimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking water	Seawater desalination from coastal aquifer	Scientific management model and theoretical background.	1. Used for drinking water and agriculture irrigation mainly.	1. Constraint on the amount of seawater along shore. 2. Coastal soil strip as filter for fouling control.
(Ahmed, 2018) / Feasibility Study & Design of a Seawater Air-Conditioning System for USP Tuvalu Campus	Seawater air conditioning (SWAC)	Phase 1: Feasibility study, load calculation and system sizing Phase 2: System scaling, seawater temperature measurement, model construction, testing and economic analysis	Reduction of 2.5 tons of CO^2 per month.	Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.
(Arias-Gaviria, Larsen, & Arango-	Seawater air conditioning	Simulated scenarios and	1. Save up to 90% of the energy used in	To reduce dependence on

Aramburo, 2018) / Understanding the future of Seawater Air Conditioning in the Caribbean: A simulation approach	(SWAC)	incentives for SWAC adoption by developing system dynamics simulation model.	traditional system 2. Decrease refrigerant leaks 3. Lower operational and levelized cost	traditional AC systems and fossil fuels is uncommon.
(Xin, Lin, & Shu, Effect of seawater intake methods on the performance of seawatersource heat pump systems in cold climate areas, 2017) / Large-area seepage and heat transfer model of beach well infiltration intake system for seawater source heat pump	Seawater heat pump (SWHP)	MATLAB is used to analyse for seepage and heat transfer model, in qualitative and quantitative relationship.	Energy-efficient, environmental friendly for cooling and heating of a building.	Energy consumption relies on intake seawater level and temperature.
(Herzen, et al., 2017) / A feasibility study of an integrated air conditioning, Desalination and marine permaculture system in Oman	Seawater air conditioning (SWAC)	Technical analysis has been done by including simulation, economic analysis, and strategy to implement this project.	1. The energy saved in SWAC compared to conventional systems ranging from 75% to 90 %.	1. Distance offshore influencing the economic viability. 2. Payback periods of 4-7 years have been analysed.
(Xin, Lin, & Shu, Effect of seawater intake methods on the performance of seawatersource heat pump systems	Seawater heat pump (SWHP) with beach well infiltration	Field test is conducted for SWHP in Liaodong Peninsula, China	Improve the stability, reliability and energy efficiency effectively for SWHP systems.	1. Seawater in the heat exchanger would stop running and freeze under extreme weather conditions.

in cold climate areas, 2017) / Effect of seawater intake methods on the performance of seawater source heat pump systems in cold climate areas	intake			2. Intake seawater temperature affects SWHP performances.
(Shu, et al., 2016) / Energy efficiency enhancement potential of the heat pump unit in a seawater source heat pump district heating system	Seawater heat pump (SWHP)	Field measurement with an actual SWHP system was conducted, analysed and evaluated.	Heat pump units allow 24.2% potential energy efficiency enhancement.	Performance of the heat pump units is the key to improve the energy efficiency of the seawater source heat pump heating system.
(Osorio, et al., 2016) / Beyond electricity: The potential of ocean thermal energy and ocean technology ecoparks in small tropical islands	Seawater air conditioning (SWAC)	Information obtained from San Andres Island from a reanalysis model data available.	1. Alternative for small tropical islands. 2. Save up to 85% of energy consumed in typical AC. 3. Decreases the use of fossil fuels.	1. Unknown environmental impacts. 2. High initial investment costs. 3. Commitment of local authorities.
(Ni, et al., 2015) / A review of heat pump systems for heating and cooling of buildings in China in the last decade	Seawater heat pump (SWHP)	Collecting database of more than 20 domestic SWHP to compare with traditional AC.	Good economic benefit, energy-saving and environmental benefit.	Maintenance for high corrosion of seawater and dirt sediment.
(Lilley, Konan, & Lerner, 2015)	Seawater air conditioning	Data estimation based on SWAC	25,000 ton SWAC: 1. Saves a notable	1. Lack of familiarity with the technology.

/ Cool as a (sea) cucumber? Exploring public attitudes toward seawater air conditioning in Hawaii	(SWAC)	at the Natural Energy Laboratory of Hawaii Authority (NELHA)	amount of fresh water by eliminating cooling towers. 2. Save 260 million gallons of potable water per year. 3. Decrease waste water by to 84 million gallons per year. 4. Decrease 40% of thermal pollution.	2. Not feasible for single home residences.
(Zheng, Ye, You, & Zhang, 2015) / The thermal performance of seawater-source heat pump systems in areas of severe cold during winter	Seawater heat pump (SWHP)	Two separate sets of experimental setup and data reduction in the Bohai Sea, Tianjin, North China.	Compared to air-source heat pump (ASHP), SWHP is more efficient than ASHP due to frost formation in ASHP during winter time.	Close-loop SWHP is more preferable compared to open-loop SWHP due to freezing of surface seawater during winter.
(Surroop & Abhishekanand, 2013) / Technical and Economic Assessment of Seawater Air Conditioning in Hotels	Seawater air conditioning (SWAC)	Numerical method to estimate the cooling load of a system and dehumidify outdoor air to the desired indoor air.	Direct seawater air conditioning has 88% of energy saving compared to conventional system.	Direct seawater air conditioning is more expensive than conventional, however, with higher energy efficiency, the payback can be achieved in 6.46 years.
(Wang, Liu, Wang, & Bi, 2012) / Simulation Computation and Analysis of	Seawater heat pump (SWHP)	Simulation using computation methods of dynamic operation energy in seawater source	The energy efficiency ratio of SWHP is higher by 61.8% and 27.2% respectively than air source heat pump.	Energy consumed by water pumps in SWHP is more than that by air source heat pumps for 4.2 times higher.

Dynamic Operation Energy of Seawater Source Heat Pump		heat pump system.		
(War, 2011) / Seawater Air Conditioning (SWAC) a renewable energy alternative	Seawater air conditioning (SWAC)	Case study in Hurghada - Upper Egypt to carry out technical, environmental and economic analysis.	1. Offset energy demand by 75-85%. 2. Terminate the use for cooling towers and chillers.	ROI in 6-8 years.

Table 2. Compilation of Benefits and Challenges
on Seawater Air Conditioning and Plumbing System.

Author	Benefits							Challenges						
	Water and Energy Efficiency	Economic / Cost Effectiveness	Decreases UHI Effect / GHG / Refrigerant Leak	Potable Water, Irrigation, Flushing Toilet	Decrease Fossil Fuel / Cooling Tower Reliance	Decrease Wastewater / Save Freshwater	Low Energy Consumption	ROI and Payback	High Investment / Retrofitting / Desalination Cost	Not Feasible / Fouling	Uncommon / Detailed Knowledge	Less Localization / Incomplete Law & Policy	Seawater Condition, Level and Temperature
(Chang, Madani, Liu, Wang, & Palm, 2020)	x				x				x				
(Yan, et al., 2020)	x	x											x
(Schibuola & Tambani, 2020)	x		x							x	x		
(Gong, Wang, Zhu, Bai, & Wang, 2019)			x			x			x			x	x
(Arias-Gaviria, 2019)	x						x		x		x		x

(Hernandez-Romero, et al., 2019)	x	x	x										x
(Inayat & Raza, 2019)		x											x
(Hunt, Byers, & Sanchez, 2018)	x	x	x						x		x		
(Hezi, et al., 2018)				x						x			x
(Ahmed, 2018)	x	x						x					
(Arias-Gaviria, Larsen, & Arango-Aramburo, 2018)	x	x	x								x		
(Xin, Lin, & Shu, Effect of seawater intake methods on the performance of seawatersource heat pump systems in cold climate areas, 2017)	x												x
(Herzen, et al., 2017)	x	x						x					x
(Xin, Lin, & Shu, 2017)	x												x
(Shu, et al., 2016)	x												x
(Osorio, et al., 2016)	x				x				x			x	
(Ni, et al., 2015)	x	x											x
(Lilley, Konan, & Lerner, 2015)			x			x				x	x		
(Zheng, Ye, You, & Zhang, 2015)	x												x
(Surroop & Abhishekanand, 2013)	x	x						x					
(Wang, Liu, Wang, & Bi, 2012)	x												
(War, 2011)	x							x					

5. Conclusion

"We need to ensure operational performance for the people who live, work, and interact in buildings. Pursue the steps to develop new standards and guidelines for good performance designs and strategies to achieve effective performance and experience of users" said Daryll Boyce, ASHRAE president 2019/2020.

The seawater air conditioning and plumbing taps into the most valuable and significant energy resources that is available at coastal area. The application of seawater air conditioning and plumbing system has various benefits to our environment, considering it is the best sustainable option to increase the water and energy efficiency, optimize cost effectiveness, reduce the urban heat island (UHI) effect, greenhouse gas (GHG) emission and refrigerant leaks. The system also allows 'tap to toilet' concept and landscape irrigation, making full use of direct usage of seawater and seawater desalination. Hence, it decreases the reliance on cooling tower, subsequently decrease the usage of fossil fuel, wastewater production and save more freshwater.

In short, seawater air conditioning and plumbing system is a sustainable alternate-energy system that utilizes seawater from ocean to cool down the buildings and provide freshwater for water-related activities after desalination process is carried out. It is supported by many research papers that it performs better than the conventional type of building system in terms of energy efficiency, environmental friendly and cost effectiveness. However, it is not widely implemented and incentivized in local law and policy. Although there are a few challenges posed on this new technology, it is undeniably an attractive investment especially in tropical region which demands a lot of energy in air conditioning. The innovative seawater air conditioning and plumbing system terminates the unsustainability and high cost fuel incurred by traditional system.

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