

Assessing the economic, environmental, and energy impacts of natural gas-powered VRF system for building sector decarbonization: An integrated all-in-one package methodology based on open BIM approach

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ABSTRACT

In the context of the global energy transition, innovative HVAC solutions are essential, particularly those suited to temperate climates and local energy strategies. This study evaluates the potential of natural gas-powered Variable Refrigerant Flow (NG-VRF) systems, functioning as Gas Heat Pumps (GHPs), as a decarbonization strategy for countries reliant on natural gas power plants. A key aspect of this research is the comparison between NG-VRF systems and electric VRF systems with boilers for domestic hot water production. Using Life Cycle Assessment (LCA), the study assesses energy, environmental, and economic impacts in three climatic zones in Algeria: Mediterranean, semi-arid, and arid. The analysis incorporates the OpenBIM workflow and "Price Generator" database, offering an all-in-one package methodology as decision-support tool for energy consumption, environmental impact assessment, and economic evaluation aligning with trends in digitalization and energy transition. The findings reveal that the NG-VRF system, with its trigeneration capability, providing heating, cooling, and hot water from a single unit, achieves lower environmental impacts and energy consumption compared to mono-generation electric VRF systems. Heat recovery from the NG-VRF system eliminates the need for a separate hot water boiler, further enhancing efficiency. Paradoxically, promoting GHP systems in natural gas-producing countries helps preserve natural gas resources while reducing operational CO₂ emissions and primary energy consumption by 40% in Mediterranean climates, 35% in semi-arid, and 25% in arid climates. Furthermore, energy cost savings of up to 63% are achieved compared to international pricing. Consequently, energy savings in subsidized energy markets can increase natural gas exports, benefiting national revenues.

Nomenclature

CO ₂ eq	Global warming potential - (GWP) [Kg]
CFC 11 eq	The ozone depletion potential - (ODP) [Kg]
SO ₂ eq (kg)	Acidification potential of land and water - (AP) [Kg]
(PO ₄) ₃₋ eq (kg)	Eutrophication potential - (EP) [Kg]
POCP (Ethylene eq)	Photochemical ozone creation potentials [Kg]
Sb eq	Abiotic Resources Depletion - (ADPE) [Kg]
(ADFP)	Abiotic depletion for fossil resources potential [MJ]
(PERT)	Primary energy renewable - total [MJ]
(PERNRT)	Primary energy non-renewable - total [MJ]
FW	Flow water net use [m ³]

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DFS	Discounted Future Savings
UES	Updated Energy Saving
AES	Annual Energy Saving
DMC	Discounted Maintenance Cost
AMC	Annual Maintenance Cost
ΔP _E	Annual increase in energy costs (7 %)
T _{inflation}	Expected inflation (6.5 %)
T _{interest}	Nominal interest type (9 %)
Tr	Discount rate taken as 2.5 % (T _{interest} - T _{inflation}).

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1. Introduction

In recent years, there has been a significant increase in the emission of greenhouse gases. Among these emissions, 40 % can be attributed to the building industry [1,2]. Despite the considerable efforts made by the participating nations, the objectives of COP 21 are diverging. Current trends indicate a warming of 2.4° to 2.8 °C, on top of the 1.1 °C that has already been recorded, compared to pre-industrial levels, specifically the late to XIXe century. In actuality, greater efforts are required to meet the 1.5 °C target. Therefore, an immediate, deep, and sustainable reduction in GHG emissions during this "critical decade" is required. This rhetorical gap must be bridged for achieving net zero by 2050, and at least limiting the rise in global temperatures to 1.5 °C [3]. The growth in energy use for HVAC systems is particularly significant [4], accounting for as much as 50 % of building consumption and 20 % of total energy consumption in the United States [5]. In Algeria, the building sector accounts for around 43 % of final energy consumption [6], essentially related to heating and cooling.

Climate change is mainly caused by GHG emissions from energy consumption. For this reason, GHG emissions must be limited. Regarding this, Algeria has implemented a National Climate Plan (NCP) to outline a series of measures that contribute to the attainment of objectives in terms of adapting to climate change impacts and reducing greenhouse gas (GHG) emissions by 2030 [7,8]. The overall objective of this program is to align greenhouse gas emissions with international commitments, resulting in a voluntary reduction of 7 % in GHG emissions by 2030 and a conditional reduction of 22 %.

In order to plan and build responsibly for the future, it is necessary to have an overview of the topic at hand [9]. The improvement of the energy efficiency of the buildings contributes to the preservation of the environment [10]. Thus, it is essential to evaluate the GHG emissions of the building through an assessment that takes into consideration all stages of building life cycle. This assessment is crucial for advancing towards the use of more ecologically sound technologies. Building Life cycle Assessment (LCA) and environmental impact assessment (EIA) play crucial roles in achieving net zero emissions targets by providing a comprehensive understanding of the environmental impacts associated with products, processes, or systems throughout their entire life cycle. Research on the area of the interaction effect of buildings on the environment has been substantially focused on by many researchers over the past decades. Previous studies have shown that whole-building LCA tends to prioritize certain life-cycle stages of buildings while overlooking others. Specifically, there is a heavy focus on the manufacturing of building materials in the cradle-to-gate stage, and the analysis typically only considers the structural systems of the building [11–18]. As a result, important aspects such as building envelope and Mechanical, Electrical and Plumbing (MEP) systems impact is often neglected. On the other hand, there are a handful of research studies that include the impact of MEP systems. H. Cai et al. [19] focused on addressing embodied greenhouse gas emissions and the potential trade-off between embodied and operational GHG emissions in the context of energy efficiency improvements in building design. The researchers included the embodied impacts of MEP systems, providing a more comprehensive analysis of building environmental footprint. However, no optimization work was carried out on the MEP system, especially to HVAC systems. The study did not include a detailed analysis of operational energy consumption and GHG emissions at the equipment/appliance level, such as MEP systems, which could provide valuable insights into opportunities for reducing building environmental impact in the use phase.

R. Kathiravel et al. [20] Investigated the environmental and economic aspects of different climatic conditions in Canadian regions throughout a building life cycle. Focusing on HVAC systems, choice between electricity, natural gas and solar sources. Using whole building life cycle assessments and energy simulations, the research examines 36 scenarios, considering three popular HVAC systems with six weather conditions employing BIM and fuzzy-based methods. As a result, Ground

Source Heat Pump (GSHP) presents lower emissions despite higher upfront costs and is preferred when considering both environmental and economic factors. However, the authors found that in mild climates like Vancouver, Air Source Heat Pump (ASHP) remains optimum solution. On the other hand, M.F.D. Morales et al. [21] presented a retrospective dynamic life cycle assessment of residential heating and cooling systems in four locations in the United States. The authors evaluated the GHG emissions of two alternative residential HVAC systems: natural gas furnace, electric air conditioning, and an electric heat pump, in a typical single, family house located in four different climate zones in the U.S. The authors concluded that if the decarbonization of electricity production continues and refrigerants with low GHG potential are widely used, the heat pump could be the system with lowest related GHG emissions in all studied climate zones. The optimal solutions proposed by the authors are specifically suitable for Canadian climate. Consequently, there is a need for further research for other climates as for hot and dry climate, optimal adopted HVAC systems and energy sources are different.

In the context of energy transition, Algeria, as one of a gas exporting country, is focusing its strategy on improving wasteful energy efficiency and developing investment in traditional hydrocarbons, including natural gas, which is cleaner energy than oil and will continue to be the main source of foreign currency for a long time to come, as well as further reducing methane emissions and flaring, which would make more gas available for trade. As announced in the Summit of Gas Exporting Countries in Algiers in March 2024 [22], Algeria plans to produce and export 30 to 40 TWh of gaseous and liquid hydrogen, by 2040, with a mix of both blue hydrogens, produced from gas, and green hydrogen, produced by electrolysis using extensive solar resources of the country, with the aim of supplying Europe with 10 % of its green hydrogen needs by 2040. In order to fulfill these ambitions, it becomes interesting to promote the use of natural gas as an energy source in facilities such as heating and cooling, as an alternative energy source to electricity. Since electricity is produced by power plants that consume natural gas as primary energy. Moreover, the cost of natural gas (0.003USD/kWh) is more than 10 times lower than the cost of electricity (0.04USD/kWh).

When it comes to LCA, the literature offers a variety of techniques and resources. Some have local databases and are targeted at certain nations, such as INIES for France [23], while others offer standard procedures that can be used in a number of nations worldwide [24,25]. To estimate the embodied greenhouse gas emissions in buildings, there have been significant recent initiatives to standardize life cycle assessment LCA approaches, develop tools, and create databases.

Integrating Building Information Modeling (BIM) into LCA appears to be very useful. The implementation of BIM as a process is crucial for projects to fully realize its immense potential. Throughout the building life cycle, BIM is crucial for information management. Project stakeholders can swiftly and precisely comprehend and evaluate the many pieces of information pertaining to the building thanks to its ability to facilitate communication and integration of building data and information throughout the project life cycle [26]. It contributes significantly to saving time, effort and human errors [27].

Y. Teng et al. [28] analyzed 82 buildings from selected publications between 2011 and 2021, using scientometric and detailed content analysis techniques. The results evidence that most of publications were focusing on residential, low-rise, and concrete buildings, using Autodesk Revit for establishing BIM models, with data from professional LCA tools imported into BIM objects, where the type of materials to be associated is limited. Architectural design uses many materials, so it is necessary to have easy access to LCA data. Under such circumstances, it is highly probable that the BIM model, using BIM objects, lacks the material-level detail necessary to support an LCA computation. There is currently a demand for a database containing generic information and synoptics on building compositions and the corresponding life cycle assessment profiles. The research identifies challenges in creating a uniform

database platform for BIM-LCA, and the need for region-specific databases to provide automated material classification for measuring potential environmental consequences [29]. Most published LCA related-studies on buildings have been completed in developed countries and in cold regions, such as Norway and Sweden [30], in Scotland [31], G.J. Citherlet [32] in Switzerland and France [33]. In Algeria, building LCA related-studies are very rare. Despite the effort of Algerian Center for LCA and Eco-design, the database remains limited and dedicated only to building materials.

Building upon this, the present research work aims to analyze the effect of adopting natural gas-powered Variable Refrigerant Flow (NG-VRF) systems, operating as a Gas Heat Pump (GHP), as a decarbonization strategy, for countries using natural gas power plants. The distinctive feature of this research lies in the comparison of NG-VRF systems with electric VRF systems combined with boilers for domestic hot water production. An energy, environmental, and economic analysis is performed through a (LCA), incorporating OpenBIM workflow, project management tools, and the "Price Generator" database. A comprehensive approach and integrated framework are presented in this work as an all-in-one package methodology, which provides a decision-support tool for global applications in energy simulation, environmental impact assessment through LCA, and economic evaluation. One of the greatest advantages of GHP is the energy recovery from the gas engine for hot water production, towards studying both energy and environmental impacts. The trigeneration capability of the NG-VRF system-producing heating, cooling, and domestic hot water with a single unit-results is a very important aspect to be considered and compared to the standard mono-generative electric VRF, in order to analyze the reduction potential on environmental impact and energy consumption, while assessing the economic impact. This is crucial, as moving towards innovative systems has become very important strategy in the context of energy transition, especially for temperate-climate countries.

In addition, GHP engines provide a major advantage in terms of equipment noise reduction, since the mechanical efficiency of the compressor is about 50 %, lower than the electric compressor which is about 98 %. This system has become very popular, especially in countries where natural gas is available at competitive cost and energy policies are favorable. In this work, an economic analysis of energy cost is carried out, considering subsidized prices for gas-producing countries, such as Algeria where natural gas is affordable to other countries [34].

This study is carried out for the same office buildings located in different climatic zones in Algeria, namely a Mediterranean, Semi-arid and arid climate. The proposed approach is a consequence of interoperability between CYPECAD MEP, Cypetherm EPLUS, CYPETHERM Improvement Plus and CYPEPROJECT Software through an OpenBIM workflow. Most researchers use BIM in LCA only for the construction and design phase [26]. In this work, OpenBIM workflow is used not only for the design stage, but also for HVAC system sizing and energy simulation in the use phase. The present approach and software present a Multicriteria methodology that helps designers as decision-support tools, which can be adopted in different countries worldwide. This is crucial for keeping current with trends in the building sector in terms of digitalization, energy transition and environmental impact.

While local databases usually include only a limited number of materials, global inventory databases do not accurately reflect regional manufacturing processes [19]. Therefore, the "Price Generator" [35] is used as a database, in this work, since it combines the extremely extensive content of data on building materials and equipment with the features specific to each country. This database is developed by Cype Software for different countries around the world, and used by many professionals. It has been designed to adapt to market trends and manufacturers in each country. Additionally, a generic database has been included as well. The "Price Generator" encompasses a wide range of information on building materials and equipment, including crucial aspects such as price, technical specifications and environmental

indicators.

The methodology and software showcased establish a tool for decision-making. By accurately evaluating ecological impacts, making easier the decision-making process for construction professionals in accordance with their goals. The direct connection of this database with CYPE software allows the tools or materials contained of different manufacturers in the price generator to be used right away for envelope design and MEP installation sizing studies. In addition, CYPE offers OPENBIM Systems solutions, which are different from BIM Objects, in that they include all the data required for the complete installation of the systems that are being considered, including HVAC systems.

While eco-design is fundamental to the concept of a "sustainable building," it ignores the effects that building, use, destruction, and energy source selection have on the environment. It is therefore essential to know which phase of their life has the greatest impact on the environment, and what causes this impact, in order to improve their ecological performance. After reviewing more than 230 publications from 1995 to 2018, M. Bahramian et al. [36] discovered that life cycle stages related to manufacturing and use phases are the most commonly studied, while life cycle impact categories related to embodied energy and global warming potential are the most commonly considered. Since the operation phase generally showed the highest impact [30,37–40], and negligible impact comes from the end-of-life stage [41], more efforts should be devoted to accelerating the transition to energetic clean system at a national scale. Therefore, in this research work, only construction and use phase are studied for the optimization of embodied and operational GHG. The maintenance, repair, and replacement requirements during the use phase and the end-of-life phase are not considered. This exclusion is due to the primary research objective, which does not focus on the embodied and operational GHG emissions throughout the entire life cycle of the building to assign the building an energy or environmental label. Many authors have stressed the importance of incorporating Life Cycle Assessment (LCA) during the early design stage, as the decisions made during this phase hold great significance in determining the energy and environmental efficiency that a building is expected to exhibit over its entire lifecycle [41–44].

Despite the extensive body of literature addressing building energy efficiency, life cycle assessment, and HVAC system optimization, existing studies predominantly focus on electricity-driven solutions and are mainly developed within contexts where low-carbon electrical grids are already available or rapidly expanding. In contrast, the potential role of natural gas-based HVAC systems as transitional decarbonization solutions in gas-exporting countries remains insufficiently explored. Moreover, previous research often treats energy simulation, environmental assessment, and economic evaluation as separate analyses, with limited integration within a unified methodological framework capable of supporting early-stage design decisions. Several critical research questions remain open and warrant further investigation: (i) To what extent can an integrated, holistic methodology combining energy simulation, environmental life cycle assessment, and economic evaluation provide an effective decision-support framework for early-stage building design?; and (ii) Can natural gas-based variable refrigerant flow (NG-VRF) systems constitute a technically reliable and environmentally viable transitional decarbonization solution for the building sector in gas-exporting countries?

In an attempt to answer to these questions, the present study proposes an integrated "all-in-one" OpenBIM-based workflow that combines building energy simulation, life cycle assessment, and economic analysis to evaluate the adoption of Natural Gas Variable Refrigerant Flow (NG-VRF) systems. The methodology is applied to office buildings located in different climatic zones in Algeria, a representative gas-exporting country, with the aim of assessing the energetic, environmental, and economic implications of NG-VRF systems as a pragmatic decarbonization pathway. By jointly analyzing embodied and operational greenhouse gas emissions (construction phases A1–A5 and use phase B6), the proposed approach provides a comprehensive decision-

support framework that bridges the gap between methodological integration and region-specific energy transition strategies.

Accordingly, this study aims to evaluate the potential of Natural Gas Variable Refrigerant Flow (NG-VRF) systems as a transitional decarbonization solution for office buildings in gas-exporting countries by applying an integrated OpenBIM-based methodology that combines building energy simulation, life cycle assessment, and economic analysis across different climatic conditions.

2. Methodology

The integration of BIM at the early design stages is crucial for LCA energy consumption analysis and cost evaluation. In this work, a new all-in-one package methodology is proposed with a particular focus on keeping current with trends in the building sector in terms of digitalization, energy transition and environmental impact. An overview of the adopted methodology is depicted in Fig. 1.

The proposed methodology is based on an integrated BIM-driven workflow that enables a multicriteria assessment combining building energy simulation, life cycle assessment, and economic analysis. The building geometry is developed as a three-dimensional model and exported in IFC format, ensuring interoperability within the OpenBIM environment [45]. When IFC models originate from external BIM platforms, an analytical model is generated to guarantee the completeness of geometric and thermal information required for simulation [46,47].

Building performance simulation is first conducted to estimate heating and cooling demands using CYPECAD MEP, followed by the

integration of the VRF systems in accordance with ASHRAE guidelines [48]. Building envelope materials and HVAC system components are defined using the *Price Generator* database, allowing a parametric description of construction elements and equipment. Energy consumption and operational CO₂ emissions are then simulated using the EnergyPlus calculation engine (v22.2), considering both electric VRF and NG-VRF (Fig. 2) configurations across Mediterranean, semi-arid, and arid climatic zones in Algeria, based on EPW weather files.

A key advantage of the BIM-LCA integration lies in the direct extraction of parametric quantities from the BIM model, which facilitates the automatic generation of the Bill of Quantities (BoQ), one of the most time-consuming steps in building LCA studies [49]. These quantities are subsequently linked to environmental indicators to assess embodied greenhouse gas emissions in accordance with established LCA standards [50]. In parallel, the economic assessment is performed by exporting the BIM-based scenarios to a dedicated evaluation tool, enabling the comparison of investment costs under both local subsidized prices and international market conditions.

It is important to clarify that the Price Generator database used in this study is not a generic or hypothetical cost dataset, but a professional construction cost database widely adopted in engineering practice. The database is populated through direct contributions from manufacturers and suppliers of construction materials and HVAC equipment, who integrate their technical and economic data into the platform under a contractual agreement with CYPE. As a result, the database contains manufacturer-specific information, including detailed technical specifications, construction assemblies, labor requirements, and market-

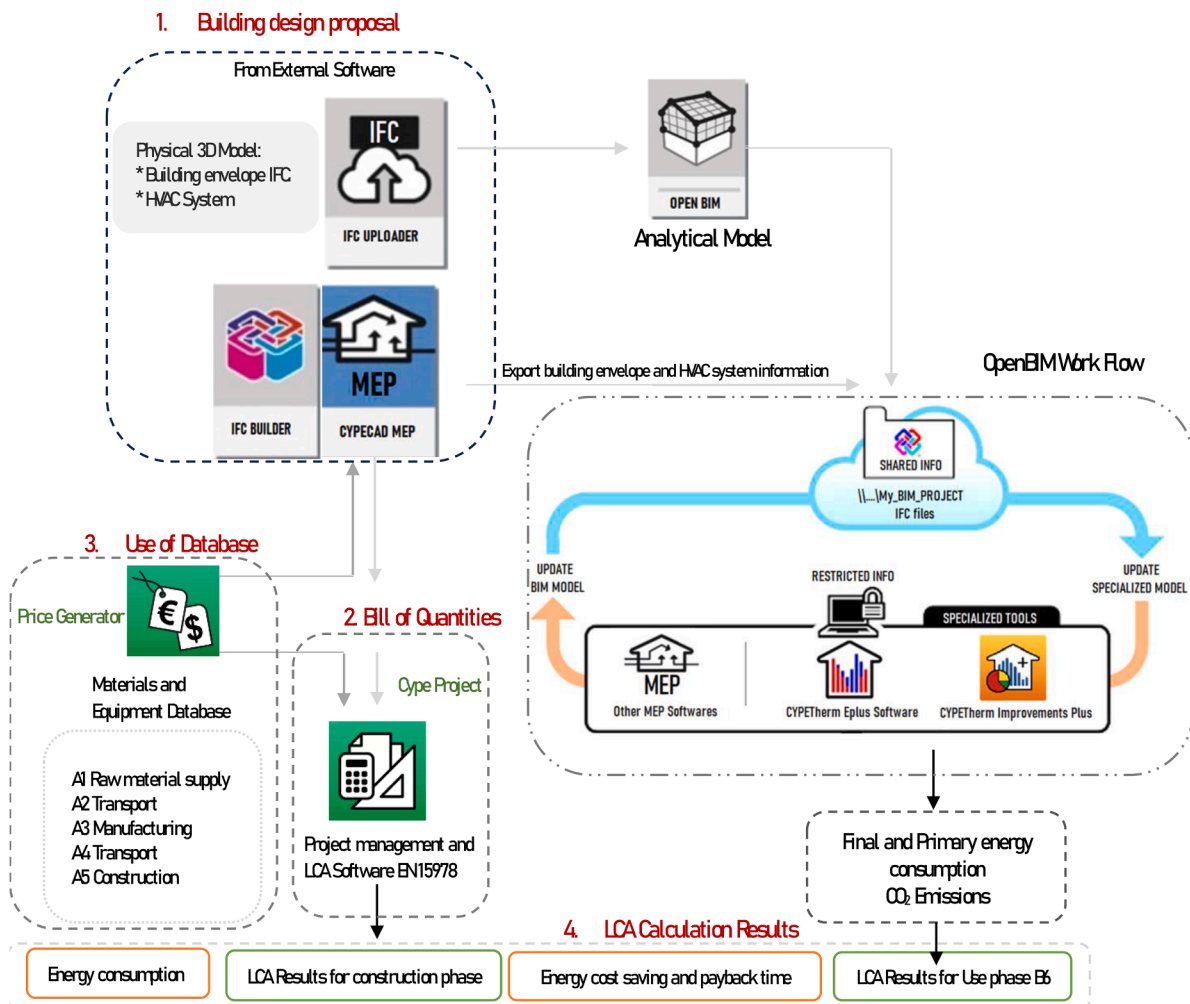


Fig. 1. All-in-one package methodology based on Open BIM Workflow framework for LCA.

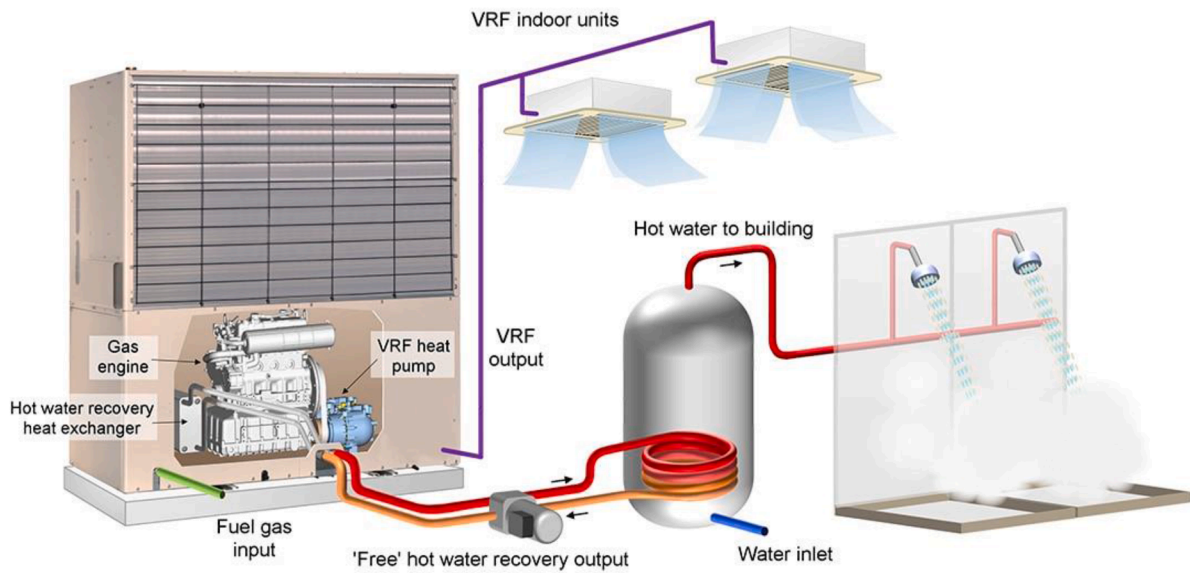


Fig. 2. A schematic illustration of an NG-VRF system with heat recovery for domestic hot water production [51].

based price ranges.

Moreover, the Price Generator is extensively used by professionals in Algeria for cost estimation, feasibility studies, and bill of quantities, even outside a BIM environment, through its freely accessible online version. This widespread professional adoption reinforces the reliability and practical relevance of the cost data employed in this study. Within the proposed OpenBIM workflow, the database ensures methodological consistency by applying the same pricing structure, assumptions, and data sources across all simulated scenarios. Consequently, the economic analysis focuses on relative cost differences and trends between design alternatives, rather than on absolute market prices, which may vary over time and between regions.

Fig. 3, shows the different life cycle phases according to EN 15,978 [52,53]. In this work, only construction phase and use phase are considered for an optimization purpose. As previously shown in Fig. 1, the life cycle phases considered for the construction phase are: A1, A2, A3, A4, A5. To assess the environmental impact of the design phase on the use phase, operational CO₂ emissions and energy consumption are considered only in phase B6.

The environmental impact and greenhouse gas emissions, expressed as Global Warming Potential (GWP), are calculated for the building system under study considering construction phase from Module A1 to Module A5 (see Fig. 3), as illustrated in Fig. 1. The (VRF) system is designed and sized using the CYPECAD MEP software. Equipment selection is carried out through the integrated 'Price Generator' database, which provides detailed technical specifications along with corresponding environmental indicators. Once the system design is completed, the software automatically generates the complete bill of quantities (BoQ) for the entire installation. This quantitative data is then exported to CYPEPROJECT, which is directly linked to the Price Generator. Using this connection, the software automatically produces the Life Cycle Assessment (LCA) report based on the specific quantities and environmental indicators of all components of the electric VRF system with boiler and NG- VRF system, including the number and type of units, as well as the lengths and dimensions of the piping. The results will be presented in Table 3.

Building assessment information																
Building life cycle														Supplementary information		
Product			Construction		Use stage							End-of-life				Benefits and loads beyond the system boundary
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
Raw materials supply	Transport	Manufacturing	Transport	Construction	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction Demolition	Transport	Waste processing	Disposal	Re-use-Recovery-Recycling-potential
Scenarios																

Fig. 3. Building life cycle adapted in EN 15,978 [53].

3. Case study and modeling procedure

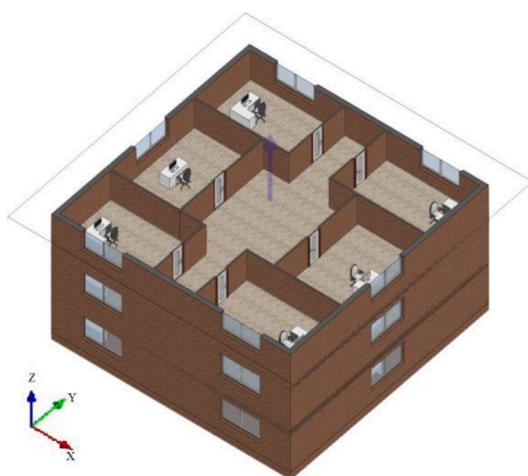
The reference building is a square shaped office building as illustrated in Fig. 4. For modeling purpose, CYPECAD MEP tool is used. Three different climate zones, namely Mediterranean climate, Semi-arid climate and arid climate, in Algeria, are considered in numerical simulation.

The building envelope is designed based on the optimum results recommended by previous research works with 10 % Window to wall Ratio (WWR) of single glazing with a U-value of 2.32 W/m². °C with Solar heat gain coefficient (SHGC) of 77 % [54]. The building case study has a total of four stories, floor area of 225m², total height of 12 m and an air change rate of 0.5 ACH.

For this building case study, the wall types considered are those frequently used in Algeria, namely horizontal and vertical walls, derived from Tunnel Form Construction Technique [55]. The Tunnel Form Construction technique was adopted in this study as it reflects current construction practices in Algeria, where fast execution is required to meet high building demand within short project timelines. This technique is widely used despite its relatively high thermal loads due to the predominance of reinforced concrete. Its selection therefore provides a realistic baseline for assessing energy performance and HVAC system impacts. Moreover, applying the same construction system across all climatic zones ensures consistent comparison and allows the influence of climate and HVAC systems to be isolated.

Table 1 shows the construction systems considered. Structural elements are not detailed in this study. Occupancy scenarios and internal loads were not included in the present study. The HVAC systems are instead operated according to fixed temperature setpoints of 21 °C for heating season and 24 °C for cooling season, which directly act on the operation of HVAC systems.

Fig. 5 illustrates the monthly variation of average temperatures and Heating Degree Days (HDD) for the three climatic zones considered in this study: Mediterranean, semi-arid, and arid. The weather data used in the simulations were obtained from EnergyPlus meteorological files (*epw* format), corresponding to representative locations of each climate. These data were employed as inputs for the Building Performance Simulation (BPS) carried out with the EnergyPlus simulation engine, integrated into the OpenBIM workflow. The presentation of both average temperatures and HDD values provides a clear basis for comparing climatic conditions between zones and for explaining variations in heating demand observed in the simulation results.



Perpendicular section to the overall Z-axis of the Office building case study

Fig. 4. Reference building case study with square shape and 10 % WWR of single glazing.

Table 1
Building construction systems.

Building elements	Reference building	U-value [W/m ² . °C]
Floor	20 cm -flat concrete slab	2.29
Structure		
External wall	1 cm -Porcelain stone cladding, 20 cm -concrete,	3.88
Windows	6 mm -single glazing with aluminum joinery	3.3
Roof	0.45 cm -bitumen, 10 cm -concrete, 5 cm -MINERAL wool, 30 cm -One-way slab (with concrete hollow blocks), 3 cm -mortar.	0.36

4. Results and discussion

4.1. Embodied GHG

To analyze the embodied GHGs in construction phase, building materials are selected with CYPECAD MEP using the price generator database. The technical details of the VRF system designed for each building is shown in Table 2.

The bill of quantities is carried out once VRF system is sized and exported to the Cype Project tool and combined with the price generator database to produce the LCA for the construction phase.

Table 3 shows the results of LCA in the construction phase A1, A2, A3, A4 and A5, comparing electric VRF system with boiler and NG-VRF System. Results are obtained using the Cypecad mep and Cype project software with Price generator. Detailed LCA results and BoQ of the building for the construction phase (Modules A1- A5), including both the construction elements and the technical equipment are presented in appendix in Table A.1 and A.2 to ensure a more comprehensive and coherent representation of the study's scope.

From Table 3, it is clear that using NG-VRF System leads to lower environmental impact than electric VRF, with 2 % reduction in carbon footprint and embodied energy consumption. The generation of hot water is secured via the heat recovery from the natural gas engine, thereby skipping the need for a boiler. Similarly, the reduction in the amount of equipment in the MEP installation contributes to the decrease in the embodied GHG emissions of the installation itself. The difference in this scenario is marginal, considering that the building case study is small and equipped with a single outdoor unit. However, it is crucial to highlight that in case of a larger building, the number of outdoor and indoor units is expected to rise, leading to a significant difference. The findings indicate that the incorporation of MEP systems in LCA, through BIM, for optimization purpose plays a substantial role in reducing embodied GHG emissions as the size and quantity of units undergo alteration.

4.2. Operational energy consumption

The environmental impact of the operational phase of the building is assessed by evaluating the energy consumed by the two VRF systems: an electric VRF combined with a boiler, and an NGVRF. The technical details of the energy simulation are presented in Table 4:

Fig. 6 illustrates that primary energy consumption is higher for the scenario involving an electric VRF system with auxiliary boiler across all climate zones. In this study, electricity is assumed to be generated by a natural gas power plant with a 35 % efficiency. Transitioning to the NG-VRF system allows for direct natural gas consumption, potentially reducing primary energy consumption by up to 65 %. However, as Fig. 8 indicates, this potential reduction was not fully realized, primarily due to the Coefficient of Performance (COP) of NG-VRF systems, which typically ranges from 1.2 to 2.4, significantly lower than the 3 to 6 range of electric VRF systems. This discrepancy arises from the mechanical efficiency of the natural gas engine, which is 50 %, compared to the 98 % efficiency of electric VRF systems.

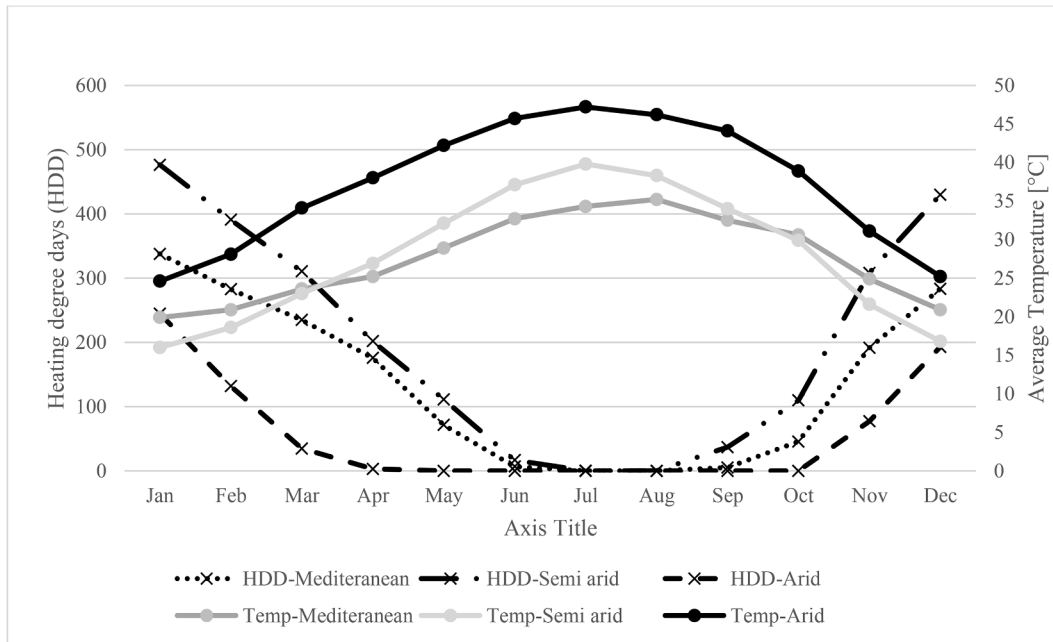


Fig. 5. Monthly HDD and Average Temperature for Mediterranean climate, Semi-arid climate and Arid climate [56].

Table 2
Main characteristics of HVAC Systems.

	Building 1	Building 2
Piping type	Copper pipe	
Type of air conditioning system	Electric VRF	NG-VRF
Indoor unit type	28 Four-way cassette fan coil	
Outdoor unit type	Electric heat pump	Gas heat pump
Hot water production	From boiler	Heat recovery from outdoor unit
Global system classification	Mono-generative system	Trigenerative system

Table 3
LCA, cradle-to-gate phases (A1-A3 and A4-A5) of electric VRF system and boiler vs NG-VRF System.

	VRF system with boiler	NG-VRF system
CO2 eq (kg)	4286,52	4181,75
CFC 11 eq (kg)	0,07	0,07
SO2 eq (kg)	23,9	23
(PO4)3- eq (kg)	3,89	3,24
POCP (Ethylene eq) (Kg)	5,96	5,93
Sb eq. (kg)	1,38	1,36
ADFP (MJ)	62,823,79	61,569,29
PERT (MJ)	11,614,07	11,413,7
PERNRT (MJ)	58,398,39	57,001,38
FW (m3)	404,75	403,85

Despite this, significant primary energy savings were achieved: 40 % for Mediterranean climates, 35 % for semi-arid climates, and 25 % for arid climates, contributing to both governmental and national economic benefits. These results align with the findings of A. Ileri and S. Moshiri [57].

4.3. Operational CO₂ emissions

Fig. 7 presents operational CO₂ emissions considering both electricity and natural gas as energy sources. The emission factors recommended by the RTB+ [58] are applied considering a thermal power

Table 4
Input parameters in EnergyPlus V.22.2.

Climatic zone	Indicators	Building with electric VRF and boiler	Building with VRF-NG
Mediterranean climate	Refrigerant type	R410a	R410a
	Energy source	electricity and Natural gas	natural gas
	Compressor type	scroll electric compressor	natural gas engine
	Summer setpoint temperature	24	
	Winter setpoint temperature	21	
	hot water production capacity [kW]	20	24
	Noise level [dBA]	65	58
	Compressor efficiency (%)	98	50
	COP	3,52–3,59	2
	EER	6,47–6,62	2,4
	Cooling capacity demand [kW]	45–50,4	
	Heating capacity demand [kW]	50–56,5	
Semi-arid climate	Heating capacity demand [kW]	1,7–2,2	
	indoor unit capacity [kW]		
	COP	3,58–3,68	2
	EER	6,36–6,65	2,4
	Cooling capacity demand [kW]	56–61,5	
	Heating capacity demand [kW]	63–69	
Arid climate	Heating capacity demand [kW]	1,7–2,8	
	indoor unit capacity [kW]		
	COP	3,5–3,68	2
	EER	6,8–6,36	2,4
	Cooling capacity demand [kW]	56–78,5	
	Heating capacity demand [kW]	63–87,5	

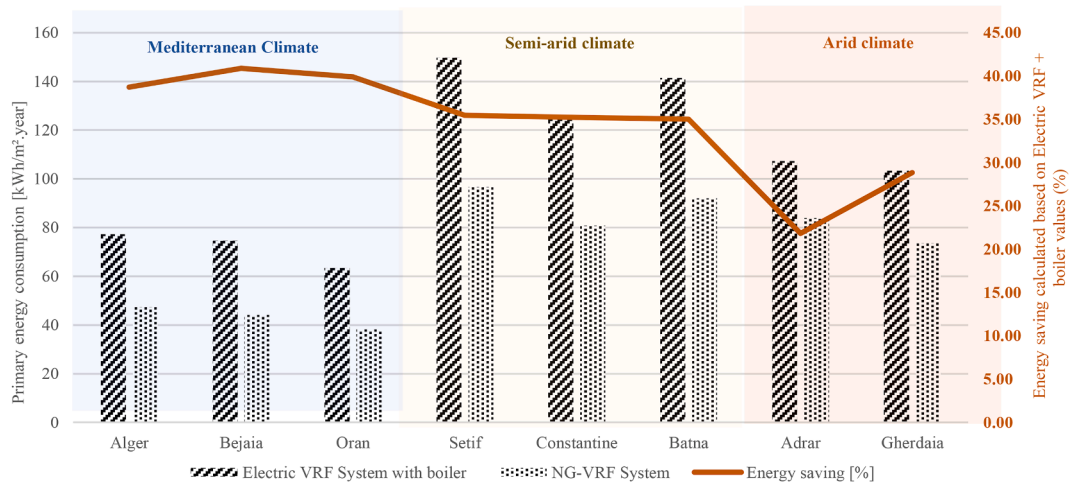


Fig. 6. Evolution of energy saving percentage and operational primary energy consumption for electric VRF System with auxiliary boiler vs NG-VRF System.

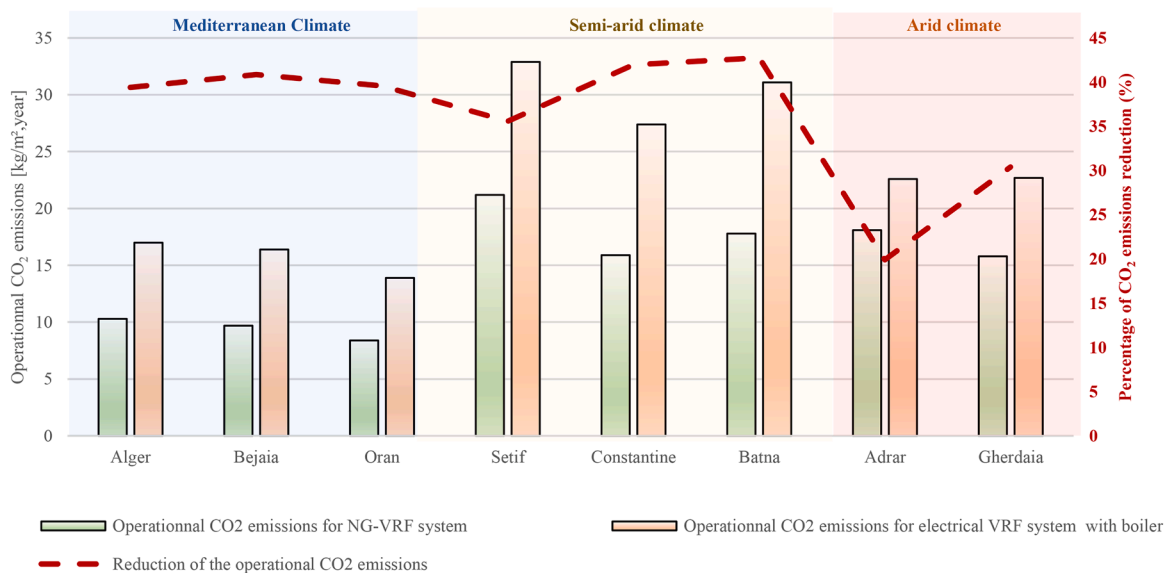


Fig. 7. Evolution of operational CO₂ emissions for electric VRF System with auxiliary boiler vs NG-VRF System.

plant with an efficiency of 35 %. Specifically, a value of 0.22 kgCO₂/kWh is used for natural gas, and 0.627 kgCO₂/kWh is used for electricity. These conversion factors enable a consistent and comparative assessment of the carbon intensity associated with the building's energy consumption during the operational phase.

As illustrated in Fig. 7, systems combining electric VRF technology with auxiliary boilers exhibit significantly higher operational CO₂ emissions compared to NG-VRF systems. This disparity is particularly pronounced in Mediterranean and semi-arid climates, where the NG-VRF systems achieve a 40 % reduction in CO₂ emissions. In arid climates, although the reduction is less substantial, NG-VRF systems still demonstrate a 25 % decrease in emissions relative to their electric counterparts. These findings underscore the environmental benefits of NG-VRF systems in regions with distinct climate characteristics. Furthermore, primary energy consumption is notably elevated in semi-arid climates. This increase is attributed to prolonged heating requirements in these regions, which intensifies energy demands. This heightened demand reveals the sensitivity of energy efficiency metrics to regional climate conditions, emphasizing the necessity of climate-specific strategies in HVAC system design. In addition to the emission and energy savings, NG-VRF systems exhibit operational advantages,

notably in acoustic performance. As presented in Table 4, the mechanical efficiency of NG-VRF systems, while slightly lower than that of electric VRF systems, contributes to quieter operation, thus enhancing indoor acoustic comfort. This attribute strengthens the case for NG-VRF systems, particularly in urban environments or settings where sound levels significantly impact user experience.

4.3.1. Sensitivity analysis

It is important to emphasize that national energy policies are dynamic and evolve over time toward energy transition pathways characterized by an increasing share of cleaner energy sources. In this context, Algeria has expressed a long-term strategic objective to significantly expand the deployment of renewable energy, particularly solar photovoltaic (PV) systems. Consequently, it is relevant to consider future scenarios in which electricity used for building operation is partially or predominantly supplied by renewable sources.

From an operational perspective, CO₂ emissions associated with renewable electricity are substantially lower than those generated by natural gas-based systems. For instance, while electricity produced from fossil-based sources may reach emission factors of approximately 0.418 kgCO₂e/kWh, renewable electricity can exhibit values as low as 0.0439

kgCO₂e/kWh [59]. Under such conditions, electric heat pumps would become an environmentally favorable solution in terms of operational emissions. However, a comprehensive environmental assessment should not be limited to the use phase alone.

Indeed, life cycle assessment studies consistently show that photovoltaic systems are characterized by non-negligible embodied environmental impacts, mainly originating from energy-intensive manufacturing processes (e.g., silicon purification, metal extraction and processing), material consumption, and associated emissions during production and transportation stages [60,61]. These impacts include greenhouse gas emissions, resource depletion, land use, and potential toxicity related to specific materials. Although the clean electricity generated during operation offsets these impacts over the system lifetime—often resulting in lower total life cycle emissions compared to fossil fuel-based energy sources—the embodied emissions of PV systems remain a critical factor, particularly in early life cycle stages. End-of-life management and recycling strategies can significantly reduce these burdens but require appropriate infrastructure and policies.

In gas-exporting countries, an additional economic dimension must also be considered. The large-scale deployment of photovoltaic systems generally relies on imported technologies, which may represent a substantial financial burden for the state and affect the overall economic feasibility of renewable-based electrification strategies. Therefore, the identification of the most appropriate decarbonization pathway cannot rely on a single criterion but must account for environmental, energetic, and economic dimensions simultaneously, as well as local energy resources and policy priorities.

In this regard, the results of the present study support the interpretation of NG-VRF systems as a context-dependent transitional solution. Their relevance is strongly linked to local energy structures, grid carbon intensity, and economic conditions, highlighting the importance of adopting flexible and regionally adapted decarbonization strategies rather than universal solutions.

Beyond the specific case study presented in this work, the proposed “all-in-one” OpenBIM-based methodology is inherently transferable and can be applied to a wide range of climatic, economic, and regulatory contexts. The generalizability of the approach relies on the interoperability of the BIM workflow and the availability of region-specific input data, including climate files, energy prices, emission factors, and construction cost databases. In regions where the Price Generator database (or equivalent localized cost and environmental datasets) is available, the same workflow can be directly implemented without methodological modification. By adapting only the contextual inputs, such as climatic conditions, energy mix characteristics, and economic parameters—the integrated framework enables a consistent evaluation of energy performance, environmental impacts, and economic feasibility across different countries and regions. Consequently, the methodology does not prescribe a universal technological solution but rather functions as a decision-support tool, allowing stakeholders to identify the most appropriate HVAC and energy strategy based on local environmental, energetic, and economic conditions. This context-sensitive nature reinforces the relevance of the proposed approach for supporting regionally adapted decarbonization strategies rather than one-size-fits-all solutions.

4.4. Economic analysis

4.4.1. Current scenario

Table 5 summarizes the economic considerations and the equipment costs adopted for this study.

The adoption of the NG-VRF system as a decarbonization strategy involves higher initial investment costs compared to the electric VRF system. The estimated investment for the NG-VRF system is approximately 11,089 USD. However, due to the elimination of the boiler, facilitated by the heat recovery feature of the natural gas engine, the cost of the boiler is deducted, bringing the net investment to 9737 USD, with

Table 5
Input economic parameters.

Parameters	value
Investment price on NG-VRF system	9737 (USD)
Estimated life period	20 years
Estimated Current maintenance costs	2 % of investment price per year
Associated price	11,80 % of investment price
Price of electric VRF system	14,588,28 (USD)
Price of electric NG-VRF system	25,678,35 (USD)
Price of Boiler	1352,19 (USD)

a reduction of 12.2 %. A detailed analysis of energy savings and payback time is conducted by comparing the final energy consumption of the electric VRF system with the primary energy consumed by the boiler and the NG-VRF system. This study accounts for both subsidized energy prices in Algeria and international market prices, allowing for a comprehensive assessment of the financial and environmental impacts of adopting the NG-VRF system as a decarbonization solution in both natural gas-producing and importing countries. Figs. 10 and 11, respectively, illustrate the evolution of final, primary energy costs, and payback time considering international and subsidized prices. The subsidized energy prices considered for gas-producing countries like Algeria are 0.003 USD/kWh for natural gas and 0.04 USD/kWh for electricity, while the international prices are 0.04 USD/kWh for natural gas and 0.178 USD/kWh for electricity [34]. The payback time is calculated using Cypetherm Improvement plus tool, integrated to the OpenBIM Workflow, in order to assess the cost-effectiveness of project improvement measures. The following formula is adopted:

$$PBP = \frac{IC}{EG - MC} \quad (1)$$

With IC, is the investment cost of NG-VRF system (USD), EG, is the energy gains of the first year (USD/year) and MC, is the maintenance cost (USD/year).

Figs. 8 and 9 show that the energy consumption cost is highest in the semi-arid climate. On the other hand, this climate has the shortest payback period. This is due to the high energy consumption during the heating period, which leads to higher energy cost savings than other climatic zones.

For the same investment price, the payback time shown in Fig. 8, for international prices is significantly shorter than for subsidized prices in Fig. 9. This reflects the high cost of energy in countries where energy costs are approaching international costs. At international market prices, the NG-VRF system offers dual advantages by both reducing greenhouse gas (GHG) emissions and lowering energy costs by 50 %. This significant cost reduction not only improves energy efficiency but also provides economic benefits for countries that import natural gas, with a faster payback period. By reducing reliance on imported natural gas, these countries can achieve substantial savings, thereby enhancing energy security and alleviating the financial burden associated with natural gas imports. The adoption of NG-VRF systems thus presents a strategic opportunity for both environmental sustainability and economic resilience in natural gas-importing nations.

Fig. 10 demonstrates that, under subsidized energy prices, cost savings from the NG-VRF system exceed 63 %, compared to approximately 50 % at international market prices. This difference underscores the relatively high cost of energy in regions that do not benefit from subsidies. Consequently, it can be inferred that the payback period for NG-VRF system investments is significantly shorter in contexts of international prices, where energy costs are elevated, as illustrated in Fig. 8. Higher energy costs, or increased energy consumption, such as in semi-arid climates, accelerate the return on investment by generating substantial energy cost savings. In these cases, the savings effectively offset the initial capital investment in NG-VRF equipment, making it a financially viable solution for regions with higher energy cost or energy demands.

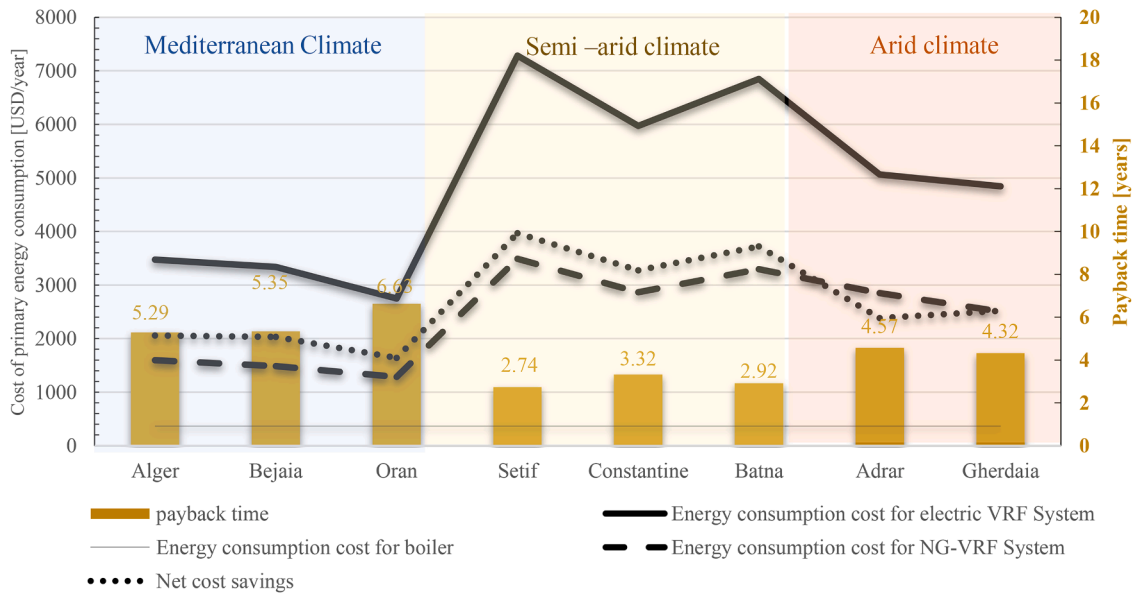


Fig. 8. Cost of primary energy consumption and payback time considering international prices.

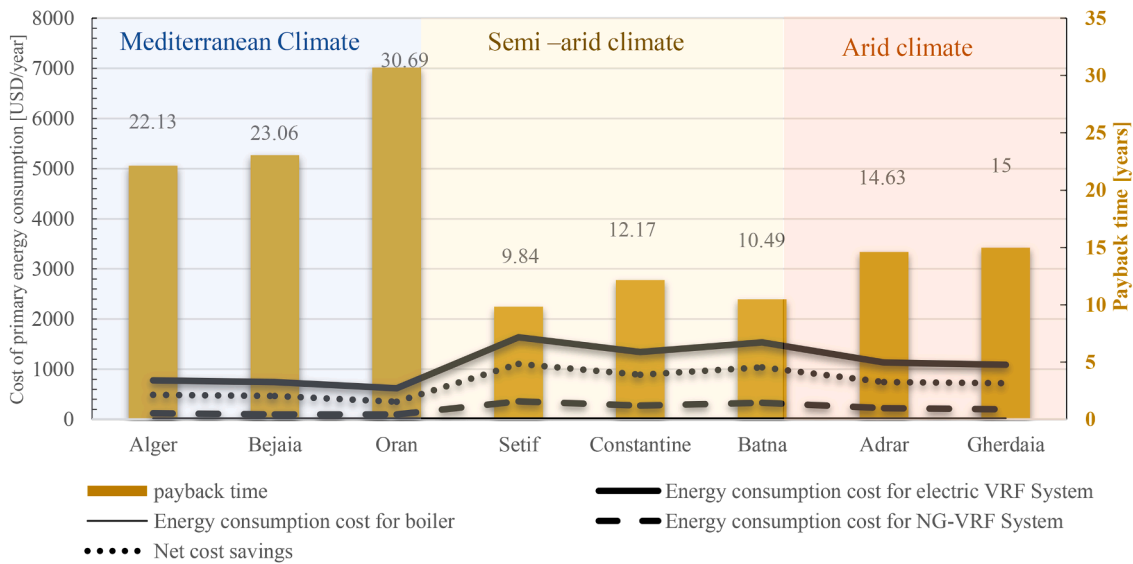


Fig. 9. Cost of primary energy consumption and payback time considering subsidized prices.

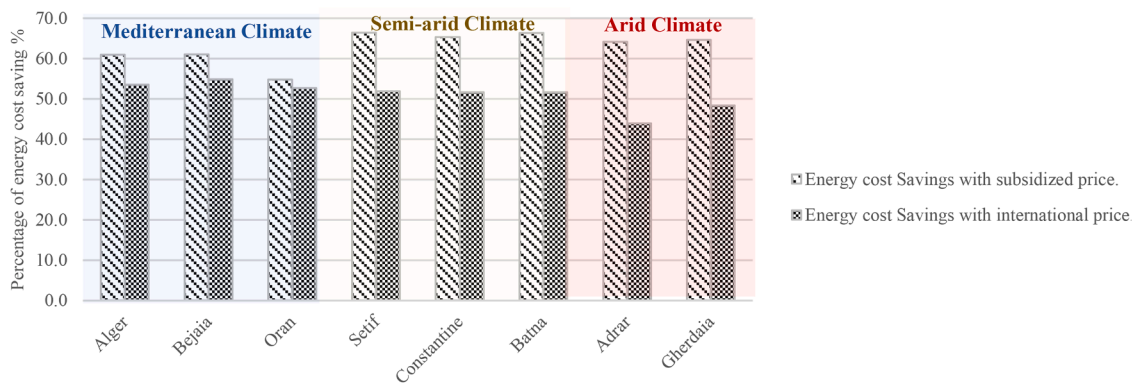


Fig. 10. Cost saving for subsidized prices and international prices when using NG-VRF system.

In addition to the energy and environmental benefits of the NG-VRF system for natural gas exporting countries, this system may not be cost-

effective in the short term for the building owner. On the other hand, its economic advantage lies in the reduction in the building owner's energy bill, which can be as much as 63 %. Moreover, the energy saved, will be used directly for further exports, encouraging the national economy linked to the export of hydrocarbons, and generating significant profits for the country. Conversely, the market dynamics in natural gas-exporting countries are susceptible to fluctuations, particularly due to potential shifts in NG-VRF system pricing and variations in energy policies, including subsidy adjustments. To enhance the accuracy of economic assessments, it is essential to examine various plausible scenarios, facilitating more robust future economic projections regarding the adoption of NG-VRF systems as a decarbonization solution in these countries.

4.4.2. Other possible scenarios

Scenario 1 is defined as the energy price remains constant, while the cost of the NG-VRF system fluctuates based on government-provided subsidies (Figure 13). For Scenario 2, a dynamic payback analysis is conducted using the Economic Net Present Value (ENPV) calculation, which represents a dynamic investment valuation criterion. The aim is to establish the payback period for the investment in a more realistic way. In this case, the investment cost of the NG-VRF system is held constant, and the energy price is modeled to increase by 7 % annually (Figure 14). The ENPV is calculated using the following formula:

$$ENPV = DFS - \Delta \text{ net investment cost} \tag{2}$$

$$DFS = UES - DMC \tag{3}$$

$$UES = \sum_{i=1}^n [(1 + \Delta P_E)/(1 + T_r)]^i \times AES \tag{4}$$

$$DMC = \sum_{i=1}^n [(1 + T_{inflation})/(1 + T_{interest})]^i \times AMC \tag{5}$$

$$\Delta \text{ net investment cost} = \text{investmentcost} - \text{aids and grants} \tag{6}$$

The results are shown in Fig. 11 and 12. In Fig. 12, Energy consumption and cost savings vary considerably from one area to another, requiring tailored support strategies to ensure an optimum payback period. In Scenario 1, increasing the subsidy leads to a shorter payback period. To achieve a potential effective payback period around 5 years, the recommended levels of government subsidy are 80 % for

Mediterranean climates, 60 % for semi-arid climates and 70 % for arid climates. These subsidies should be understood as strategic investments by the government, with the long-term objective of capitalizing on natural gas savings for export, generating significant economic gains through increased natural gas exports. This analysis provides valuable information for policy- and decision-makers, facilitating the adoption of potential energy transition strategies. The results provide a clear understanding of how public subsidies influence the financial viability of decarbonization technologies, helping to steer investment towards sustainable energy solutions. In Scenario 2 (Fig. 12), the return on investment is achieved more rapidly. Through dynamic analysis, benefits are realized once the Economic Net Present Value (ENPV) reaches a positive value. Specifically, the payback period is determined to be 12 years for arid climates, nine years for semi-arid climates, and 15 years for Mediterranean climates. An annual increase in energy prices of 7 % contributes significantly to reducing the payback period and enhances the economic viability of the investment. This escalation in energy costs not only facilitates amortization but also enables continuous energy savings over the building's entire lifecycle, reinforcing the long-term financial and environmental benefits of NG-VRF system adoption.

5. Conclusion, work limitations and perspectives

This work introduces an integrated “all-in-one” OpenBIM-based methodology that simultaneously combines building energy simulation, life cycle assessment, and economic evaluation within a unified workflow. Rather than presenting new simulation tools, the proposed approach structures existing methods into a coherent decision-support framework, enabling stakeholders and decision-makers to assess trade-offs between embodied and operational greenhouse gas emissions at early design stages. The combined focus on NG-VRF systems and on a holistic, decision-oriented assessment framework constitutes the key contribution of this study to the literature on building decarbonization strategies. The primary novelty of this study resides in the investigation and adaptation of Natural Gas Variable Refrigerant Flow (NG-VRF) systems as a pragmatic decarbonization solution in gas-exporting countries. While most existing decarbonization strategies in the building sector emphasize electrification and the deployment of heat pumps in low-carbon grid contexts, this work demonstrates that, in regions where natural gas is abundant and electricity is predominantly fossil-based, NG-VRF systems can represent an effective transitional pathway for reducing greenhouse gas emissions. The originality of the study therefore lies in the quantitative evaluation of the energetic,

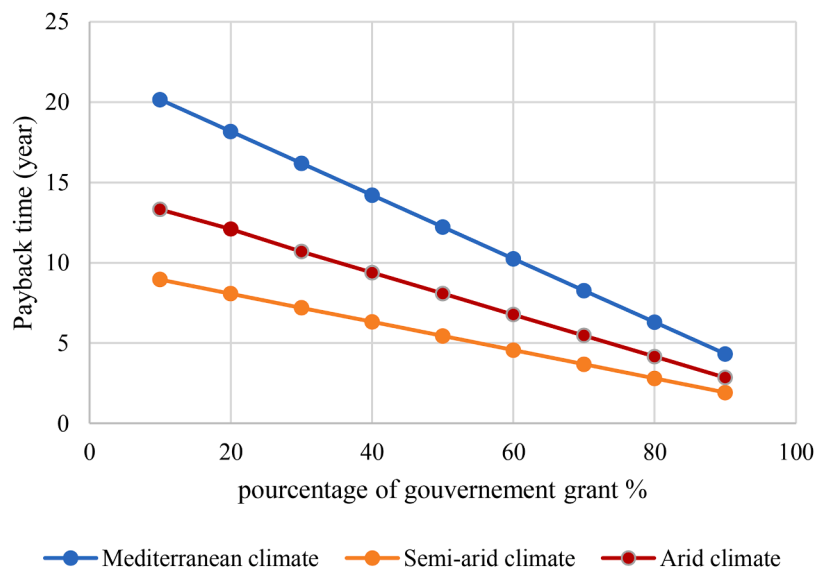


Fig. 11. Payback period for Scenario 1.

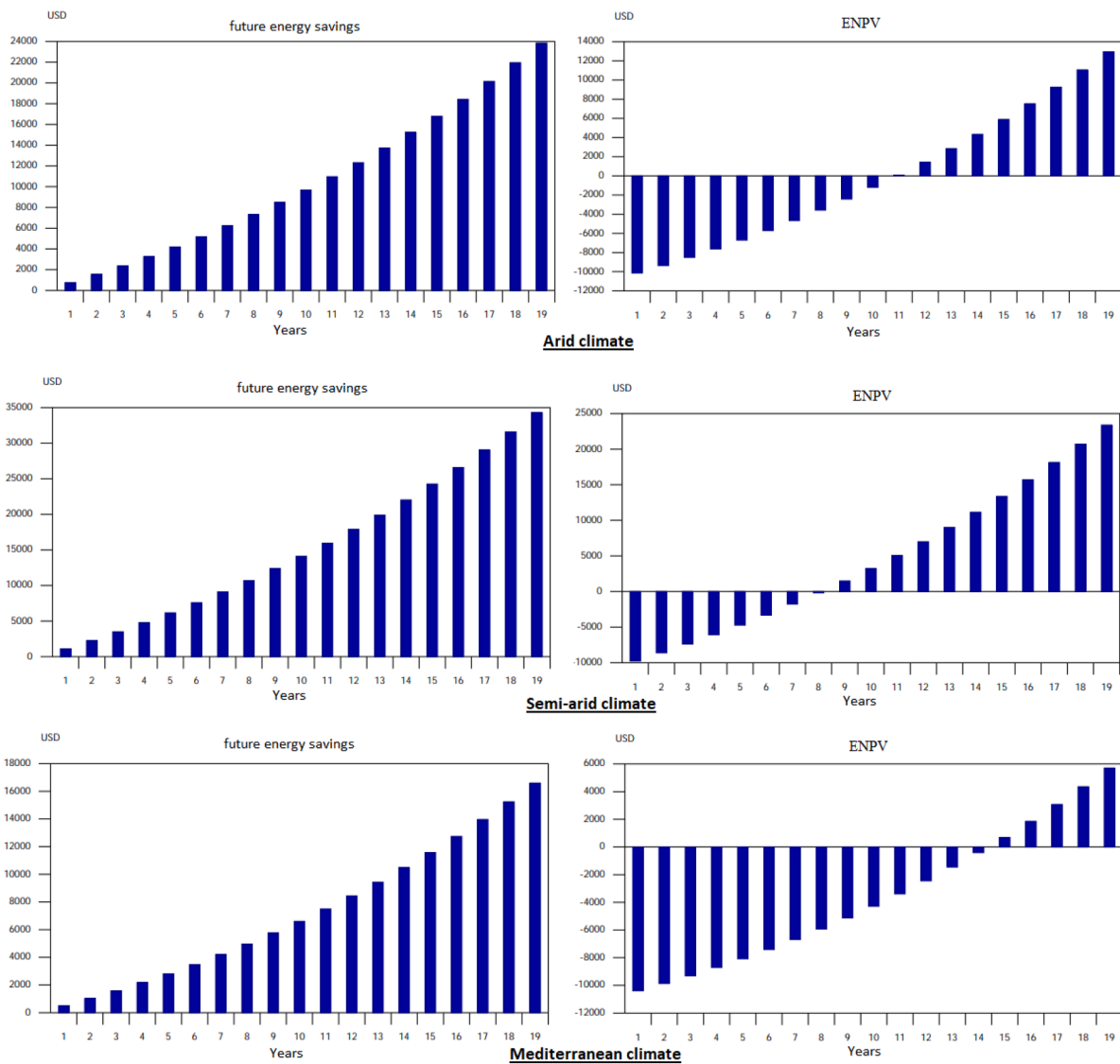


Fig. 12. Future energy saving and ENPV for Scenario 2.

environmental, and economic performance of NG-VRF systems under real climatic and energy conditions, and in the resulting insights regarding their potential advantages compared to conventional electric VRF solutions.

The findings underscore the environmental benefits of the NG-VRF system over electric VRF systems, particularly regarding hot water production. NG-VRF systems can recover waste heat from the natural gas engine to generate hot water, thus eliminating the need for a separate boiler. This heat recovery process significantly enhances the system's COP, despite the compressor's lower mechanical efficiency compared to electric models, and contributes to energy savings of up to 40 % in Mediterranean climates, 35 % in semi-arid climates, and 25 % in arid climates. In terms of acoustic comfort, NG-VRF systems have the added benefit of reduced noise levels, enhancing indoor comfort, a factor critical in densely populated urban settings.

The study reveals substantial economic advantages of NG-VRF systems, especially when considering different pricing structures. Under subsidized pricing, energy cost savings can exceed 63 %, while for international pricing, savings surpass 50 %. Unexpectedly, the implementation of the NG-VRF system supports natural gas conservation, crucial for natural gas-producing nations. Thus, deploying NG-VRF systems aligns with Paris Agreement commitments by reducing greenhouse gas emissions and supporting the national economy.

Despite these benefits, the payback period for NG-VRF systems remains a notable challenge. The research suggests that lowering these costs through government subsidies or financial assistance from international development partners could make these systems more financially feasible and appealing for widespread adoption. Furthermore, the analysis evaluates various payback scenarios based on subsidy levels and energy prices, providing policy insights for decision-makers on potential energy transition strategies. This analysis illustrates how government support can substantially impact the financial viability of decarbonization technologies, guiding investment in sustainable energy solutions.

Through trigeneration capabilities—providing heating, cooling, and domestic hot water from a single source—the NG-VRF system reduces operational waste and lowers carbon emissions on-site, positioning it as an effective low-carbon solution in the building sector.

In conclusion, the integration of NG-VRF systems represents a dual pathway for economic growth and environmental sustainability. As energy-efficient technologies continue to evolve, NG-VRF systems stand out as strategic tools for both natural gas-rich and gas-importing nations to support carbon neutrality goals by 2030. It is recommended that policymakers and engineers prioritize the adoption of GHP systems in the HVAC sector, particularly for projects with high heating and cooling demands. Tailoring decarbonization strategies based on each country's

energy profile and climate commitments will facilitate meaningful progress toward global climate targets, enhancing resilience against climate change while optimizing resource use and operational efficiency.

The present work obviously presents some limitations. From economical point of view, the economic evaluation is based on local Algerian energy prices. We acknowledge that for a more generalizable payback time assessment, gas and electricity prices for multiple countries should be considered, as significant variations particularly in natural gas costs can substantially affect economic outcomes. From environmental point of view, the LCA presented does not cover all life cycle phases of the building, focusing primarily on the construction and operational phases B6. Including additional phases, such as maintenance, renovation, and end-of-life, would provide a more comprehensive environmental assessment. From technological point of view, the analysis is limited to three Algerian climatic zones. Considering additional climates, both within and outside Algeria, would allow for broader applicability of the findings. Furthermore, long-term validation through field measurements would be essential to better estimate the actual energy performance.

As perspectives, it would be interesting to address the economic and environmental impact of adopting the NG-VRF System for large buildings with several outdoor VRF Unit, to estimate accurately the payback time. It would also be interesting to adopt the approach presented in this work for other different climates, to analyze which are the adequate HVAC system for each country regarding their energy policy and environmental commitments.

Appendix A

Table A.1

Quantities of construction materials and equipment.

N°	Building elements	U	Quantities
1	Concrete ground slab	m ²	231.96
2	Reinforced concrete wall	m ³	127.68
3	One-way ribbed slab with precast beams	m ²	927.84
4	Warm flat roof, inaccessible, self-protected, conventional type, Single-layer bituminous waterproofing membrane.	m ²	231.96
5	Horizontal thermal insulation of ground-contact slabs using extruded polystyrene (XPS)	m ²	305.06
6	Aluminum window frames	U	24
7	Standard double glazing	m ²	29.28
8	porcelain stoneware cladding, thin-set installation	m ²	692.98
9	Insulated gypsum board partition	m ²	572.84
10	Wooden hinged interior door.	U	24
11	Refrigerant piping line	m	218.41
12	Refrigerant charge	kg	7.92
13	Ceiling cassette indoor air conditioning unit for VRV-IV system with R-410A refrigerant	U	28
14	Heat pump outdoor unit for VRV-IV air conditioning system with R-410A refrigerant	U	1
15	Refrigerant piping Y-branch kit	U	27
16	Conventional gas water heater (not to be considered in the NG-VRF system)	U	1

Table A.2

Detailed LCA results for different building construction elements and equipment's.

GWP (CO2 eq) (kg)	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	133 994.40	6 478.67	261.97	140 735.04
Building envelope and external finishes	27 215.10	1 119.44	0.36	28 334.90
Technical equipment (VRV with boiler)	4 235.45	51.06	0.01	4 286.52
Technical equipment (NG-VRF system)	4 131.50	50.4	0.01	4 181.75
Interior fittings and finishes	6 666.47	30.42	480.05	7 176.94
CFC 11 eq. (kg)				

(continued on next page)

Table A.2 (continued)

CFC 11 eq. (kg)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	0,01	8.42	0	8.43
Building envelope and external finishes	0	1.46	0	1.46
Technical equipment (VRV with boiler)	0	0.07	0	0.07
Technical equipment (NG-VRF system)	0	0.04	0	0.07
Interior fittings and finishes	0,03	0.04	0	0.07
SO2 eq. (kg)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	377.71	453.51	1.15	832.37
Building envelope and external finishes	111.94	78.36	0	190.3
Technical equipment (VRV with boiler)	20.33	3.57	0	23.9
Technical equipment (NG-VRF system)	19.56	3.52	0	23.08
Interior fittings and finishes	33.46	2.03	7.35	42.84
(PO4)3- eq. (kg)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	90.29	90.7	4.72	185.71
Building envelope and external finishes	16.33	15.67	0.01	32.01
Technical equipment (VRV with boiler)	3.18	0.71	0	3.89
Technical equipment (NG-VRF system)	2.54	0.7	0	3.24
Interior fittings and finishes	12.17	0.41	0.76	13.34
Ethylene eq. (kg)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	84.17	23.97	0.22	108.36
Building envelope and external finishes	20.31	4.14	0	24.45
Technical equipment (VRV with boiler)	5.77	0.19	0	5.96
Technical equipment (NG-VRF system)	5.74	0.19	0	5.93
Interior fittings and finishes	2.89	0.11	0.14	3.14
Sb eq. (kg)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	1.23	3.89	0.01	5.13
Building envelope and external finishes	0.19	0.67	0	0.86
Technical equipment (VRV with boiler)	1.35	0.03	0	1.38
Technical equipment (NG-VRF system)	1.33	0.03	0	1.36
Interior fittings and finishes	525.61	0.02	0.03	525.66
ADFP (MJ)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	1 070 855.87	712 654.20	3 667.65	1 787 177.72
Building envelope and external finishes	414 685.72	123 138.51	5.06	5.06
Technical equipment (VRV with boiler)	57 206.58	5 617.09	0.12	0.12
Technical equipment (NG-VRF system)	56 042.77	5 526.40	0.12	61 569.29
Interior fittings and finishes	112 616.13	3 206.40	6 275.57	6 275.57
Total renewable primary energy use. (MJ)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	126 083.64	0	0	126 083.64
Building envelope and external finishes	53 111.28	0	0	53 111.28
Technical equipment (VRV with boiler)	11 614.07	0	0	11 614.07
Technical equipment (NG-VRF system)	11 413.70	0	0	11 413.70
Interior fittings and finishes	106 687.81	0.13	3 084.40	109 772.34
Total non-renewable primary energy use. (MJ)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	1 125 180.84	87 549.66	3 503.40	1 216 233.90
Building envelope and external finishes	510 425.43	15 127.58	2.49	525 555.5
Technical equipment (VRV with boiler)	57 708.27	690.06	0.06	58 398.39
Technical equipment (NG-VRF system)	56 322.40	678.92	0.06	57 001.38
Interior fittings and finishes	128 425.39	409.57	7 905.24	136 740.20
FW (m3)				
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
	A1-A2-A3 product	A4 Transportation	A5 Construction	TOTAL
Structure and shell works	30 420.27	1 360.52	523.95	32 304.74
Building envelope and external finishes	6 945.21	235.08	0.72	7 181.00
Technical equipment (VRV with boiler)	394.01	10.72	0.02	404.75
Technical equipment (NG-VRF system)	393.28	10.55	0.02	403.85
Interior fittings and finishes	803.91	6.09	4.11	814.11

Data availability

Data will be made available on request.

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