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# Energy Performance Analysis of Variable Refrigerant Flow System Retrofit: A Building Consumption Comparison Study

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## ABSTRACT

This study investigates the energy-saving potential of retrofitting an academic building at Universiti Teknologi MARA (UiTM) by replacing a conventional water-cooled chiller system with a Variable Refrigerant Flow (VRF) system. The research focuses on the College of Built Environment's academic building, which has a total area of 251.68 m², comprising 3,441.76 m² of conditioned space. Using Option C of the International Performance Measurement and Verification Protocol (IPMVP), the study compared pre-retrofit (2019) and post-retrofit (2023) energy consumption data. The analysis revealed that the VRF system implementation resulted in a 15.13% reduction in total building energy consumption, from 32,233 kWh to 27,356 kWh. With air conditioning accounting for 66% of the building's energy usage, the retrofit achieves a significant decrease in the ACMV system's energy consumption from 21,273.78 kWh to 16,396.78 kWh. The economic analysis, based on TNB Tariff C1 (Medium Voltage General Commercial), demonstrates monthly cost savings of RM 5,411, equivalent to an annual reduction of RM 64,935. These findings provide empirical evidence supporting the effectiveness of VRF systems in achieving substantial energy and cost savings of academic building applications within Malaysia's tropical climate.

**Keywords**: VRF, energy performance, retrofit, IPMVP, academic building

### *Abbreviations*

| | |
|---|---|
| ACMV | Air Conditioning and Mechanical Ventilation |
| AHU | Air Handling Unit |
| AHRI | Air-Conditioning, Heating, and Refrigeration Institute |
| CAV | Constant Air Volume |
| CBE | College of Built Environment |
| CHWP | Chilled Water Pump |
| COP | Coefficient of Performance |
| CT | Cooling Tower |
| CWP | Condenser Water Pump |
| ECM | Energy Conservation Measure |
| EEV | Electronic Expansion Valve |
| 5FCU | Fan Coil Unit |
| FRS | Frequency Regulation Service |
| HAP | Hourly Analysis Program |
| IPMVP | International Performance Measurement and Verification Protocol |
| M&V | Measurement and Verification |
| MD | Maximum Demand |
| OA | Outdoor Air |
| SDG | Sustainable Development Goals |
| TNB | Tenaga Nasional Berhad |
| UiTM | Universiti Teknologi MARA |
| VAV | Volume Air Variable |
| VFD | Variable Frequency Drive |
| VRF | Variable Refrigerant Flow |
| WCH | Water-Cooled Chiller |

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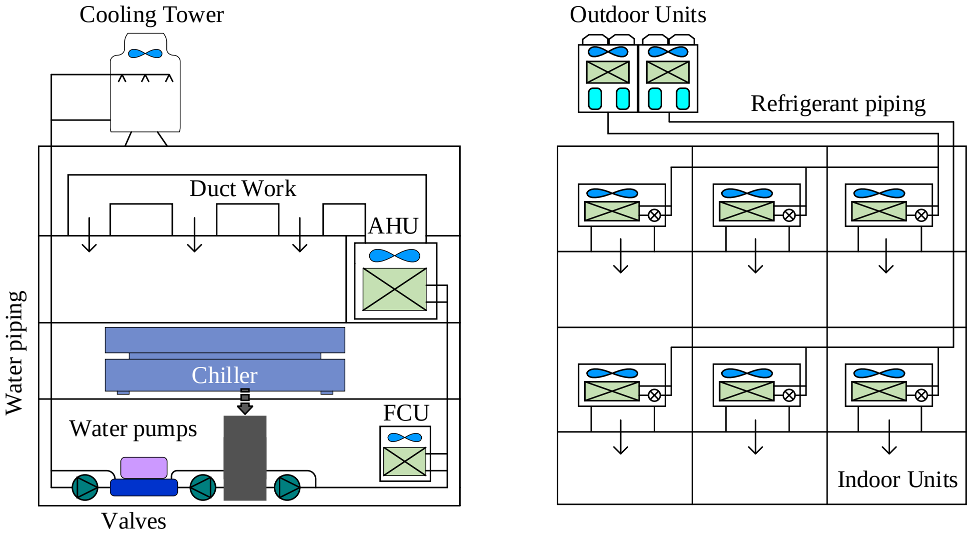
## 1.0 INTRODUCTION

Universiti Teknologi MARA (UiTM) ranks 107th globally and 6th in Malaysia in the UI GreenMetric ranking, demonstrating its strong commitment to advancing the SDG17 agenda [1]. Among various sustainability initiatives, UiTM focuses on energy saving as a key strategy to improve its ranking and achieve its goal of becoming a sustainable and smart campus. This endeavor is in accordance with the UiTM Energy Management Policy, which seeks to ensure that new development projects, renovations, and upgrades are economically viable while also minimizing energy usage and associated maintenance costs. Furthermore, this initiative aligns with UiTM's Strategic Plan 2025, specifically under Strategic Theme 8 (Smart Campus) [2], and and contributes to the university's commitment to sustainability, benefiting not only the institution but also its surrounding community and the global environment.

Energy consumption plays a vital role in urbanization, development, and modernization, particularly in rapidly developing countries experiencing increased energy intensity due to urbanization and population growth. The residential and commercial sectors accounted for 14% of national energy consumption in 2016, while globally, the building sector represents 20-60% of total energy consumption [3]. Air Conditioning and Mechanical Ventilation (ACMV) systems have emerged as major contributors to both industrial energy consumption and carbon emissions [4]. Despite their high power consumption, these systems offer significant potential for energy conservation and efficient regulation services. Their widespread presence in buildings and ability to regulate demand at various power levels creates opportunities for supplementary services [4].

One key development in ACMV technology involves two types of air-conditioning systems: inverter and non-inverter. The main difference lies in their compressors, which are the most energy-intensive components. Non-inverter AC compressors operate in binary ON/OFF modes, with their operational capacity determined by alternating between full power and zero power [5]. In contrast, inverter AC compressors can continuously adjust their speed through frequency modulation, enabling better power output management and FRS compliance [5]. The inverter technology optimizes air conditioner performance through precise motor speed control.

Among building ACMV technologies, Variable Refrigerant Flow (VRF) systems stand out for their exceptional energy performance in both heating and cooling applications. Following their debut in Japan's market during the 1980s, these systems gained significant traction internationally, with Europe adopting the technology in 1987 [6]. The United States later embraced VRF systems, which have since become a prevalent choice in commercial buildings [7], particularly after the 2010 introduction of ANSI/AHRI performance standards [8]. One key advantage of VRF technology lies in its retrofit versatility. The minimal ductwork requirements make these systems particularly attractive for building renovations compared to traditional ducted alternatives [9]. When evaluated against conventional cooling solutions like CAV, VAV, and FCU systems with fresh air capability, VRF installations demonstrate superior energy efficiency. Studies have demonstrated that VRF systems can reduce energy consumption by 40-53% when compared to VAV systems, with variations depending on temperature settings and operational modes [10]. The VAV system normally uses the chiller system (water side) to cool the air through the air handling unit (AHU). Figure 1 shows the schematic diagrams of the VAV system and VRF system, while the details of design and operation of both systems are presented in Table 1.



(a) (b)

**Figure 1.** Schematic diagram for ACMV system. (a) VAV with chiller system and (b) VRF system

Table 1: The design and operation characteristics for VAV with Chiller system and VRF system

| Feature | VAV - Chiller system | VRF System |
|---|---|---|
| System composition | • Chiller<br>• FCU<br>• AHU<br>• Cooling tower<br>• Water piping, Duct working<br>• Water pumps | • Outdoor Unit (air-cooled type)<br>• Indoor unit<br>• Refrigerant piping |
| Control system | • Complicated control structure, additional control manager in the system needed, increasing cost<br>• Third part control provider needed, interconnectivity problems | • Simple control structure No additional control provider<br>• Central control and energy monitoring with low cost available |
| Capacity control | • The systems commonly condition the entire building at predetermined times, with no regard to user demands | • The systems condition only the necessary rooms with regard to user demands |
| Temperature control | • Require 1ºC to 2ºC | • Very precise ±0.5ºC |
| Energy Efficiency | • Can be efficient if properly managed. Leaks in ductwork can waste conditioned air which reduces efficiency | • More energy efficient due to inverter technology that adjusts referigerant flow based on demand, reducing unnecessary energy consumption. |

VRF systems represent a sophisticated approach to building climate control, characterized by their modular architecture consisting of an outdoor unit connected to multiple indoor units through an intricate refrigerant piping network [10]. These systems are available in two primary configurations: heat pump type, which alternates between cooling and heating modes, and heat recovery type, which enables simultaneous cooling and heating operations across different zones. The systems' fundamental operation relies on variable speed compressors in the outdoor unit and electronic expansion valves (EEVs) in each indoor unit, allowing precise control of refrigerant flow rates in response to varying thermal demands [11].

Advanced VRF implementations demonstrate the capability to integrate up to 60 indoor units of diverse capacities with a single outdoor unit, while offering the flexibility of modulating evaporating temperatures to match specific cooling requirements [12]. Previous studies have demonstrated energy savings of 35% relative to central chiller/boiler-based systems in humid subtropical climates [13] and 30% compared to chiller-based systems in tropical environments. Additionally, VRF systems enhance occupant thermal comfort through their distinctive individual control capability [14].

In Malaysia, the discipline of Measurement and Verification (M&V) has matured into a well-established field for evaluating energy efficiency project outcomes. The practice now includes standardized protocols and professional certification pathways for practitioners. The fundamental role of M&V is ensuring that investments in building energy reduction initiatives achieve their intended results. This verification encompasses various project types, from comprehensive building renovations and equipment upgrades to changes in operational procedures and occupant behaviour. M&V plays a critical role in multiple contexts: government-sponsored energy programs, utility company incentive schemes, and performance-based energy contracts where savings are guaranteed. The methodology for calculating energy savings varies based on project scope, particularly the ratio of anticipated savings to total building energy consumption. For projects expecting substantial savings (exceeding 10% according to IPMVP criteria), practitioners develop a baseline model derived from utility consumption data [15].

At UiTM Shah Alam campus, VRF systems have been progressively implemented since February 2004, starting with the Faculty of Sports Science and Recreation (FSR) and expanding to other facilities, including the College of Built Environment (CBE). While efforts are made to enhance the efficiency of new constructions, retrofitting existing buildings is equally imperative for advancing energy sustainability. This research specifically examines the energy consumption dynamics at the CBE Academic Building, with the primary objective of quantifying and evaluating the potential energy savings achievable through VRF system implementation as an alternative to the existing water-cooled package system.

The paper is structured as follows: Section 2 and Section 3 describe the methodology and analysis methods, Section 4 presents the energy-saving performance and discusses the savings, and Section 5 concludes with main findings and suggestions for future work.

## 2.0 METHODOLOGY

The methodology of this study is divided into five main steps, as shown in Figure 2. Detailed explanations for these steps are discussed in subsections 2.1 to 2.4.

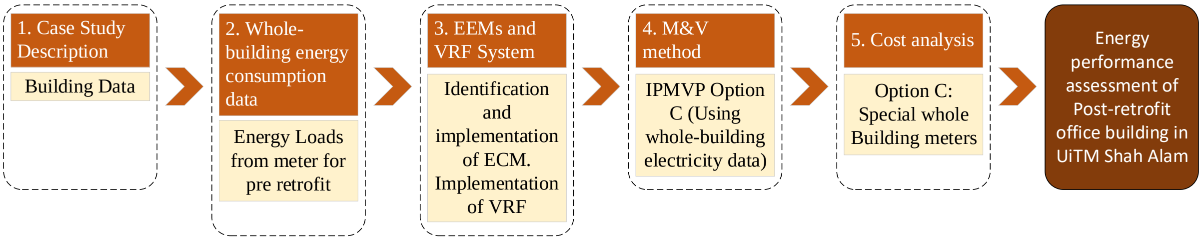


**Figure 2.** Research methodology flowchart

### 2.1 Case study description

The College of Built Environment (CBE) was selected for this case study. This building consists of lecture rooms and administrative offices. Two TNB substations serve the overall building complex at CBE. The assessment of the academic building included data collection encompassing various aspects such as the layout plan, energy consumption, and the classification of different areas within the building. The areas of the academic building are succinctly presented in Table 2. The total building area is 4,251.68 m², consisting of 3,441.76 m² of conditioned area and 809.92 m² of unconditioned area. The data were obtained from building as-built drawings made available to the authors.

**Table 2:** The area of accademic building

| Type of area | No |
|---|---|
| Lecturer room | 172 |
| Meeting room | 3 |
| Toilet | 18 |
| Head room | 9 |
| Dean room | 1 |
| Office Area | 15 |
| Pantry | 1 |
| AHU room | 2 |
| Electrical riser | 6 |

### 2.2 Data collection and pre-retrofit energy consumption

Figure 3 shows the annual electricity consumption audit at the College of Built Environment (CBE), UiTM Shah Alam. According to data collected from the Energy Management Department, the highest total electricity consumption was recorded in 2015 at 2,472.04 MWh, followed by 1,690.78 MWh in 2016 and 1,682.20 MWh in 2019. The electricity consumption encompasses all electrical appliances.

The energy distribution within the case study building, classified by end-use systems such as ACMV and lighting as well as various equipment and devices including pumps, elevators, and plug loads, is presented in Figure 3. The data clearly indicated that ACMV operations constitute the predominant portion of energy consumption, amounting to 66% of the total energy utilized by the building. Lighting and other equipment account for 15% and 19% of the building's energy consumption, respectively. Although direct measurements of the air conditioning consumption were not available, the energy consumption percentages were evaluated based on assumptions derived from previous studies by Alamin et al. [16].

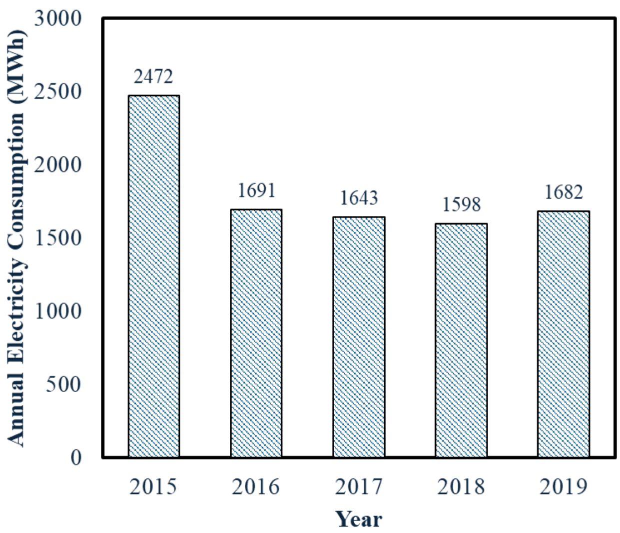


**Figure 3**. An annual electricity consumption audit in College of Built Environment (CBE) UiTM Shah Alam

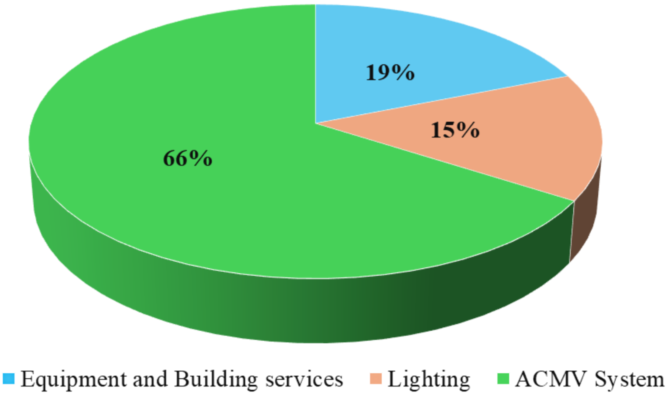


**Figure 3.** Energy distribution by end-use in a Malaysian institutional building [16]

### 2.3 Data collection and pre-retrofit energy consumption

The International Performance Measurement and Verification Protocol (IPMVP) provides four standardized options for measuring energy savings [17]:

- Option A: Evaluates installation adequacy following equipment replacement using engineering calculations to quantify energy savings.
- Option B: Measures savings at the device or system level post-project completion, utilizing engineering calculations.
- Option C: Determines savings at the whole-building level by analysing pre-retrofit and post-retrofit utility meter data, employing methods ranging from direct comparison to regression analysis.
- Option D: Calculates savings through energy simulation tools, particularly useful when direct measurements are not feasible.

This research implemented Option C methodology, as it aligns with the study's objective of analysing whole-building energy performance. The analysis utilized electricity meter data to measure and validate energy savings. The baseline consumption data from 2019, as shown in Figure 2, represent the pre-retrofit condition while measurements from 2023 constitute the post-retrofit data.

### 2.4 Coefficient of Performance

The coefficient of performance (COP) is a key metric for assessing an air conditioning system's efficiency. Calculating the COP is essential for evaluating system performance and quantifying potential energy savings through efficiency improvements. The COP for an air-conditioning system can be expressed using the equation (1) [18].

$$\text{COP} = \frac{\text{Total Heat Load}}{\text{Total Electrical Load}} = \frac{\text{kWt}}{\text{kWe}} \qquad (1)$$

The full load COP utilised in HAP program is derived from the full load power input and capacity of the water-cooled chiller and Variable Refrigerant Flow (VRF). The operational COP of a water-cooled chiller fluctuates based on the chilled water temperature, condenser water temperature, and load factor. The part load factor and external air temperature will influence the operational COP of the VRF system. In HAP program, COP values and the associated energy consumption for each system type are simulated by polynomial model using the hourly load profile and outdoor air temperature based on typical meteorological data (test reference years) for Subang, Malaysia.

### 2.5 Cost analysis

The economic benefits of the implemented Energy Conservation Measure (ECM) and the holistic energy retrofitting of the academic building are evaluated. The estimated savings are calculated as the difference between the baseline and current energy consumption of the whole building. The economic analysis utilizes the national electricity rates based on TNB Tariff C1 – Medium Voltage General Commercial Tariff, as shown in Table 3.

**Table 3:** Electricity Energy Tariff

| TARIFF CATEGORY | CURRENT RATES (1 JAN 2014) |
|---|---|
| TARIFF B – LOW VOLTAGE COMMERCIAL TARIFF | |
| For the first 200 kWh (1 – 200 kWh) per month | 43.5 sen/kWh |
| For the next kWh (201 kWh onwards) per month | 50.9 sen/kWh |
| The minimum monthly charge is RM7.20 | |
| TARIFF C1 – MEDIUM VOLTAGE GENERAL COMMERCIAL TARIFF | |
| For each kilowatt of maximum demand per month | 30.3 RM/kWh |
| For all kWh | 36.5 sen/kWh |
| The minimum monthly charge is RM600.00 | |
| TARIFF C2 – MEDIUM VOLTAGE GENERAL COMMERCIAL TARIFF | |
| For each kilowatt of maximum demand per month during the peak period | 30.3 RM/kWh |
| For all kWh during the peak period | 36.5 sen/kWh |
| For all kWh during the off-peak period | 22.4 sen/kWh |
| The minimum monthly charge is RM600.00 | |

## 3.0 RESULTS AND DISCUSSION

### 3.1 Building Description

An academic building formerly utilizing a water-cooled chiller system was upgraded with a new Variable Refrigerant Flow (VRF) system to replace the obsolete one. The facility encompasses a total air-conditioned space of 3,441.76 m², primarily designated for offices and lecture rooms, operating during standard business hours from 8:00 a.m. to 5:00 p.m. The specifications for the academic building's air conditioning system, both pre- and post-retrofit, are presented in Table 4.

**Table 4:** Air Conditioning System Specification

a) Pre-retrofit (Baseline): Water-cooled chiller system

| Component (Duty) | Duty Capacity (each) | Total electrical full load power (kWe) | Full load COP at AHRI condition |
|---|---|---|---|
| Two (2) x reciprocating WCH | 526.8 kWt | 283.2 | 3.72 |
| Two(2) x CHWP | 81.7 $m^3$/hr @ 33.0 m.wg | 24.8 | |
| Two (2) x CWP | 102.1 $m^3$/hr @ 18.5 m.wg | 17.4 | |
| Two (2) x CT | 791.3 kWt | 22 | |
| Total Full load Power Input (kWe) | | 347.4 | |
| Total Full load Cooling Capacity (kWt) | | 1053.6 | |
| Total System COP | | 3.03 | |

b) Post-Retrofit: Variable Refrigerant Flow (VRF)

| Component (Duty) | Duty Capacity (each) | Total electrical full load power (kWe) | Full load COP at AHRI condition |
|---|---|---|---|
| Eight (8) nos x 28.0 kW OA | 28.0 kWt | 6.95 | 4.03 |
| Twelve (12) x 33.0 kW OA | 33.5 kWt | 8.68 | 3.86 |
| One (1) x 100.0 kW OA | 100 kWt | 25.9 | 3.86 |
| One (1) x 142.5 kW OA | 142.5 kWt | 41.9 | 3.4 |
| Total Full load Power Input (kWe) | | 227.56 | |
| Total Full load Cooling Capacity (kWt) | | 868.5 | |
| Total System COP | | 3.82 | |

### 3.2 Energy Baselining

Regression models linking important variables to building energy consumption have been explored in numerous research studies [19-21]. Physical attributes such as gross floor area, building age, window-to-wall ratio, envelope element thermal transmittance values, occupant count, operating hours, and cooling/heating degree days are considered influencing factors in the majority of these studies. In determining the energy baselining of retrofitted buildings, three categories of independent variables are frequently utilized as input variables in residential and commercial buildings to construct energy baseline models: weather, time, and occupancy [22].

In the absence of comprehensive energy consumption data and related energy variables prior to retrofitting works, the energy baseline estimation is computed with the following assumptions.

i. Weather conditions are cyclical and no substantial difference in pre- and post-retrofit period.
ii. Operation time for the building remains constants throughout the year.
iii. Similar occupancy rate in pre- and post-retrofit period.
iv. Energy consumption for all lighting and equipment is consistent before and after the retrofit.

Based on these assumptions, the energy baseline for the retrofitted buildings is simply the reference pre-retrofit historical energy consumption obtained from the electricity bulk meter of Tenaga Nasional Berhad (TNB).

### 3.3 Total building energy consumption in baseline and post retrofit

The energy consumption data from December 2019, serving as the baseline period prior to the retrofit, were chosen to represent the total electrical load, which includes but not limited to the air-conditioning and mechanical ventilation systems, lights, plug loads, and other equipment. The actual energy reduction from the new Variable Refrigerant Flow (VRF) installation was determined by assessing the building's energy consumption one year after the VRF's commissioning. The energy baseline and post-retrofit energy consumption data are reported in Table 5 and illustrated in Figure 4. The realized energy reduction is given by equation (2).

Based on the prior assumption, the overall energy reduction in the building due to the installation of the VRF system is 15.13%, attributable to the enhanced efficiency of the VRF system compared to the previously existing water-cooled chiller system.

$$\text{Energy Reduction} = \text{Energy baseline} - \text{Post retrofit energy consumption} \quad (2)$$

**Table 5**: Total building energy consumption (energy baseline and post retrofit)

| | Baseline Dec 2019 | Post Retrofit Dec 2023 | Energy Reduction | |
|---|---|---|---|---|
| | | | Energy | % Reduction |
| Total energy consumption, kWh | 32,233 | 27,356 | 4,877 | 15.13% |

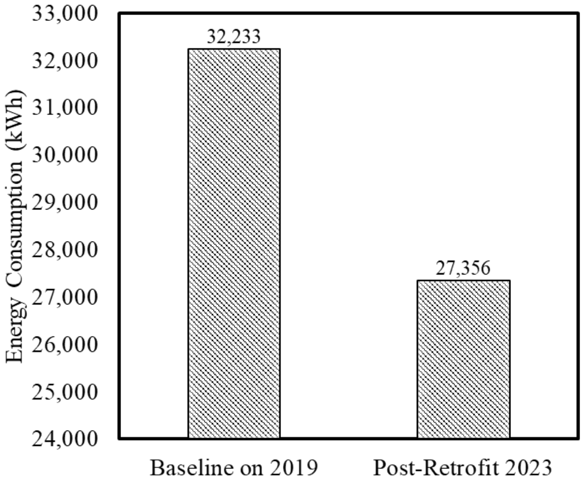


**Figure 4.** Energy baseline and post retrofitting energy consumption.

### 3.4 Baseline and pre retrofit energy consumption of air conditioning system

The energy baseline for the air-conditioning system cannot be reliably established due to the lack of baseline data for the water-cooled chiller system. Nevertheless, several research studies have indicated that in Malaysia, the energy consumption of air conditioning systems contributes between 55% and 70% of total energy consumption [16, 23-25]. A previous study at an educational facility in Malaysia revealed that the air-conditioning system accounts for almost 66% of the overall energy use at these institutions [16]. The building operating characteristics and total air-conditioned floor area in the study are relatively similar and thus used as the basis for estimating baseline air conditioning energy consumption of the building. In line with the previous assumption that energy consumption for all lighting and equipment remains consistent before and after the retrofit, energy consumption for the air conditioning system can be estimated as shown in Table 6 and depicted in Figure 5. The total air conditioning system energy reduction from the installation of the VRF system is 4,877 kWh, representing a 15.17% reduction from the baseline.

**Table 6:** Baseline and post retrofit energy consumption for air-conditioning system

| Application | Percentage from Total Building Energy | Energy Consumption (kwh) | |
|---|---|---|---|
| | | Pre-Retrofit | Post-Retrofit |
| Air-conditioning system | 66% | 21,273.78 | 16,396.78 |
| Other equipment | 34% | 10,959.22 | 10,959.22 |

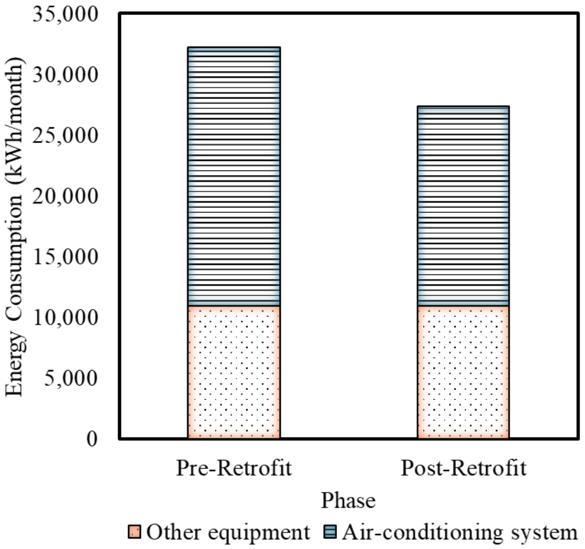


**Figure 5.** Energy comparison between baseline and post retrofit

### 3.5 Reduction in overall energy cost

The current TNB Tariff for the building is Tariff C1 - Medium Voltage General Commercial Tariff, as indicated in Table 7. The total energy cost for C1 tariff consists of maximum demand charge (MD) and energy charge (E). The MD reduction is determined by the difference in peak power between the pre-retrofit water-cooled chiller system and the post-retrofit VRF system. The disparity in peak power consumption between the two systems is 119.84 kW, which is the difference between total full load power input of the pre- and post-retrofit air conditioning systems (see Table 4). The air-conditioning system cost reduction is RM5,411.00. The details of cost reduction are shown in equations (3), (4), and (5). Table 8 illustrates the associated reduction in energy costs for the air conditioning system in the month of December.

$$\begin{aligned}\text{Maximum demand cost reduction (MD)} &= \left[\text{Baseline MD, kW - Post retrofit MD, kW}\right]\\ &\quad\times\left[\text{Maximum demand charge (RM/kW)}\right]\\ &= \left[347.4\text{ kW} - 227.56\text{ kW}\right]\times \text{RM}30.3 = \text{RM}3631.00 \end{aligned} \tag{3}$$

$$\begin{aligned}\text{Energy cost reduction (E)} &= \left[\text{Baseline energy consumption, kWh}\right.\\ &\quad\left.\text{- Post retrofit energy consumption, kWh}\right]\times\text{ Energy tariff (RM/kWh)}\\ &= \left[21{,}273\text{ kWh} - 16{,}396\text{ kWh}\right]\times\text{RM }0.365/\text{kWh} = \text{RM}1780.00\end{aligned} \tag{4}$$

$$\begin{aligned}\text{Total cost reduction in baseline period} &= \text{Maximum demand cost reduction + Energy cost reduction}\\ &= \text{RM }3631.00 + \text{RM }1780.00 = \text{RM }5411.00\end{aligned} \tag{5}$$

**Table 7:** TNB C1 Tariff Structure

| | |
|---|---|
| Maximum Demand Charge | RM 30.3/kWh |
| For all kWh | RM 0.365/kWh |

**Table 8:** Air Conditioning System Energy cost comparison

| Baseline (Dec 2019) | | | | Post retrofit (Dec 2023) | | | | Air Conditioning System Cost Reduction (RM) | |
|---|---|---|---|---|---|---|---|---|---|
| MD (kW) | E (kWh) | MD (RM) | E (RM) | MD (kW) | E (kWh) | MD (RM) | E (RM) | RM | % |
| 347.40 | 21,273 | 10,526 | 7,764 | 227.56 | 16,396 | 6,895 | 5,984 | 5,411 | 29.6% |

### 3.5 Discussion

Water-cooled chiller system replacement with the Variable Refrigerant Flow (VRF) system has resulted in a substantial reduction in energy usage and cost. The total air conditioning system energy savings of 15.13% (4,877 kWh) demonstrate that the VRF system functions with superior efficiency compared to the prior system. This reduction is attributed to both capacity reduction and system COP improvement, as tabulated in Table 9. The total cooling capacity of the VRF system is reduced by 17.6% from the existing system, yet it meets the building's cooling demand efficiently due to better load modulation and reduced overcooling. This might also indicate that the previous capacity was overestimated and thus operated at lower COP. The full load COP of the VRF system shows a remarkable improvement of 26% compared to the pre-retrofit system, resulting in lower energy consumption. This aligns with another comparative study that demonstrates VRF performance superiority over water-cooled chiller systems [26].

In actual field operation, chiller's COP varies under different load conditions, rather than remaining constant at full load. Malaysia Standard MS 1525: 2019 estimates that chillers typically operate 65% of the time at 50% load and only 1% of the time at 100% load [27]. Reciprocating water-cooled chillers regulate load mainly through cylinder unloading, which modifies chilling capacity by sequentially deactivating compressor cylinders. This technique employs solenoid valves to inhibit refrigerant compression in specific cylinders, thereby diminishing cooling output while maintaining compressor operation. However, it provides incremental modulation instead of seamless, continuous control, resulting in diminished temperature accuracy and reduced energy efficiency at partial loads compared to Variable Frequency Drive (VFD) control. The water-cooled chiller system utilizes a constant-speed pumping system and cooling tower fan, operating independently of the load, resulting in a relatively stable but lower COP. In contrast, the VRF system utilizing inverter technology dynamically modulates the compressor speed and associated refrigerant flow according to real-time demand, thereby substantially decreasing power consumption during off-peak hours.

To demonstrate the COP variation of both VRF and water-cooled chiller systems, hourly load simulation was conducted using Hourly Analysis Program (HAP) 5.11, an ASHRAE 140 approved energy simulation software, under similar weather conditions, typical occupancy of an academic building, and measured system COP. The simulation model is not intended to replicate the exact academic building but rather to assess both air conditioning systems' hourly COP in the months of December and July. The fluctuation of the hourly system Coefficient of Performance (COP) in December (baseline period) and July (the hottest month of the year) is illustrated in Figure 6. The average operating COP for the VRF system in December is 5.31 and 3.40 for the water-cooled chiller (WCC), owing to VRF's ability to modulate compressor speed at part-load conditions. The average operating COP in July is similarly shown for comparison purposes. The average operating COP for the VRF system and water-cooled chiller (WCC) in July is 3.45 and 3.20, respectively. Average COP for the VRF system shows substantial reduction from 5.31 in December to 3.45 in July, mainly due to the higher outdoor dry bulb temperature which negatively affects its COP value. Maximum dry bulb temperature in July is 33.7°C and 30.4°C in December based on test reference years (TRYs) weather data for Subang, Malaysia.

The combined impact of the VRF system's lower installed capacity and improved COP, particularly at partial load, contributes to lower energy consumption of the building. The analysis underscores the importance of considering part-load efficiency when selecting an air conditioning system replacement, as real-world operation rarely occurs at full load. While reciprocating water-cooled chillers maintain a relatively stable COP, their reliance on step-wise cylinder unloading results in lower efficiency at partial loads. In contrast, VRF systems, with their inverter-driven technology, dynamically adjust to cooling demands, significantly improving energy efficiency and reducing power consumption.

**Table 9:** Capacity and COP Comparison (Pre- and Post-Retrofit)

| System | Total Cooling Capacity (kWt) | Total Power Input (kWe) | Coefficient of Performance (COP) | Energy Reduction (%) |
|---|---|---|---|---|
| Water Cooled Chiller System (Reciprocating Compressor) | 1,053.6 | 347.4 | 3.03 | - |
| VRF System | 868.5 | 227.56 | 3.82 | 15.13 |

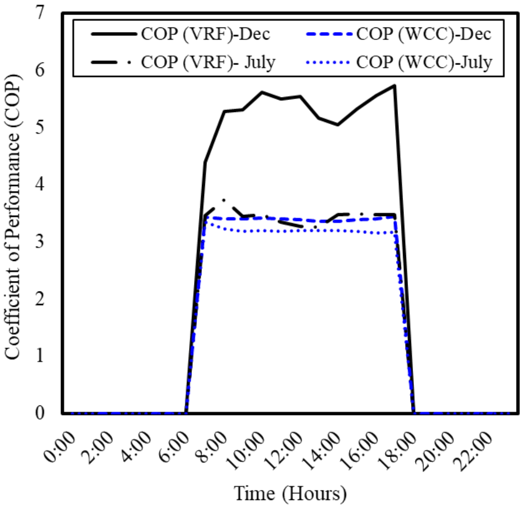


**Figure 6.** Hourly COP comparison between water-cooled chiller and VRF systems

## 4.0 CONCLUSION

This study demonstrates the effectiveness of replacing a conventional water-cooled chiller system with a Variable Refrigerant Flow (VRF) system in an academic building at UiTM's College of Built Environment. The key findings include:

1. Energy Performance:
    i. Achieved 15.13% reduction in total building energy consumption (4,877 kWh)
    ii. The VRF system's total cooling capacity was reduced by 17.6% while maintaining adequate cooling performance
    iii. System COP improved from 3.03 to 3.82 at full load conditions
    iv. In part-load operations, the VRF system achieved an average operating COP of 5.31 compared to 3.40 for the water-cooled chiller.

2. Economic Benefits:
    i. Monthly cost reduction of RM 5,411
    ii. Annual cost savings of RM 64,935, representing a 29.6% reduction in air conditioning system energy costs
    iii. Reduced maximum demand charges due to 119.84 kW lower peak power consumption.

3. Technical Advantages:
    i. Superior part-load performance through inverter-driven technology
    ii. Better load modulation and reduced overcooling
    iii. More efficient operation during off-peak hours
    iv. Enhanced temperature control accuracy.

These findings validate the effectiveness of VRF systems in tropical climates, particularly for academic building applications. The success of this retrofit project can serve as a reference for similar building upgrades in Malaysia's educational sector. Future research should focus on long-term performance monitoring, maintenance requirements, and the potential application of this technology in different building types and operational conditions.

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## DECLARATION OF COMPETING OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## AUTHORS CONTRIBUTION

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by M.A. Adul Aziz, A. Jaafar, and M. F. Mohamad. The first draft of the manuscript was written by A. Abd Razak and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript**.**

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