# Seawater as Renewable Energy in Air Conditioning and Plumbing

# Systems for Coastal Development

#### **Ong Poh Yin**

Postgraduate Student, School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia Email: <u>opy1121@gmail.com</u>

## Zalena Abdul Aziz

Lecturer, School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia Email: zalena@usm.my

## 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<sup>2</sup> 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 Challengeson Seawater Air Conditioning and Plumbing System

ISSN 2411-2933

01-09-2021

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

41 D				· · · · · · · · · · · · · · · · · · ·
the Present				and policy supports.
Situation,				
Restrictive Factors				
and Potential				
Counter-measures				
(Arias-Gaviria,	Seawater air	Diffusion models	Energy supply:	1. High investment
Adoption of sea	conditioning	to study the effect	SWAC provides	costs.
water air	(SWAC)	on SWAC	thermal energy for	
conditioning		adoption rates,	air conditioning.	2. Limited adoption
(SWAC) in the		comparing the		of SWAC.
Caribbean:		effectiveness of	Energy demand:	
Individual vs		country and	SWAC increases the	3. Lack of
regional effects,		regional level	cooling efficiency	knowledge.
2019)		incentives.	and removes the	
/			electricity	4. Uncertain about
Adoption of sea			consumption.	ocean environmental
water air			-	impact.
conditioning				-
(SWAC) in the				
Caribbean:				
Individual vs				
regional effects				
(Hernandez-	Seawater air	Mathematical	Compare to	Seasonal energy
Romero, et al.,	conditioning	programing	conventional AC:	demand uncertainty
2019)	(SWAC)	formulation to	1. Reduce the energy	leads to uncertainties
/		obtain the	by 75-90%.	for seawater
Multi-scenario		operation policy		extracted
model for optimal		and design of the	2. Life cycle cost	
design of seawater		SWAC at tourist	around 50% lower.	ier cooring.
air-conditioning		zone in Mexico.		
systems under			3. Contributing less	
demand			greenhouse gas	
uncertainty			(GHG).	
(Inayat & Raza,	Seawater air	Study on technical	1. Saving of 80% as	Strategic location
(Illayat & Kaza, 2019)	conditioning	and economic	compared to the	with sufficient cold
/	(SWAC)	analysis of	conventional cooling	water supply from
<sup>7</sup> District cooling	(SWAC)	SWAC.	e	
e		SWAU.	systems.	deep sea.
system via			2 Economic-1 - 1	
renewable energy			2. Economical and	
sources: A review			not sophisticated.	

ISSN 2411-2933

01-09-2021

(Hunt, Byers, & Sanchez, 2018)Seawater air conditioningDatainputs1. Reduction of around 80% in electricity1. High capital costs around 80% in electricityZenhical potential and cost estimates(SWAC)develop SWAC develop SWACelectricityand consumption.and building consumption.Technical potential conditioningand analysethe and analyse the data.2. Reduce GHG emission, urban heat and water2. Reduce GHG system requirements. phenomenon, fuel and water2. Reduce GHG system requirements. phenomenon, fuel and water3. Risk of high nutrient loading and thermal shock in seawater outlet.(Hezi, et al., 2018) costal aquifer for scawater desalination and meeting nitratesScawater aquiferScientific management model and background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Hezi, et al., 2018) costal aquifer for scawater desalination and meeting nitratesScawater aquiferScientific management model and background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Ahmed, 2018) conditioning seawater Air- ConditioningScawater air econditioningPhase 1: econditioningReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging control.(Ahmed, 2018) conditioningScawater air and system sizing System for USPIoad calculation and system sizingSystem scaling, of CO <sup>2</sup> per month. <td< th=""><th></th><th>[</th><th></th><th>Г</th><th>· · · · · · · · · · · · · · · · · · ·</th></td<>		[		Г	· · · · · · · · · · · · · · · · · · ·
/(SWAC)developSWACelectricityandbuildingTechnical potential and cost estimates for seawater air conditioning(SWAC)developSWACelectricityandbuildingfor seawater air conditioningand analyse the data.2.ReduceGHG2.Require detailed knowledge on island (UHI) phenomenon, fuel and water3.Risk of high nutrient loading and thermal shock in seawater outlet.(Hezi, et al., 2018) (Dpimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking waterScawater aquiferScientific management theoretical background.1.Scawater aquifer1.Constraint on the amount of seawater along shore.(Ahmed, 2018) Feasibility Study & (SWAC)Scawater air peasibility study & (SWAC)Phase 1: reasibility study, and system sizing System for USPReduction of 2.5 tons and system sizingPayback ranging of CO <sup>2</sup> per month.Payback ranging of CO <sup>2</sup> per month.			1		C I
Technical potential and cost estimates for seawater air conditioningworld potential model frameworkconsumption.retrofitting.for seawater air conditioningand analyse the data.2. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and water2. Reduce GHG system requirements. phenomenon, fuel and water3. Risk of high nutrient loading and thermal shock in seawater outlet.(Hezi, et al., 2018) (Lecostal aquifer for seawater desalination and meeting nitrates level of drinking waterScawater aquiferScientific management theoretical background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Ahmed, 2018) (Athmed, 2018)Scawater air conditioning (SWAC)Phase 1: load calculation and system sizingReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging of CO <sup>2</sup> per month.(SWAC) Design of a Seawater Air- ConditioningPhase 2: System scaling,System scaling,Feasibility Study, System scaling,Phase 2: System scaling,System scaling,	Sanchez, 2018)	e		around 80% in	for district cooling
and cost estimates for seawater air conditioningmodel framework and analyse the data.Z. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and water and waterZ. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and waterZ. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and water and waterZ. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and waterZ. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and water and waterZ. Reduce GHG emission, urban heat island (UHI) phenomenon, fuel and water and waterZ. Reduce off system requirements.(Hezi, et al., 2018) (Hezi, et al., 2018) (Pimal managing for seawater desalination meeting nitrates level of drinking waterSeawater desalination from coastal aquiferScientific management model and theoretical background.I. Used for drinking water and agriculture irrigation mainly.I. Constraint on the anount of seawater along shore.(Ahmed, 2018) Design of a Seawater Air- ConditioningSeawater air Feasibility study, (SWAC)Phase 1: Feasibility study, of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.	/	(SWAC)	develop SWAC	electricity	and building
for seawater air conditioningand analyse the data.2. Reduce GHG emission, urban heat island (UHH) phenomenon, fuel and water ocusumption.2. Reduire detailed knowledge on system requirements.(Hezi, et al., 2018) / (Hezi, et al., 2018) phenomenon and the coastal aquifer for scawater level of drinking waterSeawater desalination from coastal aquiferScientific management model background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the anount of seawater along shore.(Hezi, et al., 2018) / (Chezing in the coastal aquifer for scawater level of drinking waterSeawater model1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the anount of seawater along shore.(Ahmed, 2018) / / Design of a Seawater Air- Conditioning System for USPSeawater air phase 1: Phase 2: System scaling,Reduction of 2.5 toms of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.	Technical potential		world potential	consumption.	retrofitting.
conditioninglata.emission, urban heat island (UHI) phenomenon, fuel and water consumption.knowledge on system requirements.(Hezi, et al., 2018) (Piptiani managing the coastal aquiferSeawater desalination from coastal aquiferScientific management model and background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Hezi, et al., 2018) (Piptiani managing the coastal aquiferScientific management model and aquifer1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Ahmed, 2018) (Seawater (ConditioningSeawater air conditioningPhase 1: conditioningReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.(Ahmed, 2018) (SwAC)Seawater air onditioningPhase 1: conditioningReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.(SWAC)Ioad calculation and system sizing System for USPPhase 2: System scaling,System scaling,	and cost estimates		model framework		
Image: Appendix and the second seco	for seawater air		and analyse the	2. Reduce GHG	2. Require detailed
Image: phenomenon, fuel and consumption.phenomenon, fuel and consumption.3. Risk of high nutrient loading and thermal shock in seawater outlet.(Hezi, et al., 2018) (Hezi, et al., 2018) Optimal managing the coastal aquifer for seawater desalination from coastal aquiferScientific management model background.1. Constraint on the amount of seawater adjuint in theoretical background.(Hezi, et al., 2018) (Pimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking waterScientific management model and theoretical background.1. Constraint on the amount of seawater adjuint in theoretical background.(Ahmed, 2018) (Seawater Air- Conditioning Seawater Air- ConditioningSeawater air (SWAC)Phase 1: reasibility study, and system sizingReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.	conditioning		data.	emission, urban heat	knowledge on
Image: And the second				island (UHI)	system requirements.
Image: Construct of the				phenomenon, fuel	
(Hezi, et al., 2018) / Optimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking waterSeawater socientific management model and theoretical background.Scientific management model and theoretical background.I. Used for drinking water and agriculture irrigation mainly.I. Constraint on the amount of seawater along shore.(Ahmed, 2018) / Feasibility Study & Design of a Seawater Air- ConditioningSeawater air (SWAC)Phase 1: reasibility study, and system sizingReduction of 2.5 tons of CO2 per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.				and water	3. Risk of high
Image: seawater outlet.Seawater outlet.Seawater outlet.Seawater outlet.(Hezi, et al., 2018)SeawaterScientific1. Used for drinking1. Constraint on the amount of seawater irrigation mainly.Optimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking waterScientific management model and theoretical background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Ahmed, 2018) V Leven of drinking waterSeawater air conditioning Seawater Air- ConditioningPhase 1: reasibility study, load calculation and system sizingReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiler system.				consumption.	nutrient loading and
Image: Constraint of the constra					thermal shock in
Image: definitionImage: definitioncooling process.Image: definition(Hezi, et al., 2018)Seawater desalinationScientific management1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.Optimal managing the coastal aquiferfrom coastal aquifermodel theoretical background.1. Used for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.desalination and meeting nitrates level of drinking wateraquifertheoretical background.2. Coastal soil strip as filter for fouling control.(Ahmed, 2018)Seawater air conditioningPhase 1: feasibility study, load calculation and system sizingReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.ConditioningSwaxter Air- ConditioningPhase 2: System for USPSystem scaling,Feasiling,				3. Cost and energy	seawater outlet.
(Hezi, et al., 2018) / Optimal managing the coastal aquifer desalination from coastal aquiferScientific management model theoretical background.1. User for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Mezi, et al., 2018) (seawater desalination and meeting nitrates level of drinking wateraquiferScientific management model background.1. User for drinking water and agriculture irrigation mainly.1. Constraint on the amount of seawater along shore.(Ahmed, 2018) (seawater Air- Conditioning Seawater Air- ConditioningSeawater air (SWAC)Phase 1: level of a spiter spiter passibility study, and system sizingReduction of 2.5 tons of CO2 per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.				savings for base load	
/desalination from coastal aquifermanagement model background.water and agriculture irrigation mainly.amount of seawater along shore.desalination a aquiferaquifermodel background.and theoretical background.water and agriculture irrigation mainly.amount of seawater along shore.desalination meeting mitrates level of drinking wateranuifermodel background.water2. Coastal soil strip as filter for fouling control.(Ahmed, 2018)Seawater air conditioningPhase Feasibility Study & Ioad calculation and system sizingReduction of 2.5 tons of CO2 per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.Conditioning Seawater Air- ConditioningPhase 2: System for USPPhase 2: System scaling,Phase 2: System scaling,Phase 2: System scaling,				cooling process.	
/desalination from coastal aquifermanagement modelwater and agriculture irrigation mainly.amount of seawater along shore.the coastal aquifer for seawater desalination and meeting nitrates level of drinkingaquiferheoretical background.Amount of seawater along shore.(Ahmed, 2018)Seawater air conditioningPhase 1: feasibility study, load calculationReduction of 2.5 toon of CO2 per month.Payback ranging between 8.6 to 12.6Feasibility Study & Seawater Air- Conditioning(SWAC)Ioad calculation and system sizingSeawater air phase 2: System for USPPhase 2: system for USPPhase 2: system scaling,Feasibility Study, system scaling,Feasibility Study, system,Feasibility Stu	(Hezi, et al., 2018)	Seawater	Scientific	1. Used for drinking	1. Constraint on the
Optimal managing the coastal aquiferfrom coastal aquifermodel and theoretical background.irrigation mainly.along shore.for seawater desalination and meeting nitrates level of drinking wateraquiferheoretical background2. Coastal soil strip as filter for fouling control.(Ahmed, 2018) / / Design of a Seawater Air- ConditioningSeawater air (SWAC)Phase 1: level of drinking background.Reduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.Keawater Air- ConditioningPhase 2: System for USPPhase 2: System scaling,System scaling,Image 1.1 ConditioningPhase 2: System scaling,Image 1.1 conditioning	/	desalination	management	water and agriculture	amount of seawater
the coastal aquifer for desalination and meeting nitrates level of drinking wateraquifertheoretical background.2. Coastal soil strip as filter for fouling control.(Ahmed, 2018) / (Ahmed, 2018) / / Peasibility Study & Design of a Seawater Air- ConditioningSeawater air (SWAC)Phase 1: Phase 1: Icoad calculation and system sizingReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6 years compared to split system and chiller system.	Optimal managing	from coastal	-	irrigation mainly.	along shore.
forseawaterbackground.as filter for fouling control.desalination and meeting nitrates level of drinking wateras filter for fouling control.as filter for fouling control.(Ahmed, 2018)Seawater air conditioningPhase 1: Feasibility study, load calculation and system sizingReduction of 2.5 tons of CO <sup>2</sup> per month.Payback ranging between 8.6 to 12.6Feasibility Study & Seawater Air- Conditioning(SWAC)load calculation and system sizingof CO <sup>2</sup> per month.between 8.6 to 12.6System for USPPhase 2: System scaling,System scaling,System scaling,control.control.	the coastal aquifer	aquifer	theoretical		
desalinationand meetingnitratescontrol.level of drinking water	for seawater	-	background.		-
meeting nitratesintratesintratesintratesintratesintratesintratesintrateslevel of drinkingintratesintratesintratesintratesintratesintrateswaterintratesintratesintratesintratesintratesintrates(Ahmed, 2018)Seawater airPhase1:Reduction of 2.5 tonsPayback ranging/conditioningFeasibility study,of CO <sup>2</sup> per month.between 8.6 to 12.6Feasibility Study &(SWAC)load calculationyears compared toDesign of aand system sizingsplit system andSeawater Air-intratesintrateschiller system.ConditioningPhase 2:System for USPSystem scaling,intrates	desalination and				-
waterImage: sequence of the sequence	meeting nitrates				control.
waterImage: sequence of the sequence	level of drinking				
/conditioningFeasibility study, load calculationof CO2 per month.between 8.6 to 12.6Feasibility Study &(SWAC)load calculationyears compared toDesign of aand system sizingsplit system andSeawater Airchiller system.ConditioningPhase 2:System for USPSystem scaling,					
/conditioningFeasibility study, load calculationof CO2 per month.between 8.6 to 12.6Feasibility Study &(SWAC)load calculationyears compared toDesign of aand system sizingsplit system andSeawater Airchiller system.ConditioningPhase 2:System for USPSystem scaling,	(Ahmed, 2018)	Seawater air	Phase 1:	Reduction of 2.5 tons	Payback ranging
Designofaand system sizingsplitsystemandSeawaterAir <t< td=""><td>/</td><td></td><td>Feasibility study,</td><td>of CO<sup>2</sup> per month.</td><td>between 8.6 to 12.6</td></t<>	/		Feasibility study,	of CO <sup>2</sup> per month.	between 8.6 to 12.6
SeawaterAir- ConditioningPhase 2: System for USPchiller system.	Feasibility Study &	(SWAC)	load calculation		years compared to
ConditioningPhase 2:System for USPSystem scaling,	Design of a		and system sizing		split system and
System for USP System scaling,	Seawater Air-				chiller system.
System for USP System scaling,	Conditioning		Phase 2:		
	-		System scaling,		
Iuvalu Campus   seawater	Tuvalu Campus		seawater		
temperature			temperature		
measurement,			-		
model			-		
construction,			construction,		
testing and			-		
economic analysis			e		
(Arias-Gaviria, Seawater air Simulated 1. Save up to 90% of To reduce	(Arias-Gaviria,	Seawater air	-	1. Save up to 90% of	To reduce
Larsen, & Arango- conditioning scenarios and the energy used in dependence on	Larsen. & Arango-	conditioning	scenarios and	the energy used in	dependence on

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

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

/ Cool as a (sea) cucumber? Exploring public attitudes toward seawater air conditioning in Hawaii	(SWAC)	at the Natural Energy Laboratory of Hawaii Authority (NELHA)	<ul> <li>amount of fresh water by eliminating cooling towers.</li> <li>2. Save 260 million gallons of potable water per year.</li> <li>3. Decrease waste water by to 84 million gallons per year.</li> </ul>	2. Not feasible for single home residences.
			4. Decrease 40% of thermal pollution.	
(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)/TechnicalandEconomicAssessmentofSeawater AirConditioninginHotels	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.
<ul> <li>(Wang, Liu, Wang, &amp; Bi, 2012)</li> <li>/</li> <li>Simulation</li> <li>Computation and</li> <li>Analysis of</li> </ul>	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		heat pump system.		
Operation				
Energy of				
Seawater Source				
Heat Pump				
(War, 2011)	Seawater air	Case study in	1. Offset energy	ROI in 6-8 years.
/	conditioning	Hurghada - Upper	demand by 75-85%.	
Seawater Air	(SWAC)	Egypt to carry out		
Conditioning		technical,	2. Terminate the use	
(SWAC) a		environmental	for cooling towers	
renewable energy		and economic	and chillers.	
alternative		analysis.		

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

Author			I	Benefit	s			_		Chall	enges		
	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)	Х				х				X				
(Yan, et al., 2020)	X	X											х
(Schibuola & Tambani, 2020)	х		x							х	X		
(Gong, Wang, Zhu, Bai, & Wang, 2019)			x			х			х			х	х
(Arias-Gaviria, 2019)	X						Х		X		X		х

#### International Journal for Innovation Education and Research

(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					х
(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										х
(Lilley, Konan, & Lerner, 2015)			x			x			х	X		
(Zheng, Ye, You, & Zhang, 2015)	x											x
(Surroop & Abhishekanand, 2013)	х	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.

## 6. Acknowledgement

The author would like to express sincere gratitude to all lecturers and relevant parties involved in this research for their encouragement and guidance throughout this journey.

# 7. References

- Abdullah, W., Osman, M., Ab Kadir, M., & Verayiah, R. (2019). The Potential and Status of Renewable Energy. *Energies*.
- Ahmed, M. R. (2018). *Feasibility Study & Design of a Seawater Air-Conditioning System for USP Tuvalu Campus*. Suva: The University of The South Pacific.
- Arias-Gaviria, J. (2019). Adoption of sea water air conditioning (SWAC) in the Caribbean: Individual vs regional effects. *Journal of Cleaner Production*, 280-291.
- Arias-Gaviria, J., Larsen, E., & Arango-Aramburo, S. (2018). Understanding the future of seawater air conditioning in the Caribbean: A simulation approach. *Utilities Policy*, 73-83.
- Balaban, M. (2009). Seawater Desalination: Conventional and Renewable Energy Processes. In A. Cipollina, G. Micale, & L. Rizzuti, *Green Energy and Technology*. Springer Heidelberg Dordrecht London New York.
- Berning, M. J. (2014, Oct). Water Reuse Goes to School . Rainwater Harvesting, pp. 16-17.
- Chang, S., Madani, H., Liu, H., Wang, R., & Palm, B. (2020). Seawater heat pumps in China, a spatial analysis. *Energy Conversion and Management*.
- Ezugbe, E., & Rathilal, S. (2020). Membrane Technologies in Wastewater Treatment: A Review. *Membranes MDPI*.
- Gong, S., Wang, H., Zhu, Z., Bai, Q., & Wang, C. (2019). Comprehensive Utilization of Seawater in China:

A Description of the Present Situation, Restrictive Factors and Potential Countermeasures. *Water MDPI*.

- Hernandez-Romero, I., Fuentes-Cortes, L., Mukherjee, R., El-Halwagi, M., Serna-Gonzalez, M., & Napoles-Rivera, F. (2019). Multi-scenario model for optimal design of seawater air-conditioning systems under demand uncertainty. *Journal of Cleaner Production*.
- Herzen, B., Theuretzbacher, T., Newman, J., Webber, M., Zhu, C., Katz, J., & Ramaswamy, M. (2017). A Feasibility Study of an Integrated Air Conditioning, Desalination and Marine Permaculture System in Oman. 10th International Conference on Thermal Engineering: Theory and Applications. Muscat.
- Hezi, Z., Shpak, S., Fliesher, M., Gillerman, L., Kasher, R., & Oron, G. (2018). Optimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking water. *Desalination*.
- Hunt, J., Byers, E., & Sanchez, A. (2018). Technical potential and cost estimates for seawater air conditioning. *Energy*.
- Inayat, A., & Raza, M. (2019). District cooling system via renewable energy sources: A review. *Renewable and Sustainable Energy Reviews*, 360-373.
- Jordan, R. (2019, July 29). Stanford researchers develop technology to harness energy from mixing of freshwater and seawater. Retrieved from Stanford News Service: https://news.stanford.edu/press-releases/2019/07/29/generating-energy-wastewater/
- Lilley, J., Konan, D., & Lerner, D. (2015). Cool as a (sea) cucumber? Exploring public attitudes toward seawater air conditioning in Hawaii. *Energy Research & Social Science*, 173-183.
- Liu, X., Dai, J., Wu, D., Jiang, F., Chen, G., Chui, H.-K., & Loosdrecht, M. (2016). Sustainable Application of a Novel Water Cycle Using Seawater for Toilet Flushing, *Engineering*, 460-469.
- Ni, L., Dong, J., Yao, Y., Shen, C., Qv, D., & Zhang, X. (2015). A review of heat pump systems for heating and cooling of buildings in China in the last decade. *Elsevier*, 30-45.
- Osorio, A., Arias-Gaviria, J., Devis-Morales, A., Acevedo, D., Velasquez, H., & Arango-Aramburo, S. (2016). Beyond electricity: The potential of ocean thermal energy and ocean technology ecoparks in small tropical islands. *Energy Policy*, 713-724.
- Pure Aqua. (2018, Oct 11). Retrieved from https://pureaqua.com/blog/9-advantages-of-seawater-desalination-systems/
- Santillán-Soto, N., García-Cueto, O., Lambert-Arista, A., Ojeda-Benítez, S., & Cruz-Sotelo, S. (2019). Comparative Analysis of Two Urban Microclimates:Energy Consumption and Greenhouse Gas Emissions. *Sustainaibility MDPI*.
- Schibuola, L., & Tambani, C. (2020). Performance assessment of seawater cooled chillers to mitigate urban heat island. *Applied Thermal Engineering*.
- Shamsuddin, A. H. (2012). Development of renewable energy in Malaysia-strategic initiatives for carbon reduction in the power generation sector . *Procedia Engineering* (pp. 384-391). Kajang: Elsevier Ltd.
- Shu, H., Wang, T., Xin, J., Ren, Z., Yu, H., & Lin, D. (2016). Energy efficiency enhancement potential of the heat pump unit in a seawater source heat pump district heating system. 8th International Cold Climate HVAC 2015 Conference, CCHVAC 2015 (pp. 134-138). Procedia Engineering 146.
- Surroop, D., & Abhishekanand, A. (2013). Technical and Economic Assessment of Seawater Air Conditioning in Hotels. *International Journal of Chemical Engineering and Applications*.
- Sustainable Water & Energy Solutions Network. (2020). Retrieved from United Nations: https://www.un.org/sites/un2.un.org/files/case\_study\_14\_-\_sustainable\_airconditioning\_and\_water\_heating\_cooling\_systems\_of\_seaside\_commercial\_buildings\_using\_sea water.pdf
- Wang, J., Liu, K., Wang, H., & Bi, W. (2012). Simulation Computation and Analysis of Dynamic Operation

Energy of Seawater Source Heat Pump. Przegląd Elektrotechniczny, 219-221.

- War, J. (2011). Seawater Air Conditioning (SWAC) a renewable energy alternative. OCEANS'11 MTS/IEEE KONA (pp. 1-9). Waikoloa, HI, USA: IEEE.
- Wu, Z., You, S., Zhang, H., & Zheng, W. (2020). Model development and performance investigation of staggered tube-bundle heat exchanger for seawater source heat pump.
- Xin, J., Lin, D., & Shu, H. (2017). Effect of seawater intake methods on the performance of seawatersource heat pump systems in cold climate areas. *Energy and Buildings*.
- Xin, J., Lin, D., & Shu, H. (2017). Large-area seepage and heat transfer model of beach well infiltration intake system for seawater source heat pump. *Energy and Buildings*.
- Yan, M., He, S., Gao, M., Xu, M., Miao, J., Huang, X., & Hooman, K. (2020). Comparative study on the cooling performance of evaporative cooling systems using seawater and freshwater. *International Journal of Refrigeration*.
- Yang, M., Liu, J., Zhang, X., & Richardson, S. (2015). *Comparative Toxicity of Chlorinated Saline and Freshwater Wastewater Effluents to Marine Organisms*. Environmental Science & Technology.
- Zheng, W., Ye, T., You, S., & Zhang, H. (2015). The thermal performance of seawater-source heat pump systems in areas of severe cold during winter. *Energy Conversion and Management*.

#### **Copyright Disclaimer**

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).