International Journal of Engineering Materials and Manufacture (2025) 10(2) 26-34
https://doi.org/10.26776/ijemm.10.02.2025.01

Optimization of Indoor Airflow Distribution in Variable Refrigerant Flow Air Conditioning System: A Review

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Received: 10 September 2024
Accepted: 15 April 2025
Published: 30 April 2025
Publisher: Deer Hill Publications

ABSTRACT
Variable Refrigerant Flow (VRF) air conditioning systems have gained widespread acceptance for their energy efficiency, precise temperature control, and flexibility in multi-zone applications. However, the optimization of indoor airflow distribution remains a critical factor for enhancing system performance and occupant comfort. This review synthesizes the current research on the strategies and methodologies employed to optimize the indoor airflow distribution in VRF systems. Key areas of focus include advanced sensor integration, computational fluid dynamics (CFD) modeling, and the impact of indoor unit placement and design of the system. Studies highlight the importance of adaptive control strategies that respond to real-time occupancy and thermal load variations. Additionally, advancements in sensor technology and CFD simulations offer detailed insights into airflow patterns and temperature distributions, facilitating more effective system design and operation. This review also identifies the existing gaps in the literature and suggests the future research directions, emphasizing the need for integrated approaches that combine empirical data and advanced control mechanisms to achieve the optimal indoor air quality and the energy efficiency in the VRF systems. It is found that the VRF system is more economic and efficient such that the VRF system is found to have 44% cost profit when compared with the conventional HVAC system. On the other hand, the energy saving obtained with solar energy based VRF for the hot-dry climate is 17.5% and 11.6% against conventional all-air VAV and VRF systems, respectively. Furthermore, the proposed control strategy can improve energy efficiency by 12.6% and control room temperature fluctuations within ± 0.5°C.

Keywords: Variable Refrigerant Flow, Indoor Airflow Distribution, Air Conditioning, CFD, Energy Efficiency, Thermal Comfort.

1 INTRODUCTION

The building industry is largely responsible for the global energy consumption and carbon emissions. Buildings are responsible for 30% of the world's energy usage, according to the International Energy Agency (Zhou et al., 2022; Wu et al., 2023; Xiao et al., 2023; Oh & Kim, 2024). The energy consumption in 2021 for buildings worldwide rose by approximately 4% from 2020 to 135 EJ - the highest rise in the previous ten years (Zhang et al., 2024). The total amount of electricity used by residential and commercial buildings is significantly impacted by the use of air conditioning equipment. Enhancements in these systems' energy efficiency, operating features, and hybridization drive energy savings and spur a number of research initiatives. Consequently, VRF systems have been regarded as the competent option in the recent years (Singh & Das, 2022). For warm-humid climate, electrical energy saving potential of the proposed solar energy-assisted VRF system is around 23.9% and 9.5% than the conventional all-air VAV and VRF systems, respectively. Under composite climate the saving offered by the proposed system with respect to VAV and VRF is determined as 13.8% and 9.4%, respectively. Finally, the energy saving obtained with solar energy based VRF for the hot-dry climate is 17.5% and 11.6% against conventional all-air VAV and VRF systems, respectively (Singh & Das, 2022). For a very long time, people have struggled to provide various sources of energy for urban areas' offices and residential areas. In the past few decades, new arrangements for producing different forms of energy (such as power, heat, and cooling) have been put into place as a result of a better awareness of the biological and environmental potentials in different areas. Energy networks may benefit from novel strategies with low costs and minimal environmental impact due to financial and environmental limitations (Gilani et al., 2022). Building HVAC systems have a big influence on how much energy residential and commercial buildings use. When used in the

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Reference: Amal, A. C. K and Abedin, M. Z. (2025). Optimization of Indoor Airflow Distribution in Variable Refrigerant Flow Air Conditioning System: A Review. *International Journal of Engineering Materials and Manufacture*, 10(2) 26-34

individual mode, VRF systems can offer superior thermal comfort while saving energy. They are being utilized extensively in both residential and commercial structures worldwide and are growing in popularity. Heat recovery (HR) or heat pump (HP) configurations are available for VRF systems. It can only function in one mode for HP systems, either heating or cooling. HR systems have the ability to function simultaneously in both heating and cooling modes (Hu et al., 2023). Between 2000 and 2017, the cooling energy consumption of residential buildings in cities increased by about ten times due to the significant increase in the ownership of air conditioners. Taking into account, the most recent suggestion is to cut carbon emissions and energy use (Liu et al., 2022). A building performance simulation can be used to solve this issue more effectively (Liu et al., 2022). HVAC systems consume a significant amount of energy in buildings; they supply around 40% of the electricity used in commercial buildings. Additionally, since most individuals spend more than 90% of their time in the indoor environment, therefore a comfortable interior atmosphere is a very crucial factor.

In the meantime, current energy assessments reveal that over 40% of all energy consumed in Europe and the United States is consumed by the building industry. Building energy consumption is predicted to rise further in emerging nations like India due to economic growth and urbanization. Consequently, increasing HVAC energy efficiency is essential for combating climate change and promoting sustainable development. Because of its excellent part-load performance, flexible management, and simplicity of installation and maintenance, VRF systems are progressively becoming more and more common in small and medium-sized business and residential buildings (Saryazdi et al., 2024). A key strategy for assisting in the achievement of carbon peaking and carbon neutrality objectives is building carbon reduction. About half of the energy used in buildings is used by central HVAC systems (Wang et al., 2023). However, a VRF system typically runs in part load conditions, and if the evaporating temperature remains constant, the excessive temperature differential brought on by a low evaporating temperature will result in an excessive cooling capacity supply (Zhang et al., 2023). A UK building survey found that 25–50% of energy was lost due to HVAC system malfunctions (Cao et al., 2024). The proposed control strategy can improve energy efficiency by 12.6% and control room temperature fluctuations within ± 0.5°C (Cao et al., 2024). Thus, accurate VRF power consumption prediction is significantly essential for day-ahead demand response management (Zhou et al., 2021).

The creation of a data-driven air conditioning fault diagnosis system to achieve intelligent fault detection and diagnosis is of great significance to energy saving, emission reduction, and system stability that leads to the rapid development of the Internet of Things (IoT) and artificial intelligence (AI). On the other hand, the air conditioning system will unavoidably have some malfunctions after extended use. These errors may result in equipment damage, energy waste, and decreased interior comfort (Yue et al., 2023).

2 BUILDING CHARACTERISTICS

VRF systems are often distributed systems, with each evaporator unit located at a different location within the building and the outside unit kept at a remote site, such as the top of the building or remotely at grade level. Large multi-story buildings typically have liquid and suction lines that are several hundred feet long, making up the refrigerant pipework. Long pipe lengths will obviously cause pressure losses in the suction line, and if the wrong pipe diameter is used, the indoor units will run out of refrigerant, which will leave the end user without enough cooling. Therefore, it is crucial to ensure that the feeder pipes that supply each indoor unit as well as the main header pipe are sized appropriately. Although the maximum length permitted varies according to the manufacturer, the following general principles (Devecioglu & Oruc, 2020) apply:

i. 164 feet is the maximum permitted vertical separation between an outdoor unit and its furthest indoor unit;
ii. Between two separate indoor units, the maximum allowable vertical distance is 49 feet.
iii. Up to 541 feet is the maximum total length of refrigerant piping between an outside unit and the furthest indoor unit.

It is noted that the longer the lengths of refrigerant pipes, the more expensive the initial and operating costs in the VRF air conditioning system.

As previously mentioned, different manufacturers have different requirements for refrigerant pipe. For Fujitsu, a Japanese manufacturer, the system design limitations [16] are:

i. Maximum height difference between outdoor unit and indoor unit = 50 m
ii. Maximum height difference between indoor unit and indoor unit = 15 m
iii. Maximum piping length from outdoor unit to first separation tube = 70 m
iv. Maximum piping length from outdoor unit to last indoor unit =100 m
v. Maximum piping length from header to indoor unit = 40 m
vi. Total piping length = 200 m (Liquid pipe length)

3 FUNDAMENTALS OF VARIABLE REFRIGERANT FLOW (VRF) SYSTEMS

3.1 VRF Systems

In 1982, Daikin revolutionized air conditioning with its variable refrigerant volume (VRV) system, pioneering what is now known as VRF. VRF systems use only the necessary refrigerant for each cooling or heating cycle, allowing independent control of multiple zones. Originating in Japan, these systems are now widespread in the Far East, Europe, and North America. They are extensively used in hospitals, commercial centers, hotels, educational institutions, and official buildings, especially popular in APAC and European countries. The core of VRF technology is adjusting the refrigerant flow rate to match the cooling or heating load, maintaining efficiency even at partial loads.

With variable speed fans and compressors, VRF systems minimize energy loss and offer quick adjustments to environmental changes, maintaining comfort with less energy consumption. These systems can modulate capacity from 10% to 100%, making them highly efficient and responsive to varying demand, significantly reducing energy usage (CED Engineering). The same technique is referred to by two different names: variable refrigerant flow (VRF) and variable refrigerant volume (VRV). Due to Daikin Industries, Ltd.'s trademark status, any other firm that replicate this technology call it a VRF system (CED Engineering).

3.2 Features and Benefits of VRF

The key features and benefits of VRF system (DAIKIN) can be written as follows:

i. Similar to a chiller, a VRF system pumps refrigerant, rather than water, to each zone.
ii. The design and functionality of a VRF heat pump system are comparable to those of a 2-pipe chiller.
iii. The design and functionality of a VRF heat recovery system are comparable to those of a 4-pipe chiller system.
iv. Opportunities for scalable projects with modular design.
v. Wide coverage of the majority of climates and vertical markets.
vi. Personalized zone management for enhanced zoning functionalities.
vii. Capable of running up to 64 fan coil units indoors.
viii. The auto charging feature.
ix. Continuous heating when the defrost function is in use.
x. Adaptable pipe restrictions to accommodate different building requirements.
xi. Outstanding energy efficiency, particularly when operating at partial load (IEER).
xii. Connect to Building Automation systems using Lon Works® and BACnet® open protocol gateways.

3.3 Space Layout

Understanding the space layout is the first step in designing a VRF system. It is necessary to take into account the building's orientation and the times of year when peak loads happen. The intended usage of the space will determine the kind of load (heating or cooling) and how loads are distributed among the zones. These elements will therefore decide which system will be more efficient: a heat pump system or a heat recovery system (Kamal & Khan, 2021).

An even larger heat recovery system could be installed as an alternative. An efficiency analysis and cost comparison of the two possibilities should be carried out in order to identify the optimal design decision. Furthermore, since the quantity of refrigerant in the system affects compliance with ASHRAE 15 criteria, the effect of a higher amount of refrigerant flowing through the bigger system should be taken into account (Kamal & Khan, 2021).

4 PACKAGE VRF SYSTEM

The 1OU-3IU systems' experiments were conducted in the same type of conventional psychometric chambers, which allowed for strict control over the inside and outside air temperatures for the dry and wet bulbs. The chamber tests the room air conditioners' ability to cool (or heat) by using the principle of air enthalpy potential and using an indoor-side air enthalpy differential measurement instrument.

There is a 50 HP outside component and a 30 HP inside component to the chambers. Additional details (such as the chambers' layout and specifics of the measuring tools), among other things, are available in the references of Zhou et al. (2022) and Gou et al. (2023). The schematic diagram and critical sensor locations for the 1OU-3IU system in cooling mode are displayed in 1OU-3IU system. The specifications of the indoor air conditioning units for the one systems are listed in Table 1. Furthermore, every interior unit has an electronic expansion valve (EXV) to more easily control the refrigerant flow; the EXV's target superheat ranges from 1 to 5 degrees Celsius. A double-rotor DC inverter compressor, an oil and gas separator, a fin-tube heat exchanger, an outdoor electronic expansion valve, a pressure balance valve, and other components are the primary components of the outdoor unit. When the system is in cooling mode, the outdoor heat exchanger serves as the condenser; the outdoor EXV never closes; and the pressure balance valve balances the suction and discharge pressures to guarantee the compressor starts up successfully. The four-way valve's solenoid coil only becomes active when it is in the heating mode. The average values of the system during stable operation for at least 14 minutes in the corresponding condition are used to determine the parameter values examined in the following sections (Zhang et al., 2024).

Table 1: The parameter information for indoor and outdoor units (Zhang et al., 2024).

	Indoor units			Outdoor units
	#1	#2	#3	#1
1OU-3IU system	√	√	√	√
Rated cooling capacity (kW)	2.2	2.8	2.8	8.0
Rated cooling condition (°C)	Indoor 27DB 19WB/Outdoor 35DB			

The impact of frequent errors on a 1OU-3IU system's system performance at various load rates and experimental settings is the main topic of Section 3. Table 2 provides the specific condition parameters. Table 1 indicates that the matching. The corresponding load rates are 42%, 74%, and 100% (Zhang et al., 2024).

Table 2: Settings of experimental conditions (Zhang et al., 2024).

Mode	Load rate	Indoor-side condition		Outdoor-side condition	
		Dry-bulb temperature (°C)	Wet-bulb temperature (°C)	Dry-bulb temperature (°C)	Wet-bulb temperature (°C)
Cooling	1IU_open/	21	15	31	22
	2IU_open/	27	19	35	24
	3IU_open	32	23	43	26

5 METHODS FOR INDOOR UNIT AND ASSESSING AIRFLOW DISTRIBUTION

5.1 Indoor Airflow Distribution

When the air flow that is moved by the machine is calculated, it is shared amongst the grilles and diffusors of the discharge duct. The program takes different configurations (CARRIER, 2013) into account:

i. A single device that supplies air to multiple diffusers and grilles within space. The software will split the flow between them in this instance.
ii. Users who set a grille or diffuser's flow at a fixed value will divide the machine's leftover flow between the grilles and diffusors without set flow values.
iii. A single device that supplies air to multiple rooms in homes, this is typically the situation. The discharge flow is distributed among the discharge duct grilles based on the cooling load of each room.

Air return

The configuration of the return position is defined directly in the panel of the indoor unit. There are two possible return positions (CARRIER, 2013):

i. Rear: In this instance, a network of return ducts must be installed.
ii. Bottom: It won't have a return duct network because it will be positioned opening to a grille in the artificial ceiling.

5.2 Ductwork Design Methods

For any situation, provide the most cost-effective duct system. One or more of the following techniques, or their modifications (some of which are out-of-date), have been used to design duct systems:
(a) Equal friction (b) Static regain (c) Extended plenum or semi-extended plenum (modification of equal friction or other design methods.) (d) T-Method (e) Velocity reduction (f) Total pressure (g) Total pressure (h) Constant velocity (i) Residential system design method.

It is important to carefully consider every cost factor that enters a duct system when choosing a design approach or set of methods. The cost of the duct material (aspect ratios play a significant role in this), duct insulation or lining (duct heat gain or loss), fitting type, space requirements, fan power, balancing needs, sound attenuation, air distribution terminal devices, and heat recovery equipment are some of the cost variables to take into account.

Using the various design techniques, slightly varying duct system pressure losses can be achieved. Some call for extensive training and experience in design. The designer may effectively size HVAC duct systems for bigger homes, businesses, and institutions, including some light industrial process ducts, by carefully applying these techniques. The following are the conventional duct design techniques (CYPE).

5.3 Indoor Unit Duct Type Installation

Installation to slab, from side wall minimum 250 mm and from finished floor 2500 mm (GREE).

5.4 Indoor Unit Cassette Type Installation

Installation to slab, gap is slab and unit is 20 mm minimum, from side wall minimum 1500 mm and from finished floor 1800 mm (SMACCNA).

5.5 Indoor Unit Wall Mounted Type Installation

Installation to slab, gap is slab and unit is 150 mm minimum, from side wall minimum 150 mm and from finished floor 2500 mm and from front wall 3000 mm (SMACCNA).

5.6 Selection of ASTDs

Five different kinds of frequently used air supply terminal devices (ASTDs) were examined in total. Various scenarios using these air terminal devices were examined at a steady airflow rate. In every example that was examined, the bar grille diffuser was utilized as an exhaust terminal since the kind of exhaust terminal had no effect on the airflow pattern. The return/exhaust terminal was positioned 0.33 meters above the floor, while the supply air terminals were mounted on the side wall at a height of 1.9 meters. The stratum ventilation system's design standards served as the basis for the selection of these heights. The locally installed thermal sensor, also known as the room thermostat, was used to closely monitor and alter the internal temperatures of the walls, which were all set at 26°C. Table 3 displays the dimensions of the diffusers as well as the specific testing settings (GREE).

Table 3: Details of the initial/boundary parameters (GREE).

Case	Diffuser Type	Diffuser Size (mm)	Airflow Rate (m^3/s)	Supply Temperature (°C)	Room Temperature (°C)
1	Bar grille diffuser	500 x 300	0.25	18.7 ± 0.3	26.0 ± 0.1
2	Perforated diffuser	500 x 300	0.25	18.7 ± 0.3	26.0 ± 0.1
3	Double deflection grille	500 x 300	0.25	18.7 ± 0.3	26.0 ± 0.1
4	Drum louver diffuser	500 x 300	0.25	18.7 ± 0.3	26.0 ± 0.1
5	Jet slot diffuser	1000 x 135	0.25	18.7 ± 0.3	26.0 ± 0.1

5.7 CFD Model of the Studied Domain

The current study looked into various VRF-SV system design configurations for a sizable tropical retail establishment. The common design configurations using linked, decoupled, and fully integrated approaches have been analyzed (Ozahi et al., 2017). To gather enough data for evaluating thermal comfort standards, a number of computer simulations were run using all of the planned configurations (Ozahi et al., 2017).

5.7.1 The Numerical Scheme and Sensitivity Analyses

The turbulence k–ε (2-equation) model was utilized in this study to precisely forecast the distribution of interior airflow. Using the SIMPLE algorithm and a second-order upwind approach, the governing equations have been discretized. In this investigation, a typical wall function was used to get the near-wall flow characteristics.

The buoyancy effect was investigated using the Boussinesq model. With the exception of the energy residual, which was fixed at 10^{-6}, the solution was deemed to have converged when the residual values reached 10^{-3}. Two workstations were used to conduct the simulations. With an Intel Xeon(R) CPU E3-1240 v5 3.5 GHz processor, 32 GB RAM, and Windows 7 Professional 64-bit operating system, each states that it will take between 48 and 96 hours to complete the created grids' solutions. Using the commercial CFD application ANSYS Fluent, a UDF code was designed and produced to analyze the thermal comfort indices. To get results that were independent of grid sizes, mesh sensitivity analyses were performed. There are numerous methods for creating high-quality meshes. Sanaullah et al. recently created a novel method that used SM's method to generate random grids. To create a mesh with more control, the size function was employed in this study's global mesh control. For the SV/VRF supply and exhaust air terminals, a very small element size was chosen because of its intricate and sensitive design elements. The remaining fluid domain and boundary surfaces were subsequently discretized, using unstructured tetrahedral mesh elements of variable quality (coarse to fine), as demonstrated by adjusting the elements and wall/surface sizes (Ozahi et al., 2017).

5.7.2 Effective Draft Temperature for SV

The VRF-SV system's good thermal stratification produced a lower EDT in the occupied region than in the higher zone. Because of the increased face velocity in the VRF-SV system, the EDT values are highest close to the supply jets. As a result, substantial planning should go into the supply terminals' selection and placement (Ozahi et al., 2017). The VRF system is more economic and efficient such that the VRF system is found to have 44% cost profit when compared with the conventional HVAC system (Ozahi et al., 2017).

6 CONTROL SYSTEM

6.1 Wireless Zone Controller

i. Controls up to 16 indoor units
ii. Built-in 23-hour timer
iii. Wireless receiver must be added for all indoor units except Wall Mount models (Yau et al., 2022).

6.2 Advanced Wire Remote Controller

New wired remote controller for VRF with the brand-new global visual design

i. Stylish curve surface with easy-to operate touch buttons placed at a touch angle
ii. Integrated housing with in-mold labeling (IML) process increases durability and creates a cleaner look
iii. Improved visual monitoring with a large 4.3-inch color screen
iv. New home menu design with a different display color for each operation mode (Yau et al., 2022).

6.3 VRF Central Touchscreen Controller

With Remote Access Software (included) & Energy Calculation Software - Tenant Metering (Add-on). Easily control VRF systems in large, commercial properties with the Hitachi Central Touchscreen Controller. And enjoy accurate, easy tenant billing feature with the optional Energy Calculation Software (CCSE01). The intuitive user interface makes monitoring systems a breeze. Colors and icons enable quick identification and monitoring of commonly00 checked items such as (a) Room name (b) Run/stop (c) Mode (d) Temperature (e) Fan speed (f) Louver (g) Current status icon (h) Air intake temperature (Yau et al., 2022).

6.4 Monitoring and Controlling

The app that gives you control on the go, it's never been easier to control Hitachi VRF Systems. Using Internet of Things (IoT) technology, air Cloud Pro enables you to manage Hitachi VRF equipment any time/anywhere. On the web or through a smartphone, control is always close-at-hand. With airCloud Pro's intuitive interface, you can manage an unlimited number of VRF systems quickly and easily:

(a) Adjust temperature, fan speed and equipment modes (b) Receive error and maintenance alerts (c) Set operating schedules (d) Add users with customized permissions and more

Set up is simple with true plug-and-play installation. And functionality is always current with new features and updates pushed to the app. airCloud Pro puts the latest technology to work for you (Yau et al., 2022).

6.5 Motion Sensor Technology

It senses the amount of human activity, under takes automatic saving and achieves intelligent saving. Perceives the amount of human activity and undertakes automatic saving (Yau et al., 2022).

7 CHALLENGES AND LIMITATIONS

VRF systems are not suitable for all applications. A VRF system being the split installation is restricted by distance criteria between the condensing unit and the evaporator. The maximum lengths of refrigerant pipework for a VRF or any other split system is determined by the compressors ability to overcome the pressure drop and for the system to maintain proper oil return. All 'split' systems therefore have a maximum allowable vertical and total refrigeration pipework length. This is a considerable disadvantage compared with hydraulic systems which are pumped; and as the pump may be sized to suit the system, then theoretically, the hydraulic pipework may be run almost infinite distances. It is important that the designer/building owner is aware of these limitations. Each manufacturer specifies both the size of the pipework required for their system and the maximum permissible vertical and total refrigerant pipework runs [25]. The results indicated that the ASTD type had a significant impact on airflow pattern. Furthermore, the bar grille diffuser provided the occupants with greater thermal comfort and acceptable indoor environment. Almost all the EDT values determined in the breathing zone in the case with bar grille diffuser found under the satisfactory range, i.e., $-1.2 < K < 1.2$. Based on these values, the ADPI for bar grille diffuser was calculated as 92.8%. Thus, the bar grille diffuser is recommended to be installed with the VRF-SV hybrid system in buildings.

8 SUMMARY

The overview of the above discussion can be summarized in the following tabular form in a way to ensure the optimization of indoor airflow distribution in variable refrigerant flow air conditioning system as shown in Table 4.

Table 4: Optimization of Indoor Airflow Distribution in VRF Air Conditioning System.

Field of Review	**Observation**	**Ref**
Refrigerant flow system with common faults	During single fault and simultaneous fault, outdoor fouling fault has the greatest impact, which can cause a 47.6% COP drop and 80.27% cooling capacity reduction.	(Zhou et al., 2022)
Behavior pattern, online monitoring data	It could be noticed that 90% of occupants had relatively low cooling demand less than 40 kWh/m^2 during the cooling season. Moreover, comparing to the performance of fixed AC schedule model in district cooling demand evaluation, the extracted typical AC behavior patterns improved the accuracy up to 30.4% when calculating the bias between average modelled cooling demand and measured data.	(Wu et al., 2023)
Operation characteristics	The energy efficiency and evaporating temperature decrease with a reduction in CUR under specific ambient temperatures and part-load rates.	(Xiao et al., 2023)
Energy consumption	The prediction performance of the proposed model has an R^2 higher than 0.9 and root mean squared error (RMSE) less than 0.2, whereas the typical catalog-based model has an R^2 of 0.07 and RMSE of 0.54.	(Oh & Kim, 2024)
Common faults	The magnitude of the parameter change rates is mainly influenced by the parameter values during normal operation, and this shows the necessity of adding normal data from the diagnosed target equipment. Besides, the different fault tolerance of the systems can cause opposite trends in parameter changes. Especially for the fault of the electronic expansion valve stuck at a big opening, the poor similarity of the four	(Zhang et al., 2024)

	parameters shows a risk of negative transfer for cross-equipment fault diagnosis.	
Solar regeneration	For warm-humid climate, electrical energy saving potential of the proposed solar energy-assisted VRF system is around 23.9% and 9.5% than the conventional all-air VAV and VRF systems, respectively. Under composite climate the saving offered by the proposed system with respect to VAV and VRF is determined as 13.8% and 9.4%, respectively. Finally, the energy saving obtained with solar energy based VRF for the hot-dry climate is 17.5% and 11.6% against conventional all-air VAV and VRF systems, respectively.	(Singh & Das, 2022)
Solar thermal driven ORC-VFR system	The designed solar-driven ORC delivers a net of (8,154 – 454) kWh = 7,700 kWh energy each year, meaning 7,700 kWh energy saving per year, equal to 97% of VRF annual energy demand. This amount of yearly energy saving yields 2,010 USD yearly capital saving as the reward of investment in this system, and defining a 20-year project, the implementation of this solar-driven power generation system at the end of the project's lifetime would save 25,049 USD.	(Gilani et al., 2022)
Detection of the refrigerant charge level	The results demonstrated its effectiveness in detecting an undercharged system, specifically a 30% undercharge.	(Hu et al., 2023)
Cooling operation and performance in residential buildings based on large-scale dataset	(1) The “part-time part-space” operation mode of residential VRF systems can be analyzed according to the statistical results of the UD and PSI. (2) An LR of <30% is the main operating condition for VRF systems in residential buildings. (3) Extracted typical LR patterns can reflect different user behavior. The statistical results obtained in this study provide a basis for VRF engineering projects.	(Liu et al., 2022)
Factors affecting the performance of buildings equipped with VRF system in Middle East climates	VRF cost and HVAC electricity use per area have a greater coefficient of variation compared with other output parameters. The density distribution of output parameters indicated that uncertainty parameters had the greatest impact on output parameters in Kuwait (hyper arid climate), whereas in Istanbul (humid subtropical climate), they were the least. Among the variables examined in the Sensitivity Analysis (SA), cooling setpoint had the greatest impact on residential building energy consumption in ME climates	(Saryazdi et al., 2024)
Modelling variable refrigerant flow system for control purpose	We find the model proposed by Hu et al. in 2019, which regresses the VRF cooling capacity and COP as a linear combination of indoor and outdoor temperatures times a cubed polynomial function of compressor frequency, is the most accurate physics-based model, with a prediction error of 22.19% in the training dataset and 22.44% in the validation dataset. XGBoost is the most accurate data-driven model, with a prediction error of 19.29% in the training dataset and 22.02% in the validation dataset.	(Wang et al., 2023)
Charge fault diagnosis strategy	The classification accuracy (CA) of the model optimized by the proposed strategy in the training set and the test set is improved by 3.9% and 4.02% respectively, and there is little difference between the two, indicating the model generalization ability is improved.	(Zhang et al., 2023)
Temperature control strategy	The proposed control strategy can improve energy efficiency by 12.6% and control room temperature fluctuations within ± 0.5°C.	(Cao et al., 2024)
Fault diagnosis method	The proposed convolutional neural network (CNN) model has excellent performance in multi-fault coupling diagnosis considering defrosting and sensor biases. The recognition accuracy of the CNN model for each fault are all higher than 97.5%. The GMA of the CNN model is as high as 98.46%, which is higher than 20.04%, 11.565% and 6.36% compared to the decision model, the support vector machine model and the multilayer perceptron model. In addition, the FAR of CNN model is only 0.58%, which is 8.93%, 4.05% and 1.62% lower than the other three models.	(Zhou et al., 2021)
Power consumption	The model is capable of predicting the power consumption accurately under high time resolution. During the online test, the MAE, CV-RMSE, and R2 of the model are 1296.41 W, 24.65% and 0.90, respectively. The proposed model can be used as the evaluation tool of DR management for decision making.	(Yue et al., 2023)

Performance analysis of R466A as an alternative to R410A	Both cooling capacity and heating capacity amounts of R466A were greater in comparison with R410A. COP values of R466A were determined as higher than R410A about by 5–15% and 4% in cooling mode and heating mode, respectively. Thus, R466A can be utilized as a suitable refrigerant for VRF systems and air-conditioners as an alternative to R410A. In the short term, R466A can be directly used without performing any constructional modification in the system operating with R410A.	(Devecioglu & Oruc, 2020)
System Configuration and Energy Efficiency	With the help of these advanced compressor like the twin rotary compressor the metering device can be closed to controls the flow of refrigerant between the indoor and outdoor unit which helps in avoiding the overheating or overcooling of the space. VRF system also helps in covering the duct losses which is impossible to cover in traditional system as VRF system is ductless or minimum duct are used in the process.	(Kamal & Khan, 2021)
Conventional HVAC and VRF system in a social and cultural center building	The VRF system is more economic and efficient such that the VRF system is found to have 44% cost profit when compared with the conventional HVAC system.	(Ozahi et al., 2017)
Effects of Air Supply Terminal Devices	The results indicated that the ASTD type had a significant impact on airflow pattern. Furthermore, the bar grille diffuser provided the occupants with greater thermal comfort and acceptable indoor environment. Almost all the EDT values determined in the breathing zone in the case with bar grille diffuser found under the satisfactory range, i.e., $-1.2<K<1.2$. Based on these values, the ADPI for bar grille diffuser was calculated as 92.8%. Thus, the bar grille diffuser is recommended to be installed with the VRF-SV hybrid system in buildings.	(Yau et al., 2022)

9 CONCLUSIONS

This review represents the existing gaps in the literature of the optimization of indoor airflow distribution in variable refrigerant flow (VRF) air conditioning system and suggests future research directions for emphasizing the need for integrated approaches that combine empirical data and advanced control mechanisms to achieve the optimal indoor air quality and energy efficiency in the VRF systems. The following conclusions can be drawn from the present review analysis.

i. The VRF system is more economic and efficient such that the VRF system is found to have 44% cost profit when compared with the conventional HVAC system.
ii. The energy saving obtained with solar energy based VRF for the hot-dry climate is 17.5% and 11.6% against conventional all-air VAV and VRF systems, respectively.
iii. The proposed control strategy can improve energy efficiency by 12.6% and control room temperature fluctuations within ±0.5°C.

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