



Energy Assessment of VRF Systems Integrated with ERV and DOAS under Variable Supply Air Temperatures in Tropical Office Buildings

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Abstract. Ventilation significantly affects HVAC energy consumption in hot-humid tropical office buildings, yet the comparative performance of energy recovery ventilation (ERV) and dedicated outdoor air systems (DOAS) under different supply air temperatures remains insufficiently understood. This study evaluates the combined effects of ventilation strategy and supply air temperature on the energy performance of a variable refrigerant flow (VRF) air-conditioning system serving a tropical office building. Four operating scenarios were investigated using the hourly analysis program (HAP), consisting of VRF integrated with ERV and VRF integrated with DOAS operating at supply air temperatures of 18 °C and 14 °C. The results show that the DOAS configuration effectively reduced the cooling load imposed on the VRF indoor units by pre-conditioning outdoor ventilation air. However, this benefit was offset by the additional energy required for outdoor air treatment, leading to an increase in the annual energy use intensity (EUI) from 169.5 to 176.0 kWh/m²·year (3.8%) compared with the ERV configuration. Decreasing the DOAS supply air temperature from 18 °C to 14 °C produced only marginal improvements in indoor thermal conditions while increasing cooling energy demand, indicating diminishing energy returns under tropical operating conditions. These findings demonstrate that lower terminal cooling loads do not necessarily result in lower whole-building energy consumption. The study highlights the importance of integrated ventilation-system optimization and showing that ERV offers superior overall building energy performance. The study also provides practical engineering guidance for selecting ventilation strategies that balance cooling load reduction and whole-building energy efficiency in tropical office buildings.

Keywords: Cooling Load, DOAS, Energy Use Intensity, ERV, VRF

1 Introduction

Commercial buildings, particularly office buildings, are among the major contributors to global energy consumption. In commercial buildings, heating, ventilation, and air conditioning (HVAC) systems represent the largest energy-consuming component, accounting for approximately 40% of the total building energy consumption (Anarene, 2024; Yang et al., 2014). This high energy consumption is primarily driven by the need to maintain indoor environmental quality (IEQ), which includes air quality and thermal

comfort and plays an important role in occupant health and productivity (Mewomo et al., 2023). In this context, outdoor air ventilation becomes a significant factor, as it can account for approximately 20–40% of the total cooling load, particularly in hot-humid climates (Cho et al., 2023). This indicates that ventilation management not only affects indoor air quality but also the overall energy performance of HVAC systems.

In an effort to improve energy efficiency in HVAC systems, various technologies have been developed, one of which is the Variable Refrigerant Flow (VRF) system. This system is widely applied in commercial buildings due to its ability to operate efficiently under partial load conditions and its flexibility in zone control according to space requirements (Lyu et al., 2025; Yun et al., 2016). However, despite its high operational efficiency, the VRF system has a fundamental limitation in that it cannot directly handle outdoor air ventilation and therefore cannot independently control indoor air quality (Zhu et al., 2014). Consequently, VRF systems need to be integrated with additional ventilation systems to ensure that the required fresh air supply is met.

In such integrations, two common ventilation approaches are Energy Recovery Ventilation (ERV) and Dedicated Outdoor Air System (DOAS). ERV operates by utilizing energy exchange between exhaust air and outdoor air, thereby reducing the ventilation load entering the cooling system (Cho et al., 2023; Fan et al., 2014). Meanwhile, DOAS adopts a different approach by processing outdoor air separately before it is supplied to the indoor space, allowing more focused control of latent load and indoor air quality (Yau & Rajput, 2022). However, the enhanced capability of outdoor air treatment in DOAS is often accompanied by increased energy demand and therefore does not always result in better overall energy efficiency. As a result, each ventilation strategy exhibits different performance characteristics, and their selection cannot be made in a straightforward manner.

The integration between the main cooling system and the ventilation system does not always lead to improved energy efficiency. Although ventilation systems such as ERV and DOAS can enhance indoor air quality and control latent loads, these improvements are often accompanied by increased energy consumption (Hieu, 2025; Park et al., 2017). This indicates the presence of a trade-off between air quality, thermal comfort, and energy efficiency in HVAC system design. This condition becomes more significant in hot-humid tropical climates, where latent loads contribute substantially to the cooling load (Yau & Rajput, 2022). The selection of ventilation strategy becomes a key factor influencing overall system energy performance. However, studies that directly compare the performance of VRF systems integrated with ERV and DOAS, particularly considering variations in supply air temperature, remain limited.

Unlike previous studies that primarily evaluated either ERV or DOAS independently or focused on system-level energy performance, this study systematically compares VRF integrated with ERV and DOAS under two practical supply air temperatures (18 °C and 14 °C) using an identical tropical office building model. The novelty lies in evaluating how supply air temperature influences the redistribution of cooling load between the VRF and ventilation systems and how this affects whole-building energy consumption rather than only terminal cooling demand. This integrated assessment provides engineering guidance for selecting ventilation strategies in hot-humid tropical office buildings. This study aims to evaluate the effect of ventilation strategy and supply

air temperature on cooling load characteristics and system energy consumption in office buildings under hot-humid tropical conditions through building energy simulation.

2 Methodology

This study employs building energy simulation to evaluate the performance of a Variable Refrigerant Flow (VRF) system integrated with Energy Recovery Ventilation (ERV) and Dedicated Outdoor Air System (DOAS) under hot-humid tropical conditions. The methodology comprises building modelling, HVAC configuration, simulation parameters, and performance evaluation.

This study has several limitations, involving: (1) the analysis was performed using building energy simulation for a single office building located in a hot-humid tropical climate with fixed occupancy schedules and ventilation rates; and (2) the DOAS configurations were evaluated without advanced control strategies such as reheat, demand-controlled ventilation, or adaptive supply air temperature control.

2.1 Building Model and Climate Conditions

The simulation was conducted using a four-story office building located in Denpasar, Indonesia, representing a hot-humid tropical climate. Weather data were obtained from the Hourly Analysis Program (HAP) database based on Typical Meteorological Year (TMY) data and ASHRAE climate references. The building was modelled using a single-zone-per-room approach to accurately represent room-specific operating characteristics and cooling load distribution under different ventilation scenarios.

Table 1. General Building Characteristics

Parameter	Value
Building function	Office building
Location	Denpasar, Indonesia
Number of floors	4
Total floor area	6308 m ²
Conditioned floor area	5041.6 m ²
Indoor temperature setpoint	24 °C
Indoor relative humidity	55 %

Indoor environmental conditions were defined in accordance with ASHRAE Standard 55, while the indoor temperature and relative humidity setpoints followed the Indonesian National Standard (SNI 03-6572-2001) to ensure acceptable thermal comfort conditions. Building envelope properties were assigned using the standard construction libraries available in HAP. The principal characteristics of the simulation model, including building function, floor area, indoor setpoint temperature, and relative humidity, are summarized in Table 1, providing a consistent basis for comparing all simulated HVAC configurations.

2.2 HVAC System Configuration

Three configurations of variable refrigerant flow (VRF) based HVAC systems are used in this study to evaluate the effects of ventilation strategy and supply air temperature on cooling load characteristics and system energy consumption. The analyzed configurations include the integration of VRF with energy recovery ventilation (ERV) and the integration of VRF with a dedicated outdoor air system (DOAS) under two supply air temperature conditions.

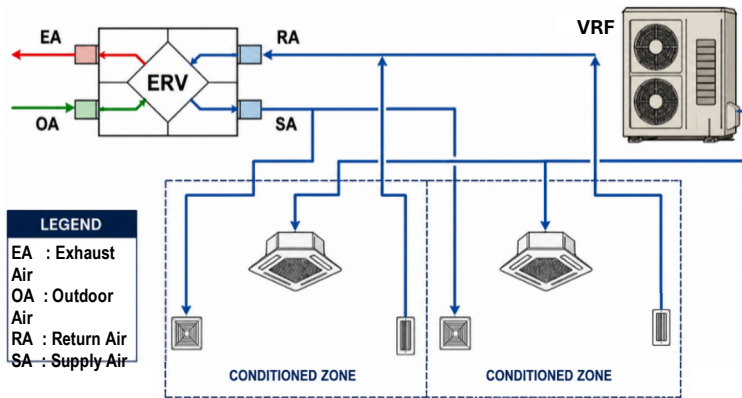


Figure 1. Schematic of the VRF integrated with ERV system

In all configurations, the VRF system serves as the primary system to handle the space cooling load, while fresh air is processed through the respective ventilation units and supplied directly into the indoor space. The VRF with ERV configuration utilizes heat and moisture exchange between outdoor air and exhaust air before the fresh air is supplied to the space.

In the VRF with DOAS configuration, outdoor air is processed separately through the DOAS unit until it reaches the specified supply air temperature before being delivered to the space. The schematic of each system configuration is shown in Figures 1 and 2.

The supply air temperature in the DOAS system is set at 18 °C and 14 °C to evaluate its effect on cooling load characteristics and system energy consumption. The selected supply air temperatures represent two commonly adopted operating conditions in dedicated outdoor air systems. A supply air temperature of approximately 18 °C is widely applied in practical DOAS design to provide ventilation air without excessive overcooling, whereas 14 °C represents a lower-temperature condition frequently reported in previous studies and engineering practice for enhanced latent load removal. Comparing these two conditions enables evaluation of the trade-off between cooling load reduction and overall energy consumption under tropical climate conditions.

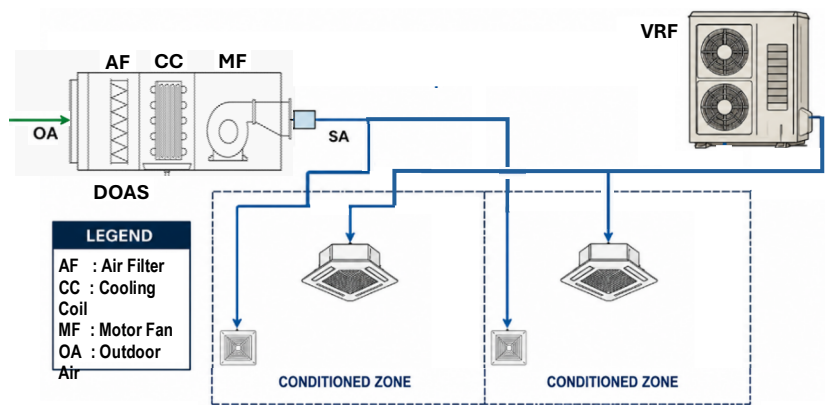


Figure 2. Schematic of the VRF integrated with DOAS system

2.3 Simulation Parameters

Building energy simulations are conducted using the Hourly Analysis Program (HAP) to evaluate the performance of the HVAC system under each analysed configuration. All simulation scenarios use identical building parameters, indoor environmental conditions, and operational assumptions to ensure a consistent basis for comparison. The simulation parameters include indoor temperature and humidity conditions, outdoor air ventilation requirements, system operation schedules, and HVAC operational parameters. Parameter variations are only applied to the type of ventilation system and the supply air temperature in the DOAS system according to the analyzed scenarios.

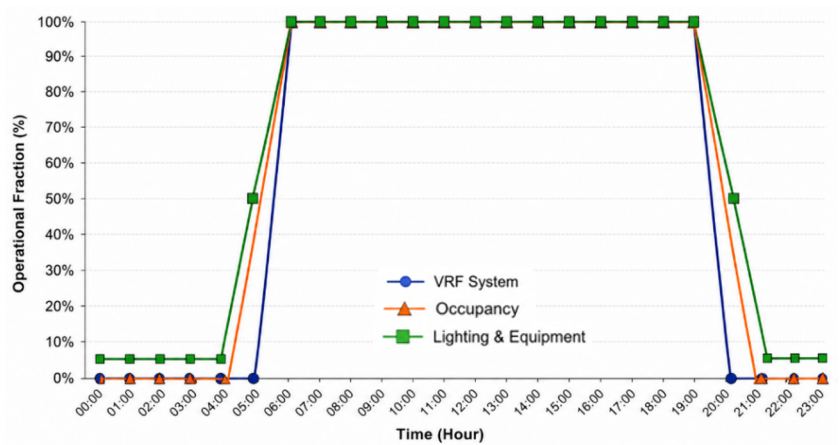


Figure 3. Operational schedule profiles of the VRF system, occupancy, as well as lighting and electrical equipment

The operation schedules of the HVAC system, occupancy, as well as lighting and electrical equipment are defined using hourly percentage profiles that represent the operational characteristics of an office building. The HVAC system is represented based on occupied and unoccupied operation states, which are converted into 100% and 0% operation levels, respectively. The occupancy, lighting, and electrical equipment profiles are expressed as load fractions relative to their maximum conditions. The operational schedule profiles used in the simulation is shown in Figure 3.

Table 2. Ventilation Parameters

Space Type	Outdoor Air Rate (L/s·person)	Outdoor Air Rate (L/s·m ²)
Office	2.5	0.3
Meeting room	3.5	0.3
Multipurpose room	3.5	0.3
Lobby	2.5	0.3

Outdoor air requirements and occupancy parameters are determined based on the function of each space. The outdoor air rates refer to applicable ventilation standards, while the method for determining occupancy in several spaces is adjusted based on the operational characteristics and actual capacity derived from building layout drawings, allowing for a more realistic representation of usage conditions. Ventilation parameters, internal loads, and occupancy are presented in Tables 2 and 3.

Table 3. Internal Load and Occupancy Parameters

Space Type	Occupancy Density (person/m ²)	Lighting Power Density (W/m ²)	Power Density (W/m ²)
Office	Based on seating layout	8	8.07
Meeting room	Based on seating layout	10.5	10.76
Multipurpose room	1.9	10.5	10.76
Restroom	1.9	6.8	4.31
Storage room	0	4.1	0
Lobby	9.3	9	4.31

3 Result and Discussion

3.1 Cooling Load Analysis

The cooling load analysis evaluates the effects of ventilation strategy and DOAS supply air temperature on the cooling demand of the VRF-based HVAC system. The assessment considers both the cooling load handled by the main VRF system and the total system cooling load, including the contribution of the ventilation unit. Three configurations are compared: VRF integrated with ERV, and VRF integrated with DOAS operating at supply air temperatures of 18 °C and 14 °C. The corresponding cooling loads are presented in Figures 4 and 5.

Figure 4 shows that the cooling load handled by the VRF system decreases when DOAS is employed. The VRF load is 765.2 kW in the ERV configuration, compared with 688.2 kW for DOAS at 18 °C and 635.6 kW at 14 °C. This reduction indicates that part of the ventilation load is removed from the main system because outdoor air is pre-conditioned in the DOAS unit before entering the conditioned space. Lowering the DOAS supply air temperature further reduces the sensible cooling load imposed on the VRF system.

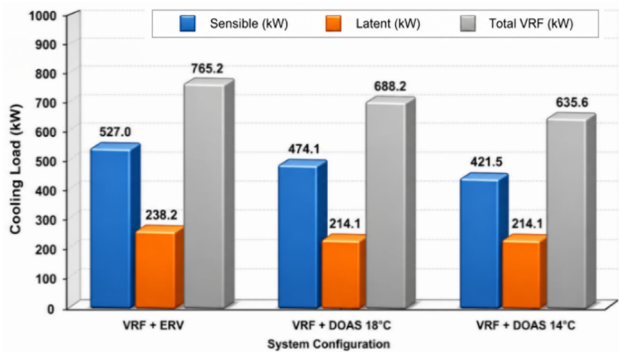


Figure 4. Comparison of cooling load in the main system (VRF)

Although the VRF cooling load decreases, the total system cooling load follows the opposite trend. As shown in Figure 5, the ERV configuration records a total cooling load of 765.2 kW, whereas the DOAS configurations increase to 851.8 kW at 18 °C and 873.0 kW at 14 °C. The additional cooling capacity required to condition outdoor air offsets the reduction achieved by the main VRF system.

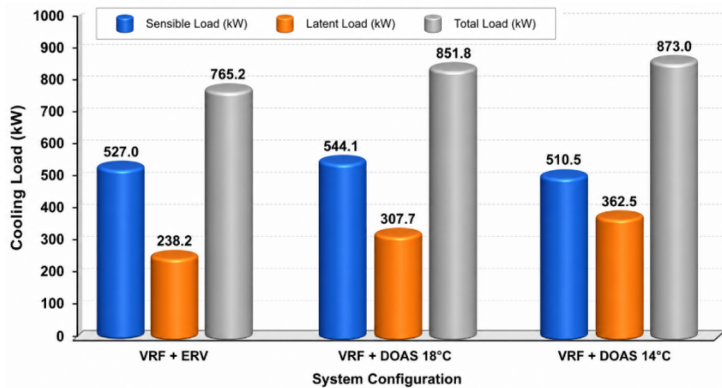


Figure 5. Comparison of total system cooling load (VRF and ventilation units)

Overall, the results demonstrate that DOAS redistributes rather than reduces cooling demand. Lower supply air temperatures shift a greater portion of the cooling process to the dedicated outdoor air unit, reducing the operating demand of the VRF system while

increasing the total cooling load handled by the combined HVAC system. These findings indicate that reducing the cooling load of the terminal units should not be interpreted as an improvement in overall system efficiency because the energy demand associated with outdoor air conditioning becomes the dominant factor. This distinction is particularly important in tropical climates where latent loads are substantial.

3.2 Energy Consumption Analysis

The energy consumption analysis evaluates the influence of ventilation strategy on the annual energy performance of the VRF-based HVAC system. The assessment focuses on cooling and fan energy, which represent the primary HVAC energy components. Total building energy also includes lighting and electrical equipment. Monthly cooling and fan energy consumption for each configuration are presented in Figures 6 and 7.

Figure 6 shows that the DOAS configurations consistently require more cooling energy than the ERV configuration throughout the year. The difference becomes more pronounced as the DOAS supply air temperature decreases, with the 14 °C configuration exhibiting the highest cooling energy demand. Although DOAS reduces the cooling load imposed on the VRF indoor units by pre-conditioning outdoor air, the additional energy required to condition ventilation air outweighs this benefit, resulting in higher overall cooling energy consumption.

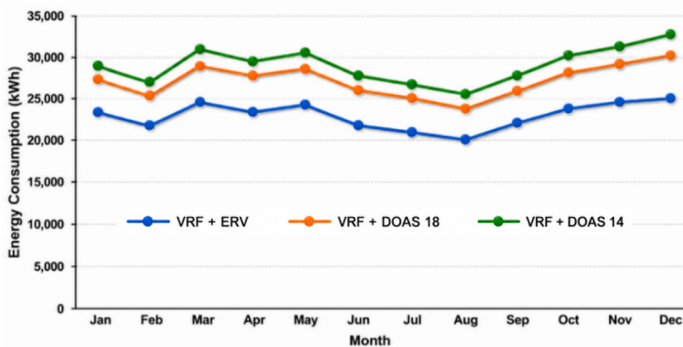


Figure 6. Comparison of monthly cooling energy consumption for each system configuration

In contrast, Figure 7 indicates that fan energy consumption is consistently lower in the DOAS configurations than in the ERV system. Because a portion of the ventilation load is processed by the dedicated outdoor air unit, the operating demand on the main VRF system is reduced, thereby lowering fan energy use. However, the reduction in fan energy is considerably smaller than the increase in cooling energy and therefore cannot compensate for the additional energy required for outdoor air treatment.

Annual total building energy consumption confirms this trend. The ERV configuration records an annual energy use of 854,280 kWh, compared with 873,859 kWh for DOAS operating at 18 °C and 887,421 kWh at 14 °C. Since lighting and electrical equipment remain identical in all simulation scenarios, these differences are primarily attributed to changes in HVAC energy consumption. The corresponding EUI

increases from 169.5 kWh/m²·year for the ERV system to 173.3 and 176.0 kWh/m²·year for the DOAS configurations at 18 °C and 14 °C, respectively.

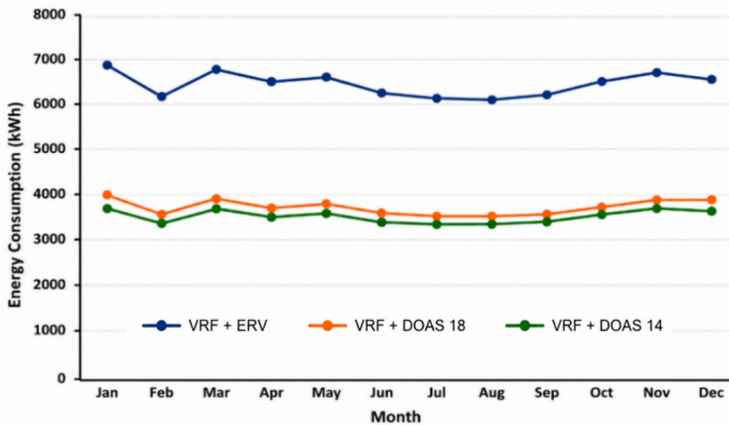


Figure 7. Comparison of monthly fan energy consumption for each system configuration

The results indicate that DOAS redistributes rather than reduces HVAC energy use. While pre-conditioning outdoor air lowers the cooling demand on the VRF system, it substantially increases the energy required for ventilation air treatment. Consequently, lowering the DOAS supply air temperature further decreases the VRF cooling load but does not improve overall energy efficiency because the additional outdoor air conditioning energy exceeds the savings achieved by the main system. The results also suggest that evaluating only the energy consumption of the VRF system may lead to misleading conclusions regarding system efficiency. Whole-building energy assessment is therefore essential when comparing alternative ventilation strategies.

4 Conclusion

This study evaluated the performance of a VRF-based HVAC system integrated with either an Energy Recovery Ventilator (ERV) or a Dedicated Outdoor Air System (DOAS) under different supply air temperature settings. The results demonstrate that DOAS reduces the cooling load handled by the main VRF system, particularly at lower supply air temperatures. However, this reduction does not translate into lower overall energy consumption. Instead, total system energy use increases, with EUI rising from 169.5 to 176.0 kWh/m²·year (3.8%) due to the additional energy required for outdoor air treatment, despite reduced fan energy. Furthermore, lowering the DOAS supply air temperature provides only marginal improvement in indoor thermal conditions, indicating limited benefits relative to the associated energy penalty. These findings suggest that DOAS alone does not inherently improve energy efficiency over ERV. Achieving both thermal performance and energy efficiency requires an integrated design approach incorporating optimized control strategies, including supply air temperature optimization and advanced ventilation control. Future studies should

investigate DOAS configurations with advanced control strategies such as reheat, demand-controlled ventilation, or adaptive supply air temperature control and validate the simulation results through field measurements in actual buildings.

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