Techno-Science Research Journal V13 (2) (2025) P 78-89

Content list available at ITC

Techno-Science Research Journal

Journal Homepage: http://techno-srj.itc.edu.kh/

Techno-Science Research Journal

Techno-Economic Comparison of VRF and Water-cooled Chiller System at the Ministry of Tourism in Sihanouk Province, Cambodia

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Received: 06 September 2024; Revised: 18 September 2024; Accepted: 14 October 2024; Available online: 31 August 2025

Abstract: *Nowadays, air-conditioning is steadily increasing from year to year. In 2012, the usage in Cambodia was only 77 thousand units, and in 2019 up to 134 thousand units. Variable refrigerant flow (VRF) was introduced in 1982, and the Water-cooled chiller was patented by an inventor named Willis Carrier in 1921. In this work, the objective aims to evaluate the cooling load and study the techno-economic of VRF and Water-cooled chiller of the Ministry of Tourism in Sihanouk province as a case study. Before getting the accurate techno-economic related to operation costing, investigation costing, and maintenance costing, heat calculation in the building is the most important parameter. Heat calculation was applied to manual calculation, estimation calculation, and HAP software. After getting the heat total, the methodology has been explored through the internet and secondary data from relevant published academic literature from journal articles and research papers. The data collected in the qualitative research are the data that comes from a direct survey of air-conditioning companies. In the building, the investigation costs of VRF and water-cooled chiller are 89759$ and 120369$.The operation cost of VRF in 1 year is 5158$ and the operation of water-cooled chiller in the same 1 year is 5017$. The maintenance cost of VRF is 620$ for every six months spent on cleaning air-conditioning and gas recharging. For the water-cooled chiller, the maintenance cost is related to cooling tower, AHU system, and chilled water pump, which costs 1500$. In conclusion, a water-cooled chiller has a lot of components and it is more expensive and requires much budget than a VRF system. For recommendation, for the small office, school or small building we should better use VRF system and for the larger commercial building we should use water-chiller it is profitable.*

Keywords: VRF System, Water-Cooled Chiller, Techno-Economic, manual Calculation, HAP Software

1. INTRODUCTION

Variable refrigerant flow (VRF) systems are widely adopted in buildings. VRF system is highly efficient in energy-saving. However, when VRF systems faults such as refrigerant leakage, the efficiency of the system could drop drastically. VRF system is more complex comparing to the split air conditioner, as there are more units and more correlative factors in it. Therefore, the fault diagnosis for VRF systems is more challenging [1]. In recent years, some researchers have been explored that VRF systems which are also known as VRV systems are similar to the multi-split systems which connect one outdoor section to several evaporators and continually varying the flow of refrigerant through a pulse-modulating valve whose opening is determined by the microprocessor receiving information from the thermistor sensors in each indoor unit. The indoor units are linked by a control wire to the outdoor unit which responds to the demand from the indoor units by varying its compressor speed to match the total cooling requirement [2]. Additionally, a study found that Variable refrigerant flow system is a popular building air conditioning solution. Modern variable refrigerant flow systems such as multi-functional variable refrigerant flow systems can also provide space cooling, to the building simultaneously [3].

Furthermore, according to Kameke [4] found that In Cambodia, air-conditioning is steadily increasing because people's living standards increasing and climate change.In 2012, the usage of the VRF system was 77 thousand

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units and in 2019, it increased to 134 thousand units. Once again, a study by Yazan Alsalem [5] determined that the COP of the VRF system is higher than the heat pump chiller in cooling and heating. The COP at the full load of the VRF system was 4.05 for cooling and 4.51 for heating, while the heat pump chiller system was 2.83 for cooling and 2.9 for heating. The initial and running costs of the VRF system were better than a heat pump chiller. On top of that, the selection of the variable refrigerant flow (VRF) system is one of the important options, as the VRF system is one of the most versatile HVAC systems. The operation of the VRF system depends on the indoor environmental requirements and the outdoor conditions [6]. Besides that, research from Haider Latif [7] that relevant to the VRF system was realized that actual data measured from the centralized chiller already installed in the building is compared with the modeled VRF's data in terms of electricity consumption, operational, ownership & maintenance costs. Considering the local climatic conditions of the region, the VRF system is more energy efficient and around 23% more profitable than the conventional chiller system already installed in the chosen building. In a recent MDPI journal publication by Atallah & Tarlochan [8], a thorough comparison between variable and constant refrigerant flow systems was conducted. The study considered a 15-year lifespan and factored in all associated costs, including initial, operating, and maintenance costs. The initial investment cost encompasses the primary equipment of both systems, such as the CRF and VRF units, as well as ducting, piping, insulation, dampers, grills, diffusers, and other accessories. This comprehensive analysis revealed that the techno-economics of VRF systems involved investigation, installation, and maintenance costs.

Water-cooled chiller systems are the heart of central HVAC cooling, providing cooling throughout a building or group of buildings from one source. Centralized cooling offers numerous operating, reliability, and efficiency advantages over individual DX systems and, on a life-cycle basis, can have significantly lower total costs. For water-cooled chillers, the condenser is a second shell-and-tube heat exchanger with refrigerant in the shell and condenser water in the tubes. Condenser water is typically supplied at 70–85 Fahrenheit and the flow rate is selected for a 10–15 Fahrenheit range. A cooling tower is typically utilized to provide condenser water cooling, but other cool water sources such as wells, productivity. Water-cooled systems offer advantages over air-cooled systems, including smaller physical size, longer life, and higher operating efficiency. The success of their operation depends, however, on the proper sizing, selection, application, operation, and maintenance of the cooling tower [9].

Water chiller is a broad term describing an overall package that includes a refrigeration plant, water chiller, and air or water-cooled condenser. This name infers that the compressor, condenser, and chiller with internal piping and controls are combined into a single unit. Water chiller plants may range in size from small-capacity reciprocating compressor units with air or water-cooled condensers up to large units incorporating centrifugal or screw compressor [10]. In a study from Ogbonnaya Agwa [11] in the European Journal of Engineering and Technology, it was noted that the overall capital cost comprises the capital investment and the assumed operational and maintenance (O&M) costs, which are estimated to be 2.5% of the overall capital investment. We can find detailed information on the techno-economic aspects of the water-cooled chiller in this cloud. The investigation cost, operation cost, and maintenance cost will be the focus of our study. Here is a literature reviews of project A (2022), that studied the techno-economic of a Water-cooled chiller and was using a Water-Cooled Chiller capacity of 150.7 RT, Cooling Tower 1 set model GPC 250, Water Circulation Pump 04 sets (With VFD Motor), VFD Inverter for water circulation Pump 01 set, Supply of Flow Meter, Supply of Plate Type Heat Exchanger 01 set, Supply of Valve Accessories for Chilled Water, Cooling Water Line, and AHU, and all. equipment charge. The total cost of the project was 95704.00$.

Likewise, by their design and operation, air-cooled chillers appear costlier at face value when compared to water-cooled units. To begin with, air-cooled systems will feature installation costs for air ducts, fans, and thermoregulation controls. Water-cooled chillers despite the higher initial investment, due to their longer lifespan and energy-saving benefits [12].

From Nassab M. K [13] in the topic of Techno-economic Optimization of Combined Cooling, Heating, and Power systems based on Response Surface Methodology, it has been stated that the total annual cost includes the annual investment cost, annual maintenance, and operation cost. This proves that the need to study the techno-economic aspects of VRF and water-cooled chillers based on investigation costs, operation costs, and maintenance costs.

This study focuses on the techno-economic aspects of water-cooled chillers and VRF systems, we need to consider three main factors. The first is the initial investment cost, which includes the investment material cost and installation cost of indoor, outdoor units of VRF and chillers and salaries of co-workers and staff. The second factor is the operating cost, which includes the expenses incurred while running the system.operation cost required to study specific of energy efficiencyratio(EER),cooling seasonal performance(CSPF), coefficient of performance(COP), seasonal energy efficiency ratio(SEER) and integrated energy efficiency ratio(IEER).

Maintenance is also crucial for both chillers and VRF systems. VRF systems require cleaning every six months. The indoor unit system consists of two distinct parts : the evaporator coil and the condenser coil. Both of them play a crucial role in transporting refrigerant and redistributing the air that moves through the system. According to experts, it is recommended to clean all VRF air conditioning systems twice per year.(CompanyA,CompanyB published paper). while chillers require maintenance for specific components such as the chilled water pump, cooling tower, and AHU system. Water chillers typically need routine maintenance every three to six months. Regular maintenance includes checking refrigerant levels, inspecting and cleaning heat exchangers, ensuring proper water flow and pressure, checking for leaks.

2. RESEARCH METHODOLOGY

In this paper qualitative research method has been used. The systematic literature review has been explored through the internet and secondary data from relevant published academic literature from journal articles and research papers. The data collected in the qualitative research is the data that comes from a direct survey of air-conditioning companies.

The basic concepts and backgrounds are investigated through literature online media, and observations to work for the qualitative analysis conducted in Air Conditioning of Buildings with references to system operation.

2.1 Data Collection

The quantitative data was collecting pricing data from published literature, technical specifications, and manufacturer catalogues. Additionally, conduct a survey of local contractors and suppliers to obtain current market prices for equipment, installation, and maintenance.

2.2 Data Analysis

The quantitative analysis was develop a detailed cost model for each system, including initial capital costs, operating costs, and potential savings over the lifetime of the system. Perform a sensitivity analysis to assess the impact of different assumptions and parameters on the overall cost-effectiveness of each system. Conduct a life-cycle cost analysis (LCCA) to compare the total cost of ownership of each system over its expected lifespan. Calculate relevant performance metrics, such as energy efficiency ratio (EER) and coefficient of performance (COP).

2.3 Data Collection of each floor

Table 1. The data collection of each floor

Description	Total Area	Units
Basement Floor	38	m^2
Ground Floor	338	m^2
First Floor	585	m^2
Second Floor	64	m^2
Third Floor	52	m^2

2.4 Heat load Calculation(Manual Method, EEtom1 book)

The heat balance or manual calculation [14] (Bilan Thermique Calculation) is the method used to calculate the cooling load of the building space with minimum errors.

$$\boldsymbol{Q_T = Q_{sensible} + Q_{latent}} \quad \text{(Eq. 1)}$$

Heat by transmission through the external walls & glazing:

$$Q_s = K \times S \times \Delta_T \quad \text{(Eq. 2)}$$

Heat transfer by thermal radiation of solar pass the wall

$$Q_{srm} = \propto \times F \times R_m \quad \text{(Eq. 3)}$$

- Some specification which reqire to calculate in manual method such as: (EEtom1 Book)
  - Heat by air exchange and infiltration:

$$Q_{sr} = q_v \times (Q_e - Q_i) \times 0.33 \quad \text{(Eq. 4)}$$

- Heat by lighting
  - Fluorescent lampe:

$$Q_{secl} = 1.25 \times P \quad \text{(Eq. 5)}$$

- Heat latent occupant:
  - Heat by occupants:

$$Q_{loc} = n \times C_{loc} \quad \text{(Eq. 6)}$$

2.5 Heat load Calculation(Estimation Method)

The estimation method is a technique for calculating the quantities some parameters that need to know are the area of the rooms and the ratio of its.

- Formulation of Estimation method:(Follow company)

$$Q = A \times R \quad \text{(Eq. 7)}$$

2.6 Heat load Calculation(HAP Software)

HAP is a dual function program - full-featured load calculation and system sizing for commercial buildings plus versatile hour-by-hour energy modeling [15].

- Some specification that require in HAP software
  - Country
  - Temperature (weather)
  - Spacing (area)
  - Location
  - Time which using energy (hour by hour).

2.7 The value of manual method, estimation method and HAP software after calculation

Table 2. The value of three methods

Description	Total Area m^2	Manual result	Estimation result	HAP result
Basement Floor	38	14.5kW	20.2kW	16.7kW
Ground Floor	338	70.448kW	91.79	76.4kW
First Floor	585	102.2kW	139kW	110.25kW
Second Floor	64	13kW	31.2kW	16.5kW
Third Floor	52	12kW	16kW	14kW

- After calculation by three methods, HAP was selected because HAP software is more accurate and specific than manual and estimation methods and moreover, it was recognized globally [16-18].

3. INVESTIGATION COST OF VRF AND WATER-COOLED CHILLER

3.1 Investment material cost

3.1.1 Indoor and outdoor selection of VRF System

Table 3. The indoor unit selection of VRF system

Description	Selection (kW)	Pricing per unit $
BASEMENT FLOOR		
Sever Room	Double of 3.6kW FCNQ26MV1	786.99
IT room	11.2kW FXFSQ100AVM	1529.28
GROUND FLOOR		
Seminar Room	Double of 14kW FCFC125DVM	1735.41
Restaurant Room	Triple of 14kW FCFC125DVM	1735.41
Office Room	4.5kW FCFC50DVM	1036.29
Tourist Front Room	7.1kW FCNQ26MV1	1291.47
FIRST FLOOR		
First Aid	7.1kW FCNQ26MV1	1291.47
Computer Lab	14kW FCFC125DVM	1735.41
Admin	7.1kW FCNQ26MV1	1291.47
Cashier	4.5kW FCFC50DVM	1036.29
Meeting Room	9.0kW FCFC85DVM	1389.11
School Director	5.6kW FCFC50DVM	1036.29
Teacher Office 01	9.0kW FCFC85DVM	1389.11
Teacher Office 02	11.2kW FXFSQ100AVM	1529.28
Office 02,03&04	Triple of 7.1kW FCNQ26MV1	1291.47
Director	Double of 4.5kW FCFC50DVM	1291.47
Meeting Room	Double of 7.1kW FCNQ26MV2	1291.47
SECOND FLOOR		
Hotel Room01	7.1kW FCNQ26MV2	1291.47
Hotel Room02	11.2kW FXFSQ100AVM	1529.28
THIRD FLOOR		
Computer Room	14kW FCFC125DVM	1735.41

Table 4. Commons Pitfalls of selection VRF [2]

Commons Mistake	Best Practice
Thinking VRF is just a big multi-split DX system	VRF is a chiller circulating refrigerant instead of water
It's a zoning system thus an indoor unit in Every room	Design VRF system using same approach as VAV or WSHP
VRF is a ductless system	More than 55% of units used are ducted types!
Upgrade indoor Unit to the next capacity size	Use accurate load calculated values and trust selection software
Optimum selection of Controls is not important	Be knowledgeable on controls capabilities-minimize
The entire application needs to be VRF	BAS or even elimination of BAS is often possible

3.1.2 Outdoor selection of VRF System

Table 5. The outdoor unit selection of VRF system

Description	Model	Pricing $
78.5kW(Double)=26800Btu/h	REYQ264TATJU	15000
83.5 kW=28500Btu/h	REYQ288TATJU	18543.08

3.1.3 Indoor and outdoor selection of Water-cooled Chiller

3.1.4. Indoor selection of Water-cooled chiller System

Table 6. The indoor unit selection of Water-cooled chiller

Description	Selection (kW)	Pricing per unit $
BASEMENT FLOOR		
Sever Room	Double of 3.5 (FWKE08E)	765.129
IT room	9.7(FWKE11E)	1764.42
GROUND FLOOR		
Seminar Room	Double of 9.7(FWKE11E)	1764.42
Restaurant Room	Triple of 12.6(FWMJC13BV1)	2291.91
Office Room	7.33(FWMJC8BV1)	1333.31
Tourist Front Room	7.33(FWMJC8BV1)	1333.31
FIRST FLOOR		
First Aid	7.33(FWMJC8BV1)	1333.31
Computer Lab	7.33(FWMJC8BV1)	1333.31
Admin	7.1kW FCNQ26MV1	1333.31
Cashier	7.33(FWMJC8BV1)	1333.31
Meeting Room	Double 4.54(FWMJCC5BV1)	1036.29
School Director	9.7(FWKE11E)	1764.42
Teacher Office 01	6.15(FWMJC6BV1)	1202.83
Teacher Office 02	7.81 (FWMH8A0(Z)V1)	1420.64
Office 02,03&04	Triple of 7.81 (FWMH8A0(Z)V1)	1420.64
Director	Double 4.54(FWMJCC5BV1)	1036.29
Meeting Room	Double 7.33(FWMJC8BV1)	1333.31
SECOND FLOOR		
Hotel Room01	7.33(FWMJC8BV1)	1333.31
Hotel Room02	11.14(FWMJC11BV1	2073.64
THIRD FLOOR		
Computer Room	Double of 7.33(FWMJC8BV1)	1333.31

3.1.5 Outdoor selection of Water-cooled chiller System

To select water-cooled chiller, we must have or know the total cooling load of the building or total cooling capacity of all fan coil unit (FCU) selected in that designing.

$$Q_{Total} = Q_{BF} + Q_{F1} + Q_{F2+}Q_{F3} \quad \text{(Eq. 8)}$$

$$Q_{Chiller} = 233.85kW = 234kW \quad \text{(Eq. 9)}$$

Table 7. The outdoor unit selection of Water-cooled chiller

Description	Model	Pricing $
71.08RT=250kW	(ZUWV)	25047.80$
1RT		352.38$

Table 8. The outdoor unit of Water-cooled chiller selction

Description	Model	Pricing $
Schedule-1	Electric Chiller, Actual Cooling Capacity: 32.47&43.19 RT	25047.80$
Schedule-2	Cooling Tower (01 set, model MKX/XP)	8500.50$
Schedule-3	Total water circulation pump-04 sets with (VFD Motor)	7500$
Schedule-4	VFD inverter for water circulation pump	5000$
Schedule-5	Supply of Flow Metter	3000$
Schedule-6	Supply of Plate: Heat Exchanger, 01 set	2000$
Schedule-7	AHU (Air-handling Unit)	8000$
Schedule-8	Duct suppler in Water-cooled chiller	6000$

We compared the prices of outdoor units of water-cooled chillers from companies A, B, C, and D in Cambodia. We also conducted a direct survey of air-conditioning and chiller companies. Additionally, we compared the pricing of outdoor units of water-cooled chillers from a published paper to determine if the costs from the selling companies were reasonable.

Table 9. The pricing references from each companies

Description	Project (RT)	Pricing $
Company A	1200RT and 600RT	1200RT=418993.416 600RT=208496
Company B	400.07RT	135000.91
Company C	70RT	24340.50
Company D	150.07RT	51700.58
Chiller selling company (e)	500RT and 950RT	500RT=174580.59 950RT=336983.60

- Rank comparision in 1RT from each companies

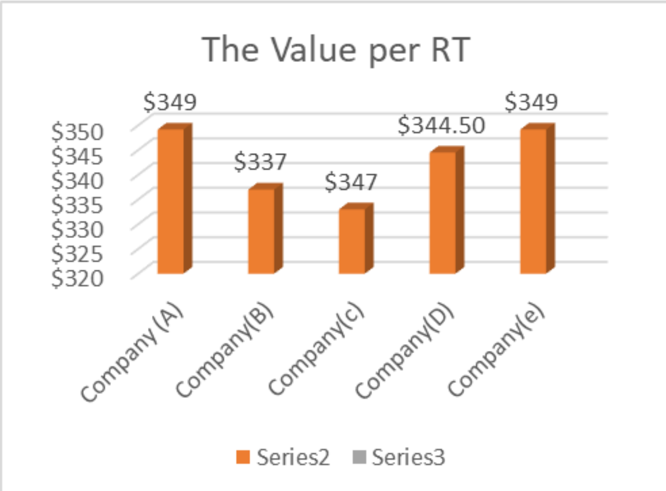

Fig. 1. The Water-cooled chiller ranking

- After getting the result in 1 RT from each company, it started from 337$ per RT to 349$ because it relied on the model used in that project. Furthermore, compared to our project pricing of a Water-cooled chiller, 1 RT equals 352.38$ it stayed in the rank and an acceptable cost with appropriate cost as well.

3.2 Investment in Installation cost

3.3 Installation cost of VRF and Water-cooled chiller

3.3.1 Installation cost of VRF system

Table 10. The installation cost's company A, B, C and our project

Cooling Capacity	Number of indoor unit	Number of floor	Number of worker	Companies	Total Price $
332kW	35	5	10	A	4440
420kW	60	10	16	B	7000
500kW	80	15	20	C	10000
234kW	26	5	10	Our project	3600

- In the context of performing regression analysis in Excel, the significant parameter is the indoor unit number. Company A was completed in 2 months, Company B was completed in 70 days, and the last company (C) was finished in 3 months. Our project was completed in 30 days. The installation cost was higher for our project, as it is located in Sihanouk province, whereas the other three companies were in Phnom Penh. The installation cost in PhnomPenh was only 10$ and for the installation cost in the province was 12$ per person in a day.

- The number of indoor units is significant compared to other parameters because the R square equals 0.9775, and the p-value is 0.02, which is smaller than 0.05.[19-21].

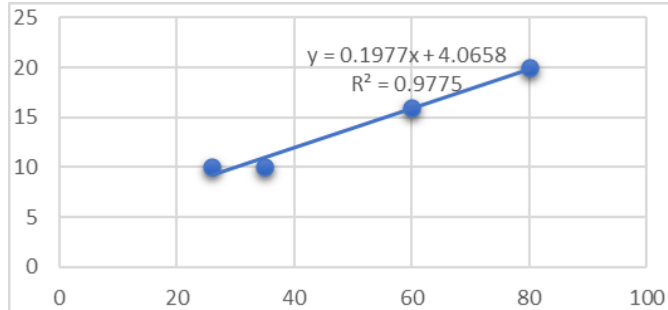

Fig. 2. The regression of VRF system.

- The R-squared value of 0.9775 indicated the regression line fits the data relatively well. This mean that the regression line is able to predict dependent variable (y) with a high degree accuracy [22, 23].

3.3.2 Installation cost of Water-cooled Chiller system

3.3.3 The Testing commissioning cost of Water-cooled Chiller system

Testing companies in Cambodia, such as Company A, Company B, Company C, and Company D, located in Phnom Penh, have extensive experience in this field. The price for testing a water-cooled chiller model (YCWE032XSME), (YCWE032XSME are $8,000, and it has a capacity of 75.66 RT for a single test. This cost reflects the comprehensive nature of testing required for the efficient operation of the chiller, as it has multiple systems that need to be thoroughly assessed and prepared for optimal performance.

Table 11. The testing cost of Water-cooled chiller

Testing Commissioning Parts
Check water piping Connection at the evaporator.
Check all compressor valve connections for tightness.
Vent the air from evaporator as well as from the system start the chilled water pump after opening all water flow valves.
Ensure that the ball valves are opens on the refrigerant lines entering the evaporator.
Adjust the leaving chilled water temperature set in the chiller controller to the desired chilled water temperature.
Check water piping Connection at the evaporator.

- The installation in our project was spending on the in door unit, chilled water pump, cooling tower, air-handling unit , check valve accessories and outdoor unit.

- Related to company B which used to have the project of a Water-cooled chiller such as 400.07 RT in a 15-floor building, company C 70RT in a 5-floor building, and company D 150.07RT in the project 10-floor building.

Table 12. The installation with testing commissioning cost's company B1, C1, D1 and our project

Cooling Capacity	Number of indoor unit	Number of floor	Number of worker	Companies	Total Price $
400.07RT	150	15	30	B1	51000
70RT	25	5	15	C1	10000
150RT	70	10	25	D1	21000
75.66RT	29	5	20	Our project	13110

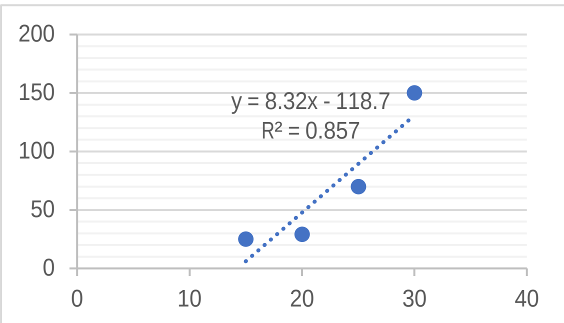

Fig. 3. The regression of Water-cooled chiller system

- The number of indoor units is significant compared to other parameters because the R square equals 0.857, and the *p-value* is 0.04, which is smaller than 0.05 [19-21].
- The R-squared value of 0.857 indicated the regression line fits the data relatively well. This mean that the regression line is able to predict dependent variable (y) with a high degree accuracy [22, 23].

4. OPERATIN COST OF VRF AND WATER-COOLED CHILLER

4.1. Operation cost of VRF system

Due to the VRF system being utilized 3 outdoor units. The first uses using double of 78.5kW and the last one is 83.5.

Table 13. Specification of outdoor unit capacity 78.5kW

Cooling capacity	Model	SEER	Airflow	EER
274,000 Btu/h	REYQ288TATJU	15.56	233 + 233 m³/min	10.85

Table 14. The cooling load in Jan to December(HAP)

JANUARY	2945.6Ton. hrs
FEBURARY	3150.9 Ton. hrs
MARCH	3466.3Ton. hrs
APRIL	4190.5Ton. hrs
MAY	4002.1Ton. hrs
JUNE	4146.4Ton. hrs
JULY	4027Ton. hrs
AGUST	4040.8Ton. hrs
SEPTEMBER	3756.4Ton. hrs
OCTOBER	3362.5 Ton. hrs
NOVEMBER	3226.8Ton. hrs
DECEMBER	2981.1Ton. hrs

By following

$$SEER = \frac{Output\ cooling\ energy\ BTU/h}{Input\ electrical\ energy\ Wh} \quad \text{(Eq. 10)}$$

$$Input\ electrical = \frac{151970.364\ \text{kWh}}{15.56}$$

$$= 9766.7\text{kWh}$$

- Due to the electricity at Sihanouk province is 700Riels per kWh equal 0.175$.
- It is the building of ministry of Tourism so, the work time will be possible from 7am to 11 am and from 1pm to 5 pm.
- The operation cost in 1 year

  In 1 year = 9766.732kWh×0.175$=1709.1781

- Related to the system was using double of 78.5kW then,

  78.5kW=1709.1781$×2= 3418.35$ (Eq. 11)

Table 15. Specification of outdoor unit capacity 83.5kW

Cooling capacity	Model	SEER	Airflow	EER
296,000 Btu/h	REYQ312TATJU	15.28	233 + 233 m³/min	10.50

By following Hailu, G [24]

Then,

$$Input\ electrical = \frac{151970.364\ \text{kWh}}{15.28} \quad \text{(Eq. 12)}$$

$$Input\ electrical = 9945.70\text{kWh}$$

- Due to the electricity at Sihanouk province is 700Riels per kWh equal 0.175$.
- The operation cost in 1 year

  In 1 year = 9945.7kWh × 0.175$ = 1740.49$

- The total operation cost of VRF

  Thus, = (3418.35+1740.49)$

  Hence, operation in 1 year= 5158.84$ (Eq. 13)

4.2. Operation cost of Water-cooled chiller system

Table 16. Performance rating's water-cooled chiller 71.08RT

%of full Load	Capacity kW	Input kW	COP kW/kW
100%	250	47.97	5.211
75%	187.5	32	5.107
50%	125	22.42	5.576
25%	62.5	12.50	5.301

By following:
AHRI Standard 551/591-2020 (SI) with Addendum 1[25]

$$SEER = 0.06COP_{100\%} + 0.48COP_{75\%} + 0.36COP_{50\%} + 0.10COP_{25\%}$$

$$SEER = 0.06(5.211) + 0.48(5.1070) + 0.36(5.5760) + 0.1(5.301)$$
$$SEER = 0.3126 + 2.451 + 2.007 + 0.530 = 5.3$$

$$SEER = \frac{Output\ cooling\ energy\ \text{Btu/h}}{Input\ electrical\ energy\ \text{Wh}} \quad \text{(Eq. 14)}$$

$$Input\ electrical\ energy = \frac{151970.364\ \text{kWh}}{5.3} = 28673.65\text{kWh}$$

➢ The operation cost in 1 Year

1 year= 28673.65kWh ×0.175$= **5017.88$**

4.3. Operation cost of VRF and Water-cooled chiller system in 1 Year

The operating costs of a VRF system and a water-cooled chiller are not the same. In the VRF system, the SEER of the outdoor unit is 15.56 for a 78.5kW capacity and 15.28 for an 83.5kW capacity. In contrast, the SEER for the water-cooled chiller is only 5.3.The operation of Water-cooled chiller cheaper than VRF system beacsue as the reason as below:

Efficiency of Heat Rejection:

- Water-Cooled Chillers: These systems use water to reject heat from the refrigerant. Water has a higher thermal conductivity compared to air, meaning that water-cooled systems can reject heat more efficiently. This often results in better performance and lower energy consumption for the same cooling load.
- VRF Systems: VRF systems use air-cooled condensers, which are less efficient at rejecting heat than water-cooled systems. The efficiency of air-cooled systems can vary significantly with ambient temperature, leading to higher energy consumption during peak heat conditions.

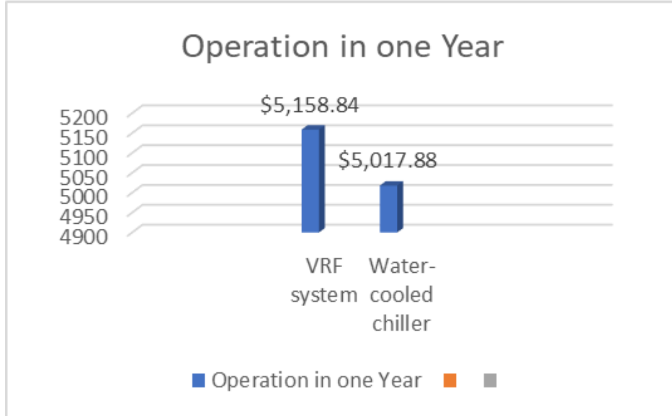

Fig. 4. The operation cost in 1 Year of VRF and Water-cooled chiller system

5. MAINTENANCE COST OF VRF AND WATER-COOLED CHILLER

5.1. Maintenance cost of VRF system

- According to experts, it is recommended to clean all VRF air conditioning systems twice per year. (Company A2, CompanyB2).

Table 17. The maintenance cost of VRF system

Description	Model	Pricing $
Indoor Unit of VRF System	25 Units	250$
Outdoor Unit of VRF System	3 Units	120$
Air-conditioning Gas Recharge	25 Units	250$

The maintenance cost of VRF system= 620$ (Eq. 15)

5.2. Maintenance cost of Water-cooled chiller system

Water chillers typically need routine maintenance every three to six months. Regular maintenance includes checking refrigerant levels, inspecting and cleaning heat exchangers, ensuring proper water flow and pressure, checking for leaks.

Table 18. The maintenance period of Water-cooled chiller

Recommended from company C		
Electric Chiller	From 3 to 6 months	Minimum to Maximum
Cooling Tower	From 3 to 6 months	Minimum to Maximum
Total water circulation pump	From 3 to 4 months	Minimum to Maximum
VFD inverter for circulation pump	From 3 to 4 months	Minimum to Maximum
AHU (Air-handling Unit)	From 3 to 6 months	Minimum to Maximum
Indoor Units of Water-cooled chiller	Twice per Year	Minimum to Maximum

Table 19. The maintenance period of Water-cooled chiller

Recommended from company D		
Electric Chiller	From 3 to 6 months	Minimum to Maximum
Cooling Tower	From 3 to 5 months	Minimum to Maximum
Total water circulation pump	From 4 to 6 months	Minimum to Maximum
VFD inverter for circulation pump	From 3 to 5 months	Minimum to Maximum
AHU (Air-handling Unit)	From 3 to 5months	Minimum to Maximum
Indoor Units of Water-cooled chiller	Twice per Year	Minimum to Maximum

Table 20. The maintenance period of Water-cooled chiller

One Project in Bangladesh		
Electric Chiller	From 3 to 6 months	Minimum to Maximum
Cooling Tower	From 3 to 5 months	Minimum to Maximum
Total water circulation pump	From 4 to 6 months	Minimum to Maximum
VFD inverter for circulation pump	From 3 to 6 months	Minimum to Maximum
AHU (Air-handling Unit)	From 3 to 6months	Minimum to Maximum
Indoor Units of Water-cooled chiller	Twice per Year	Minimum to Maximum

- From companies C and D, all the components in the water-cooled chiller can be maintained together every six months or twice per year to prevent breakdowns and avoid excessive repair costs.
-

Table 21. The maintenance period of Water-cooled chiller

Number	Description	Maintenace cost
Schedule-1	Electric Chiller, Capacity: 71.08 RT	500$
Schedule-2	Cooling Tower (model MKX/XP)	200$
Schedule-3	Total water circulation pump-04 sets	200$
Schedule-4	VFD inverter for circulation pump	100$,
Schedule-5	AHU (Air-handling Unit)	200$
Schedule-6	Indoor Units of Water-cooled chiller	300$

The maintenance cost = 1500$

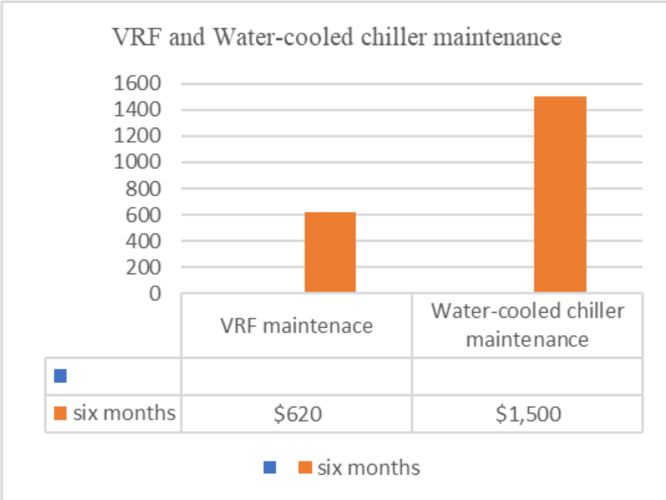

Fig. 5. The maintenance cost of VRF and Water-cooled chiller

6. RESULTS AND DISCUSSION

6.1. The Total Cost of VRF and Water-cooled chiller System

The project involves several stages, including investigation costing, operation cost, and the project involves several stages, including investigation costing, operation cost, and maintenance costing. The investigation costs are the most expensive stage, as they need to be separated into two parts: investment cost on material and investment cost on installation.

The total cost of the VRF was 95537$. The investigation cost was 89759$. The operation cost in 1 year 5158.84$ was and the maintenance cost in 1 year was 620$. The total cost of a Water-cooled chiller was 126887$. The investigation cost was 120369$. The operation cost in 1 year was 5017$, and the maintenance cost was 1500$.

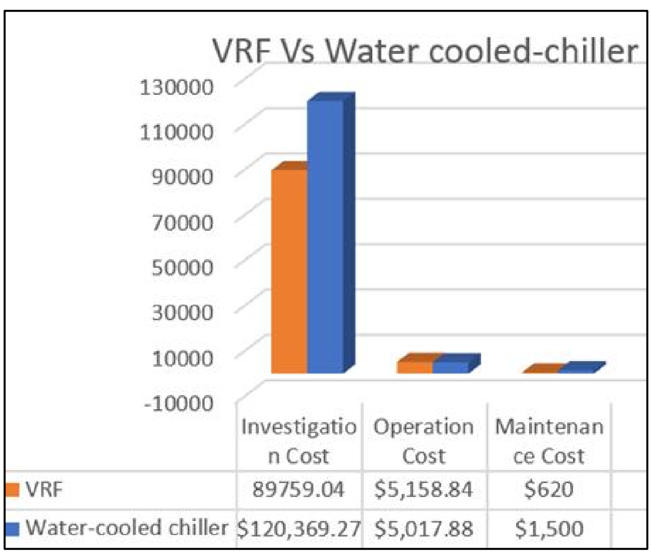

Fig. 6. The comparision cost of VRF and Water-cooled chiller

7. CONCLUSIONS

The techno-economic analysis of Variable Refrigerant Flow (VRF) and Water-cooled Chiller systems is crucial and beneficial. Once we have gathered the necessary data, conducting a survey should be our first step. The VRF system and Water-cooled Chiller have produced a result of 95537$ and 126887$ respectively. The bias of VRF and Water-cooled chiller were, the investigation of the Water-cooled chiller was more expensive than VRF 1.17 time, the operation cost of Water-cooled chiller was smaller than VRF 1.02 times and the maintenance cost of Water-cooled chiller was high-cost than VRF 2.41 times. The investigation of the VRF system is less expensive because the investigation cost of a water-cooled chiller requires more equipment such as cooling towers, pumps, and air handlers. Moreover, the investment installation cost of the Water-cooled chiller needs more people than the VRF system. For operational costs, the water-cooled chiller is smaller due to chillers are also more energy efficient, therefore, the operational cost lessens in the long run. Additionally, the maintenance cost of a water-cooled chiller is higher because the system in each component is more complicated than a VRF system, and need to spend more time handling it. Furthermore, all components in a water-cooled chiller require a higher budget and longer maintenance periods than VRF systems. This explains why a water-cooled chiller is more expensive than a VRF system. Future research should concentrate on utilizing alternative methods or software to verify results and enhance maintenance or software to verify results and enhance maintenance.

ACKNOWLEDGMENTS

I am grateful to the project owners of the Ministry of Tourism in Sihanouk Province for allowing me to conduct research and providing me with detailed information and support. I would also like to express my appreciation to my company and my senior for their assistance in giving me the necessary documents and recommendations.

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