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Numerical study on the influence of louver design on VRF system thermal performance in enclosed spaces in Erbil city

Kawa Abdulghany Abdullah [1]*, ***Ramzi Raphael Ibraheem Barwari***

[1] *Mechanical and Mechatronics Department, College of Engineering, Salahaddin University, Erbil 44001, Iraq*

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ABSTRACT

Variable Refrigerant Flow (VRF) systems are extensively employed for space heating and cooling, particularly in multi-story buildings where outdoor units are discreetly placed behind aluminum louvers for architectural considerations. However, these metal louvers can hinder ventilation and heat rejection of the VRF air-conditioning outdoor unit, adversely affecting system performance. This impact manifests in elevated suction temperatures, increased energy consumption, and a diminished coefficient of system performance due to hot air recirculation behind the louvers. Additionally, the expelled hot discharge air from outdoor units rises, increasing the suction air temperature for the upper floors' VRF system. This numerical analysis study investigates the impact of louver tilt angle and opening ratio factors on the thermal performance of VRF air conditioners when installed on building balconies. The objective is to optimize louver designs for concealing condensing units, thereby enhancing overall performance and minimizing power consumption. Two proposed louver designs, incorporating varying tilt angles and opening ratios, are presented as solutions and compared with the existing design. The optimal solution to alleviate the unintended "stuck and stack effects" in the current design involves a proposed modification. The first option suggests decreasing the louver's tilt angle to 20° while maintaining a 60% opening ratio to lower suction temperatures and improve thermal performance. Additionally, increasing the louver opening ratio to 80% effectively reduces air recirculation, providing an alternative solution to optimize the overall performance of the VRF system. Comparisons with previous studies underscore local climate variations and operational disparities, emphasizing the need for tailored louver designs specific to environmental conditions.

1. Introduction

Variable Refrigerant Flow (VRF) system, introduced globally over two decades ago, represents a cutting-edge HVAC technology that has garnered considerable attention and widespread implementation. Its adoption is driven by a multitude of benefits, particularly in addressing the escalating energy consumption of buildings. This innovative system operates by efficiently transferring or removing heat from an outdoor condensing unit, distributing it across a network of strategically positioned indoor units within the conditioned space through a network of refrigerant piping as shown in Fig 1. Its hallmark lies in its remarkable flexibility, accommodating various indoor unit types, enabling individualized zone control, and offering simultaneous heating and cooling in distinct zones via a shared refrigerant circuit. A pivotal feature facilitating this adaptability is the electronic expansion valve (EEV), a crucial component that precisely controls the capacity of every indoor unit by modulating the flow of refrigerant in response to fluctuations in room temperature. This personalized capacity control not only holds the promise of substantial energy savings but also ensures a heightened level of thermal comfort for occupants [1].

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* *Corresponding author.*
E-mail address: kawa.abdullah@su.edu.krd (Kawa Abdulghany Abdullah)

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Nomenclature:

AC	Air conditioner
COP	Coefficient of performance
CMM	Air flow rate ($m^3.min^{-1}$)
CFD	Computational fluid dynamics
DC	Direct current
EER	Energy Efficiency Ratio
HR	Heat Recovery
HP	Heat Pump
K	Turbulence kinetic energy ($m^2 \cdot s^{-2}$)
MIS	Mesh independency study
Q_H	Condenser heat dissipation ($kJ.S^{-1}$)
Q_L	Evaporator heat absorption ($kJ.S^{-1}$)
Win	Compressor input power
Cp	specific heat ($J\ kg^{-1}\ K^{-1}$)
g	gravitational acceleration ($m\ s^{-2}$)
p	pressure ($kg\ m^{-1}\ s^{-2}$)
v	Velocity ($m.s^{-1}$)
h	Enthalpy (kJ/kg)
T	Temperature C

Greek symbols

e	turbulence heat dissipation ($m^2\ s^{-2}$)
µ	dynamic viscosity ($kg\ m^{-1} s^{-1}$)
ρ	Density (kg/m^3)

Subscripts

H	heat dissipation
L	heat absorption
In	input power

The VRF condensing unit is a crucial element in sophisticated air conditioning and heating systems, designed for both residential and commercial applications. Its primary role involves managing refrigerant flow to individual indoor units, enabling precise temperature control in various zones. Enclosed in sturdy housing, the condensing unit includes key components such as a compressor and condenser coil. The compressor is pivotal in pressurizing and circulating the refrigerant throughout the system. As the refrigerant passes through the condenser coil, heat dissipation occurs, transforming the substance from a high-pressure, high-temperature gas to a high-pressure liquid. The condensing unit utilizes advanced technology to modulate refrigerant flow according to specific heating or cooling demands in each zone, ensuring optimal energy efficiency. This intelligent modulation allows for customized climate control and reduces energy consumption by adapting to variable load conditions [2]. The placement of outdoor units for VRF air conditioning systems within building grooves, with an obscured louver, serves the purpose of preserving the aesthetic integrity of building facades. Nevertheless, it is crucial to emphasize that an improper arrangement of these outdoor units can result in a decline of the thermal conditions within the indentations consequently influencing the total operational performance of the air conditioning unit. The empirical evidence underscores a consequential relationship between the temperature of the entering condenser coil cooling air and the Coefficient of Performance, (COP) of the air conditioning system. Specifically, a marginal increase of 1 degree Celsius in the temperature of the cooling air entering the condenser coil correlates with a notable 3% reduction in the COP value of the system [3]. Moreover, the implementation of an automatic safety system is triggered when the ambient temperature surpasses 43 °C. This protective measure initiates a cessation of the compressor operation, thereby protecting the air conditioning system from operational complications under extreme thermal conditions. This description underscores the critical significance of particular outdoor unit placement and efficient cooling strategies, not only to sustain optimal system performance but also to prevent system malfunctions arising from elevated ambient temperatures [4]. Numerous scholars have conducted investigations into the thermal conditions and enhancements of the operational temperature of VRF outdoor units situated within aluminum louver-clad balconies in multi-story buildings. Rosyida Permatasari et al. conducted a thorough CFD simulation on a multi-story building ranging from the 11th to the 30th floor. The study examined three different configurations of condensing unit positions: (1) on every floor (option 1), (2) on every two floors (option 2), and (3) on the roof (option 3). In option 1, the recorded result indicated an average temperature of 35.32 °C, with a relatively narrow temperature range of 3.9°C between the highest and lowest points.

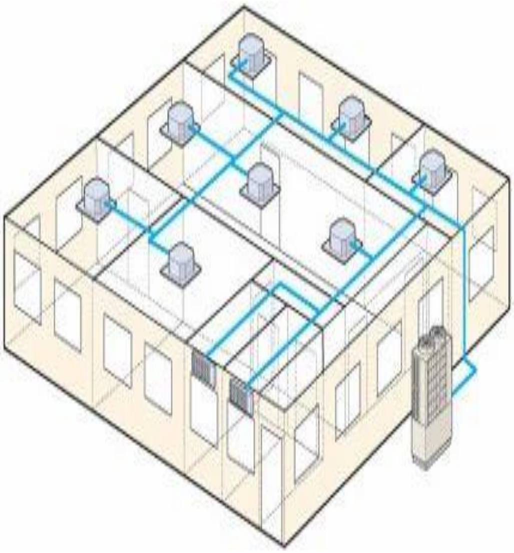

Figure 1. Typical layout of VRV System [3]

For option 2, the mean temperature was 34.44 °C, demonstrating a minimal temperature difference of 0.92 °C. In option 3, the mean temperature reached 36.65 °C, with a more substantial temperature range of 8.03 °C. Comparatively, option 2 exhibited a lower condensing unit input air temperature, suggesting improved cooling efficiency and a more uniform distribution of air across the floors. Importantly, none of the condensing unit positions in options 1, 2, and 3 exceeded the operational temperature limit of 52 °C specified by Panasonic VRF air conditioners [5]. Wufeng Jin et al. investigated the effect of optimal locations and arrangements of louvers on an outdoor unit of a split air conditioner in a confined space, utilizing an enthalpy difference laboratory platform. The objective of the research was to evaluate the impact of installation of the outdoor unit and louver design on air-conditioning power consumption and Energy Efficiency Ratio (EER). Optimal performance was observed when the condenser was placed at a minimum distance of 80mm from the walls. The EER showed improvement with increasing distance from the installation site, reaching an optimum at approximately 300mm away from the fan louver. Improved heat dissipation was observed with greater louver spacing, indicating enhanced air conditioner performance. The research pinpointed an ideal louver inclination of around 30° when the ambient wind originated from a lateral direction, outperforming conditions where the wind came from the front [6]. Ran Duan et al. carried out a study examining how the installation parameters of louvers (specifically, spacing and tilt angle) and the arrangement of outdoor split-type air conditioner units (including location and style) affect system ventilation. This investigation utilized computational fluid dynamics (CFD) simulation. The findings indicated that an augmentation in louver spacing and a reduction in the space between adjacent outdoor air conditioner units led to a higher operational temperature. To improve the dissipation of thermal energy and protect devices from rainwater, an optimal louver inclination of 100° was determined. Additionally, the vertical positioning of condensing units demonstrated greater efficiency in expelling hot air when compared to the horizontal configuration [7]. Nguyễn Văn Hạp numerically modeled 2-array air conditioners prevalent in high-rise apartments. Using Ansys Fluent software, a technical room model assessed air-conditioning condensers' efficiency based on external air vent tilt angles (0° to 40°). Results indicated that increasing the tilt angle elevated the air temperature entering the condenser, causing a decline in the COP. A stable temperature was observed up to a 30° tilt angle, exceeding these compromised operational limits (48°C). To optimize the 2-array system, it's recommended to limit outside air vent angles to approximately 30° or less for enhanced working efficiency [8]. Ching Yin Ho examined the efficiency of split-type AC outdoor units in multi-story residential buildings, where aesthetic considerations often lead to their placement in re-entrances with metal grilles. Various grille patterns were analyzed, revealing that grille voids of 40%, 60%, and 80% negatively affected the COP of the AC system by approximately 25%, 5%, and 1%, respectively, compared to cases with no grille. Despite the COP deterioration, the presence of metal grilles resulted in less heat being rejected from the outdoor unit to the surroundings. This variation influenced heat accumulation within the re-entrance area of the building due to the developed vertical temperature gradient along the re-entrance in high-rise structures [9]. As explained in antecedent literature, the configuration of louvers, including factors such as the opening ratio and blade tilt angle, exerts a notable influence on the suction air temperature.

This influence consequently extends to the thermal efficacy of VRF outdoor units situated within confined spaces of high-rise edifices. The primary aim of this inquiry is to analyze the influence of louver design on the thermal efficiency of VRF systems, employing CFD simulations conducted through ANSYS FLUENT software. Additionally, a pragmatic illustration involving a VRF system within a 23-story commercial building in Erbil is undertaken, showcasing diverse designs. This analysis is visualized to furnish a valuable benchmark for optimizing the configuration of VRF outdoor unit emplacement within semi-enclosed spaces shielded by metallic louvers.

1.1. Research method

Numerical models for this study were developed using CFD (Computational Fluid Dynamics) software, with simulations executed in ANSYS FLUENT (Release 19.2). The research was conducted on a operational VRF system in a 23-floor commercial building within the Empire World enterprise in Erbil city. This approach aimed to thoroughly examine the thermal efficiency of VRF air conditioning systems in partially enclosed areas of multi-story buildings. CFD simulations were chosen as the most suitable technique for assessing the impact of the thermal plume effect on VRF systems serving different floors. The research revealed that louvers contribute to the entrapment of hot air, leading to increased air temperatures around the outdoor units. Consequently, the study delved into investigating various louver tilt angles and opening ratios for outdoor unit covers. The objective was to identify the most suitable design to enhance the optimal operating conditions of the VRF system.

1.2. Geometry modeling

In the present project configuration, each floor is comprised of five distinct offices, each varying in size and cooling load capacity. The cooling infrastructure is facilitated by five VRF outdoor units installed on every typical floor. These outdoor units possess capacities of 2*10, 12, 14, and 16 horsepower (hp) respectively as shown in figure 2. Comprehensive specifications for the selected models can be referenced in Table 1 of the product Databook catalogue for the Samsung brand used in this study. [10]. The parameters calculated are essential for establishing boundary conditions in ANSYS Fluent software.

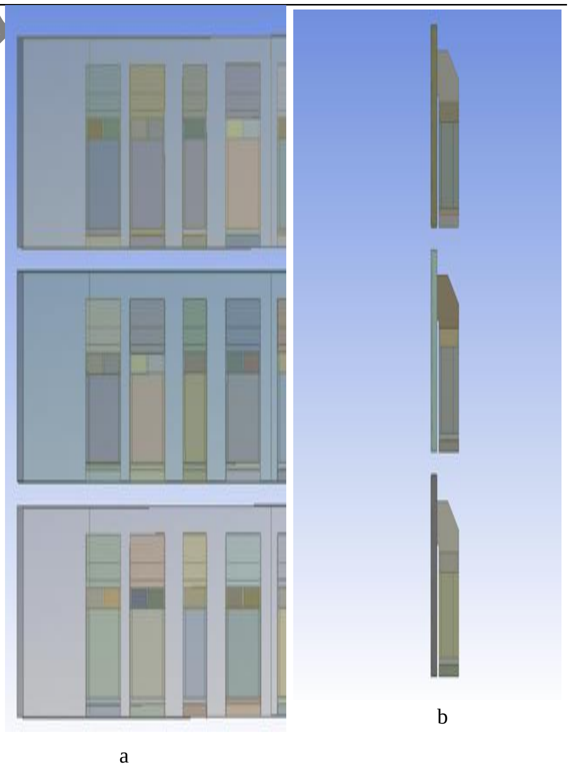

Figure 2. (a) Front view of the condensing units; (b) side view of the condensing units on three floors of office building.

Table 1. Specifications and models of VRF outdoor units [10].

Model	CMM	QL (kW)	QH (kW)	COP
AM100HXVFGH	205	28	35.23	3.87
AM120HXVFGH	255	33.6	42	4.0
AM140HXVFGH	255	40	48.9	3.82
AM160HXVFGH	255	45	56.81	3.81

1.3. Simulation framework

In this study, Ansys Fluent software 19.2 was employed to model and simulate the distribution of airflow speed and temperature around VRF outdoor units of the Samsung brand. The simulation took place in a real-world commercial building positioned within the Empire World complex in Erbil City. The Empire commercial towers constitute four buildings, with two already completed and the other two presently in the construction phase, each comprising 23 floors. The VRF condensing units are positioned on balconies and shielded by metal louvers. Every floor is equipped with five condensing units of varying capacities. The outdoor units expel hot discharge air into the environment through their air direction adjusters, and fresh air is drawn in through the louver inlets on the front view. Fig. 3 shows an isometric perspective of the building from various angles, showcasing a barrier structure composed of wire mesh and metal louvers that conceals the condensing units in the frontal view. The profile view reveals the louvers' inclination angle is approximately 50° and the around %60 opening ratio of the inlet entrance for airflow. A higher opening ratio generally means more airflow is allowed [11].

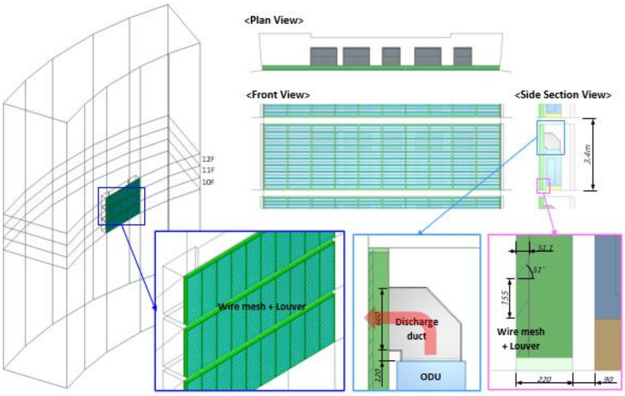

Figure 3. Isometric perspective of a 23-floor commercial building alongside the VRF condensing unit equipped with a guide duct [11]

In the context of these large buildings, layer-based VRF air conditioning systems have been specifically developed for the purpose of cooling specific zones during the summer season. The strategic placement of VRF condensing unit systems on each floor, collectively placed on balconies, is intended to optimize functionality and ensure effective temperature regulation throughout the building. A simulation was conducted, focusing on middle floors ranging from the 10th to the 12th floor of the building. This analysis aims to evaluate and comprehend the practical operational features of VRF systems within the specified vertical range. The objective was to estimate the ascent of the thermal plume to the upper floors caused by buoyancy-driven forces, resulting in an elevation of suction temperatures for the top outdoor units. Additionally, louvers were observed to impede the direct escape of hot discharged air into the environment. This obstruction resulted in the recirculation of the heated air back to the same outdoor units. The consequential increase in suction temperature detrimentally impacted the overall thermal performance of the VRF systems.

1.4. Meshing process

Meshing is a vital step in engineering simulations, breaking down intricate geometries into discrete elements for localized approximations within the computational domain. The mesh quality significantly influences simulation precision, convergence, and computational efficiency. Given the time investment in meshing, enhanced and automated tools, such as ANSYS, are crucial for expediting and refining solutions. ANSYS provides advanced, high-speed, and intelligent meshing software for optimal meshes in Multiphysics simulations. It covers automated meshing for simple applications and finely tuned meshing for complex scenarios, offering various methods from high-order to linear elements, including options for fast tetrahedral, polyhedral, hexahedral, and Mosaic meshes. Smart defaults streamline the meshing process, ensuring precise results by capturing solution gradients effectively. In the ongoing simulation, a hexahedral mesh with a standard element size of 40 mm is employed. Notably, in regions characterized by high airflow near ducts and louvers, a more refined mesh is strategically selected. Mesh sizes of 10 mm and 20 mm for the element size are chosen to enhance accuracy and facilitate solution convergence in these critical areas, as depicted in Fig. 4.

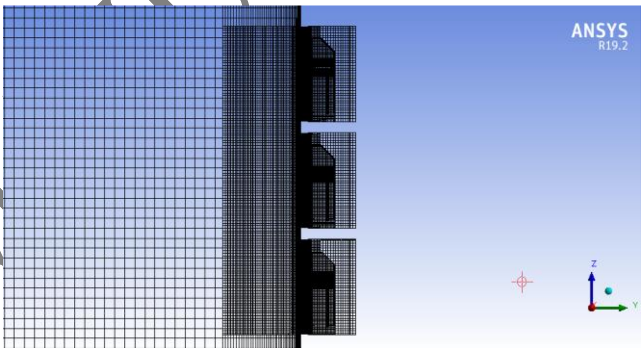

Figure 4. Illustration of VRF outdoor unit schematics and airflow domain utilized in CFD simulation

1.5. Mesh Independency Study (MIS)

In numerical simulations and finite element analysis, the Mesh Independence Study (MIS) assumes a crucial role. It systematically explores various mesh resolutions to assess their impact on simulation outcomes, aiming to identify the minimum mesh refinement level that balances accuracy and reliability. Specifically, MIS determines the lower limit of mesh density needed to maintain grid independence in CFD results. Grid independence implies that increasing mesh cells should not significantly affect the flow solution or related variables. In practical terms, mesh independence is achieved when further refinement results in only minor adjustments in simulation data, confirming the model's robustness. In the present research, Fluent meshing utilized three distinct sizes, namely 6 million, 15 million, and 23 million cells as shown in Fig. 5. The study reveals that beyond 15 million cells, up to approximately 23 million, the alterations in results become inconsequential. Therefore, to ensure result stability and independence from mesh size, a consistent cell count will be maintained across all models. This not only guarantees result consistency but also contributes to a reduction in computational time.

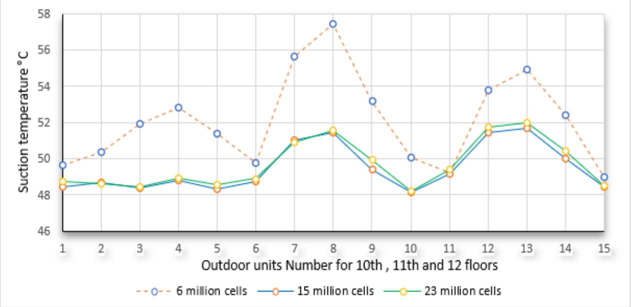

Figure 5. The study of mesh independence in relation to the average suction temperature of outdoor units

1.6. Reynolds number estimation

The Reynolds number (Re) is a dimensionless quantity used in fluid mechanics to describe the flow characteristics of a fluid, whether it's a gas or a liquid, around an object. It helps determine whether the flow is laminar, turbulent, or transitional. The Reynolds number is calculated using the following formula:

$$\mathbf{Re} = \frac{\boldsymbol{\rho} * \mathbf{V} * \mathbf{Dh}}{\boldsymbol{\mu}}$$

To calculate the Reynolds number for the discharge air of a VRF outdoor unit, specific data is required, including air velocity, air density, characteristic length, and dynamic viscosity of the air. The characteristic length is typically associated with the geometry of the outdoor unit's discharge area or any specific component of interest for analysis. It is crucial to consider that the Reynolds number provides valuable insights into the flow regime; however, its applicability and indispensability can fluctuate within diverse engineering or HVAC applications [12]. Upon ascertaining pertinent data, wherein the density of air is posited as 1.25 kg/m^3, the velocity of the discharge air is measured at 6 m/s, the hydraulic diameter of the rectangular duct is specified as 75 cm, and the dynamic viscosity of air is quantified at 1.86 * 10^{-5} kg/(m·s), the ensuing Reynolds number is computed as 3.1 * 10^5. This numerical outcome unequivocally designates the flow regime as turbulent, thereby signifying a pronounced deviation from laminar characteristics.

1.7. Governing Equations

The Navier-Stokes equations are crucial for understanding incompressible fluid behaviour, but when dealing with turbulent airflow around VRF outdoor units, solving them directly becomes challenging. To address this, numerical simulations are employed with fine mesh resolutions, though this increases computational time inappropriately. Practical CFD applications often turn to time-averaged equations like the Reynolds-averaged Navier-Stokes (RANS), offering a smoothed representation of turbulence. The widely-used k-ε turbulence model supplements RANS equations, describing turbulent kinetic energy transport and dissipation. Regardless of the approach, the conservation of mass remains a fundamental principle in fluid dynamics, expressed through the mass continuity equation, crucial for maintaining model integrity.

$$\frac{d\rho}{dt} + \nabla.(\rho V) = 0 \Rightarrow \nabla.(\rho V) = \sum_i \frac{\partial(\rho Vi)}{\partial xi} = -\frac{d\rho}{dt} = 0$$

where ρ denotes flow density in kg/m³ and V represents the velocity vector in m/s, the accelerated velocity of air flow is determined by both surface and mass forces, as per Newton's second law of motion. The momentum equation is derived from the generalized Newtonian viscous stress. Then according to Newton's second law of motion, the accelerated velocity of the air flow is a function of both surface and mass force. Based on the generalized Newtonian Viscous stress, the momentum equation can be obtained:

$$\frac{\partial(\rho V)}{\partial t} + V,\frac{\partial(\rho V_i)}{\partial x_j} = F - \frac{\partial P}{\partial x_i} + \mu \nabla^2 V$$

where μ represents kinematic viscosity in kg/(m²·s) and P denotes static pressure in Pascals, the energy balance equation is given as:

$$\frac{\partial \rho H}{\partial t} + \frac{\partial}{\partial x_i}(V_i \rho H) = \frac{\partial}{\partial x_j}\left(\frac{\lambda}{c_p}\frac{\partial H}{\partial x_j}\right) + S$$

where H signifies enthalpy in kJ/kg, λ represents thermal conductivity in W/mK, and cp denotes specific heat in kJ/kgK, with S representing the heat source in kW, the mentioned equation encompasses these variables [13].

1.8. Heat dissipation calculation

The calculation of the overall heat dissipation from a VRF condensing unit is intricately linked to the efficiency of the refrigeration cycle. Refrigeration cycles, including those employed in VRF systems, are engineered to extract heat from a designated area (e.g., indoor units) and release it into the surrounding environment through outdoor units. The complete heat rejection from the outdoor units in a VRF system can be estimated using the following formula:

$$\mathbf{Q}_{H} = \mathbf{Q}_{\mathbf{L}} + \mathbf{W}_{\mathbf{in}}$$

The COP ratio of a refrigeration cycle serves as a measure of its efficiency and is characterized as the proportion of the intended output (cooling effect) to the required input (work done by the compressor). For a cooling cycle, the COP is given by the formula [14]:

$$\mathbf{COP} = \frac{\mathbf{Q}_{\mathbf{L}}}{\mathbf{W}_{\mathbf{in}}}$$

1.9. Thermal performance of VRF system

The performance of VRF outdoor units is significantly affected by the suction air temperature of condensing units. Elevated coil air temperatures can lead to a reduction in cooling efficiency. In this scenario, condensing units are typically placed on each floor, often on balconies. The heat dissipated, especially in high temperatures, can result in a thermal plume effect. This rising heat, in turn, increases the outdoor unit air temperature for systems on the upper floors. Additionally, hot air exhaust gas may be trapped behind aluminum louvers and recirculated to the outdoor units on the same floor. Consequently, there is a risk of an air short-circuit phenomenon occurring for the condensing units owing to both phenomena contributing to an increase in the suction air temperature. When the inlet temperature exceeds the working threshold value (e.g., 54°C), a high-pressure cut-off is triggered, causing the operation to stop [15].

Fig. 6 illustrates the impact of variations in ambient air temperature during the cooling season on the cooling capacity and electrical power consumption of the VRF system. A pronounced decrease in capacity is evident with rising outdoor temperatures, particularly beyond 35 °C. The condensing unit dissipates heat into the surrounding atmosphere, aiding in the transition of the refrigerant, flowing from a vapor state to a liquid state through condensation.

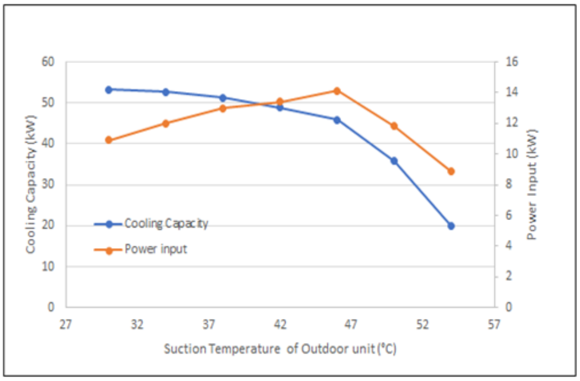

Figure 6. Influence of suction air temperature on both cooling capacity and power consumption [15]

The efficiency of this heat transfer relies on the temperature difference between ambient air and refrigerant. Higher ambient air temperatures result in the outdoor condensing unit dissipating less heat to the environment, leading to a reduced cooling effect by the evaporators. Consequently, as illustrated in Fig. 7, a rise in the temperature of the suction air corresponds to a reduction in COP. This COP reduction is linked to a simultaneous decrease in cooling capacity and a rise in power input caused by the elevated suction temperature. When the ambient air temperature rises from the standard condition temperature (T1 climate condition) of 35°C to the tropical condition temperature (T3 climate condition) of 46 °C, a 12% drop in cooling capacity, a 17% increase in power input, and ultimately a 25% decrease in the COP of the system are anticipated [15].

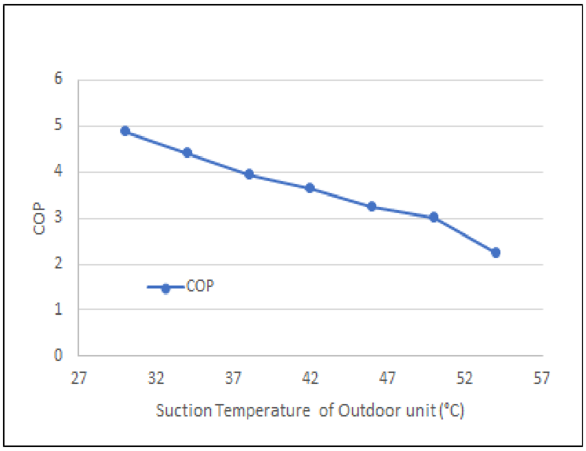

Figure 7. Influence of suction air temperature on the COP of VRF system [15]

2. Results and discussions

For this study, the Ansys Fluent 19.2 software was employed to model the airflow and temperature distribution in the outdoor units operating in the cooling mode situated within a commercial building. The building, spanning 23 floors, incorporates a total of 115 outdoor units. The three-dimensional CAD drawing of the building's geometry was created, subsequently meshed, and analyzed using Ansys Fluent for both the existing and proposed designs. The analysis employed the incompressible, steady-state Reynolds-averaged Navier–Stokes (RANS) technique to strike a balance between computational efficiency and layout accuracy. Specifically for this research, the standard k-epsilon two-equation turbulence model was chosen for the current study. In the existing design, the outdoor units release air downward through inclined louvers, generating a buoyancy effect that pulls air into the top condensing units, thereby increasing the suction temperature. Additionally, the presence of louvers traps hot air, further contributing to a rise in the intake temperature of the condensing units themselves. In the actual scenario, real-world installations from the Empire World project are investigated. The louver angle is set at 50° with a 60% spacing ratio. Four additional cases are examined, allowing a comparison of their impact on condenser suction temperature and overall VRF thermal performance. These cases include variations in louver tilt angles (20° and 35°) while keeping the opening ratio at 60%, as well as different opening ratios (70% and 80%) with a constant 50° louver tilt angle.

2.1. Case studies

In this study, the choice to focus on the 10th, 11th, and 12th floors for simulating the thermal plume generated by VRF outdoor units is strategically grounded. Opting for these middle floors provides a balanced representation of the building's average conditions, offering insights into typical thermal plume behavior in a central cross-section. Simulating middle floors ensures computational efficiency compared to examining extremes, striking a practical balance while capturing meaningful data. The analysis of these floors allows for the assessment of the thermal performance of VRF outdoor units, essential for a comprehensive evaluation of indoor comfort and energy efficiency impacts. Consistency in layout and usage patterns across these middle floors enhances the reliability and generalizability of findings. Moreover, these fully occupied office floors enable a detailed examination of thermal plume interactions in consistently cooled indoor spaces.

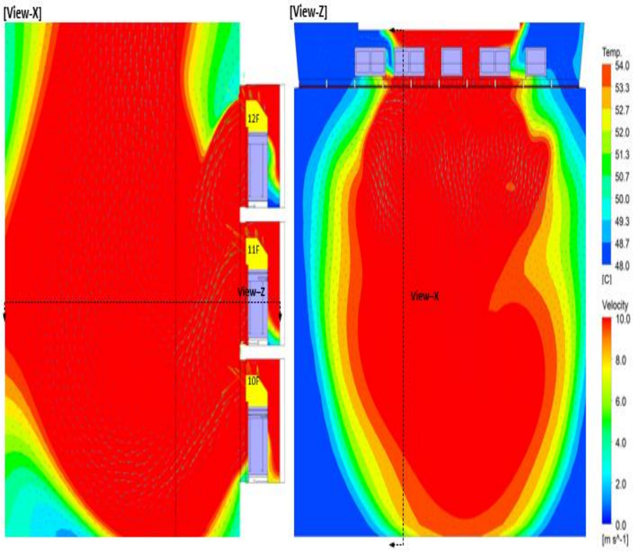

Figure 8. Temperature distributions of outdoor air on the upper floors (F10-12) for VRF condensing units for real case study

2.2. Real-world case

In the real scenario with VRF outdoor units at the Empire Tower, employing a louver angle of 50° and a 60% opening ratio, an unforeseen effect has been observed. Fig. 8 shows that, due to the acute louver angle, some hot air becomes trapped behind the louvers, recirculating back to the condensing unit's inlet. This unintended consequence turns the louvers, designed as visual barriers, into obstacles to airflow. The recirculation hampers efficient heat dissipation, creating a "stuck effect" where inlet temperatures for the same and upper floors increase. This emphasizes the need to consider not only visual and architectural aspects but also airflow patterns in louver design. To address this issue and maintain system efficiency, adjustments to louver design, placement, or additional ventilation measures may be necessary.

2.3. Effect of louver angle

In the first proposed design, featuring a 20° louver angle and a 60% opening ratio, aimed at concealing VRF outdoor units on the upper floors (10th -12th), the discharge air is directed downward through inclined louvers. The steeper 20° louver angle focuses hot air more vertically, reducing the chance of a turbulent thermal plume as illustrated in Fig. 9. This minimizes lateral dispersion, maintaining a stable and predictable heat flow for efficient dissipation. Well-designed louvers play a crucial role in achieving this desired airflow pattern and ensuring optimal HVAC system performance.

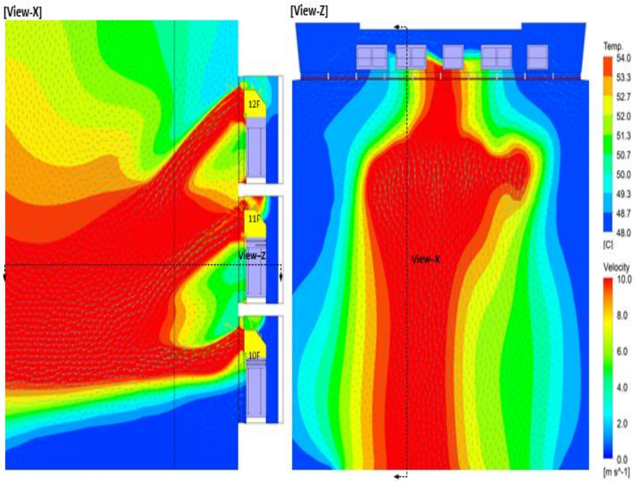

Figure 9. Temperature distributions of outdoor air on the upper floors (F10-12) for VRF condensing units for the first proposed case study

In the second scenario, the design modification involves increasing the louver angle to 35° while maintaining a 60% opening ratio for the aluminium louvers concealing VRF outdoor units. This adjustment directs hot air more vertically, creating a concentrated thermal plume, as seen in Fig. 10. This concentration can impact the condenser inlet temperature on the top floors, potentially compromising the efficiency and overall performance of the VRF system.

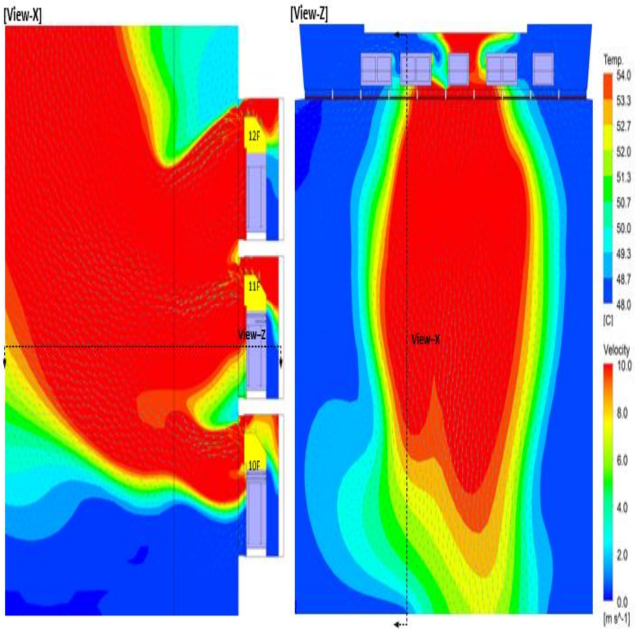

Figure 10. Temperature distributions of outdoor air on the upper floors (F10-12) for VRF condensing units for the second proposed case study

Generally, by decreasing the tilt angle of the louvers, the hot air is directed more vertically. This can result in a more focused and upward flow of the hot air, minimizing lateral dispersion. As a consequence, the suction air temperature may decrease as shown in Fig 11. This configuration is often advantageous for maintaining stable and lower condenser inlet temperatures, contributing to the overall efficiency and performance of the VRF system.

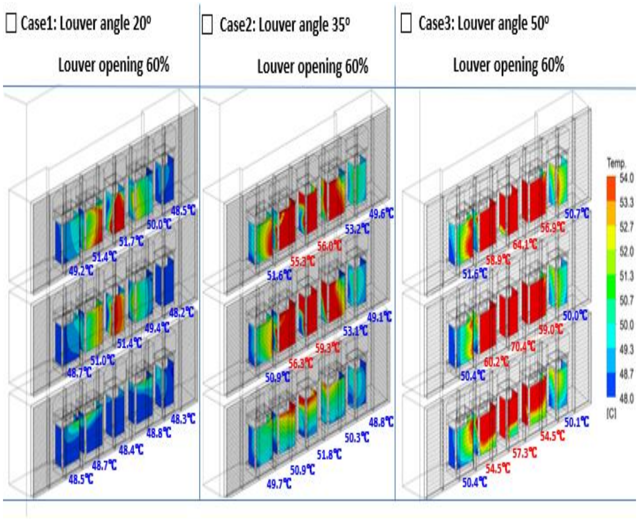

Figure 11. Effect of louver tilt angle on the condenser suction air temperature on upper floors (F10-12) for VRF condensing units

Fig. 12 shows that as the louver tilt angle increases, the average inlet air temperature on the 12th floor rises, while the VRF air conditioner's COP slightly decreases. Reducing the louver tilt angle to 20 and 35°, compared to the baseline of 50°, results in COP increases of 38% and 20%, respectively. This indicates a non-linear relationship between louvewr tilt angle and COP, highlighting the need for optimizing louver configurations for improved energy efficiency and thermal performance in VRF air conditioning systems.

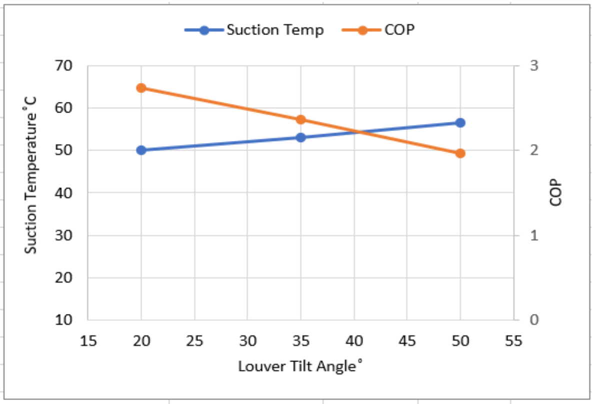

Figure 12. Effect of louver tilt angle on the condenser suction air temperature and COP of VRF condensing units

2.4. Effect of louver opening ratio

In the second design modification, the louver opening ratio was increased to 70% while maintaining a 50° louver angle, as seen in Fig. 13. This adjustment effectively reduced air recirculation around VRF outdoor units, enhancing heat dissipation efficiency. However, despite the improvement, there was still evidence of thermal plume formation, impacting the condenser intake air temperature of the top condensing units. This highlights the complexity of the louver design's interplay with airflow patterns and heat dissipation, emphasizing the need for comprehensive considerations in optimizing VRF system performance.

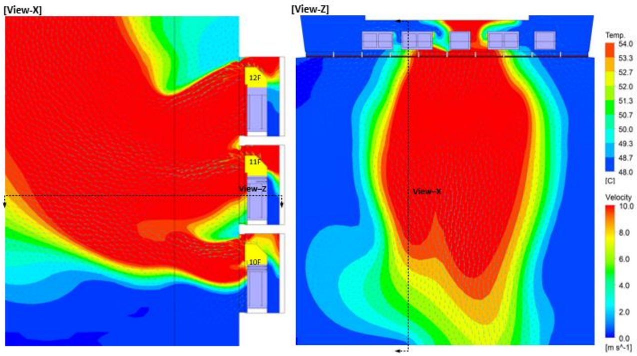

Figure 13. Temperature distributions of outdoor air on the upper floors (F10-12) for VRF condensing units for the third proposed case study

In the last suggested design, the metal louver angle was maintained at 50°, resembling the actual case. However, a significant improvement was achieved by increasing the louver opening ratio to 80%, as depicted in Fig. 14. This adjustment substantially reduced air recirculation around the VRF outdoor units, enhancing airflow efficiency and minimizing trapped air behind the louvers. This optimization is crucial for improving heat dissipation and overall system performance. The heightened louver opening ratio facilitated effective upward and vertical discharge of hot air, redirecting it away from the VRF outdoor units and promoting better heat dispersion. This design change aimed to mitigate thermal plume formation, resulting in a more favourable airflow pattern, reducing the impact on condenser inlet air temperature, and enhancing overall system efficiency. This underscores the importance of louver design and ventilation strategies in optimizing VRF system performance, particularly in scenarios where the condenser's effectiveness is crucial.

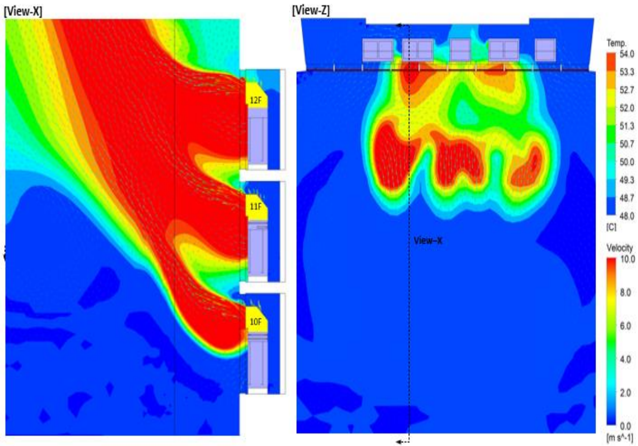

Figure 14. Temperature distributions of outdoor air on the upper floors (F10-12) for VRF condensing units for the fourth proposed case study

Typically, increasing the louver opening ratio can contribute to a decrease in air suction temperature. A higher louver opening ratio allows for more efficient airflow, reducing the recirculation of air behind the louvers as illustrated in Fig 15. This enhancement in airflow facilitates better heat dissipation into the surrounding environment. As a result, the suction air temperature tends to decrease, contributing to improved overall system performance, particularly in scenarios where maintaining lower temperatures is essential for optimal operation.

In Fig 16, a notable trend is observed: an increase in the louver opening ratio correlates with a decrease in the average inlet air temperature of VRF outdoor units on the 12th floor. Simultaneously, the COP of the VRF air conditioner shows a modest increase. Specifically, when the louver opening ratio is elevated to 70% and 80%, as compared to the baseline of 60%, there are corresponding COP increases of 13% and 23%, respectively. This observed relationship can be attributed to the improved airflow facilitated by a higher louver opening ratio. A more open configuration enhances the dissipation of heat from the VRF outdoor unit, a critical aspect for maintaining optimal operating conditions. Adequate airflow ensures efficient removal of the heat generated during the refrigeration process, contributing to the overall performance and energy efficiency of the VRF system.

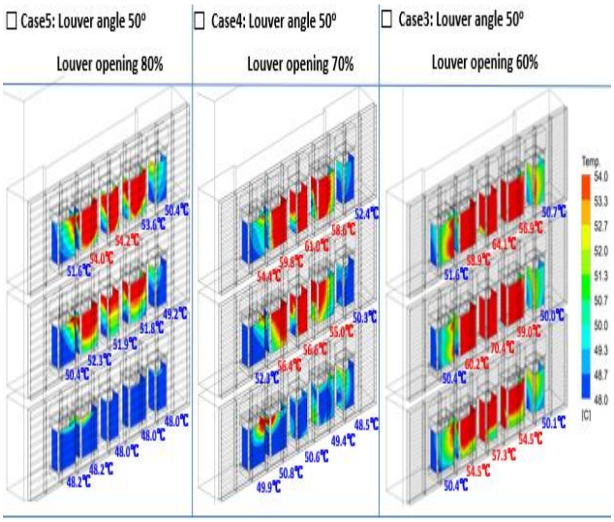

Figure 15. Effect of louver opening ratio on the condenser suction air temperature on upper floors (F10-12) for VRF condensing units

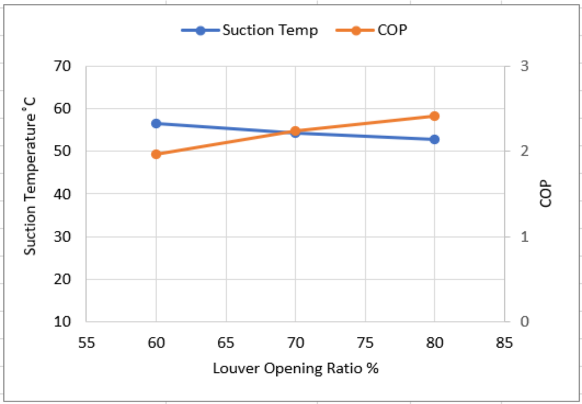

Figure 16. Effect of louver opening ratio on the condenser suction air temperature and COP of VRF condensing units

3. Validation of CFD results

Fig.17 compares the average suction air temperature of the VRF condensing units in a CFD simulation study by Yin Zhang (2017) with the present model. The current investigation reveals a higher inlet air temperature than Zhang's findings, attributed to variations in local climate and operational conditions, notably due to the disparate geographical locations of Erbil and Shenzhen. Erbil experiences elevated ambient temperatures (averaging 48°C) compared to Shenzhen's 35°C. Both studies show a consistent rise in suction air temperature with ascending floors in multi-story buildings, linked to the thermal plume influence. In the initial research, the suction air temperature exceeds operational thresholds beyond the 10th floor, while in the current study, this occurs from the 4th floor due to more outdoor units (5 per floor) in enclosed spaces with louvers. The VRF models differ in operational limits, with the Shenzhen model set at 43°C and the Erbil model at a more stringent 54°C. The highest temperature recorded in Zhang's research was 53.5°C, whereas the present study reached 71.8°C under full operational conditions, emphasizing a notable thermal performance difference [16].

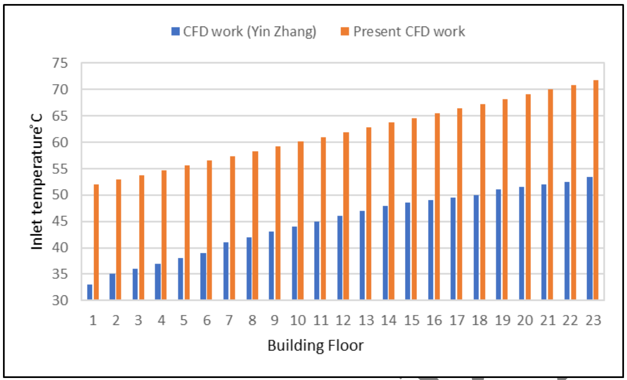

Figure 17. Comparison between CFD simulation of the current work and CFD presented by (Yin Zhang, 2017)

4. Conclusions

A numerical analysis has been conducted to assess the impact of louver tilt angle and the opening ratio of metal louvers on the efficiency of the VRF condensing units. This study involved situating the VRF condensing units on building balconies, which were shielded by louvers. Two distinct conditions for the louver design of each factor were examined, and these proposed designs were then compared with the existing design. The primary objective of this investigation is to offer guidelines for optimized louvers that conceal condensing units on building balconies, ultimately enhancing unit performance and minimizing the consumption of electrical power input. The outcomes of the airflow investigation, specific to the VRF condensing units intended for installation at Empire office buildings in Erbil, are detailed as follows:

1. Efficient heat dissipation, facilitated by the outdoor unit's crucial role in releasing heat, is essential for optimal refrigerant condensation and system efficiency. Elevated ambient air temperatures notably result in a reduction in the cooling capacity of the evaporators.
2. An increase in suction air temperature corresponds with a decrease in the COP, highlighting its interdependence with a simultaneous decline in cooling capacity and an increase in power input.
3. The existing design of the building, characterized by a 50° louver angle and a 60% opening ratio, leads to an unintended issue known as the "stuck effect." This effect involves the hindrance of heat dissipation due to hot air recirculation. Furthermore, there is an additional challenge of a thermal plume caused by buoyancy-driven forces resulting from discharging outdoor units in close proximity on balconies.
4. In the first proposed designs scenarios, optimal louvers with a 20° angle and 60% opening ratio minimize turbulent thermal plumes, ensuring stable heat flow for efficient dissipation. In contrast, a 35° angle in the second scenario creates a concentrated thermal plume, posing a risk to efficiency and VRF system performance on the upper floors. Lowering the louver tilt angle to 20 and 35° from the baseline of 50° leads to COP increases of 38% and 20%, respectively.
5. In the second proposed designs, elevating the louver opening ratio to 70% improved heat dissipation but maintained thermal plume formation. However, a substantial increase to 80% in the last design effectively reduced air recirculation, optimizing overall VRF system performance by mitigating thermal plume and enhancing heat dispersion. Particularly, raising the louver opening ratio to 70% and 80%, compared to the baseline of 60%, resulted in COP increases of 13% and 23%, respectively, attributed to improved airflow facilitated by the higher louver opening ratio.
6. Compared with Yin Zhang's (2017) study, local climate variations

and operational differences result in higher inlet air temperatures in Erbil. The thermal plume effect was observed earlier (from the 4th floor) due to more outdoor units and enclosed spaces with louvers. Notably, the present study shows a significant thermal performance distinction, reaching a maximum temperature of 71.8°C compared to Zhang's 53.5°C.

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Authors' contribution

The preparation of this article involved equal contributions from all authors.

Declaration of competing interest

The researchers declare no conflicts of interest.

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Data availability

The information substantiating the results of this research is accessible from the corresponding author upon a reasonable request.

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