The Variation of Energy Consumption and Economic Impact in Regards of Location, Building, and System Type in UAE Air Conditioning Industry

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Abstract

There is an increasing awareness of the importance and cost of the thermal comfort of buildings' occupants. For those who live in a hot climate, demand for cooling systems is rising. Researches showed that during the hot seasons in the United Arab Emirates (UAE), the increased usage of cooling systems results in increased use of energy consumption up to 70%-79% excessive amount of normal energy consumption. Because of such high-energy demands, there is an apparent expansion of the consequential economic impact countrywide. It has thus become essential to study the economic impact of air conditioning systems in the UAE. This research applies life cycle cost analyses on air conditioning systems under four major factors: (1) outside climate, (2) building type from the respect of elevation difference, (3) type of air conditioning systems, and (4) the distinctions among different brands of air conditioning systems. A mixed method research approach was considered that includes field observations, interviews with experts, document review, and mathematical/numerical data generation. Statistical analysis was applied together with the Analytical Hierarchy Processes (AHP) techniques. Results included developing decision-making for selecting the most suitable air conditioning system regarding the total cost of the lifecycle span determined against the listed four assessment factors. Results also showed that humid coastal areas are more demanding in terms of air-conditioning energy consumption compared to an internal dry area.

Keywords
Air-conditioning; Systems life cycle costing; Energy consumption; Economic impact; Climate variation

1. Introduction

Various regions worldwide have different climates with undesirable living conditions, particularly when considering indoor air quality. One of the most effective ways to improve indoor air quality is by utilizing various air conditioning systems. However, these systems consume huge amounts of energy, especially in extreme climate conditions of too high or low temperatures, such as arid (desert) regions. With the current climate changes, air conditioning systems are becoming an essential part of our daily life (Krarti & Dubey, 2018; Mathur et al., 2018), and therefore various air conditioning systems have been developed to serve various purposes.

Nowadays, air conditioning units have become "must-have" devices, an essential part of most types of properties such as residential building, commercial building and shopping centers. Therefore, there were many innovations in air conditioning systems through the years to improve their performance leading to better life quality (Alkhateeb & Abu, 2017; Lin et al., 2018; Mathur et al., 2018; Taleb, 2014).

Because of the customers' limited specialized technical knowledge about the various design and operational concepts of the variety of air condition systems currently in the market, most users find it challenging to choose the optimal air conditioning system that best fits their operational envelope, geographical location, and other aspects as well (Almutairi et al., 2015) Therefore, many property owners miss the ability to choose the best-fit of air conditioning systems for their properties, form economic, operational perspective, as well as their environmental impact. Failure in achieving an optimal selection of the adequate combination and configuration of air conditioning systems for a given building at a given location will definitely adversely impact the air-conditioning function (air quality), the energy consumption, and the other economic and environmental prints. This study will focus on developing a decision-making tool that helps the decision makers in choosing the best fit air conditioning systems for various types of building in different climates (different geographical locations) and enhance their capabilities in selecting the best fit air condition systems from both the economic and environmental standpoints.

2. Literature Review

2.1 Energy Consumption of Air Conditioning Systems in UAE

Ever since the United Arab Emirates has discovered oil in the 1960s, there has been a significant advancement in all the divisions, which also involves the construction and building infrastructure. The booming has shown its effects on the country's energy consumption that has increased (AlAwadhi et al., 2013). The high temperatures that come across this country create more obstacles to accommodate the buildings environmentally. Specifically, the cooling system undergoes such high temperatures. The outdoor temperature can get up to 50 °C during hot seasons, which urges the increased usage of the cooling system that results in wasting an excessive amount of energy that is taking up 70%-79% of the total energy demand only on air conditioning systems (Krarti & Dubey, 2018; Mathur et al., 2018).

In the last ten years, researchers have been aiming to reduce the energy consumption of the HVAC system using different ways. Various studies used passive cooling techniques to reduce energy consumption by upgrading the thermal performance (Alkhateeb & Abu, 2017; Lin et al., 2018; Mathur et al., 2018; Taleb, 2014). Other studies (Fazlollahi et al. 2012and Ooka & Komamura 2009) focused on HVAC's elements and enhanced the HVAC system by selecting the optimum component to reduce the usage of energy. They managed to reduce energy usage by 10%. On the other hand, studies (Fabrizio et al., 2010; Ghaith & Abusitta, 2014; Rastegar & Fotuhi-firuzabad, 2015) investigated how to make the most benefits of renewable energy sources by trying the multi energy system to counterbalance the energy usage that can result in the decline of consumption by 65%, but this way of working will increase the cost by 45%. Other studies (Au-yong et al., 2014; García-sanz-calcedo & Gómez-chaparro, 2017; Lin et al., 2018) investigated the effect of maintenance on the reduction of usage that can drop the consumption by 20%.

2.2 Life Cycle Cost Analysis of Air-Conditioning System.

The specific weather conditions, such as humidity and high temperatures, have led to the increasing use of the full mechanism of HVAC systems for residential and commercial buildings. Al-Sallal and Ahmed (2007) noted that UAE annual solar radiation is 2,200 kWh / m2, and direct-fall light can exceed 90,000 lx in summer at 50 °C. Because of this, the environment cooling system becomes an essential part of the building industry in the country which can have a big influence on the economic view on this sector. Based on field experts' opinions, the cost of air conditioning can reach up to 15% of the total cost of the project. Hence, it becomes necessary to study the impact of HVAC system on the economics of the building project.

Almutairi et al.(2015) studied the optimization of the cost of the lifecycle assessment of air condition system in an arid climate by comparing the result of three types of single-family accommodations (villa, apartment, and traditional house). Other studies such as Alrwashdeh and Ammari (2019) performed an economic analysis of two types of refrigerant systems ,a) vapor absorption refrigeration system powered by a solar evacuated tubes thermal unit and b) a vapor compression refrigeration system powered by a photovoltaic array. A recent study by

Ristimäki et al. (2020) studied the cost over the lifecycle of a district energy system comparing the life cycle cost of the system under different energy sources.
However, none of the studies considered the effect of combining various building types with different HVAC systems and various energy sources.

This study is focusing on the effect of the combination of the various parameters (buildings type, different geographical locations with different climate conditions, air conditioning systems and different air conditioning manufacturer) on the life-cycle cost of the system.

3. Methodology

This study aims to introduce guidelines of investment in air conditioning (A/C) systems, taking the industry in the UAE as a case study. This is to be achieved by considering the variation profile of the cooling load and life cycle cost analysis and comparing the performance and predictability of each approach's performance and predictability. The proposed methodology focuses on investigating the impact of several factors on life durability and cost efficiency on the air conditioning system by studying:

1) Climatic condition impact on cooling load of system installed at coastal and arid climates, and its effect on lifecycle cost and lifecycle assessment.
2) Building type impact on the selection of air conditioning system, and consequently, on life cycle cost and lifecycle assessment.
3) The influence of the type and configuration of the refrigeration system on power consumption, lifecycle cost, and environmental impact.
4) The effect of the distinctions among different brands of air conditioning systems on power consumption, maintenance process, life cycle cost.

The research will be accomplished based on case-study methodology. This methodology will be applied to life cycle analysis of each variant of the systems combination of climate type, building type, air conditioning systems, air conditioning manufacturers and energy sources where the cost and environmental impact are considered as the outcome of this research.
There are four main stages of work in this study; the first stage is concerned with the weather aspect of this study. The second stage deals with the analysis of the collected data and finding the cooling load of the required zones. The third stage deals with the cooling systems selection aspects such as the type of the system and energy sources. In the fourth stage, cost lifecycle analysis. The methodology stages are illustrated in Figure 1.

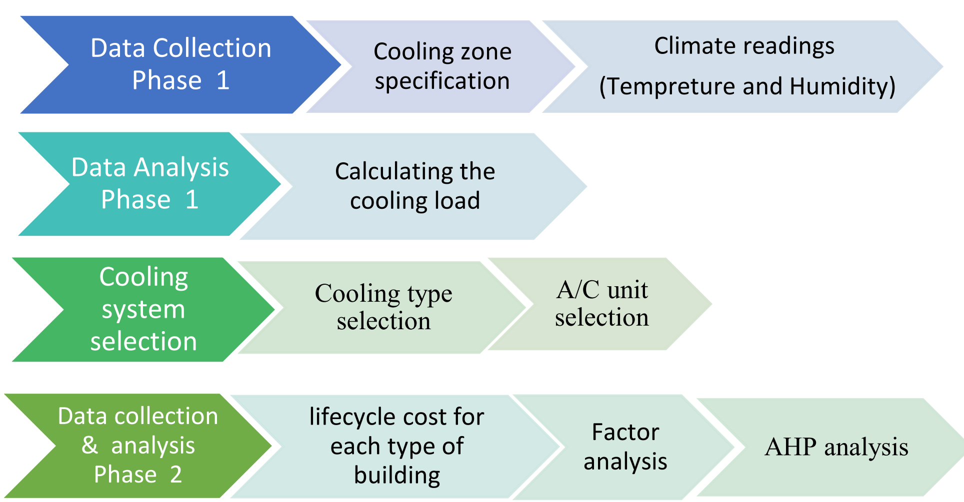

Figure 1 Research Methodology Steps

The first step is data collection (phase 1), where the real-life project layouts and thermal specifications of the cooling zone and climate are identified and defined clearly. Were project layouts and thermal specifications of the cooling zone collected from field observations and experts informants interviews, climate readings collected from weather climate centers.
The second step is the first phase of the data analysis, where the thermal comfort zone is investigated, and the cooling load of the study sample is calculated using ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard.

The third step is cooling system selection, where the systems are selected according to the processed dataset of cooling load. In this stage, two refrigeration systems (all air system and all water system) are considered with the eye on manufacturers who can produce both types of air conditioning systems. Then, the refrigeration systems' power consumption from each selected brand will be calculated.
The fourth step is data collection and analysis phase 2, which investigates the impact of each influencing factor on the cost by Life cycle analysis via a comparative study that can, eventually, provide a guideline for investment in the air conditioning systems.
The last step is building the framework for the selection of air conditioning systems under different operating conditions and design parameters using several statistical methods (Two-Way ANOVA and AHP). Finally, a guideline table will be formulated to select the best air conditioning system for each type of climate and buildings types.

4. Results

4.1 Collected Data

The collected data represent life cycle cost per power consumed. This data was collected for three types of buildings: 1) skyscraper buildings height of more than 150 m, 2) high rise buildings height between 35 m-150 m. , and 3) low rise buildings height of less than 35 m, these three types of buildings were considered at two different geographical locations with different climate conditions: 1) costal area 2) arid (desert) area. Further, for each of these combinations, a third folder of variations is introduced by considering two different design concepts of air conditioning systems; namely: 1) all-air system, and 2) all-water system. Fourth degree of variation is introduced by considering two different main manufacturers: 1) manufacturer A 2) manufacturer B, as a logical representation of the different design and manufacturing techniques available within the industry. , based on two kind of air conditioning. Table 1 show the data collected given here in terms of the total life cycle price over energy consumption for each configuration of the 24 different configurations resulting from applying the four-folded variations

Data in table 1 represent the total life cycle price over energy consumption for each configuration. This data where calculated by summing the prices of the life cycle phases starting from purchasing phase, installation phase, operation phase, maintenance phase and ending with disposal phase over 20 years then divided into energy consumed in kilowatt by the configuration for running the system.

Table 1 Life cycle cost per power consumed

			Skyscraper	High Rise	Low Rise
Coastal Area	All-Air System	Manufacturer A	24725 (AED/KW)	25916 (AED/KW)	29479 (AED/KW)
		Manufacturer B	23549 (AED/KW)	24847 (AED/KW)	28596 (AED/KW)
	All-Water System	Manufacturer A	22524 (AED/KW)	23909 (AED/KW)	26309 (AED/KW)
		Manufacturer B	21782 (AED/KW)	22353 (AED/KW)	25491 (AED/KW)
Arid Area	All-Air System	Manufacturer A	24666 (AED/KW)	25843 (AED/KW)	29453 (AED/KW)
		Manufacturer B	23308 (AED/KW)	24777 (AED/KW)	28526 (AED/KW)
	All-Water System	Manufacturer A	22467 (AED/KW)	23861 (AED/KW)	26300 (AED/KW)
		Manufacturer B	21734 (AED/KW)	21916 (AED/KW)	25454 (AED/KW)

4.1.1 Normality Checking

For using parametric statistical methods, it should be known that the used sample data behavior is following normal distribution for that normality test of Kolomonrov-Sminrov test and Shapiro –Wilk test were applied

Kolomonrov-Sminrov test assuming null hypothesis is that there is no statistically significant difference between the Price per power consumed (Data collected) and normal destitution, and the alternative hypothesis is that there is no statistical significant difference between the Price per power consumed (Data collected) and normal destitution, as shown in table 2 Kolomonrov-Sminrov level of significant is more than the level of significant 0.2 > 0.1 which means that null hypothesis can be accepted and the sample data are following the normal distribution behavior, and this can be proved by the normal Q-Q- plot figure (2)

Shapiro –Wilk test assuming null hypothesis is that there is no statistically significant difference between the Price per power consumed (Data collected) and normal destitution and the alternative hypothesis is that there is no statistically significant difference between the Price per power consumed (Data collected) and normal destitution , as shown in table 2 Shapiro –Wilk level of significant is more than the level of significant 0.101 > 0.1 which means that null hypothesis can be accepted and the sample data are following the normal distribution behavior and this can be proved by the normal Q-Q- plot figure (2)

Table 2. Normality test analysis results of Kolomonrov-Sminrov test and Shapiro –Wilk test

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
Price Per Kilowatt	.110	24	.200*	.931	24	.101

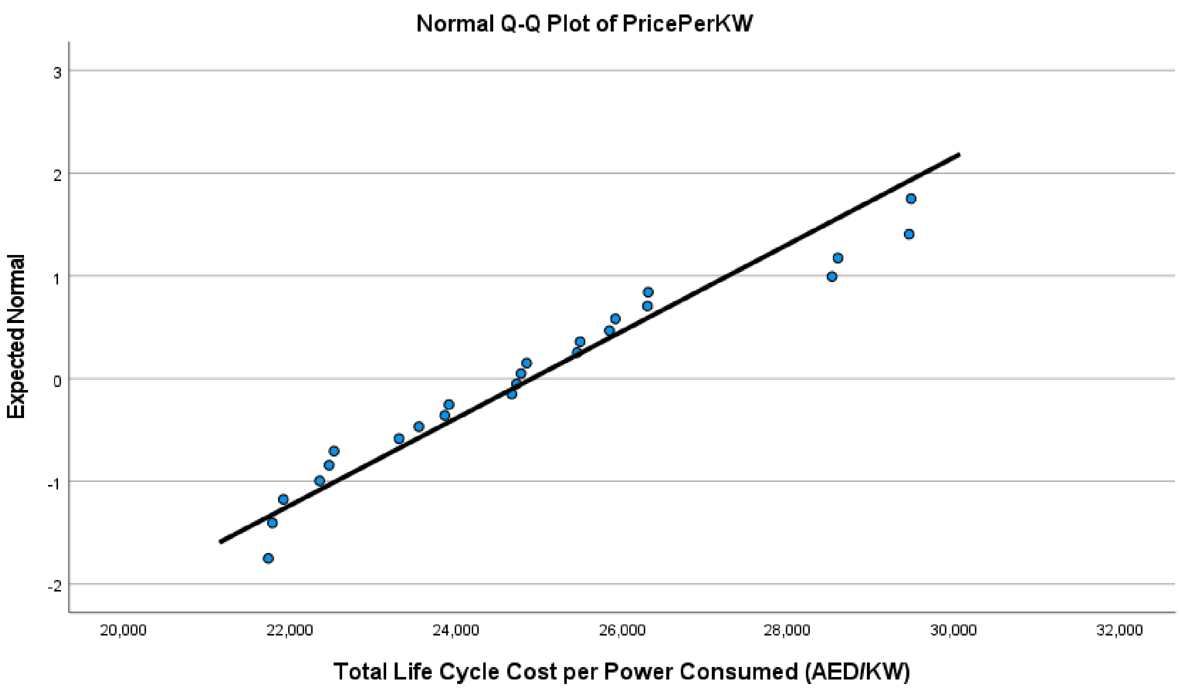

Figure (2) normal Q-Q- plot of total life cycle cost price of the system per consumed power

4.2 Test of the Effect of Different System Types and Different Building Height on the Total Life Cycle Cost per Power Consumption

In order to ensure that the different air conditioning systems or building height have no impact on the test variables, a Two-Way ANOVA analysis was done to compare the price of difference of air conditioning systems per power consumed means of the different air conditioning systems, and different building heights as shown in Table 3. Given that the null hypothesis is that the mean of the different air conditioning system is equal, and the alternative hypothesis is that they are not equal

. Ho = μ all- air = μ all water

$H1$ = μ all-air ≠ μ all water

Sum of squares, degrees of freedom (df), mean square, and F value are utilized to calculate the level of significance of the difference between the different groups. The significance level is set to 0.1, and any value equal to or less than 0.1 ($\propto\ \leq 0.1$) is considered to be significant. As illustrated in Table 3 in terms of the price of difference of air conditioning systems per power consumed, the significance level is 0.001which is less than 0.1 (0.001 < 0.1) , what means that type of air conditioning system has an effect on the sample means. In terms of building heights, ANOVA was also conducted such that:

Ho = μ low rise = μ high rise = skyscraper

$H1$ = μ low rise ≠ μ high rise ≠ μ skyscraper

The following level of significance in term of price in different building height from Table 3, where the level of significance is 0.001 which is less than 0.1 (0.001 < 0.1) ; thus there's difference in mean between the price in different building height , what means that building heights has an effect on the sample means.

Table 3. ANOVA analysis comparing means of price of difference of air conditioning systems per power consumed and building heights in relation to the three measured values

Tests of Between-Subjects Effects

Dependent Variable: Price of deferent air conditioning systems Per power consumed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
System type	36469676.042	1	36469676.042	82.025	.001
Building Height	82314795.583	2	41157397.792	92.569	.001
System type * Building Height	1465751.083	2	732875.542	1.648	.220

4.3 Test of the Effect of Different Manufacturers and Different Building Height on the Total Life Cycle Cost per Power Consumption

In order to ensure that the different air conditioning manufacturers or building height have no impact on the test variables, Two-Way ANOVA analysis was done to compare the price of difference of air conditioning manufacturers per power consumed means of the different air conditioning manufacturers, and different building heights as shown in Table 4. Given that the null hypothesis is that the mean of the different air conditioning system is equal, and the alternative hypothesis is that they are not equal

. Ho = μ manufacturer A = μ manufacturer B

$H1$ = μ manufacturer A ≠ μ manufacturer B

Sum of squares, degrees of freedom (df), mean square, and F value are utilized to calculate the level of significance of the difference between the different groups. The significance level is set to 0.1, and any value equal to or less than 0.1 ($\propto\ \leq 0.1$) is considered to be significant. As illustrated in Table 4 in terms of the price of difference of air conditioning manufacturers per power consumed, the significance level is 0.084 which is less than 0.1 (0.084 < 0.1), that means that type of air conditioning manufacturers has an effect on the sample means. In terms of building heights, ANOVA was also conducted such that:

Ho = μ low rise = μ high rise = skyscraper

$H1 = \mu$ low rise $\neq \mu$ high rise $\neq \mu$ skyscraper
The following level of significance in term of price in different building height from Table 4, where the level of significance is 0.001 which is less than 0.1 (0.001 < 0.1) ; thus there's difference in mean between the price in different building height , what means that building heights has an effect on the sample means.

Table 4. ANOVA analysis comparing means of price of difference of air conditioning manufacturers per power consumed and building heights in relation to the three measured values

Tests of Between-Subjects Effects					
Dependent Variable: Price of deferent air conditioning systems Per power consumed					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Manufacturer	7171173.375	1	7171173.375	3.357	.084
Building height	82314795.583	2	41157397.792	19.267	.001
Manufacturer * Building height	316983.250	2	158491.625	.074	.929

4.4 Test of the Effect of Different Climate and Different Building Height on the Total Life Cycle Cost per Power Consumption

In order to ensure that the different climate of air conditioning operation, or building height has no impact on the test variables, a Two-Way ANOVA analysis was done to compare the price of different climate of air conditioning operation per power consumed means of the different climate of air conditioning operation, and different building heights as shown in Table 5. Given that the null hypothesis is that the mean of the different air conditioning system is equal, and the alternative hypothesis is that they are not equal
. $Ho = \mu$ arid $= \mu$ costal
$H1 = \mu$ arid $\neq \mu$ costal
Sum of squares, degrees of freedom (df), mean square, and F value are utilized to calculate the level of significance of the difference between the different groups. The significance level is set to 0.1 and any value equal to or less than 0.1 ($\propto \leq 0.1$) is considered to be significant. As illustrated in Table 5 in terms of the price of difference climate of air conditioning operation per power consumed the significance level is 0.882 which is more than 0.1 (0.882 > 0.1), that means that type of climate of air conditioning operation has no effect on the sample means. In terms of building heights, ANOVA was also conducted such that:
$Ho = \mu$ low rise $= \mu$ high rise $=$ skyscraper
$H1 = \mu$ low rise $\neq \mu$ high rise $\neq \mu$ skyscraper
The following level of significance in term of price in different building height from Table 5, where the level of significance is 0.001 which is less than 0.1 (0.001 < 0.1) ; thus there's difference in mean between the price in different building height , what means that building heights has an effect on the sample means.

Table 5. ANOVA analysis comparing means of price of difference air conditioning in deferent climate per power consumed and building heights in relation to the three measured values

Tests of Between-Subjects Effects
Dependent Variable: Price of deferent air conditioning systems Per power consumed

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Location	57526.042	1	57526.042	.023	.882
Building Height	82314795.583	2	41157397.792	16.152	.001
Location * Building Height	14795.583	2	7397.792	.003	.997

4.5 Benefit Analysis using AHP Method

The well-established analytical hierarchy process (AHP) Analysis technique was then applied to analyze the rich qualitative data reported from the 60 interviews to understand how studied factor and sub factors are important and how much they are important in the market. After carefully analyzing all the collected data, it was found how much each factor and subfactors weight and benefit in the marker.

4.5.1 Main Factor Results and Weights

Where it was found that the most important factor the location of the project with a weight of 57.7% because the area has significant importance on the selling price of the building. The second important factor is the height of the building with a weight of 25.1% because it was found the height of the building has an effect on the time of selling the building, then the other factors type of air conditioning system with a weight of 12.2% and type of air conditioning manufacturer with a weight of 5%. Figure 3 shows the decision matrix and weight result of each factor.

4.5.2 Sub-Factor Results and Weights

Where it was found that the most important sub-factor the coastal area with a weight of 48.0 %, then the second important sub-factor is the height of the high rise buildings with a weight of 17.2 %, the best combinations of variants is to have high rise building in the coastal area using all water air conditioning system supplied for manufacturer A with benefit percent weight of 79 %. All weight of the factors and sub-factors are described in table 6, benefit percentage weight of the combination of possible variants are discussed in table 7.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Hight	25.1%	2	23.1%	23.1%
2	Location	57.7%	1	32.4%	32.4%
3	System	12.2%	3	10.8%	10.8%
4	Company	5.0%	4	2.9%	2.9%

Number of comparisons = 6
Consistency Ratio CR = 35.6%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4
1	1	0.20	6.00	3.00
2	5.00	1	6.00	6.00
3	0.17	0.17	1	7.00
4	0.33	0.17	0.14	1

Principal eigen value = 4.971
Eigenvector solution: 10 iterations, delta = 1.1E-8

Figure 3. The weight result of each factor and the decision matrix

Table 6. The weight of main factors and sub-factors

AHP Result			
Building Height 25.1 %	Location 57.7 %	System Type 12.2 %	Manufacturer 5.0 %
Skyscraper 2%	Costal 48.0 %	All Air System 2.44 %	Manufacturer A 4.0 %
High Rise 17.2 %	Arid 9.6 %	All Water System 9.76 %	Manufacturer B 1.0 %
Low Rise 5.87 %			

Table 7. Shows the benefit weight of each combination

	Model Description	Benefit Percent
1	High Rise - Coastal - All Water– Manufacturer A	79%
2	High Rise - Coastal - All Water – Manufacturer B	76%
3	High Rise - Coastal - All Air – Manufacturer A	72%
4	High Rise - Coastal - All Air – Manufacturer B	69%
5	Low Rise - Coastal - All Water– Manufacturer A	68%
6	Low Rise - Coastal - All Water – Manufacturer B	65%
7	Skyscraper - Coastal - All Water– Manufacturer A	64%
8	Skyscraper - Coastal - All Water – Manufacturer B	61%
9	Low Rise - Coastal - All Air – Manufacturer A	60%
10	Low Rise - Coastal - All Air – Manufacturer B	57%
11	Skyscraper - Coastal - All Air – Manufacturer A	57%
12	Skyscraper - Coastal - All Air – Manufacturer B	54%
13	High Rise - Arid - All Water– Manufacturer A	41%
14	High Rise - Arid - All Water – Manufacturer B	38%
15	High Rise - Arid - All Air – Manufacturer A	33%
16	High Rise - Arid - All Air – Manufacturer B	30%
17	Low Rise - Arid - All Water– Manufacturer A	29%
18	Low Rise - Arid - All Water – Manufacturer B	26%
19	Skyscraper - Arid - All Water– Manufacturer A	25%
20	Low Rise - Arid - All Air – Manufacturer A	22%
21	Skyscraper - Arid - All Water – Manufacturer B	22%
22	Low Rise - Arid - All Air – Manufacturer B	19%
23	Skyscraper - Arid - All Air – Manufacturer A	18%
24	Skyscraper - Arid - All Air – Manufacturer B	15%

5. Conclusions

The current work studied the influence of multiple variations of indoor air conditioning systems in regards to climate – as indicated by geographical location, type of buildings in terms of height, type of cooling cycles based on air or water type of cooling agent, in addition to the variation in design concepts for different manufacturers. Data was collected in sequential steps through documents review, field observations, and expert informants' interviews. The research is intended to fill the current literature gap in regards to best selection of in-door air-conditioning systems given the stated varying parameters.

From the statistical tests and their interpretation, it could be concluded that three of the studied factors have a significant effect on the total price of the life cycle cost of air conditioning systems per power consumed; which are: 1) type of buildings in terms of height, 2) type of cooling cycles based on air or water type of cooling agent, and 3) the variation in design concepts for different manufacturers.
In the other hand, influence of climate – as indicated by geographical location, on energy consumption and thus on operational cost, have no significant effect on the total price of the life cycle cost of air conditioning systems per power consumed.

Similarly, the AHP tool - a decision making support means – was applied to rank the importance of the four previously mentioned factors and their sub-factors in the air conditioning industry of residential buildings. It is concluded that humid coastal areas are more demanding in terms of air-conditioning energy consumption compared to an internal arid dry area, but it's found that coastal regions are preferable over arid regions.
A good recommendation for future work would be to continue the study the highlited four factors but in regards to the environmental aspect. This can help to understand which of these factors have a significant impact on the environment represented by the carbon footprint of each configuration.

References

AlAwadhi, W. et al., 2013. Energy Saving Potential Due to Refurbishment of Federal Public Housing in the . UAE. Engineering, January. pp.132-36.

Alkhateeb, E., & Abu, B. (2017). Potential of upgrading federal buildings in the United Arab Emirates to reduce energy demand. *Procedia Engineering*, *180*, 61–70. https://doi.org/10.1016/j.proeng.2017.04.165

Almutairi, K., Thoma, G., Burek, J., Algarni, S., & Nutter, D. (2015). Life cycle assessment and economic analysis of residential air conditioning in Saudi Arabia. *Energy & Buildings*, *102*, 370–379. https://doi.org/10.1016/j.enbuild.2015.06.004

Alrwashdeh, S. S., & Ammari, H. (2019). Case Studies in Thermal Engineering Life cycle cost analysis of two different refrigeration systems powered by solar energy. *Case Studies in Thermal Engineering*, *16*(November), 100559. https://doi.org/10.1016/j.csite.2019.100559

Au-yong, C. P., Ali, A. S., & Ahmad, F. (2014). Automation in Construction Improving occupants' satisfaction with effective maintenance management of HVAC system in of fi ce buildings. *Automation in Construction*, *43*, 31–37. https://doi.org/10.1016/j.autcon.2014.03.013

Bore, B. (1997). *An introduction to the climate of the United Arab Emirates*. 3–16.

Chiavetta, C., Tinti, F., & Bonoli, A. (2011). *Procedia Engineering Comparative life cycle assessment of renewable energy systems for heating and cooling*. *21*, 591–597. https://doi.org/10.1016/j.proeng.2011.11.2054

Ciambrone, D. F. (1997). *Environmental Life Cycle Analysis*.

Eisenhower, B., Neill, Z. O., Narayanan, S., Fonoberov, V. A., & Mezi, I. (2012). *A methodology for meta-model based optimization in building energy models*. *47*, 292–301. https://doi.org/10.1016/j.enbuild.2011.12.001

Emporis. (2020). *No Title*. https://www.emporis.com/corporate

Fabrizio, E., Corrado, V., & Filippi, M. (2010). A model to design and optimize multi-energy systems in buildings at the design concept stage. *Renewable Energy*, *35*(3), 644–655. https://doi.org/10.1016/j.renene.2009.08.012

Farr, J. V. (2011). *Systems Life Cycle Costing: Economic Analysis, Estimation, and Management*.

Fazlollahi, S., Mandel, P., Becker, G., & Maréchal, F. (2012). Methods for multi-objective investment and operating optimization of complex energy systems. *Energy*, *45*(1), 12–22. https://doi.org/10.1016/j.energy.2012.02.046

García-sanz-calcedo, J., & Gómez-chaparro, M. (2017). Quantitative analysis of the impact of maintenance management on the energy consumption of a hospital in Extremadura (Spain). *Sustainable Cities and Society*, *30*, 217–222. https://doi.org/10.1016/j.scs.2017.01.019

Gebreslassie, B. H., Guillén-gosálbez, G., Jiménez, L., & Boer, D. (2009). Design of environmentally conscious absorption cooling systems via multi-objective optimization and life cycle assessment. *Applied Energy*, *86*(9), 1712–1722. https://doi.org/10.1016/j.apenergy.2008.11.019

Ghaith, F. A., & Abusitta, R. (2014). Energy analyses of an integrated solar powered heating and cooling systems in UAE. *Energy & Buildings*, *70*, 117–126. https://doi.org/10.1016/j.enbuild.2013.11.024

Hang, Y., Qu, M., Winston, R., Jiang, L., Widyolar, B., & Poiry, H. (2014). Experimental based energy performance analysis and life cycle assessment for solar absorption cooling system at University of Californian , Merced. *Energy & Buildings*, *82*, 746–757. https://doi.org/10.1016/j.enbuild.2014.07.078

Kiamili, C., & Hollberg, A. (2020). *Detailed Assessment of Embodied Carbon of HVAC Systems for a New O ffi ce Building Based on BIM*.

Krarti, M., & Dubey, K. (2018). *Review analysis of economic and environmental bene fi ts of improving energy e ffi ciency for UAE building stock*. *82*(September 2017), 14–24. https://doi.org/10.1016/j.rser.2017.09.013

Lin, M., Afshari, A., & Azar, E. (2018). A data-driven analysis of building energy use with emphasis on operation and maintenance : A case study from the UAE. *Journal of Cleaner Production*, *192*, 169–178.

https://doi.org/10.1016/j.jclepro.2018.04.270
Mathur, A., Muthukumaraswamy, S. A., & Varela, L. (2018). *Investigation and Analyses of Energy-Efficient Technologies for HVAC and Lighting Systems via Energy Auditing Processes*. *Level 3*, 186–190.
McQuiston, F. C., Parker, J. D., & Spitler, J. D. (2006). *Heating, Ventilating, and Air Conditioning: Analysis and Design, 6th Edition* (6TH ed.).
Ooka, R., & Komamura, K. (2009). Optimal design method for building energy systems using genetic algorithms. *Building and Environment*, *44*(7), 1538–1544. https://doi.org/10.1016/j.buildenv.2008.07.006
Prek, M. (2004). *Environmental impact and life cycle assessment of heating and air conditioning systems , a simplified case study*. *36*, 1021–1027. https://doi.org/10.1016/j.enbuild.2004.06.008
Rastegar, M., & Fotuhi-firuzabad, M. (2015). Load management in a residential energy hub with renewable distributed energy resources. *Energy & Buildings*, *107*, 234–242. https://doi.org/10.1016/j.enbuild.2015.07.028
Ristimäki, M., Säynäjoki, A., Heinonen, J., & Junnila, S. (2020). Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design. *Energy*, *63*(2013), 168–179. https://doi.org/10.1016/j.energy.2013.10.030
Shah, V. P., Debella, D. C., & Ries, R. J. (2008). *Life cycle assessment of residential heating and cooling systems in four regions in the United States*. *40*, 503–513. https://doi.org/10.1016/j.enbuild.2007.04.004
Solano, K., Romero, R. J., Santoyo, E., Herrera, I., Galindo, Y. R., Rodríguez, A., Santoyo-castelazo, E., & Cerezo, J. (2019). Life cycle assessment of a solar absorption air-conditioning system. *Journal of Cleaner Production*, *240*, 118206. https://doi.org/10.1016/j.jclepro.2019.118206
Sumper, A., Robledo-garcía, M., Villafáfila-robles, R., Bergas-jané, J., & Andrés-peiró, J. (2011). Lifecycle assessment of a photovoltaic system in Catalonia (Spain). *Renewable and Sustainable Energy Reviews*, *15*(8), 3888–3896. https://doi.org/10.1016/j.rser.2011.07.023
Taleb, H. M. (2014). Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U . A . E . buildings. *Frontiers of Architectural Research*, *3*(2), 154–165. https://doi.org/10.1016/j.foar.2014.01.002
Zheng, M., Fang, R., & Yu, Z. (2016). Life cycle assessment of residential heating systems : a comparison of distributed and centralized systems. *Energy Procedia*, *104*, 287–292. https://doi.org/10.1016/j.egypro.2016.12.049
Rahman, S., 2013. UAE's per capita energy consumption among the highest. Dubai: Gulf News.

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