Kufa Journal of Engineering
Vol. 16, No. 4, October 2025, P.P. 524-539
Article history: Received 16 January 2025, last revised 4 March 2025, accepted 21 March 2025

COMPARATIVE STUDY OF ENERGY CONSUMPTION OF MODERN AND TRADITIONAL AIR-CONDITIONING SYSTEMS IN A RESIDENTIAL COMPOUND

Feras Mutar Khalaf [1], Hussein S. Sultan[2], and Ahmed Kadhim Alshara[3]

[1] **Lecturer at Department of Mechanical Eng., Faculty of Eng., University of Basrah, Iraq. Email: feras.khalaf@uobasrah.edu.iq.**

[2] **Professor at Department of Mechanical Eng., Faculty of Eng., University of Basrah, Iraq. Email: hussein.sultan@uobasrah.edu.iq.**

[3] **Professor at Department of Mechanical Eng., Faculty of Eng., University of Misan, Iraq. Email: dr.ahmed_alshara@uomisan.edu.iq.**

https://doi.org/10.30572/2018/KJE/160430

ABSTRACT

The main purpose of this study is to investigate potential energy savings by considering two different air-conditioning systems, constant refrigerant flow (CRF) and variable refrigerant flow (VRF) systems, in a new residential compound in Basra, Iraq, where extreme temperature and humidity are observed beside facing a shortage in electrical power supply. One- and two-storey houses were considered, and the initial, installation, maintenance, repair, and energy costs for each AC system were accounted for. The required cooling loads were calculated using Carrier's Hourly Analysis Program (HAP 5.1). The findings revealed that although the VRF system exhibited a higher initial price than the CRF system by 20 % and 41 % for one- and two-storey houses, respectively, its monthly operating cost was lower by 16 % and 19 %, respectively. The energy savings percentage achieved using VRF compared to CRF in the 10th year was 20 % and 22 % in one- and two-storey buildings, respectively. The results demonstrated that implementing VRF systems can save power and minimize electricity waste in residential buildings, which may amount to significant savings in electricity consumption in buildings and compounds constructed in the future.

KEYWORDS

Constant Refrigerant Flow, Variable Refrigerant Flow, Life Cycle Cost, Hourly Analysis Program, Energy Savings, Residential Complex.

1. INTRODUCTION

In commercial buildings, thermal comfort significantly influences the well-being of occupants and the productivity and effectiveness of workers. For this reason, the use of air-conditioning (AC) in such buildings is becoming increasingly prevalent.

Cooling demands account for nearly 2.9 % and 6.7 % of the global electricity consumption in residential and industrial buildings, respectively (Santamouris, 2016). Climate change, population growth, and an increase in income could increase this figure further by 2050. In 2010, the global cooling demands of the residential sector accounted for nearly 4.5 % of the total AC requirements of residential construction; this rate is expected to increase to as much as 34 % by 2050 and 61 % by 2100 (Santamouris, 2016). The average energy demands for cooling in residential and commercial buildings are estimated to increase by 750 % and 275 % by 2050, respectively (Santamouris, 2016).

Many techniques, some simple and others advanced (Kheioon et al., 2023), are used to study each part of AC systems and connections to minimize system losses and increase efficiency.

In Iraq, temperatures have increased by 1.8 °C above the global average in the last 30 years as per the data published by Berkeley Earth, with recent summer temperatures frequently reaching 50 °C. According to the United Nations, five provinces in Iraq are threatened by climate change (Louisa Loveluck and Mustafa Salim ,2022).

In southern Iraq, the average temperature gradually increases as the year progresses, with extreme temperatures starting in May and peaking in July and August. Basra has become one of the hottest regions in the world in recent years (Naser Haider Hakeem and Hammadi Salman Hashim ,2022). As a result, its residential buildings consume the highest proportion (more than half) of the country's total energy consumed by AC systems (Hattab, 2010).

Three new residential compounds were initiated in 2023. The Al-Andalus Urban Complex is located in Basra in the Abu Al-Khasib district, for a population of 4,944 people. The second compound is the Al-Safaa residence located on Shatt al Basra’s banks, accommodating 11,142 residents. Finally, the new Modern Basra City is located close to Basra’s Sports City for 8,316 people (Al-Baaj and Alsaatee, 2023).

With the recent increase in the number of residential compounds in Basra, controlling the energy consumed by AC systems has become essential. A comparative study between traditional and modern AC systems may be particularly insightful as the aforementioned new compounds use traditional AC units.

Space cooling exhibits the highest growth in energy consumption among all end uses in buildings. The increasing need for cooling is driven by economic and population growth in the warmer parts of the world. In the long run, actions taken to improve the energy efficiency of building envelopes will result in a considerable reduction in energy consumption.

Many studies have discussed this problem and attempted to suggest practical solutions. A strategy for sizing and choosing variable refrigerant flow (VRF) systems and calculating their yearly energy usage was used to evaluate the cooling energy consumption of a packaged variable air volume (VAV) system, a traditional chiller-based VAV system, and a VRF system at a typical light business center.

Observations revealed that during the cooling season, the VRF system's peak electrical demand was approximately 60 % of that of the chiller-based VAV system and 70 % of that of the packaged VAV system. In the building under study, the operating energy consumption was approximately 53 % of that of the chiller-based VAV system and 60 % of that of the packaged VAV system. (Koh, Zh ai and ic R iva, 2009).

A lifetime cost assessment was conducted using comprehensive cooling and electrical usage profiles to estimate initial and operating costs of residential (constant refrigerant flow, i.e., CRF), commercial (VAV), and multi-power AC systems (VRF), and assess their financial viability. Findings revealed that the CRF system was less expensive than the VAV and VRF systems in terms of initial cost by approximately 53 % and 67 %, respectively. On the other hand, the VAV system exhibited a lower running cost than the CRF and VRF systems by approximately 12 % and 7 %, respectively, when a single month was considered (Salim Badran Mohammed ,2014).

An analysis and comparison of the performance of VAV and VRF cooling systems across 16 climatic regions in the United States, utilizing the comprehensive building energy modeling program Energy Plus 8.4, indicates that VRF models demonstrated potential annual HVAC site energy savings ranging from 14% to 39% in comparison to VAV systems. Consequently, VRF models demonstrated superior cost-saving potential compared to VAV variations, particularly in hot and moderately hot climates (Kim et al., 2017).

An examination of the annual energy consumption of a multi-split-type ceiling cassette air conditioning and mechanical ventilation (ACMV) system in a tropical building compared to a VRF system indicated that the ACMV system's energy consumption was 13.62% greater than that of the VRF system. The VRF system's annual operating cost was noted to be 13.63% lower than that of the ACMV system (Yau and ‘Amir, 2020).

Cost analysis was performed to assess the economic viability of VRF, VRF duct types, and conventional AC systems. The VRF system was revealed to be 15 % less expensive than traditional AC systems, and throughout the heating and cooling seasons, it used 17 % and 73 % less energy, respectively, than the rooftop system (Shawkut Ali Khan and Iftakharul Muhib, 2021).

A case study was performed in Qatar to compare the overall expenses of two alternative systems (CRF and VRF) over 15 years using the cost technique. The CRF system was observed to incur an additional expense of 18,000 QAR annually to repair damaged compressors. The well-known Program (HAP 4.9) is used to calculate the cooling load. The results revealed that the VRF system required a higher initial cost; however, after five years, its operation became more profitable. Power input consumption of VRF was 27 % lower than that of CRF. This indicated that the implementation of green construction practices, such as VRF technology, in the AC industry could have a significant national impact (Atallah & Tarlochan, 2021).

The results of using the EnergyPlus building simulation program to simulate weather conditions of an office building in Hyderabad, Pakistan, revealed that the office building's power usage was significantly reduced when VRF AC systems were used instead of traditional AC systems. VRF air conditioners are known to preserve power by up to 43.6 %. Based on its results, the study strongly recommended using VRF air conditioners instead of conventional ones to achieve greater price reductions and reduced energy consumption (Hamza Shaikh et al., 2023).

Recent studies have examined and validated the benefits of contemporary HVAC technology and its substantial impact on decreasing power usage. Based on the previously described findings, this research aims to attain significant power savings by installing contemporary air conditioning units in a new complex in Basra.

2. RESIDENTIAL COMPLEX

In this study, we focused on the residential complex, Al-Amal, located 2 km south of the Basra International Stadium (30.42 ^{o} E and 47.78 ^{o} N). We considered two types of buildings—single-storey residential units (F) and two-storey residential units (E). The compound contained 128 two-storey and 576 single-storey residential units. Each one-storey house consisted of a reception, kitchen, living room, master bedroom, and children's bedroom, whereas each two-storey house consisted of a reception, kitchen, living room, and guest bedroom on the ground floor, with master and children's bedrooms on the first floor. The details of each zone of the two building types are listed in Table 1. Fig. 1 and 2 present the architectural plans of type-E buildings, whereas Fig. 3 presents those of the type-F buildings. All buildings in the compound used traditional CRF wall-mounted split-unit AC systems.

Table 1 Architectural details and areas (in m2) of each building type

Two-Storey Building Types (E)		One-Storey Building Types (F)	
Total Building Area	258	Total Building Area	171
Kitchen Area	15.2	Kitchen Area	21.4
Reception Area	20	Reception Area	24.96
Living Room Area	23	Living Room Area	27.3
Guests Bed Room Area	17.6	Master Bed Room Area	16.2
Master Bed Room Area	22	Children's Bed Room Area	15.8
Children's Bed Room Area	15.2		

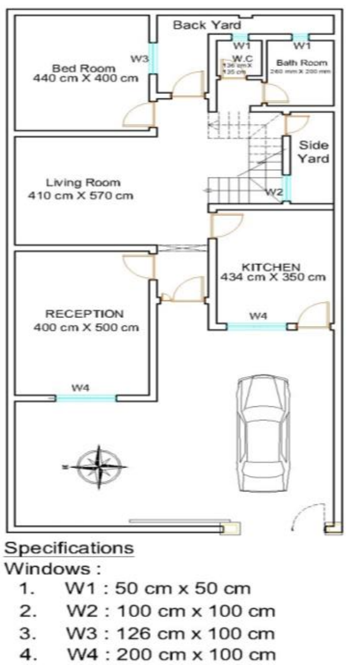

Fig. 1. Ground floor layout of two-storey house

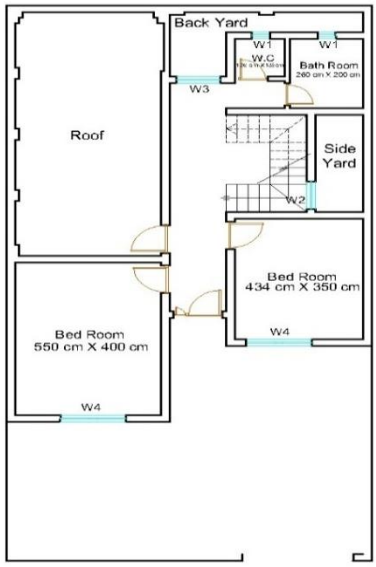

Fig. 2. First floor layout of two-storey house

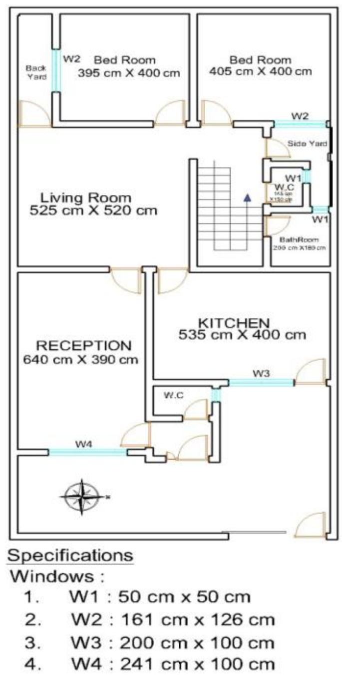

Fig. 3. Single-storey house layout

The necessary information and specifications of each building, including drawings, dimensions, and details of the wall floor and roof construction, were obtained from the sales office of the company responsible for building the residential complex and collected during periodic site visits to the compound during and after the construction period. All necessary details pertaining to the walls, roof, and floor structures are listed in Table 2.

The overall heat transfer coefficient (U) for unit area in W/m^2·K and is equal to the inverse of the total thermal resistance. (YUNUS A. ÇENGEL and AFSHIN J. GHAJAR, 2011)

$$U = \frac{1}{R_{total}} \quad (1)$$

where R_{total} denotes the total thermal resistance,

$$R_{total} = R_{conv,i} + R_{cond,1} + R_{cond,2} + R_{cond,3} + R_{cond,4} + R_{conv,o} \quad (2)$$

Besides Table 2, all considered thermal properties of the building materials are listed in Table3, computed based on more than one source to ensure accuracy (American Society of Heating Refrigerating and Air-Conditioning Engineers., 2017; The Republic of Iraq Ministry of Construction and Housing and Municipalities and Public Work, 2025; YUNUS A. ÇENGEL and AFSHIN J. GHAJAR, 2011).

Table 2 Space construction components

Part	U value (W/m^2.K)	Details
Roof	1.686	10 mm Juss plaster + 150 mm HD concrete + 70 mm Dry sand + 40 mm concrete tiles
Internal Wall	1.510	13 mm Gypsum plaster + 20 mm Cement plaster + 240 mm Common brick + 20 mm Cement plaster + 13 mm Gypsum plaster
External Wall	1.712	13 mm Gypsum plaster + 20 mm Cement plaster + 240 mm Common brick + 20 mm Cement plaster
Floor	0.568	40 mm cement mortar + 10 mm Porcelain tile

Table 3 Thermal properties of construction materials

Material	Density (kg/m^3)	Specific heat (kJ/kg·K)	Thermal conductivity (W/m. K)
Gypsum plaster	1680	0.84	0.80745
Cement plaster	1860	0.84	0.71942
Common brick	1922	0.84	0.72072
Juss plaster	806	0.84	0.16020
HD concrete	2200	0.84	1.27986
Concrete tiles	2258	0.84	1.80180
Dry sand	1515	0.80	0.33000
Porcelain tiles	2387	0.792	1.484
Cement mortar	1900	0.960	1.5

The interior air conditions required are 26 °C dry bulb temperature and 50 % relative humidity. Outdoor conditions, according to the ASHRAE Climatic Design Conditions (ASHRAE climatic design conditions), are summer dry bulb temperature of 49.1 °C, wet bult temperature of 21.5 °C, and daily range of 17.7 °C.

3. TYPES OF MODELS OF ACS USED

An LG wall-mounted ductless split AC unit with BMPN 19K1 LG dual-inverter T3 compressor 18000 BTU was used in this study. The outdoor VRF models recommended by ALHAFIDH were VR10OD7 and VR12OD7 for the one- and two-storey houses, respectively. The chosen unit models were selected because of their suitable prices for local consumers, service reliability, and warranty periods.

Because VRF are ductless HVAC systems and their internal indoor-unit indirect direct units (IDUs) are the same as the split units, they can be used without any additional construction in old houses by leveraging pre-existing IDUs. Both AC types, VRF and split unit, can be seen in Fig. 4 and 5.

Additional specifications and features of the LG AC (LG .com) and ALHAFIDH VRF models (ALHAFIDH GROUP, 2023) are listed in Table 4 below. In this study, we assumed that the

AC systems were operated 16 hours daily for nine months each year, considering 8 working hours outside the house.

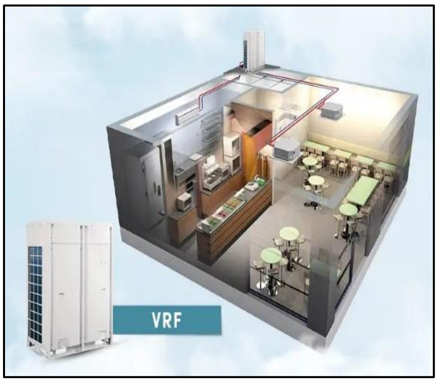

Fig. 4. VRF system type

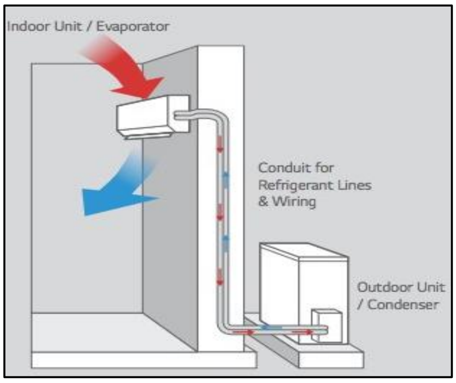

Fig.5. AC Split unit type

Table 4 Technical specifications of AC systems

LG split CRF AC unit BMPN 19K1	
Initial cost	960,000 IQD
Installation cost	50,000 IQD
Refrigerant R410A gas	1.4 kg
Power consumptionT3	1754 W
Nominal cooling capacity T3	15300 Btu/h
Warranty for T3 inverter compressor	10 years
ALHAFIDH VRF unit VR12OD7	
Initial cost out door unit	3,900,000 IQD
Initial cost in door unit VRW 18 ID	300,000 IQD
Total installation cost for all system	4,650,000 IQD
Warranty for inverter compressor	10 years
Power consumption	11.67 KW
Refrigerant R410A gas	6.2 kg
Nominal cooling capacity	102000 Btu/h
ALHAFIDH VRF unit VR10OD7	
Initial cost out door unit	3,300,000 IQD
Initial cost in door unit VRW 18 ID	300,000 IQD
Total installation cost for all system	1,500,000 IQD
Warranty for inverter compressor	10 years
Power consumption	8.11 KW
Refrigerant R410A gas	5.3 kg
Nominal cooling capacity	85,000 Btu/h

4. METHODOLOGY

4.1. Load Calculations

Load calculations were performed using the HAP software developed following the ASHRAE standards. HAP is a software tool that helps engineers design HVAC systems for commercial buildings. HAP 5.1 computes load using ASHRAE's transfer function technique (TFM) and analyzes power using 8,760 comprehensive hour-by-hour modelling methodologies.

The HAP results revealed highly accurate and reliable values compared to other methods for cooling load calculations, as reported by many researchers (Al Abir, 2019)

All values were verified to lie within the permissible ranges specified by the Republic of Iraq

Ministry of Construction and Housing and Municipalities and Public Works (The Republic of Iraq Ministry of Construction and Housing and Municipalities and Public Work, 2025).

At the site of the residential complex considered in this study, the most severe summer months are June, July, and August (Khrebish and Sultan, 2021). The outdoor HAP simulation results revealed that the maximum temperature was achieved in July, which was very close to the maximum value in August. Fig. 6 depicts the dry-bulb temperatures for two months—June and July. The maximum estimated cooling load values for each zone and unit are summarized in Table 5. The capacity and quantity of the chosen units corresponded to the computed peak cooling load during the hottest period of the day in sever summer month, July.

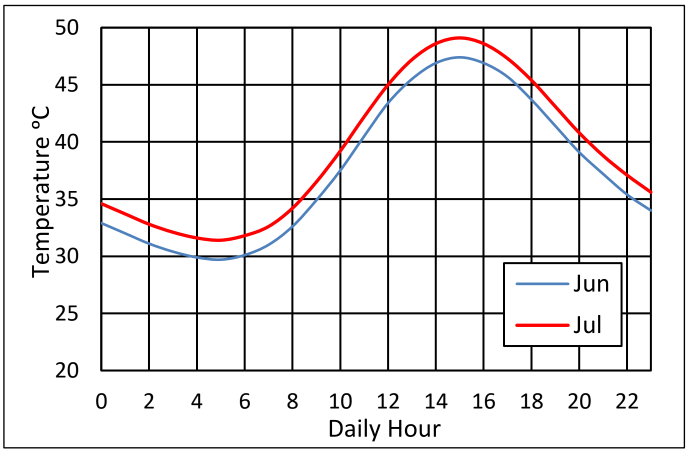

Fig. 6 Dry bulb Temperatures over two months

Table 5 Estimated cooling load values in refrigeration ton (RT)

Cooling Load Buildings Type (E)		Cooling Load Buildings Type (F)	
Kitchen	2.3	Kitchen	2.6
Reception	1.2	Reception	1.5
Living Room	1.1	Living Room	1.3
Guest Bed Room	1.0	Master Bed Room	1.0
Master Bed Room	1.4	Children's Bed Room	1.0
Children's Bed Room	1.0		
Total cooling load	8.1	Total cooling load	7.0

The cooling capacities of the selected VRF and split outdoor units were equal to or very close to the total cooling load required for each house and zone obtained via HAP, as listed in Table5. The VR10OD7, including five indoor units, was chosen to meet the specifications for building type (F), whereas the VR12OD7, with six indoor units, was picked for building type (E). Five and six split-type air conditioning units also provided the necessary cooling load for building types (F) and (E), respectively.

4.2. Cost Estimation

AC systems consist of mechanical parts and electrical circuits that may malfunction and need to be repaired. Moreover, their electricity consumption is also expensive.

All values considered in this model were actual local values obtained from trusted service agencies and maintenance at the time of research and not theoretical values.

The essential parts of an AC system include the compressor, evaporator, condenser coils, controls, motor, and fans. For all types of AC systems, all expenses over the entire lifetime period were considered. These were classified into the following categories.

4.2.1. Initial cost

The initial cost depended on the unit's type, model, and brand, as specified by the manufacturer and local agency in the area. Table 2 lists the initial costs of the CRF and VRF units under study, as per the local exclusive agent for LG and ALHAFEDH in Basra, Iraq (ALHAFIDH GROUP, 2023; LG .com).

4.2.2. Installation cost

The installation cost was determined by the size, weight, brand, and type of the unit, besides the building layout and number of stories.

The installation cost represents the price of labor and the materials required to install the AC equipment. After surveying all workshops approved by international agencies and qualified persons, we obtained the installation costs for all AC systems from the local market, as listed in Table 2.

4.2.3. Energy cost

Energy usage (EU), expressed in kWh, depends on the unit capacity, energy efficiency ratio (EER), and operating time (Almutairi et al., 2015) , and is given as follows.

$$EU = \frac{Unit\ Capacity}{EER} \times Operating\ time \qquad (2)$$

Thus, the energy cost (EC), expressed in IQD, may be obtained if the cost per unit of energy (CUE), expressed in (IQD/Kw.h), is known (Sukri and Jamali, 2018), i.e.,

$$EC = EU \times CUE \qquad (3)$$

Electricity consumption accounts for the contributions of both indoor and outdoor units of AC systems. Table 6 lists the different consumption classes and corresponding electricity unit costs as defined by the Ministry of Electricity in Iraq (“Iraqi Ministry of Electricity”).

4.2.4. Repair cost

In general, the time and price required to repair faults are unpredictable. However, Rosenquist et al. suggested the following relationship between the repair cost (RC), IC, and unit lifetime (Rosenquist et al., 2004).

$$RC = \frac{0.5\ \times IC}{Unit'sLife\ Time} \tag{4}$$

According to ALHAFIDH, main service centers in Basra (ALHAFIDH GROUP, 2023) and LG service centers in Basra (LG .com) we proposed that each air unit has a lifespan of 10 years (the value guaranteed by the manufacturer of the tropical compressor), while the entire VRF system has a 5-year warranty.

Therefore, in our calculation, we only considered the RC incurred by leakage in an AC unit, and did not consider compressor replacement as it was within the warranty period during the study period.

Table 6 Consumption classes and corresponding electricity unit costs in Iraq

Consumption Class	Cost of Energy Unit in IQD (KW/h)
Residential Consumption	
1–1500	10
1501–3000	35
3001–4000	80
4001 or more	120
Commercial Consumption	
1–1000	60
1001–2000	80
2001 or more	120
Industrial Consumption	
All Categories	60
Governmental Consumption	
All Categories	120
Agricultural Consumption	
All Categories	60

4.2.5. Maintenance cost

To guarantee the optimal operation of AC units, manufacturers often suggest cleaning the filters every two weeks and cleaning the evaporator of indoor units. Almutairi et al. stated that the MC of an AC unit over its lifetime amounts to 2.5 % of the unit cost (Almutairi et al., 2015).

Most homeowners in Iraq perform maintenance and cleaning by themselves, and the corresponding cost is very small compared to the RC; therefore, MC was not be considered in this research.

4.2.6. Operational Cost

Power intake relies on three elements—the yearly operation hours, the capacity of the unit, and its EER, which represents the ratio of the cooling capability, expressed in BTU/h, to the input power, expressed in W, represented as a percentage.

Operating costs include electricity consumption, RC, and MC. The electrical operating cost represents the expenses required to operate the interior and exterior units of the AC system.

Maintenance and repairs are performed once per season, while electricity consumption is measured monthly. Thus, the monthly running cost of an AC unit primarily comprises the cost of the electricity consumed.

In this study, each unit was assumed to be operated for 19 hours per day, 30 days per month, and 9 months per year. The operational cost model is as follows (Salim Badran Mohammed, 2014):

$$\begin{aligned} &Operational\ Cost\ per\ Month \\ &\qquad = Amount\ of\ Energy\ (Kw) \times Operating\ Time\ (hours) \\ &\qquad \times Electricity\ Fees \times 30\ Days \end{aligned} \tag{5}$$

4.2.7. Life-Cycle Cost

Life cycle cost (LCC) represents the overall price paid by the customer over the lifetime of the AC unit. This consists of purchase and operational expenses (including energy costs, repairs, and maintenance). The initial and ongoing expenses of AC systems considered in this study were examined using LCC analysis. AC systems exhibit 10-year lifespans as per the warranty of tropical compressors offered by both LG and ALHAFIDH. A suggested formulation for LCC is as follows (Lekov et al., 2012):

$$LCC = INSC + IC + \sum_{t=1}^{N} \frac{Running\ cost_t}{(1+r)^t} \tag{6}$$

Where INSC denotes the installation cost of the AC system in IQD, IC denotes the initial cost of the AC system in IQD, r is the discount rate, t is the year for which operating cost is being determined, and N is the lifetime of the appliance in years

In Iraq, no discount rate is considered for electricity consumption, as instructed by the Ministry of Electricity; thus, the following equation was obtained.

$$LCC = INSC + IC + \sum_{t=1}^{10} Running\ cost \tag{7}$$

In the LCC calculation, we accounted for MC and RC incurred over a 10-year of operational period for each AC system, with the operational cost given as follows.

$$Operational\ Cost = EC + RC + MC \tag{8}$$

5. RESULTS AND DISCUSSION

In this study, two different AC systems, VRF and CRF, were investigated in one- and two-storey building types in an Al-Amal residential complex in Basra, Iraq. Different types of AC systems were compared in terms of the initial, installation, maintenance, operating, and repair costs.

As is evident from Fig. 7 and 8, the VRF AC system exhibited a lower operational cost percentage than CRF, which exhibited values of 16 % and 19 % per month in single-storey, and double-storey buildings, respectively. Thus, over a single operational year, the savings in operational costs were expected to reach 144 % and 171 % in single- and double-storey buildings, respectively. In IQD, the one-year running cost savings were equal to 234,000 IQD and 469,000 IQD in single-storey and double-storey buildings, respectively. If these systems were implemented on all buildings in the residential compound, the total savings in operational costs, were calculated to have reached 195 million IQD per year, indicating an effective reduction in electricity consumption.

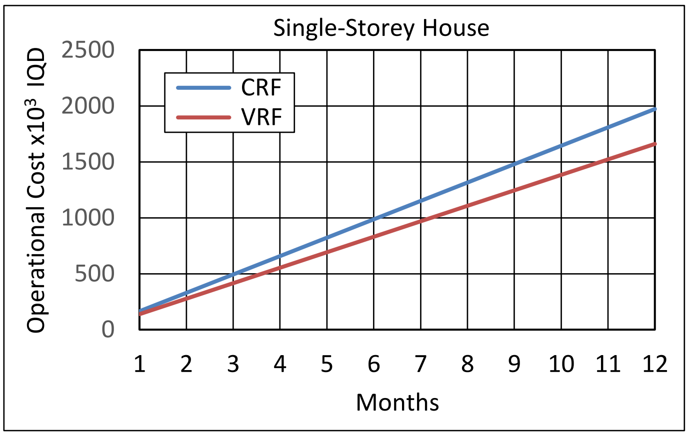

Fig. 7 Operational cost of CRF and VRF AC systems in single-storey building

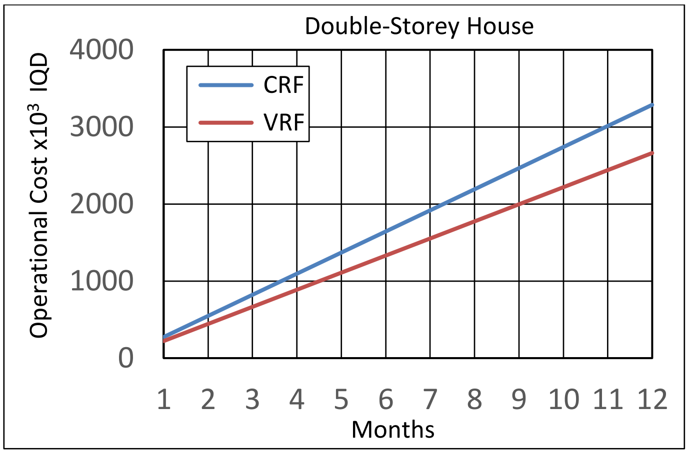

Fig. 8 Operational costs of CRF and VRF AC systems in double-storey buildings

6. LCC ANALYSIS

As expected, even though the initial cost of the VRF AC system was higher than that of the CRF system, the LCC graphs of both AC types intersected at the break-even point (BEP) point before the second year, as depicted in Fig. 9 and 10, subsequently, VRF takes precedence over CRF owing to reversal flipping. The BEP represents the point where the costs are equal with no net loss or gain. The energy savings percentage achieved by VRF compared to CRF in the

10^{th} year was 20 % and 22 % in single-storey and double-storey buildings, respectively. These percentages amounted to 3 million IQD and 5.4 million IQD for a single occupant in single- and double-storey buildings, respectively. Thus, the implementation of VRF AC systems in all compound buildings was calculated to yield savings of 2.5 billion IQD in the 10^{th} year of operation.

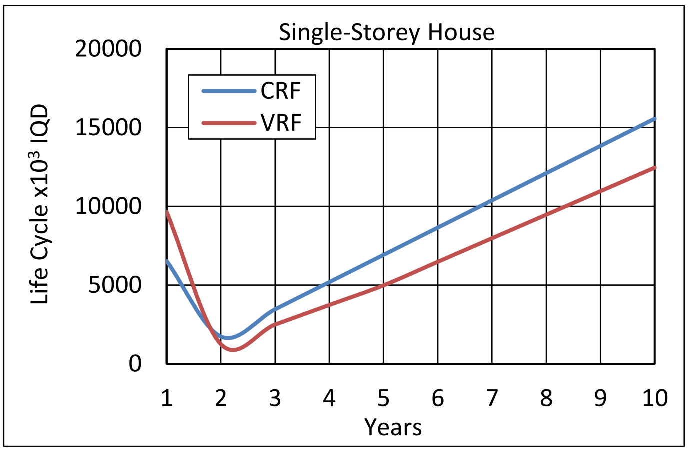

Fig. 9 LCC of CRF and VRF AC systems in single-storey buildings

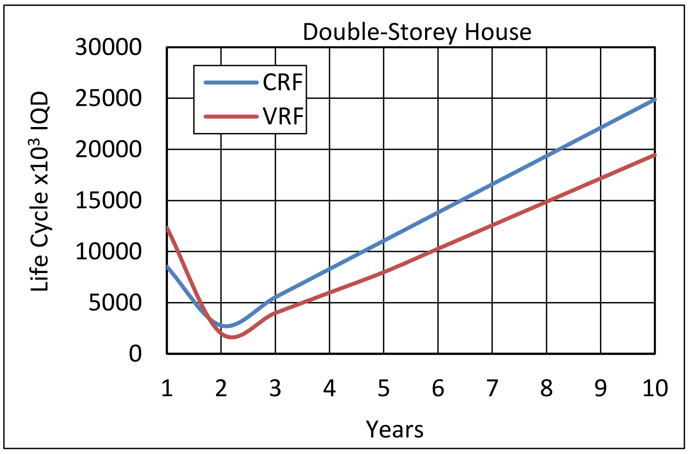

Fig. 10 LCC of CRF and VRF AC systems in double-storey buildings

7. CONCLUSIONS

In this study, we obtained actual local prices and information gathered from local trusted maintenance agencies to investigate the effect of replacing CRF split units with VRF systems in real buildings.

The results revealed that with progression in operating hours, VRF systems became more advantageous than CRF ones in terms of energy savings and RC. Thus, we deemed the VRF system to be more reliable, especially in severe humid and hot weather.

The proportion of energy savings and the operational hours each day were chosen for the parametric evaluation because they have a significant influence on and are directly linked to the everyday lives of consumers. The VRF system exhibited lower operational cost percentage than CRF by 16 % and 19 % per month for single-storey and double-storey buildings, respectively.

The VRF system's initial cost was higher than that of the CRF system, but after a couple of years, their operating costs became equal, and subsequently, the VRF system became more economically efficient. According to the supplier maintenance team records, VRF units did not need any repair except for annual cleaning and services over the warranty period and a few subsequent years. However, the MC and RC of CRF systems were observed to increase annually as the systems became outdated.

The energy savings percentage achieved using VRF compared to CRF in the 10th year was 20 % and 22 % in single- and double-storey buildings, respectively. The total quantity of refrigerant gas used in the CRF system was 7 kg and 8.4 kg in single- and double-storey buildings, respectively, while those in the VRF system were 5.3 kg and 6.2 kg, respectively. Thus, the environmental pollution caused by the production and maintenance of refrigerant gas is lower when the VRF system is used.

8. REFERENCES

Al Abir, A. (2019), HAND CALCULATION AND HAP SOFTWARE RESULT COMPARISON FOR ASSESSING TOTAL COOLING LOAD OF A BUILDING BEDROOM.

Al-Baaj, A.K. and Alsaatee, H.H. (2023), "Quality Assessment of Residential Complexes Standards of Satisfaction in Basra City of Iraq", International Journal of Sustainable Development and Planning, International Information and Engineering Technology Association, Vol. 18 No. 7, pp. 2233–2244, doi: 10.18280/ijsdp.180728.

ALHAFIDH GROUP. (2023), "COMMERCIAL AIR CONDITIONERS CATALOGUE 2023-2024", July, available at: https://alhafidhac.com/.

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

American Society of Heating Refrigerating and Air-Conditioning Engineers. (2017), 2017

ASHRAE climatic design conditions, available: https://ashrae-meteo.info/v2.0/.

ASHRAE® Handbook - Fundamentals (SI Edition)., available at: https://ashrae.org/

Atallah, G. and Tarlochan, F. (2021), "Comparison between variable and constant refrigerant flow air conditioning systems in arid climate: Life cycle cost analysis and energy savings", Sustainability (Switzerland), MDPI, Vol. 13 No. 18, doi: 10.3390/su131810374.

Hamza Shaikh, Memon, R.A., Qureshi, S., Shaikh, A. and Noonari, S.A. (2023), "The impact of the wall insulation material and variable refrigerant flow system on building energy consumption and cost", Journal of Mechanical Engineering and Sciences, University Malaysia Pahang Publishing, pp. 9383–9394, doi: 10.15282/jmes.17.1.2023.8.0742.

Hattab, K.M. (2010), Thermal Performance of Various Types of Engineering Materials In Basrah City, University of Basrah, Basrah, May.

Iraqi Ministry of Electricity, available at: https://moelc.gov.iq/?page=2982.

Kheioon, I.A., Saleem, K.B. and Sultan, H.S. (2023), "Analysis of Natural Convection and Radiation from a Solid Rod Under Vacuum Conditions with the Aiding of ANFIS", Experimental Techniques, Springer Science and Business Media Deutschland GmbH, Vol. 47 No. 1, pp. 139–152, doi: 10.1007/s40799-022-00596-z.

Khrebish, H. and Sultan, H. (2021), "THERMO-ECONOMIC IMPACT FROM USING EXHAUST GASES HEAT LOST FOR POWERING AN ABSORPTION REFRIGERATION SYSTEM USED FOR INLET AIR COOLING OF COMPRESSOR", Kufa Journal of Engineering, University of Kufa, Vol. 10 No. 3, pp. 114–133, doi: 10.30572/2018/kje/100308.

Kim, D., Cox, S.J., Cho, H. and Im, P. (2017), "Evaluation of energy savings potential of variable refrigerant flow (VRF) from variable air volume (VAV) in the U.S. climate locations", Energy Reports, Elsevier Ltd, Vol. 3, pp. 85–93, doi: 10.1016/j.egyr.2017.05.002.

Koh, J., Zh ai, J.Z. and ic R iva, J.A. (2009), Comparative Energy Analysis of VRF and VAV Systems under Cooling Mode.

Lekov, A., Franco, V. and Meyers, S. (2012), "Evaluation of Energy-Efficiency Standards for Room Air Conditioners in the US", Open Journal of Energy Efficiency, Scientific Research Publishing, Inc, Vol. 01 No. 02, pp. 9–20, doi: 10.4236/ojee.2012.12002.

LG .com.,"LG agency in Iraq"., available: https://www.lge360.com/iraq_en/air-conditioners.

Louisa Loveluck and Mustafa Salim. (2022), "Climate migrants flee Iraq's parched rural south,but cities offer no refuge", Washington Post, 7 September.

Naser Haider Hakeem and Hammadi Salman Hashim. (2022), Effect of Phase Change Material and Roof Shading on Cooling of Residential Unit in Basrah, Journal for Engineering Sciences, Vol. 22.

Rosenquist, G., Coughlin, K., Dale, L., Mcmahon, J. and Meyers, S. (2004), Life-Cycle Cost and Payback Period Analysis for Commercial Unitary Air Conditioners.

Salim Badran Mohammed. (2014), “Life-Cycle Cost Analysis for Three Different Types of A/C Systems Applied on an Apartment Located in a Multi-Floors Residential Tower in Mosul City”, Engineering and Technology Journal - University of Technology-Iraq, Vol. 32.

Santamouris, M. (2016), “Cooling the buildings – past, present and future”, Energy and Buildings, Elsevier Ltd, Vol. 128, pp. 617–638, doi: 10.1016/j.enbuild.2016.07.034.

Shawkut Ali Khan Professor, M. and Iftakharul Muhib Assistant Professor, M. (2021), “A Comparative Study of VRF Air Conditioning System over the Conventional Domestic Air-Conditioning System”, The Millennium University Journal, Vol. 6 No. 1.

Sukri, M.F. and Jamali, M.K. (2018), “ECONOMICS ANALYSIS OF AN INVERTER AND NON-INVERTER TYPE SPLIT UNIT AIR-CONDITIONERS FOR HOUSEHOLD APPLICATION”, ARPN Journal of Engineering and Applied Sciences, Vol. 13 No. 11.

The Republic of Iraq Ministry of Construction and Housing and Municipalities and Public Work. (2025), “Iraqi construction codes and technical specifications”, available at: https://iccts.moch.gov.iq/.

Yau, Y.H. and ‘Amir, M. (2020), “Energy use analysis of the variable refrigerant flow (VRF) system versus the multi - split unit using TRNSYS”, Heat and Mass Transfer/Waerme- Und Stoffuebertragung, Springer, Vol. 56 No. 2, pp. 671–690, doi: 10.1007/s00231-019-02726-7.

YUNUS A. ÇENGEL and AFSHIN J. GHAJAR. (2011), “HEAT AND MASS TRANSFER FUNDAMENTALS & APPLICATIONS, FIFTH EDITION”, McGraw-Hill Education.