

Control solutions for variable refrigerant flow systems in office buildings

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Abstract. Variable Refrigerant Flow (VRF) systems are widely adopted as high-efficiency solutions for office buildings. In Italy, the Conto Termico 3.0 scheme promotes the replacement of fossil-fuel boilers with heat pumps, fully recognizing VRF systems as eligible air-to-air technologies when minimum seasonal efficiencies are met. This positions VRF as a key solution for building electrification and decarbonisation. However, conventional VRF configurations, with long refrigerant piping and numerous indoor units, often require large refrigerant charges. Given the high global warming potential (GWP) of typical refrigerants, reducing refrigerant inventory is a critical objective alongside improving energy efficiency. This study compares two VRF configurations in an Italian office building across different climatic zones in Italy. A conventional system with multiple indoor units per zone is compared with respect to an alternative configuration using centralized ducted units supplying multiple zones with motorized dampers and aggregated control. Simulations using a new VRF model in TRNSYS18 evaluate electricity consumption, refrigerant charge, thermal comfort, and economic performance that evaluates the viability of the control solution. Results show that the proposed zoned configuration reduces both energy use and refrigerant charge. This dual benefit aligns with Conto Termico 3.0 objectives, supporting both indirect emission reductions and lower refrigerant-related environmental impact.

1 Introduction

Buildings are among the largest energy consumers and sources of greenhouse gas emissions in Europe. The European building stock accounts for roughly 40 % of final energy consumption and about one-third of energy-related emissions, which has driven the European Union to tighten building energy performance requirements and promote nearly zero-energy and, ultimately, zero-emission buildings [1]. In this

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context, high-efficiency heat pumps, and in particular Variable Refrigerant Flow (VRF) systems, have become a key option for office and commercial buildings.

VRF systems provide heating and cooling to multiple zones using variable-speed compressors and electronic expansion valves, offering high seasonal efficiency and good adaptability to part-load conditions. Comprehensive reviews highlight VRF technology as a widely adopted alternative to conventional boiler–chiller or variable air volume (VAV) systems in commercial buildings, largely due to its higher energy efficiency and individual zone temperature control [2,3]. Comparative studies in office buildings report significant reductions in cooling electricity use when VRF replaces rooftop or VAV systems, with savings that can exceed 30–40 % in some cases [4]. Moreover, VRF systems are increasingly used as the main HVAC technology in nearly zero-energy office buildings [5].

A growing body of research has focused on modelling VRF systems for building energy simulation. New physics-based and curve-fit models have been implemented and validated in tools such as EnergyPlus, enabling the representation of multi-zone VRF heat pump and heat-recovery systems under part-load operation. Torregrosa-Jaime et al. [6], developed and calibrated a detailed VRF model in EnergyPlus within an open BIM workflow for an office building, using it to assess VRF performance across different European climates. Recent reviews summarise the available VRF models – from empirical performance-curve approaches to detailed component-level and data-driven models and their applications to energy analysis, system design and operational optimisation [7,8].

Within this modelling effort, control has emerged as a central research topic. Several works have proposed VRF models specifically “for control purpose”, emphasising the need to capture compressor, expansion-valve and fan dynamics as well as multi-zone interactions [8]. Advanced control strategies include model predictive control for vapour-compression and VRF systems, dynamic optimisation control for multi-functional VRF configurations, and partially decentralised supervisory control for large-scale VRF installations [9,10]. Data-driven and machine-learning-based approaches have also been used to predict VRF energy use in office buildings and to support optimal operation [7]. These studies consistently show that appropriate supervisory and zone-level control can deliver additional energy savings and improved comfort on top of the intrinsic efficiency of VRF hardware.

Despite this progress, most published work either compares VRF with alternative HVAC systems at whole-building level [2-5] or optimises the operation of a given VRF configuration through advanced control [8-10]. There are comparatively few studies that treat the VRF system layout itself, specifically, the number and type of indoor units and the associated refrigerant network, as a design variable, and that quantify how alternative zoned configurations affect both energy consumption and refrigerant inventory in real office applications. This issue is particularly relevant from a sustainability perspective: conventional VRF architectures in offices typically employ many small cassette or wall-mounted indoor units directly connected to the refrigerant circuit. The resulting long pipe runs, and numerous indoor heat exchangers can lead to relatively high refrigerant charges compared with hydronic or all-air systems, which is problematic given the high global warming potential (GWP) of many refrigerants currently used in VRF installations.

The present study addresses these gaps by analysing a VRF system serving an office building located in four Italian cities representative of different climatic conditions. Two configurations are compared: a conventional VRF system with multiple individual indoor units per thermal zone; and an alternative zoned

configuration where higher-capacity ducted indoor units supply conditioned air to several zones via air ducts and motorised dampers. Both cases are modelled using manufacturer data for a commercially available LG MULTI V air-to-air VRF system. Dynamic building energy simulations are performed using a new VRF model in Trnsys18, to quantify the annual electricity consumption of indoor and outdoor fans and the outdoor unit, together with the total installed refrigerant charge. Finally, the work aims to demonstrate how zoning-oriented design and control strategies can simultaneously reduce fan and compressor energy use and lower the refrigerant inventory of VRF installations, providing guidance for designers and policymakers on how to minimise the overall climate impact of VRF systems.

2 VRF systems description

A VRF system requires the ability to vary the capacity of the system with one or more individually controlled indoor units through an interconnected network of pipes and communications that continuously adjust the flow of refrigerant to each indoor unit. Control is achieved by continuously varying the refrigerant flow through a pulse modulating valve, the opening of which is determined by the microprocessor that receives information from the thermistor sensors in each indoor unit. The indoor units are connected via a control system to the outdoor unit, which responds to the demand from the indoor units by varying the speed of its compressor to adapt to the total cooling and/or heating requirements (Fig. 1a). On the other hand, the zoned VRF modified proposed has the aim to overcome the drawbacks and disadvantages of this system by replacing groups of individual indoor units with ducted VRF units with a zoned control system of dampers and thermostats that achieve the same performance, but limit the amount of refrigerant in the installation, the length of the pipes, maintenance, etc. Fig. 1b shows an example of a modified VRF diagram in which the individual units have been replaced by a ducted unit implemented in a plenum, with motorised supply dampers that allow the conditioning of each zone to be adapted according to its thermal needs.

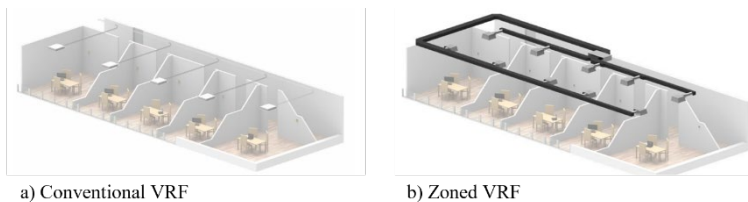


Fig. 1. Types of VRF systems considered. a) Conventional VRF. b) Zoned VRF

The installation of the control elements for zoned VRF is described in more detail. Fig. 2 shows a diagram of the different control elements in the installation.

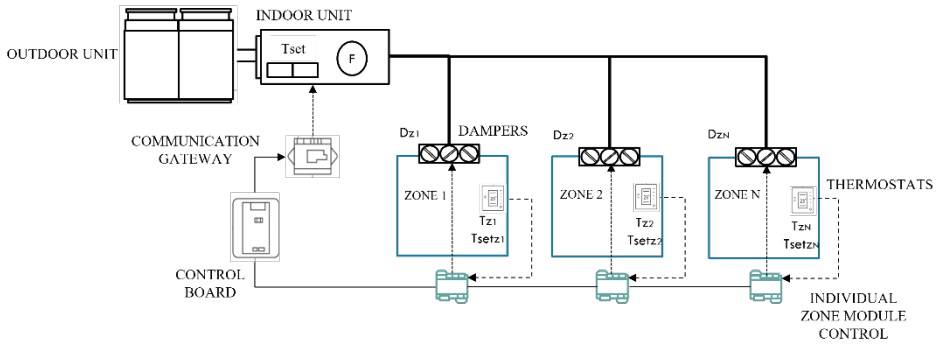


Fig. 2. Control elements of a zoned VRF system

The zoned VRF control centre is a distributed system capable of controlling up to 32 zones through air and/or radiant stages for heating and/or cooling via zone modules connected to the main control board. The control board receives the information from the rooms: the air temperature and the set-point temperature imposed by users, from the thermostat placed in each zone. With this information, the algorithm imposes, thanks to the communication gateway, the control strategy with the configuration of the next elements:

- The operation mode according to the user's preferences (stop, ventilation, cooling, or heating).
- The internal unit fan speed is dynamically selected according to the airflow rate demanded by each zone, the number of zones in demand, and the temperature difference between the zone and the air set-point temperature.
- The set-point temperature of the indoor unit based on the set-point temperatures in each zone, the air temperature, and the return air temperature to the indoor unit, considering the effect of thermal inertia in each zone.
- The position of the dampers of each room which control the amount of air supplied to the zones. The zones in which there is no occupation, the dampers will be closed.
- The control system can limit the set-point temperature of each room, avoiding too high set-point temperatures in winter or too low in summer
- The web server allows the user to interact with the air conditioning system to set their comfort requirements via the system's mobile and web applications.

3 Modelling the VRF systems

This study was conducted in TRNSYS18, a benchmark in thermo-energy facility research. The mathematical models of all the air conditioning systems defined in the previous section were implemented on this calculation platform. The control system described in section 2 has been modelled using mathematical equations in a proprietary model that allows interaction with the building and the rest of the elements in the simulation environment (Fig. 3)

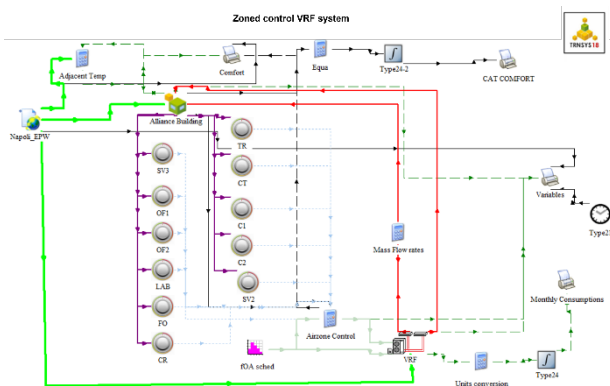


Fig. 3. Simplified Trnsys Simulation scheme of the zoned VRF system.

It is worth highlighting the VRF model, which has been developed from Trnsys' Type1254 and is based on the typical operating curves obtained from manufacturers' catalogues, modifying and adapting the equations for the control case proposed in case 2.

This model, using a variable speed compressor, couples multiple indoor units with, in this case, a single outdoor unit. These require two operating curves (one for heating and one for cooling), which allows different unit powers to be defined to suit the thermal needs of each area in which they are installed. In addition, control of the indoor unit fan speed based on the temperature difference between the zone and the setpoint has been added to the reference model.

The outdoor unit has been modelled to supply the total energy required by each indoor unit. As it is a 2-pipe unit, if there is a demand for heating and cooling at the same time, the net load of the indoor units is supplied. On the other hand, up to 5 performance curves for the outdoor unit are included, such as heating and cooling capacity, as well as correction factors included in 3 other curves, such as refrigerant pipe length, anti-freeze operation and adaptation of thermal capacity and energy consumption in relation to the System Combination Ratio, which varies between 50-130%.

4 Case of study

The case of study is the second floor of a real office building with a total area of 169 m². The geometry of the building and the definition of the thermal zones have been modelled in Google SketchUp, as shown in Fig. 4.

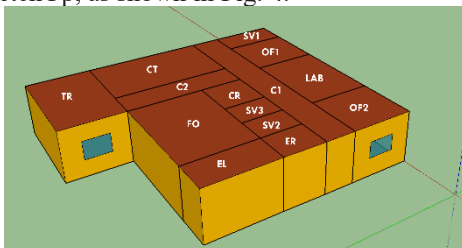


Fig. 4. 3D representation of the building according to the defined thermal zones.

Eleven thermal zones have been defined based on criteria such as usage profile, orientation and occupant activity, with the aim of efficiently sizing the indoor units

and ensuring the thermal comfort of users. The thermal zones are as follows: Teeseract Room (TR), Conference Training (CT), Corridor 1 (C1), Corridor 2 (C2), Security Vestibule 2 (SV2), Security Vestibule 3 (SV3), Office 1 (OF1), Office 2 (OF2), Laboratory (LAB), Foller (Fo) and Common Room (CR). Security Vestibule 1 (SV1), Elevator (EL) and Electrical Room (ER) are non-air-conditioned zones.

The office has been simulated in the base case for Napoli, but in order to evaluate the performance of this type of control system in different climatic conditions, simulations are proposed for three other cities in Italy with different climates: Milan, Roma and Palermo. The climate data has been obtained from the EnergyPlus database.

The properties of building envelopes are defined based on the overall heat transfer coefficient of each construction element (U). The enclosures are representative of the different regulations prevailing in climatic zones according to the Building Energy Codes of Italy [11]. External walls are brick walls with external insulation in rock wool. Roof is a reinforced concrete ceiling with EPS and the intermediate floor is a reinforced concrete and hollow tiles mixed floor with EPS. Windows are double or triple glazing with different layer thickness. More details are described in Table 1.

Table 1. Threshold U-values (W/m²K)

City	Climatic zone	Wall	Roof	Floor	Window
Napoli	C	0.34	0.14	0.8	2.2
Milan	E	0.26	0.09	0.8	1.4
Roma	D	0.29	0.10	0.8	1.8
Palermo	B	0.43	0.16	0.8	3

5. RESULTS

The results of the study analyse the suitability of the zoned VRF control system from the point of view of thermal comfort and energy consumption. In addition, an economic study is carried out to assess its technical and economic viability.

5.1 Sizing of the VRF units

Firstly, the advantages of the proposed sizing with the zoned VRF control system in relation to the power ratings of the selected outdoor and indoor units are evaluated, which leads to savings in the amount of refrigerant in the installation. This decision must be justified by an analysis that ensures thermal comfort in all areas and an assessment of the energy savings in both the indoor unit fans and the outdoor unit.

The sizing of the indoor units and the outdoor unit of the VRF system is carried out on the basis of the calculated thermal loads, with set-point temperatures of 20 °C in heating mode and 25 °C in cooling mode. Two sizing approaches are proposed:

- Case 1: Conventional VRF system. An outdoor unit is selected with a total capacity sufficient to meet the peak heating and cooling loads of the zones. Based on this, one or more indoor units with different heating and cooling capacities are distributed among the various zones to cover the thermal demand according to the characteristics of each zone (Fig. 5a).
- Case 2: Zoned VRF system. Using the same outdoor unit as in Case 1, the sizing of the indoor units is based on the selection of different indoor units of the ducted type, with higher capacity, capable of supplying treated air to a given number of zones. The aim is to reduce the number of indoor units – and consequently the total refrigerant charge and pipework length – while ensuring thermal comfort for

occupants through a control system that acts on the motorised dampers, the fan speed and the indoor unit set-point temperature. This control responds to the thermal needs of each zone, which are monitored by thermostats installed in each of them (Fig. 5b).

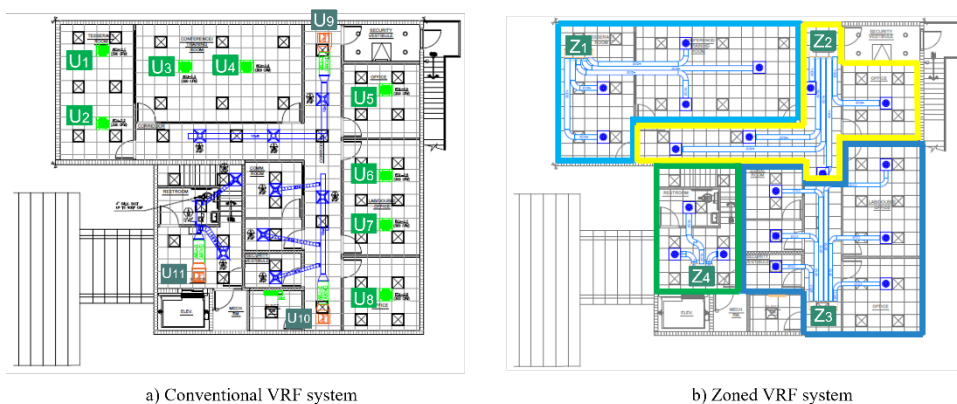


Fig. 5. Thermal zoning. a) Conventional VRF system. b) Zoned VRF system.

In this way, it can be seen how the zoned VRF system reduces the number of units, from 11 individual VRF units to 4 duct VRF units. The selection of the power ratings for all these units is described in detail below. The methodology followed is as follows:

- 1) First, the heating (Q_{heat}) and cooling (Q_{cool}) loads are calculated for the four cities under study (Table 2).

Table 2. Thermal loads

	Napoli		Milan		Roma		Palermo	
LOADS (kW)	Qcool	Qheat	Qcool	Qheat	Qcool	Qheat	Qcool	Qheat
TR	5.0	3.6	4.8	4.3	4.9	3.7	5.0	3.4
CT	5.6	4.4	5.4	4.9	5.7	4.5	5.6	4.2
C1	5.5	4.5	5.5	5.0	5.5	4.6	5.5	4.3
C2	2.8	2.2	2.7	2.4	2.8	2.3	2.7	2.2
SV2	1.2	1.0	1.2	1.1	1.2	1.1	1.2	1.0
SV3	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.0
OF1	3.2	2.4	3.2	2.8	3.1	2.4	3.2	2.3
OF2	2.8	2.2	2.9	2.5	2.8	2.3	2.8	2.1
LAB	3.9	3.1	4.0	3.5	4.0	3.2	4.1	3.0
FO	5.4	4.2	5.3	4.6	5.4	4.3	5.4	3.9
CR	1.6	1.3	1.5	1.4	1.6	1.3	1.6	1.3

- 2) Based on the loads, the VRF system design is carried out in the two proposed scenarios. In both cases, models from the manufacturer LG VRF system have been chosen, alternating cassette-type indoor units (FCU) with duct units (AHU). Tables 3 and 4 show the selection of outdoor units and indoor units according to the type of case, city and thermal zone.

Table 3. Conventional VRF system sizing

Unit	Type	Zone	Napoli	Milan	Roma	Palermo
U1	FCU	TR	ARNU093	ARNU073	ARNU073	ARNU093
U2	FCU	TR	ARNU093	ARNU073	ARNU073	ARNU093
U3	FCU	CT	ARNU093	ARNU093	ARNU093	ARNU093
U4	FCU	CT	ARNU093	ARNU093	ARNU093	ARNU093
U5	AHU	C1	ARNU183	ARNU183	ARNU183	ARNU183
U6	AHU	C2-SV2-SV3-CR	ARNU183	ARNU183	ARNU183	ARNU183
U7	FCU	OF1	ARNU093	ARNU093	ARNU093	ARNU093
U8	FCU	OF2	ARNU093	ARNU093	ARNU093	ARNU093
U9	FCU	LAB	ARNU093	ARNU073	ARNU073	ARNU093
U10	FCU	LAB	ARNU093	ARNU073	ARNU073	ARNU093
U11	AHU	FO	ARNU183	ARNU183	ARNU183	ARNU183
Outdoor Unit			ARUM168	ARUM168	ARUM168	ARUM168

Table 4. Zoned VRF system sizing

Unit	Type	Zone	Napoli	Milan	Roma	Palermo
Z1	AHU	TR-CT	ARNU363	ARNU363	ARNU283	ARNU363
Z2	AHU	C1-C2-OF2	ARNU243	ARNU363	ARNU363	ARNU243
Z3	AHU	LAB-OF1-SV2-SV3-CR	ARNU243	ARNU363	ARNU363	ARNU243
Z4	AHU	FO	ARNU183	ARNU183	ARNU183	ARNU183
Outdoor Unit			ARUM168	ARUM168	ARUM168	ARUM168

- 3) Thanks to the zoned VRF control, the thermal capacity of the system has been adjusted in duct units, which has allowed for a reduction in the refrigerant charge and the length of piping in the installation compared to scenario 1, in which cassette-type indoor units predominate (Table 5).

Table 5. Refrigerant capacity and piping length savings

	Conventional	Zoned	Savings (%)
Number of units	11	4	-
Total capacity (kW)	39.2	30.3	22.7
Refrigerant charge (kg)	20.12	18.85	6.3
Refrigerant piping length (m)	103.5	67.7	34.6

In addition to the reduction in the number of units, the total capacity has been reduced from 39.2 to 30.3 kW, the refrigerant charge from 20.12 to 18.85 kg, and the length of refrigerant piping from 103.57 to 67.76 m, representing savings of 22.7%, 6.3% and 34.6%, respectively.

5.2 Thermal comfort

A comfort analysis is evaluated in each zone according to the ISO 7730 standard [12]. The design criteria for a standing or relaxed person (1 met) wearing typical winter (1 clo) and summer (0.8 clo) indoor clothing are considered with air velocity set to 0.1 m/s. According to this standard, three comfort categories are presented as follows:

- Category A: PPD < 6% and PMV between -0.2 and 0.2.
- Category B: PPD < 10% and PMV between -0.5 and 0.5.
- Category C: PPD < 15% and PMV between -0.7 and 0.7.

Fig.6 compares the thermal comfort for both scenarios, evaluating the percentage of hours that people are in thermal comfort according to the categories defined before.

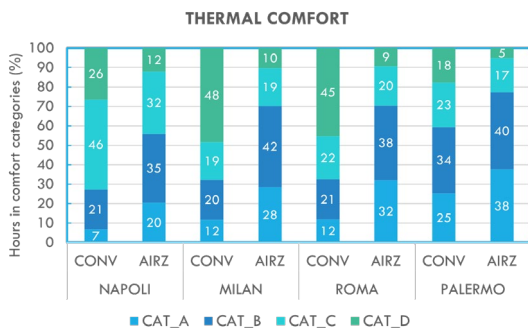


Fig. 6. Thermal comfort results.

In general, it can be seen how, in all cases, the comfort percentages obtained in cases with zoned VRF show that the percentage of thermal discomfort (Category D) is lower (from 5-18%) in all cities than with the conventional system. It should be noted that in colder cities such as Milan and Roma, the percentage of discomfort is around 45% for the conventional case, because there are many hours during which overheating occurs, causing users to experience a sensation of heat with PMV values around the unit during the heating season. This type of situation is common in VRF systems when the indoor units are sized based on cooling demand, which oversized the equipment for heating mode. In relation to the results obtained in Napoli and Palermo, it can be seen that the conventional system obtains lower discomfort values, around 12-18% respectively, and in comparison, with the zoned system, the number of hours in category C is much higher, demonstrating that the zoned control system allows for a greater number of hours of comfort in categories A and B.

5.3 Energy consumption

After assessing the thermal comfort of the building, the next step is to compare energy consumption. To do this, the results of the consumption of the fans in both the indoor unit (F_{int}) and the outdoor unit (F_{ext}), as well as the electricity consumption of the outdoor unit (C_{ext}) are represented. Fig. 7a shows the electricity consumption in kWh for both types of control systems and in the four cities analysed, while Fig. 7b shows the energy savings in percentage.

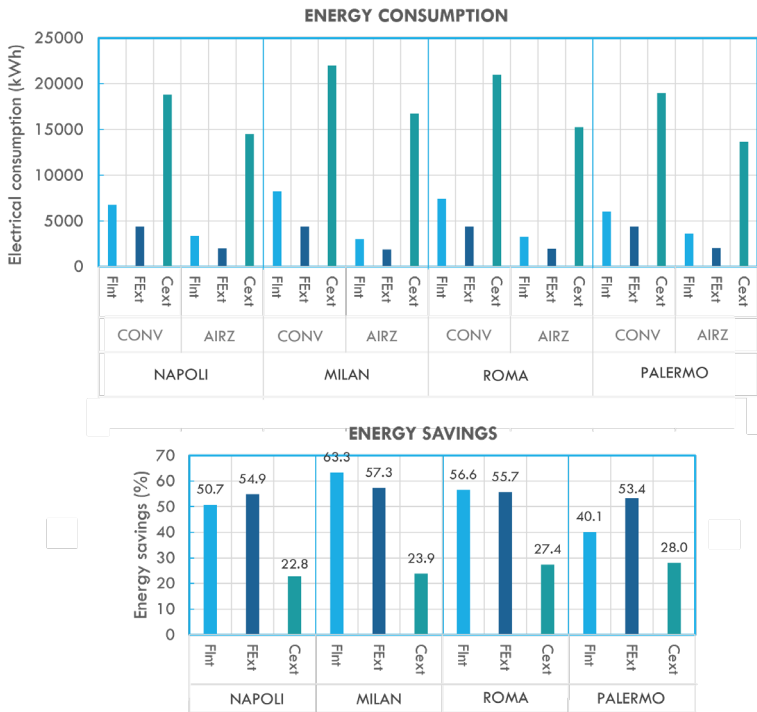


Fig. 7. Energy consumption and energy savings comparison.

In all the cases compared, it can be seen how the electricity consumption of a facility with the zoned control system compared to the conventional case results in energy savings. As shown in Fig. 7b, the savings obtained are remarkable, especially in the consumption of the compressor in the outdoor unit, which is the most significant consumption and allows for reductions of 22.8 to 28%. Indeed, indoor fan energy is reduced by about 40–65 % (50.7 % in Napoli, 63.3 % in Milan, 56.6 % in Rome and 40.1 % in Palermo), while the savings for the outdoor fan remain remarkably stable at around 53–57 %. The reduction in cassette-type indoor units replaced by ducted units contributes to a considerable reduction in the total consumption of indoor unit fans, with savings of up to 63%. These results confirm that the proposed zoning and control configuration is effective in lowering fan and compressor energy use, mainly by limiting airflow and cooling/heating capacity in zones with low demand and improving part-load operation of the VRF system.

5.4 Economic viability

The economic analysis is based on a comparison of the initial investment in the VRF system according to the indoor and outdoor units in each of the proposed configurations, to which the initial cost of the zoned VRF control system is added in case 2. The objective is to evaluate, based on the annual savings in electricity consumption, the number of years in which the initial cost of the control system can be recouped.

Table 6 shows the cost of the necessary control elements that have been implemented in the case of the ducted VRF control system, which includes the main control board, the communication gateway, the thermostats for each zone, connectivity to the webserver and the diffusion system [13]. In total, the control system costs 11297 €.

Table 6. Ducted control system initial cost

Control Element	PVP Unit (€)	Units	Total Cost (€)
Main control board	379	1	379
Thermostat wired	270	16	4320
Direct expansion control communication gateway	311	1	311
Cable motorisation zone module	81	16	1296
Webserver HUB Airzone Cloud Dual 2.4-5 GHz/Ethernet	311	1	311
Wi-Fi electricity consumption measurement pack for single-phase installation	191	1	191
Connection cable (2x0,5+2x0,22 mm ²) 100 m	129	1	129
Air diffusion: Simple motorised supply and return grilles			4360
Ducted VRF control system total cost			11297

Table 7 shows the economic study carried out with the calculation of the initial cost of the equipment, based on Tables 3 and 4 [14] and the control system, the annual energy consumption cost, the annual cost savings obtained and the payback period in years. This has been done for the conventional scenario and for the zoned ducted control system in the four cities analysed. Operating costs have been calculated based on annual electricity consumption and the national average electricity price for non-domestic customers, equal to 0.26 €/kWh (including taxes and network charges). This value is consistent with recent statistics reported by Eurostat for Italian business consumers, which indicate average electricity prices in the range of 0.23–0.30 €/kWh in the 2023–2025 period [15].

Table 7. Economic analysis. Payback period calculation

		Napoli	Milan	Roma	Palermo	
Initial cost (€)	Conventional	28061	28134	28134	28061	
	Ducted VRF	Equipment	22155	22573	22092	22155
		Control system	18665	18665	18665	18665
Energy Consumption (kW)	Conventional	117247	119818	106647	79055	
	Ducted VRF	76408	70143	61495	40998	
Electricity cost (€)	Conventional	4880	5548	8189	6603	
	Ducted VRF	3180	3248	4722	3425	
Payback period (years)		2.0	1.7	1.6	2.1	

As can be seen, the payback periods for the various case studies range from 1.6 to 2.1 years, which are very reasonable periods considered economically viable.

CONCLUSIONS

This study compared a conventional VRF system with multiple individual indoor units per zone and a zoned VRF configuration using higher-capacity ducted indoor units and motorised dampers in an Italian office building located in four different climates. Both systems are based on the same commercial air-to-air VRF range.

- The zoned VRF configuration consistently reduces electricity use of indoor and outdoor fans and of the outdoor unit in all locations. Indoor fan consumption is typically reduced by 40–65 %, outdoor fan consumption by around 53–57 %, and the electricity use of the outdoor unit by approximately 23–28 %. On average, the zoning and control strategy achieves reductions of about 53 % for indoor fans, 55 % for outdoor fans and 26 % for the outdoor unit, indicating a markedly improved part-load operation.
- In all cities, the zoned VRF layout lowers the percentage of hours in thermal discomfort (Category D) by around 5–18% compared with the conventional system. In colder climates such as Milan and Rome, the conventional VRF case shows discomfort levels close to 45 %, mainly due to overheating during the heating season caused by indoor units sized on cooling demand. The zoned configuration mitigates this effect and, in warmer cities such as Napoli and Palermo, shifts a significant number of hours from Category C into the higher comfort Categories A and B.
- From a design standpoint, the zoned layout reduces total installed capacity from 39.2 to 30.3 kW (–22.7 %), total refrigerant charge from 20.12 to 18.85 kg (–6.3 %), and the total length of refrigerant piping from 103.57 to 67.76 m (–34.6 %), in addition to a smaller number of indoor units. These reductions are relevant for limiting potential direct emissions associated with refrigerant leakage and end-of-life losses.
- When the additional cost of the zoning and control system is compared with the achieved energy savings, the simple payback periods for the different case studies range from 1.6 to 2.1 years. Such values are generally considered economically attractive for office HVAC retrofits or new installations, indicating that the proposed configuration is not only technically but also financially viable.

Overall, the results show that reconfiguring VRF systems around aggregated thermal zoning and dedicated control can simultaneously improve energy performance, enhance thermal comfort, reduce refrigerant-related indicators and achieve payback times of around two years, offering a practical pathway for aligning VRF-based solutions with energy-efficiency and climate objectives in Italian office buildings.

References

1. European Commission, Energy Performance of Buildings Directive (EPBD) – overview, https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en (2024)
2. T.N. Aynur, Variable refrigerant flow systems: A review, *Energy and Buildings* 42, 1106–1112 (2010)
3. Y.H. Yau, U.A. Rajput, A. Badarudin, A comprehensive review of variable refrigerant flow (VRF) and ventilation designs for thermal comfort in commercial buildings, *Journal of Thermal Analysis and Calorimetry* 149, 1935–1961 (2024)

4. X. Yu, D. Yan, K. Sun, T. Hong, D. Zhu, Comparative study of the cooling energy performance of variable refrigerant flow systems and variable air volume systems in office buildings, *Applied Energy* 183, 725–739 (2016)
5. D. Kim, H. Cho, J. Koh, P. Im, Net-zero energy building design and life-cycle cost analysis with air-source variable refrigerant flow and distributed photovoltaic systems, *Renewable and Sustainable Energy Reviews* 118, 109508 (2020)
6. B. Torregrosa-Jaime, P.J. Martínez, B. González, G. Payá-Ballester, Modelling of a Variable Refrigerant Flow System in EnergyPlus for Building Energy Simulation in an Open BIM Environment, *Energies* 12(1), 22 (2019)
7. J. Wang, X. Lu, V. Adetola, E. Louie, Modeling Variable Refrigerant Flow (VRF) systems in building applications: A comprehensive review, *Energy and Buildings* 311, 114128 (2024)
8. D. Wang, M. Li, M. Guo et al., Modelling variable refrigerant flow system for control purpose, *Energy and Buildings* (2023)
9. N. Jain, J.P. Koeln, S. Sundaram, A.G. Alleyne, Partially decentralized control of large-scale variable-refrigerant-flow systems in buildings, *Journal of Process Control* 24(6), 798–819 (2014)
10. Y.-S. Lee, W.-H. Kim, Development of an optimal start control strategy for a variable refrigerant flow (VRF) system, *Energies* 14(2), 271 (2021)
11. S. Di Turi, L. Ronchetti, R. Sannino, Towards the objective of Net ZEB: Detailed energy analysis and cost assessment for new office buildings in Italy, *Energy and Buildings* 279, 112707 (2023)
12. ISO, ISO 7730:2025 Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (2025)
13. AirzoneItalia, Airzone control solutions, www.airzonecontrol.com (accessed 20 December 2025)
14. LG, Recommended prices, September (2025)
15. Eurostat, Electricity prices for non-household consumers – Italy, https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_205/default/table (2024)