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Deliverable D7.2

Cost-effectiveness demonstration

WP7

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Summary

The present deliverable reports the activities related to the Task 7.2 – Demonstration of cost-effectiveness for the systems – aiming to evaluate the cost effectiveness of the proposed GEO4CIVHIC installations in both real and virtual buildings for civil and historical buildings. This is a public document delivered in the context of WP7.
While D7.1 will focus on the technologies developed in the project and deployed in the different pilot demonstrators, as well as the comparison with the existing technologies, D7.2 will focus more on the end users in terms of pricing and payback periods.

A set of economic KPIs will be provided to evaluate each demo case, real or virtual. Namely, Net Present Value, Return on Investment, and payback periods.
This will provide insights into the most important variables for the solutions to be cost effective and lead to adequate and profitable implementations of GEO4CIVHIC solutions.

Abbreviations

GEO4CIVHIC	Most Easy, Efficient and Low-Cost Geothermal Systems for Retrofitting Civil and Historical Buildings
GSHP	Ground Source heat Pump
RDC	Real Demo Case
VDC	Virtual Demo Case
RDC1	RDC Msida. Bastion Historic Garden, Valleta (Malta)
RDC2	RDC Porta degli Angeli in Ferrara (Italy)
RDC3	RDC Private house in Mechelen (Belgium)
RDC4	RDC Residential house Greystones - Wicklow (Ireland)
VDC1	VDC Museum of Alexandroupolis, Greece
VDC2	VDC Administrative building "Palacete de la Cruz Roja, Valencia (Spain)
VDC3	VDC Residential building "Avangarde Forest" Bucharest (Romania)
VDC4	VDC Residential building Bucharest (Romania)
VDC5	VDC University complex of buildings "Ex Ospedale Geriatrico" Padova (Italy)
VDC6	VDC Museum of Croatian Archaeological Monuments, Split (Croatia)
VDC7	VDC University building, Erlangen (Germany)
VDC8	VDC Castel of Attre, Brugelette (Belgium)
VDC9	VDC Carnegie Clondalkin Library (Ireland)
VDC10	VDC Operational center AIL (Aziende Industriali di Lugano) (Switzerland)
VDC11	VDC Mariënheuvel in Soest (Netherlands)
VDC12	VDC La Vall 9 Bellpuig, (Spain)
LCCA	Life Cycle Cost Assessment
KPIs	Key Performance Indicators
CBA	Cost Benefits Analysis
PP	Payback Period
NPV	Net Present Value
ROI	Return of Investment
RENOV-1	Traditional system: Boiler and fan coil units
RENOV-2	Conventional GSHP system
RENOV-3	GEO4CIVHIC system
ATA	Air to Air
ATW	Air to Water
HHP	Hybrid heat pump
SHW	Sanitary Hot Water heat pump

1 Introduction

1.1 Purpose and target group

This document is in line with Task 7.2 of the GEO4CIVHIC project: - Demonstration of cost-effectiveness for the systems.

An evaluation of the cost effectiveness of the proposed GEO4CIVHIC installations in both real and virtual buildings will be performed for all virtual and real demo cases including all civil buildings and historical buildings.

Economic performance KPIs will be provided to evaluate each demo case, real or virtual, in the form of Net Present Value, Return on Investment, and payback periods. Cross-referencing these with demo case typologies, pros and cons for system implementation will be identified and provide insights on the most important variables for the solutions to be cost effective and lead to adequate and profitable implementations of GEO4CIVHIC solutions.

This deliverable is geared towards partners of the consortium wishing to gain insight and analysis on how they can potentially price their solutions or the general public looking to understand the potential of systems and solutions from an economic perspective.

1.2 Contribution of Partners

Solintel is the task leader and responsible party for delivering the present document. Contributions from demonstration activities and demo cases have been regrouped, specifically in terms of system performance and savings.

1.3 Relation to other activities

Assessing the cost effectiveness of the GEO4CIVHIC solutions is a crucial input towards exploitation activities and defining sound business models for the project solutions. Indeed, the competitiveness of the solutions with what is already on the market will be defined.

1.4 Methodology

The first part of the document will present and contextualize the virtual and real demo cases of the GEO4CIVHIC project included in these analyses.

Then, based on information gathered at demo sites and from the partners in charge of these demonstration activities, economic performance KPIs will be calculated.

Finally, conclusions will be drawn in terms of the best applicability scenarios for the solutions in addition to providing insights on reservation prices of the end users in our demo cases. It means a maximum amount end-user ready to pay for a set of goods and services (On the demand side, it is the highest price that a buyer is willing to pay; on the supply side, it is the lowest price a seller is willing to accept for a good or service).

2 Case studies

The main goal of GEO4CIVHIC is to develop and demonstrate easier to install and more efficient ground source heat exchangers, using innovative compact drilling machines tailored for the built environment. The project also aims to develop or adapt heat pumps and other hybrid solutions in combination with renewable energy sources for retrofits through a holistic engineering and controls approach, for improving the return of investments.

GEO4CIVHIC's target is to accelerate the deployment of shallow geothermal systems for heating and cooling in retrofitting existing and historical buildings. It is based on innovative technological solutions, improvements and enrichment of results obtained from previous EU projects.

The demonstration phase is the moment of truth, where the innovations have to be tested and monitored. A cascade of test and demonstration sites is set up, having specific innovations to validate. The pilot facilities are sites where specific innovations are tested, while demonstration facilities are sites where buildings are retrofitted and the GSHP solutions of GEO4CIVHIC are installed. 4 real demonstration facilities are used in order to set-up projects' innovations. Results of real demonstration facilities give not only the performance of the proposed solutions, but also the installation costs and the possible problems in using the drilling machine and the installation of the GSHEs.

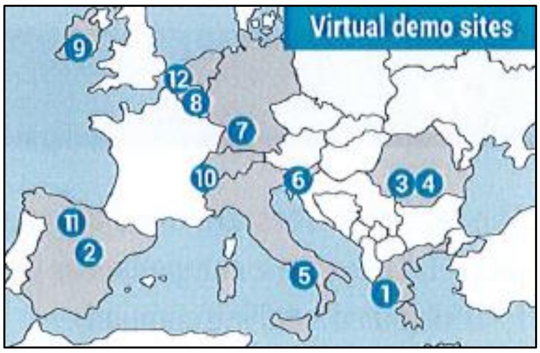
4 real demonstration facilities (1 civil and 3 historical) in different built environments, undergrounds and climate conditions have been used to test the shallow geothermal system with the innovative drilling machine, the improved ground heat exchangers and the novel heat pumps. The real cases of study are:

1. Msida Bastion Garden (La Valletta, Malta)
2. UNESCO Historical building (Ferrara, Renaissance, and its Po Delta)
3. Residential building in Battel (Mechelen, Belgium)
4. Residential House Greystones (Co. Wicklow, Ireland)

Besides, there are 12 virtual cases located in different areas and pertaining to different ages. The different cases are subdivided as a function of age (existing and historic) and climate (warm, mild warm, mild cold, cold). Overall, there are 7 existing buildings and 5 historic buildings. The climates are also distributed: 3 cases in warm climates, 4 cases are in mild warm climate, 3 in mild cold climate and 2 in cold climate. For each climate there is at least one existing building and one historic building.

1. Castle of Attre (Brugelette, Belgium)
2. Eden Residential Building (Bucharest, Romania)
3. Ex Ospedale Geriatrico (Padova, Italy)
4. Operational center AIL (Muzzano, Switzerland)
5. Marienburg residential building (Soest, Netherlands)
6. Museum Historical building (Split, Croatia)
7. Bellpuig multifamily building (Lleida, Spain)
8. Natural history museum building (Alexandroupolis, Greece)
9. Carnegie library Clondalkin (Dublin, Ireland)
10. Avangarde Forest Residential house (Voluntari, Romania)
11. Administrative building Palacete de la Cruz Roja (Valencia, Spain)
12. University building (Erlangen, Germany)

A)



B)

		Real demo sites				Virtual demo sites											
Location		Malta 1	Italy 2	Belgium 3	Ireland 4	Greece 1	Spain 2	Romania 3	Romania 4	Italy 5	Croatia 6	Germany 7	Belgium 8	Ireland 9	Switzerland 10	Spain 11	Holland 12
Age	Existing			X		X		X	X						X	X	X
	Historic	X	X		X		X			X	X	X	X	X			
Climate	Warm	X				X	X									X	
	Mild Warm		X					X	X	X	X						
	Mild Cold			X								X	X				X
	Cold				X									X	X		

C)

Figure 2.1 Mapping of A) Real Demo Cases (RDC), B) Virtual Demo Cases (VDC) and C) Characteristics

3 Synopsys of the deployed systems: Cases of study

3.1 Civil building demo-cases: Real and Virtual cases of study

Table 3.1 – Civil buildings in GEO4CIVHIC (Real and Virtual)

REAL Demo-cases (RDCs)	
Belgium	Residential Building in Battel (RDC3-MECH)
VIRTUAL Demo-cases (VDCs)	
Greece	Museum of Natural History, Alexandroupolis (VDC1-ALEX)
Romania	Residential building Avangarde Forest (VDC3-AVAN)
	Residential building Bucharest (VDC4-BUCH)
Switzerland	Administrative building "AIL (Aziende Industriali di Lugano)" (VDC10-AIL)
Netherlands	Residential Building Marienburg Soest (VDC11-SOES)
Spain	Residential Building in Lleida (VDC12-LLEI)

3.1.1 RDC3-MECH: Residential building in Battel (Belgium)

This real case is a residential building in a mild cold climate. The building is a two-story semi-detached existing building. In the ground floor radiators are present while on the first floor a radiant system has been installed.

Table 3.2 – Presentation RDC1 MECH

ITEM	**EXISTING SYSTEM**	**GEO4CIVHIC RENOVATION**
Building use	Residential	
Climate	Mild cold	
Surface (m2)	170	
Building system	Natural gas boiler with radiators	-4 Boreholes (96 m) -HYDRA-RED method -High temperature Heat pump (R744, CO_2 refrigerant)
Gas consumption (kWh/yr.)	18244	N/A
Elect. consumption (kWh/yr.)	N/A	6712,64
Price of gas (€/kWh)	0,16	N/A
price of elect. (€/kWh)	N/A	0,39

3.1.2 VDC1-ALEX: Museum of Natural History of Alexandroupolis (Greece)

The virtual museum demonstrator is a modern building fully harmonised with the local natural environment. Its architectural design makes it a piece of earth's crust of triangular shape lifted from one side, with a hinge line on the ground and the top-point at the meeting of its two equal sides. The museum includes four halls, each one with its own thematic area.

Table 3.3 – Presentation VDC1

	RENOV-1: Traditional System	**RENOV-2: Conventional GSHP System**	**RENOV-3: GEO4CIVHIC System**
Building use	Museum		
Climate	Warm		
Surface	503,55 m^2		
Building system	Gas Boiler and	GSHP	GEO4CIVHIC

	fan coil units	Conventional system	Innovative system
Total gas consumption (kwh/yr)	38943	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €
Total electricity consumption (kwh/yr)	41728	13215	11397
Price of electricity €/kwh	0,31 €	0,31 €	0,31 €

3.1.3 VDC3-AVAN: Residential building Avangarde Forest (Romania)

The proposed virtual demonstrator is composed of ground floor, first floor and attic, with 3 bedrooms and 1 large living room, 4 bathrooms, located on each floor, a spacious kitchen and a generous terrace attached to the attic. The owner is a Romanian family. The entire building is heated with a floor heating system using an independent gas boiler; for cooling, split system units are installed.

Table 3.4 – Presentation VDC3

	RENOV-1: Traditional System	**RENOV-2: Conventional GSHP System**	**RENOV-3: GEO4CIVHIC System**
Building use	Residential		
Climate	Mild Warm		
Surface	190 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	5730	0	0
Price of gas €/kwh	0,06€	0	0
Total electricity consumption (kwh/yr)	397	2148	1953
Price of electricity €/kwh	0,16 €	0,16 €	0,16 €

3.1.4 VDC4-BUCH: Residential building in Bucharest (Romania)

This virtual demonstrator has been completed in 2013 is part of a complex of 28 similar houses. The building is equipped with radiant floor heating and a gas fired boiler. The house is going to be enlarged and the envelope is going to be insulated. In this case the solution will be a small size reversible low temperature HP with co-axial GSHEs.

Table 3.5 – Presentation VDC4

	RENOV-1: Traditional System	**RENOV-2: Conventional GSHP System**	**RENOV-3: GEO4CIVHIC System**
Building use	Research centre		
Climate	Mild Warm		
Surface	114,95 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	3627	0	0
Price of gas €/kwh	0,06€	0	0
Total electricity consumption (kwh/yr)	198	962	951
Price of electricity €/kwh	0,16 €	0,16 €	0,16 €

3.1.5 VDC10-AIL: Administrative building AIL in Muzzano (Switzerland)

This virtual demonstrator was built in the 1960s, and it is actually heated through a gas co-generator, thermal solar panels and a gas burner. In 2017 the construction site began, with the goal of a complete energetic refurbishment of the building and the creation of new offices. The Energetic Reference Area of the completed building is about 6'000 m^2. The gas cogenerator and the gas burner are going to be decommissioned, and the future heat will be produced through heat pumps coupled with borehole heat exchangers. Solar panels will be kept on the roof. The building will also be cooled (only sensitive cooling) in order to regenerate the ground.

Table 3.6 – Presentation VDC10

	RENOV-1: Traditional System	**RENOV-2: Conventional GSHP System**	**RENOV-3: GEO4CIVHIC System**
Building use	Administrative office		
Climate	Cold		
Surface	6094 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	244988	0	0
Price of gas €/kwh	0,14€	0	0
Total electricity consumption (kwh/yr)	51666,67	92247	85156
Price of electricity €/kwh	0,45 €	0,45 €	0,45 €

3.1.6 VDC11-SOES: Residential Building Marienburg in Soest (Netherlands)

This Dutch virtual demonstrator is a residential building with service and support structures for elderly people with three floors and around 65 dwellings (average surface around 50 m^2). It presents high primary energy consumption for heating and domestic hot water production. In fact, it was built with quite poor construction standards and low quality.

Table 3.7 – Presentation VDC11

	RENOV-1: Traditional System	**RENOV-2: Conventional GSHP System**	**RENOV-3: GEO4CIVHIC System**
Building use	Residential for elderly		
Climate	Mild Cold		
Surface	4176 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	82205	0	0
Price of gas €/kwh	0,14€	0	0
Total electricity consumption (kwh/yr)	0	24911	24911
Price of electricity €/kwh	0,45 €	0,45 €	0,45 €

3.1.7 VDC12-LLEI: Residential building in Lleida (Spain)

This Spanish virtual demonstrator is a multifamily building with four floors and 24 dwellings (average surface around 45 m^2). Although the building is quite new, it presents high primary energy consumption. In fact, it was built during the construction bubble with poor standards and low quality. Accordingly, it represents a strategic case study for the renovation with a high replication potential for the social housing building stock in Spain.

Table 3.8 – Presentation VDC12

	RENOV-1: Traditional System	**RENOV-2:** Conventional GSHP System	**RENOV-3:** GEO4CIVHIC System
Building use	Residential		
Climate	Warm		
Surface	807 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	30129	0	0
Price of gas €/kwh	0,14€	0	0
Total electricity consumption (kwh/yr)	4600	12181	11444
Price of electricity €/kwh	0,45 €	0,45 €	0,45 €

3.2 Historical building demo-cases: Real and Virtual cases of study

Table 3.9 – Historical buildings in GEO4CIVHIC (Real and Virtual)

REAL Demo-cases (RDCs)	
Malta	Msida Bastion Historic Garden Building, La Valletta (RDC1-VALL)
Italy	Angel’s Gate, Historical Building in Ferrara (RDC2-FERR)
Ireland	Historical Residential Building in Greystones, Co. Wicklow (RDC4-WICK)
VIRTUAL Demo-cases (VDCs)	
Spain	Palacete de la Cruz Roja, Valencia (VDC2-VALE)
Italy	University building "Ex Ospedale Geriatrico" (VDC5-OSPE)
Croatia	Historical Building, the Museum of Croatian Arch. Monuments, Split (VDC6-SPLI)
Germany	University building Erlangen (VDC7-ERLA)
Belgium	Attre Castle (VDC8-ATTR)
Ireland	Clondalkin Library, South Dublin (VDC9-DUBL)

3.2.1 RDC1-VALL: Msida Bastion Historic Garden in La Valletta (Malta)

This real case served as a protestant cemetery from 1806-1856. It was restored in 2022. The majority of the property, which sits on the Floriana bastion, has been converted in tea room/museum. Based on the resulting energy demands and probable mismatch between heating and cooling demands (warm climate) a hybrid two-source low temperature heat pump has been installed.

Table 3.10 – Presentation of RDC1-VALL

ITEM	**EXISTING SYSTEM**	**GEO4CIVHIC RENOVATION**
Building use	Cafeteria/exhibition space	
Climate	Warm	
Surface (m^2)	64.79	
Building system	N/A	-4 Boreholes -Coaxial heat exchanger -Dual source Low Temp HP
Gas/oil consumption (kWh/yr.)	4785	N/A
Electricity consumption (kWh/yr.)	2864	3979
Contractual cost of gas/oil (€/kWh)	0,1166	N/A
Contractual cost of elect (€/kWh)	0,1232	0,1232

3.2.2 RDC2-FERR: Angel's gate, building in Ferrara (Italy)

This real case is a historical building in a mild warm climate where the medium size hybrid dual source high temperature heat pump has been installed and tested. The property is protected under national cultural heritage legislation: the"Codice dei Beni Culturali e del Paesaggio" (Legislative Decree 42/2004). Local offices of the "Ministero per i Beni e le Attività culturali" (Regional Management and Supervision) undertake monitoring to ensure compliance with the national legislation.

Table 3.11 – Presentation of RDC2-FERR

ITEM	EXISTING SYSTEM	GEO4CIVHIC RENOVATION
Building use	Exhibition hall	
Climate	Mild Warm	
Surface (m^2)	220	
Building system	-Natural Gas Boiler -Chiller with fan-coils	-4 Boreholes (96 m) -Coaxial heat exchanger -Hybrid Heat Pump
Gas consumption (kWh/yr.)	72710	N/A
Electricity consumption (kWh/yr.)	2562	13894
Contractual cost of gas (€/kWh)	0,2264	N/A
Contractual cost of elect (€/kWh)	0,1166	0,1166

3.2.3 RDC4-WICK: Residential house Greystones in Wicklow (Ireland)

This real demonstrator building dates back to the 1890's. The building was extended about 15 years ago to a total floor area of 165m^2 with the inclusion of a new kitchen. The bungalow is currently heated using gas fired central heating and freestanding radiators. The renovation introduced a one sourced heat pump developed in the project.

Table 3.12 – Presentation of RDC4-WICK

ITEM	EXISTING SYSTEM	GEO4CIVHIC RENOVATION
Building use	Residential	
Climate	Cold	
Surface (m^2)	165	
Building system	-Natural gas boiler with radiators	-3 Boreholes (98 m) -Coaxial heat exchanger -High temperature Heat Pump (dual stage).
Gas consumption (kWh/yr.)	38839	N/A
Electricity consumption (kWh/yr.)	N/A	12946
Contractual cost of gas (€/kWh)	N/A	N/A
Contractual cost of elect (€/kWh)	0,4985	0,4985

3.2.4 VDC2-VALE: Palacete de la cruz roja in Valencia (Spain)

This building is a special education centre for children with brain paralysis. It has: dining room, computer classroom, sports facilities, psychological and health care, motor department (hydrotherapy), communication department and learning department. All these facilities are distributed in 3 floors.

Table 3.13 – Presentation of VDC2

	RENOV-1: Traditional System	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Building use	Administrative		
Climate	Mild Warm		
Surface	1187 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	73167	0	0
Price of gas €/kwh	0,16€	0	0
Total electricity consumption (kwh/yr)	6230	25577	22093
Price of electricity €/kwh	0,24 €	0,24 €	0,24 €

3.2.5 VDC5-OSPE: Ex Ospedale Geriatrico in Padova (Italy)

This virtual demonstrator building named “Ex Ospedale Geriatrico”, an important historical complex, located in the centre of Padua, which is currently being renovated, to become the main Campus of the School of Humanities of the University of Padua.

Table 3.14 – Presentation of VDC5

	RENOV-1: Traditional System	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Building use	Administrative		
Climate	Mild Warm		
Surface	16654 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	285026	0	0
Price of gas €/kwh	0,23€	0	0
Total electricity consumption (kwh/yr)	164333	190992	169857
Price of electricity €/kwh	0,48 €	0,48 €	0,48€

3.2.6 VDC6-SPLI: Museum of archaeological monuments in Split (Croatia)

This virtual demonstrator is a historic building of the World d Heritage Site of the Historical Complex of Split.

Table 3.15 – Presentation of VDC6

	RENOV-1: Traditional System	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Building use	Museum		
Climate	Mild Warm		
Surface	XXX m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	267242,94	0	0
Price of gas €/kwh	0,05€	0	0
Total electricity consumption (kwh/yr)	86804,10	131914	124252
Price of electricity €/kwh	0,14 €	0,14 €	0,14 €

3.2.7 VDC7-ERLA: University Building Erlangen (Germany)

This virtual demonstrator belongs to the palaeontology department of the University of Erlangen. It was built in 1893 and is located in the historical city centre of Erlangen.

Table 3.16 – Presentation of VDC7

	RENOV-1: Traditional System	**RENOV-2:** Conventional GSHP System	**RENOV-3:** GEO4CIVHIC System
Building use	Administrative		
Climate	Mild Cold		
Surface	501 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	69280,92	0	0
Price of gas €/kwh	0,14€	0	0
Total electricity consumption (kwh/yr)	0	32991	27712
Price of electricity €/kwh	0,45 €	0,45 €	0,45 €

3.2.8 VDC8-ATTR: Castle of Attre (Belgium)

This virtual demonstrator is a listed building of the national list of exceptional building in Belgium. It was built in 1752. In this case the high temperature hybrid two source heat pump system with the co-axial probes will be considered for heating the building.

Table 3.17 – Presentation of VDC8

	RENOV-1: Traditional System	**RENOV-2:** Conventional GSHP System	**RENOV-3:** GEO4CIVHIC System
Building use	Family house		
Climate	Mild Cold		
Surface	1304 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	737296,84	0	0
Price of gas €/kwh	0,14€	0	0
Total electricity consumption (kwh/yr)	0	351094	294919
Price of electricity €/kwh	0,45 €	0,45 €	0,45 €

3.2.9 VDC9-DUBL: Carnegie Clondalkin Library Dublin (Ireland)

This virtual demonstrator is a detached library dating back to 1912. The Façade comprises horizontal bands of random limestone blocks, red brick and roughcast rendering with red brick buttresses and granite string. Roughcast rendered east and west elevations. Metal casement windows to ground floor, set in groups of three with central semi-circular fixed light above. Timber casement windows to first floor. Timber door with carved stone hood and fanlight. Pitched slate roof with sprocketed eaves and roughcast rendered chimney stacks. The Clondalkin library has been used as virtual case study site to test the viability of deployment of the GEO4CHIVIC technologies to listed and historical buildings in Ireland.

Table 3.18 – Presentation of VDC9

	RENOV-1: Traditional System	**RENOV-2:** Conventional GSHP System	**RENOV-3:** GEO4CIVHIC System
Building use	Public library		
Climate	Cold		

Surface	364 m^2		
Building system	Gas Boiler and fan coil units	GSHP Conventional system	GEO4CIVHIC Innovative system
Total gas consumption (kwh/yr)	58444,44	0	0
Price of gas €/kwh	0,14€	0	0
Total electricity consumption (kwh/yr)	0	27831	23378
Price of electricity €/kwh	0,45 €	0,45 €	0,45 €

4 Cost-effectiveness assessment of GEO4CIVHIC: Case of studies

Methodology

As task T7.1 has provided an LCCA of the different implementations from a techno-economic assessment point of view, T7.2 will base itself on these findings to understand the cost effectiveness and performance of the solutions from a market point of view. This involves understanding if at their current cost structures, the solutions can be priced at levels that offer on one hand the utility that is expected for end users, in the form of expected market ROI´s and payback periods for such solutions, while still being competitively priced with respect to conventional solutions and yielding sufficient returns for the organizations and companies that potentially will commercialize the solutions. This will be a crucial input in the replication and exploitation potential of the solutions and identifying key success variables such as threshold electricity or natural gas costs as required by the task and subtasks.

This section will structure itself around three levels of analysis:

i. An analysis of competing conventional solutions for all cases (real+virtual) with their adjusted costs and payback levels in order to gain an understanding of the market and end user expectations with respect to financial KPIs. This will be based in part on T7.1 findings.

ii. An analysis from the point of view of end users (whether it be public or private) implementing the solution whereby a “reservation price”, known in economic theory as the maximum amount they are ready to pay for a set of goods and services, is established conditioned by the derived expected utility that should accompany such an investment which in this instance is defined in terms of threshold payback periods and return on investment to which the prior competitive analysis should provide insights.

iii. A final analysis which takes the outputs of the past levels to contextualize them in terms of possible pricing policies (given upper limits imposed by reservation price and competitor pricing as well as lower limits imposed by partner fixed and variable cost structures) and required market penetration levels for the partners potentially taking the solutions to market to achieve sufficient returns over the CAPEX this would involve.

4.1 Analysis of competing solutions: Cases of study (real + virtual)

The objective of this section is to determine the economic and performance KPIs of more traditional renovation and retrofit strategies. As such, the implementation of such solutions and their effects have been studied and simulated on our pilot buildings in order to obtain baseline case scenarios that can be contrasted with that of the GEO4CIVHIC implementation.
In most cases, the current system was taken as a traditional gas boiler in order to compute and simulate the potential energy and economic gains.

4.1.1 Competing solutions listing and features comparison

This competition analysis segment takes into account the conventional integrated thermal solution systems and renovation scenarios applied in the 12 virtual demo cases and 4 real demo cases as well as the GEO4CIVHIC case.

For each listed solution, the document will provide an overview of the system, costs, and key features, followed by a more extensive analysis of the economic performance in the demo cases.

Table 4.1 – Assessed heating systems

COMPETING SYSTEM	DESCRIPTION OF PRODUCT
Gas boiler plus chiller	First up, conventional boilers. These are also referred to as non-condensing boilers and work by distributing the by-products of the boiler as fumes into the flue. The flue then allows the fumes to exit your home and dissipate into the atmosphere. The fumes themselves are superheated vapours and therefore conventional boilers lose a portion of the energy generated. Due to the way conventional boilers operate, they end up wasting energy, and end up polluting the air more so than other alternatives.
Condensing boiler plus chiller	Condensing boilers allow for more efficient use of the system including being able to recover and use some of the heat that would be lost in a conventional boiler system. The recovery of some of the heat is what gives these boilers the name condensing boilers. Superheated vapour moves through two heat exchangers as opposed to straight out of a flue and it is here that the vapour then cools to the point where it changes state from a gas to a liquid. This all happens within the boiler itself as the liquid formed is corrosive and needs to be kept contained within the high-grade stainless steel to prevent damage
Convectional GSHP	Ground source heat pumps (GSHPs) are units which are installed inside a building, they are powered by electricity. Ground source heat pumps are connected to a series of pipes called ground collectors which are laid underground, either in horizontal trenches or in vertical boreholes. At these depths, the ground maintains an average temperature of 10-12°C all year round (lower or higher values, respectively, are found in cold or warm climates). A water/refrigerant fluid is circulated through the ground collectors, absorbing thermal energy from the ground and circulating it back to the heat pump. A compressor inside the heat pump increases the temperature and it's then passed to a heat exchanger which transfers the heat to hot water cylinders, radiators and underfloor heating to provide space heating and hot water. Once the fluid has delivered heat to your distribution system, it's then passed through an expansion valve which cools it before it repeats the circuit all over again.
GEO4CIVHIC	GEO4CIVHIC project is fostering to retrofit civil and historical buildings by facilitating installation, reducing costs and increasing efficiency of the different components through shallow geothermal systems. On one hand by improving drilling machines and methodology, optimizing GSHE design and materials, and using more compact and hybrid HPs for high and low temperature terminals. On the other hand, a set of software tools developed within this project to provide a holistic engineering solution to optimise installation and operation of GSHPs. GEO4CIVHIC increases efficiency and ease of installation of each of the main components of the value chain of the geothermal plant by developping: technical innovations in drilling, borehole heat exchangers, heat pumps, controls and integration of other hybrids.

When comparing a gas boiler system to a geothermal heating and cooling system, several factors come into play. Here's a comparison of these systems:

Table 4.2 – Key features comparison

Competitor / Solution	Gas boiler	Condensing boiler	Conventional GSHP	GEO4CIVHIC
Energy Efficiency	LOWER			HIGHER
Environmental Impact	HIGHER			LOWER
Fuel Source	GAS or PROPANE			ELECTRICITY
Resilience to Fuel Price Fluctuations	LOWER			HIGHER
Indoor Air Quality	LOWER			HIGHER
H/C Capability	H/DHW			H/C/DHW
System Lifespan	SHORTER			LONGER
Maintenance and Repairs	HIGHER			LOWER
Flexibility	HIGHER			LOWER
Installation Costs	LOWER			HIGHER
Cost Savings	LOWER			HIGHER
Government Incentives	LOWER			HIGHER

Based on the information on the table above, installing a GEO4CIVHIC system, instead of a traditional gas boiler system, can be justified based on the following factors:

- **Energy Efficiency:** Geothermal systems are significantly more energy-efficient than gas boiler systems. Geothermal heat pumps utilize the earth's stable temperature to transfer heat, resulting in higher efficiency ratings. On average, geothermal systems can achieve efficiencies of 300% to 500% or more, meaning they produce 3 to 5 units of heat for every unit of electricity consumed. In contrast, gas boilers typically have efficiency ratings ranging from 80% to 98%. The higher efficiency of geothermal systems leads to substantial energy savings and reduced utility costs over the long term.
- **Environmental Sustainability**: Geothermal systems have a much smaller environmental footprint compared to gas boiler systems. Geothermal heat pumps utilize renewable energy from the earth, which significantly reduces reliance on fossil fuels and associated greenhouse gas emissions. By switching to a geothermal system, carbon dioxide emissions can be significantly reduced, contributing to mitigating climate change and promoting a more sustainable future.
- **Long-Term Cost Savings:** Although geothermal systems have higher upfront installation costs compared to gas boiler systems, they offer long-term cost savings. The energy efficiency of geothermal systems translates into reduced energy consumption and lower utility bills. Over the system's lifespan, these energy savings can offset the initial investment and provide significant financial benefits.
- **Durability and Longevity:** Geothermal systems have a longer lifespan and require fewer replacements compared to gas boiler systems. Geothermal heat pumps can last for 20 to 25 years or more with proper maintenance, while gas boilers typically have a lifespan of about 10 to 15 years. Investing in a geothermal system provides a more durable and reliable heating and cooling solution, reducing the need for frequent system replacements and associated costs.
- **Flexibility in Cooling and Heating:** Geothermal systems offer both heating and cooling capabilities. They can efficiently provide cooling during the summer months by extracting

heat from the building and releasing it into the cooler ground. This versatility eliminates the need for separate cooling systems, enhancing comfort and convenience.

- **Reduced Dependency on Fossil Fuels**: Installing a geothermal system helps reduce dependency on fossil fuels, such as natural gas or propane, which are finite resources. By transitioning to a renewable energy source, the reliance on fossil fuel supplies and their associated price volatility is minimized.
- **Government Incentives and Tax Credits:** In many regions, there are government incentives, tax credits, and rebates available for installing geothermal systems. These financial incentives can significantly offset the upfront installation costs, making geothermal systems more economically viable and attractive.
- **Improved Indoor Air Quality:** Geothermal systems can contribute to improved indoor air quality. Unlike gas boiler systems, geothermal systems do not burn fuel or emit combustion byproducts such as carbon monoxide, nitrogen oxides, or particulate matter. This feature helps create a healthier and safer indoor environment.
- **Resilience to Fuel Price Fluctuations:** Geothermal systems are less subjected to fuel (or electricity) prices. By relying on the stable temperature of the earth, geothermal systems provide consistent and predictable heating and cooling, unaffected by changes in the cost of natural gas or propane.

Considering these factors, installing a geothermal heating and cooling system presents a compelling case for energy efficiency, environmental sustainability, long-term cost savings, durability, versatility, and reduced reliance on fossil fuels. However, it is important to conduct a site-specific analysis and consult with a qualified professional to determine the feasibility and suitability of a geothermal system for a particular location. This analysis is being performed below.

4.1.2 Economic performance of the solutions in the real and virtual demo cases

This section will provide an overview of economic KPIs for each system applied to the real and virtual demo cases from cost ranges to Net Present Value calculations. As a result, this section will provide an analysis for GEO4CIVHIC solutions benchmarking them against standard indicators associated to conventional systems and see how they compare providing insights on the respective pricing policies that can be applied.

Before presenting economic KPIs and performance of the solutions and different alternative thermal systems for our demo cases, it is important to present the assumptions, namely in terms of energy costs, given their impact on the results observed.

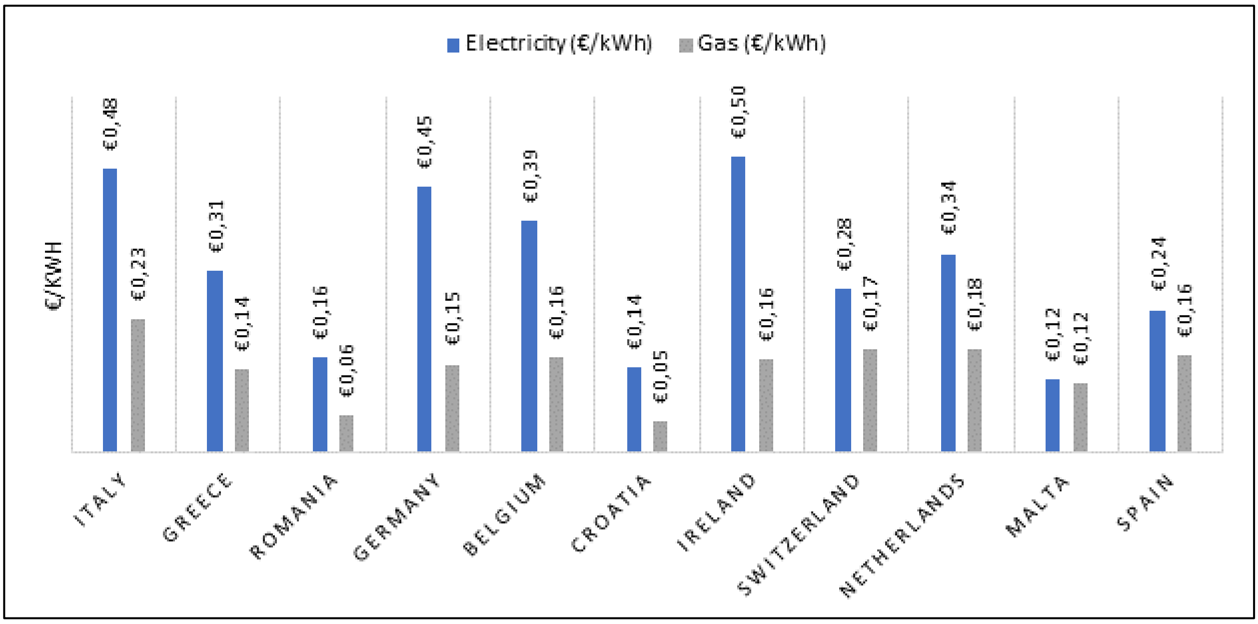


Figure 4.1 Energy prices for virtual and real demo cases

Real demo cases will apply energy prices specific to their context. These are later specified in the actual analysis.

Moreover, it is important to take into consideration that for virtual demo cases, the solutions and results are simulated.

The following table and figures provide an overview of the cost ranges in question for each system taking into consideration virtual as well as real demo cases.

Table 4.3 – Overview of cost ranges for competing solutions

COMPETING SYSTEM	COSTS		
	Initial inversion (€)	**Operation (€/Yr)**	**Maintenance (€/Yr)**
Gas boiler + chiller	3’240€ - 6’339’202€	263,96€ - 143’426,16€	60€ - 25’000€
Conventional GSHP	9’959€ - 6’741’202€	156,42€ - 157’009,12€	150€ - 25’000€
GEO4CIVHIC	9’461€ - 6’691’202€	154,63€ - 131’887,66€	40€ – 25’000€

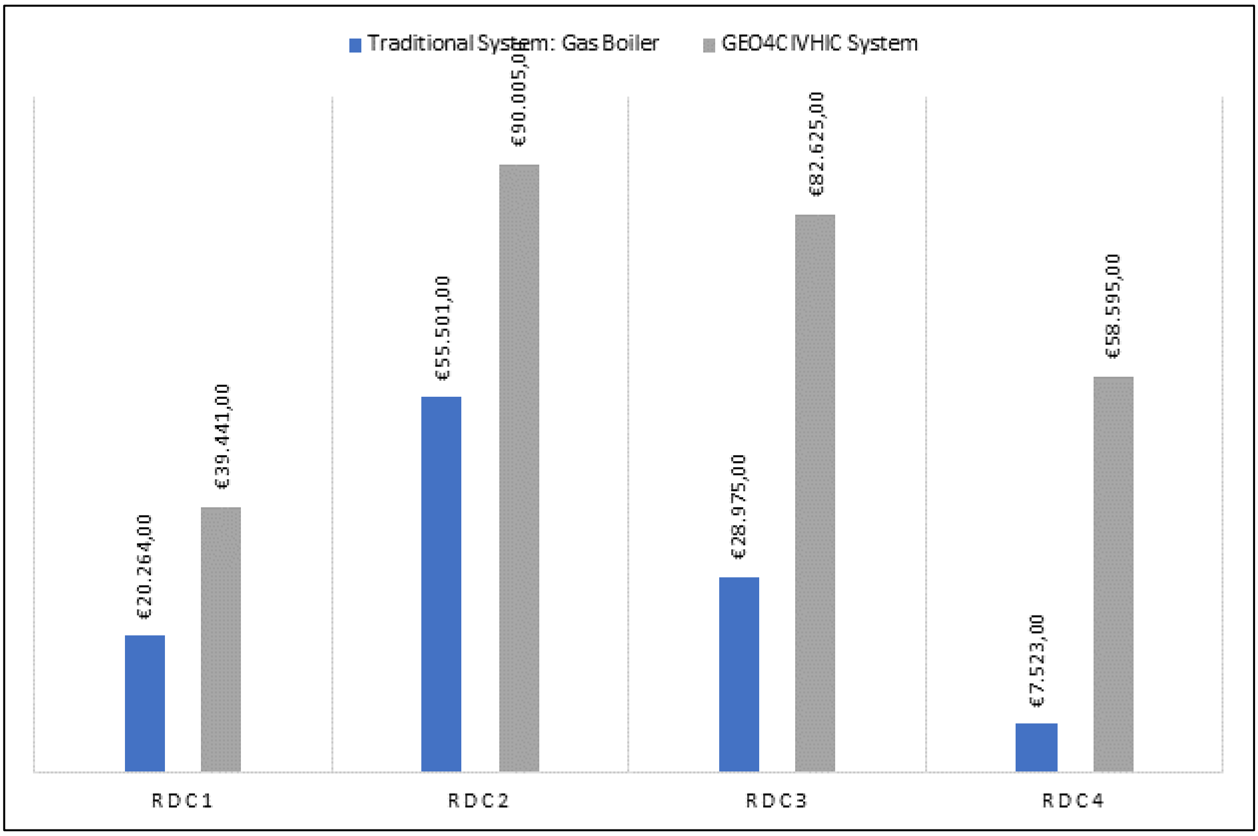


Figure 4.2 Projected investment costs for thermal systems in Real demo cases

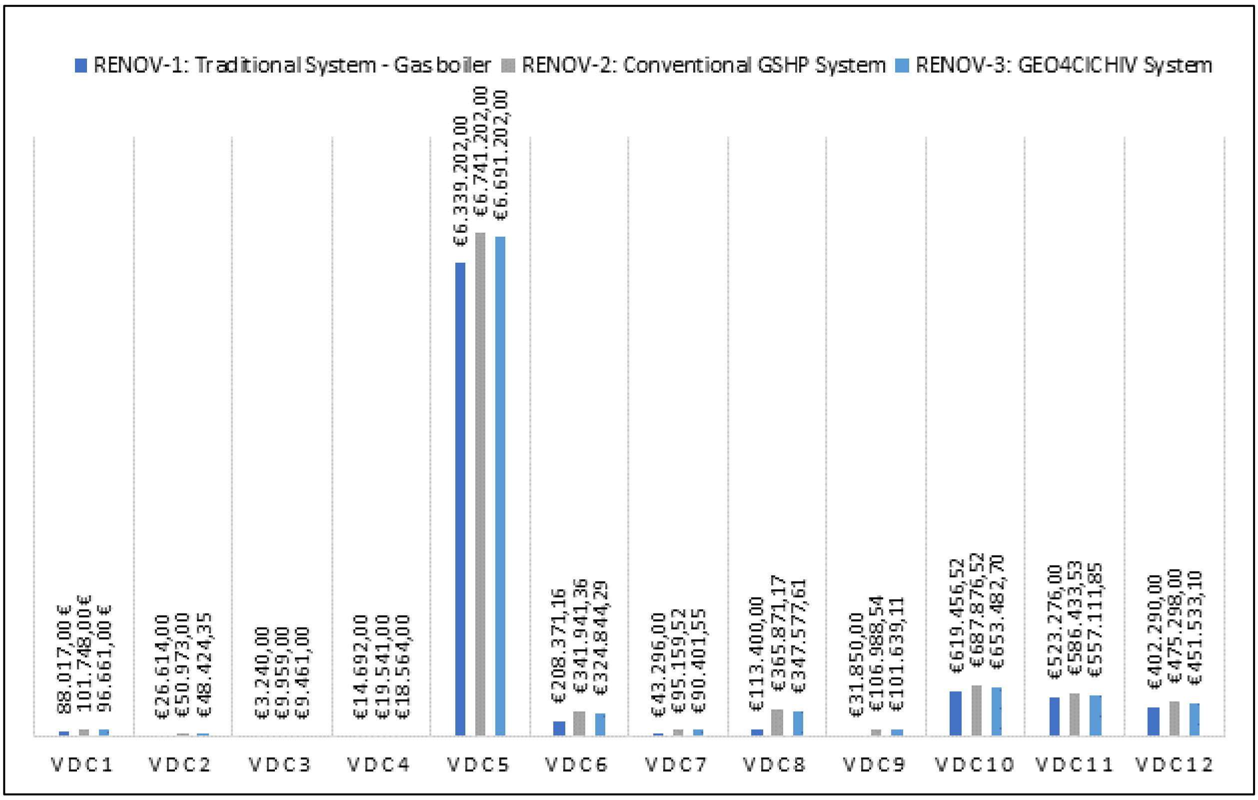


Figure 4.3 Projected investment costs for thermal systems in virtual demo cases

The investment costs listed above are commercial prices for the already existing solutions while for the GEO4CIVHIC solution they reflect non-commercial actual costs for implementing the solutions in real demo sites incurred during the project and for virtual demo sites they are an estimation in line with real demo case costs. It is important to take this into consideration given that the next sections will explore pricing considerations from the point of view of end users.

In order to obtain more detail and a full understanding of the above ranges, the economic performance of different solutions is presented in continuation of this document for each demo site. Focus is brought specifically on providing Net Present Values (NPV), Return on Investment (ROI) and payback period (PP) figures for each of the real and virtual demo cases. These will firstly be provided for the alternative solutions to GEO4CIVHIC in order to understand current market offerings´ economic performance. This will then be benchmarked against that of the GEO4CIVHIC implementations.

For this study, we have included initial cost benefit analysis considerations in the form of net present value formulas using the data on cost and savings obtained from partners and the following formula and approach:

$$NPV = \sum_{t=1}^{n} \frac{\Delta E_t}{(1+r)^t} - (I_0 + \sum_{j}^{N} \frac{C_m}{(1+r)^j} + \sum_{j}^{N} \frac{C_r}{(1+r)^j})$$

Benefit:

$$\Delta E_t = Annual\ monetary\ gain\ (dependant\ on\ energy\ prices,$$
$$energy\ performance\ of\ solution\ and\ building\ typlogy\ as\ well\ as\ maintenance\ costs\ of$$
$$new\ system\ if\ lower\ than\ the\ previous\ system)$$
$$r = discount\ rate\ (opportunity\ cost)$$

Cost:

$$I_o = Investment\ cost\ (CAPEX)$$
$$C_m = annual\ maintenance\ cost\ (OPEX)$$
$$C_r = replacement\ cost\ (OPEX)$$

Within this formula, the following KPIs and indicators may influence the NPV and help us understand dynamics at play between CBA results and solutions used, building typologies and country specific macro-economic trends such as energy prices.

More specifically, the following economic indicators and principles can influence results:

OPEX: Within the NPV formula, life span of the systems and implements **can be included through maintenance of the systems and their replacement (deconstruction costs included)**. These indicators tend to enter the operational expenses or OPEX category. Within the calculations that are performed in this deliverable no replacement cost is included as calculations are solely focused on the 30-year time span which has been chosen to assess the solutions. Moreover, given that maintenance costs can potentially be inferior with newer systems to those that are being replaced or to that of other competing solutions, than these can turn out to be cash flow savings. Maintenance costs estimated in our NPV are conservative and relatively high accounting for the 30-year service life.

Opportunity cost and discount rates: Any resource has a real value equivalent to the return he or she could obtain in the best alternative use of that resource. This is called the opportunity cost and it **refers to the rate of return an investor could earn in the marketplace on an investment**

of comparable size and risk. Therefore, in terms of economic viability, discounted savings to the expected market rate of return for equivalent renovations must be calculated. This in itself should determine the economic viability of solutions simply through obtaining a positive NPV discounted at the appropriate rate. Moreover, discounting is also a method for reflecting the perceived value of money over time. Cash and returns in the present are more valuable than cash flows years down the line.

- Discounting is the process of determining the present value of a future payment or stream of payments.
- A Euro is always worth more today than it would be worth tomorrow, according to the concept of the time value of money.
- A higher discount indicates a greater the level of risk associated with an investment and its future cash flows.

For the computation of the NPVs for every case, we have taken the same discount rates as those used for the LCCA in D7.1 as indicated beneath.

Table 4.4 – Discount rates

Demo-case	Discount rate
VDC1	4,49%
VDC2	3,99%
VDC3	7,46%
VDC4	7,49%
VDC5	3,73%
VDC6	3,44%
VDC7	3,86%
VDC8	3,43%
VDC9	3,02%
VDC10	4,00%
VDC11	3,58%
VDC12	3,99%
RDC1	3,43%
RDC2	3,02%
RDC3	3,73%
RDC4	1,58%

For the computation of the NPV, the above discount rates have not been adjusted to account for yearly energy price inflation for two main reasons. Firstly, and as demonstrated in the following statistics from Eurostat, natural gas and electricity prices generally move in similar proportions given that an important portion of electricity in Europe is generated from natural gas which reduce the relative advantages of consuming one source of energy rather than the other (Boiler vs Heat Pump). Moreover, it is estimated that the late bout of hyperinflation in energy prices due to the war in Ukraine in 2022 will taper off in the coming years with a return to more supply and demand stability albeit at a higher price than pre-2022 levels (https://ec.europa.eu/economy_finance/forecasts/2023/spring/Box_I_2_1_European%20gas%20market%20recent%20developments%20and%20outlook.pdf)

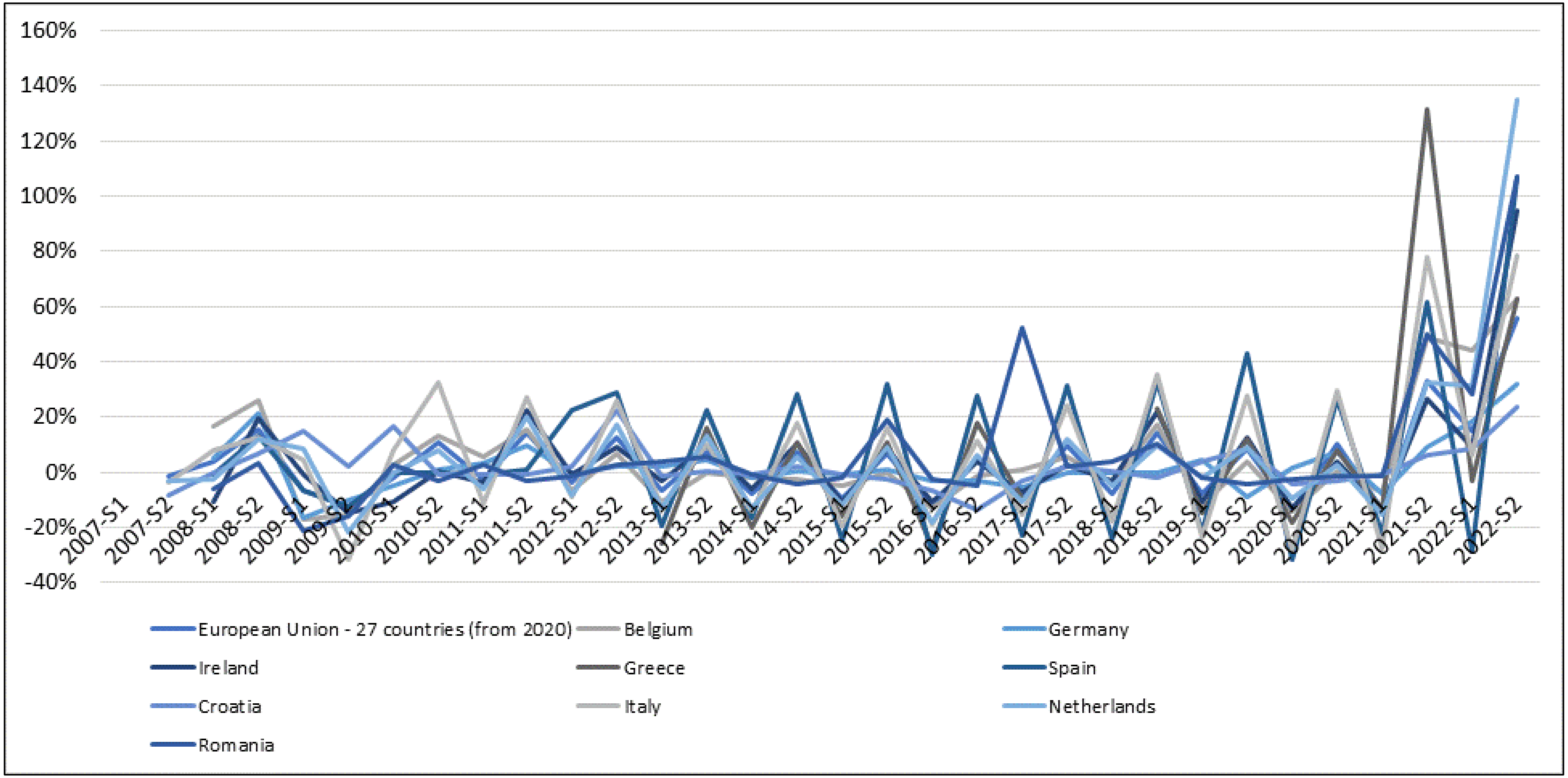


Figure 4.4 Gas prices variation for household consumers in demo-case countries (Eurostat)

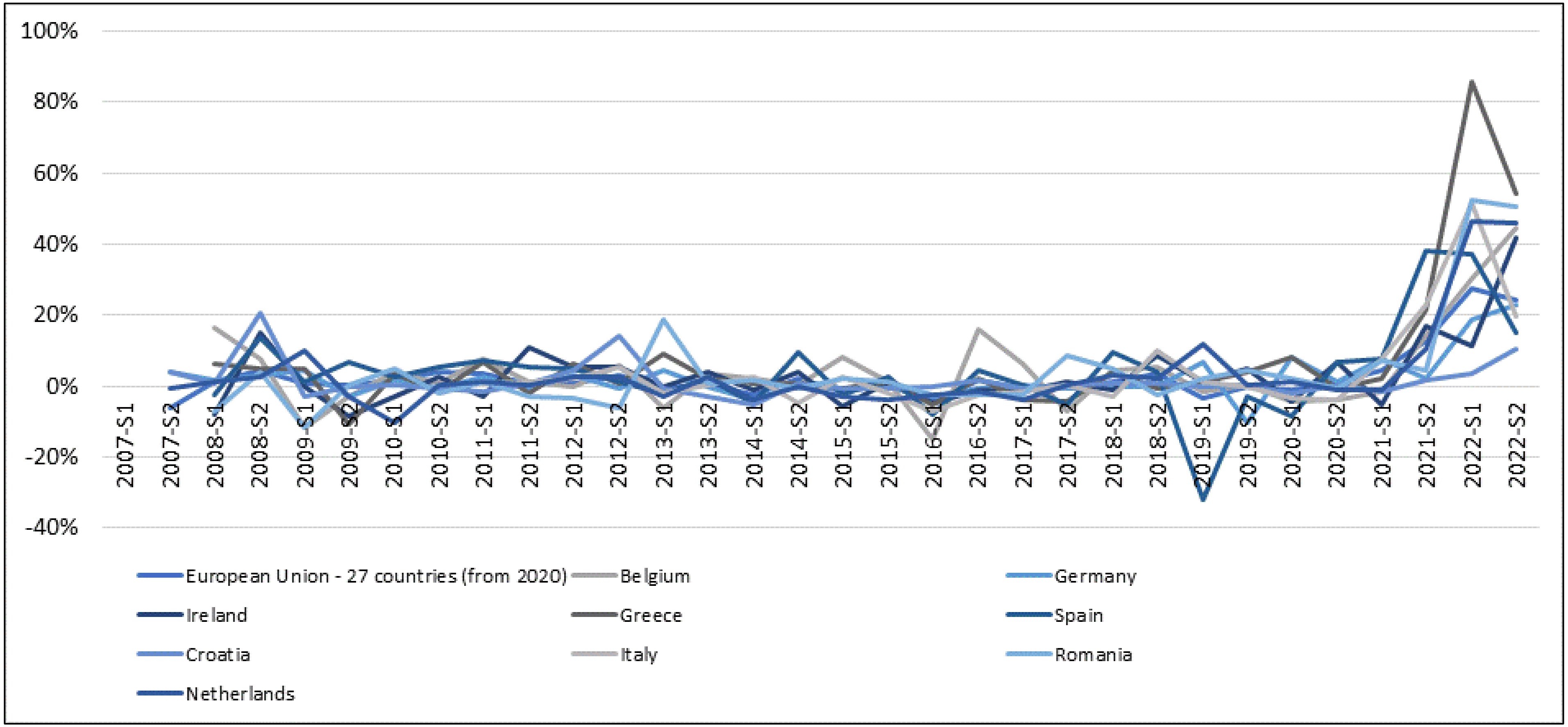


Figure 4.5 Electricity prices variation for household consumers in demo-case countries (Eurostat)

Energy prices: Economic viability methodologies are all based on **cash flow discounting or in this case energy savings brought about by the system**. These energy savings are highly dependent on energy prices. The higher the price of energy, the higher will be the return on the investment in question. Moreover, on top of this comes the actual energy mix at hand. Heating is covered either through natural gas or electricity which both have different prices per kWh. Depending on systems chosen and energy prices, different energy mixes can yield higher or lower savings.

Energy performance of solutions: Determining the energy savings attributable to solutions in different building types will enable the calculation of savings or cash flows for the economic viability analysis. **Of course, for existing buildings the amount of energy saved is calculated from post retrofit consumption compared to current systems.**

Cost of installation (CAPEX): The initial capital outlay for implementing the system at time t0 must be calculated.

ROI has been determined using the following formula:

$$ROI = \frac{Gains - Initial\ Investment}{Initial\ Investment}$$

In order to reflect time value of money and other effects described in our discount rate determination we will be calculating the discounted ROI for a 30 year period (useful life of thermal system) which is essentially our 30 year NPV divided by the initial investment.

PP has been determined using the following formula:

$$Payback\ period = \frac{Initial\ Investment}{€\ Savings}$$

Simple payback period is used although discounted payback period is observable in the following NPVs when the curves move from negative to positive signifying the initial investment is recovered from the discounted cashflows. Negative payback periods simply mean there is no payback of the investment.

All results are presented for the respective demo-sites for retrofits of gas boilers, GSHP whenever these systems have been tested or simulated and of course the GEO4CIVHIC system.

— VDC1-ALEX economic performance

30 year NPV results:

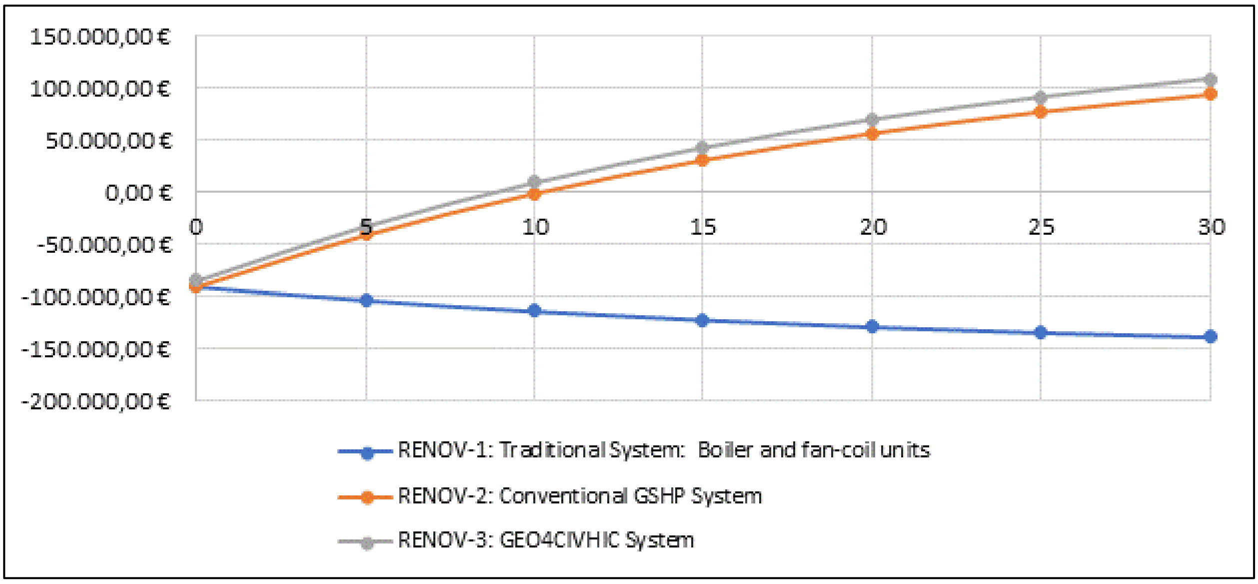


Figure 4.6 VDC1-ALEX NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.5 – VDC1-ALEX non-discounted annual savings for retrofit options.

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	0	38943	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	47822	41728	13215	11397
Price of electricity €/kwh	0,306 €	0,31 €	0,31 €	0,31 €
Maintenance cost [€/Yr]	1.500,00 €	800,00 €	800,00 €	800,00 €
Energy savings (€/Yr)	N/A	- 3.635,44 €	10.603,58 €	11.160,62 €
Maintenance loss or savings (€/Yr)	N/A	700,00 €	700,00 €	700,00 €
Total savings (€/Yr)	N/A	- 2.935,44 €	11.303,58 €	11.860,62 €

Payback and return on investment:

Moreover, the resulting simple payback periods and 30 year discount return on investment are listed in the table below.

Table 4.6 – VDC1-ALEX Simple payback period and Discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	-30	9	8
Discounted ROI (30 year)	-157,72%	92,28%	112,38%

— VDC2-VALE economic performance

30 year NPV results:

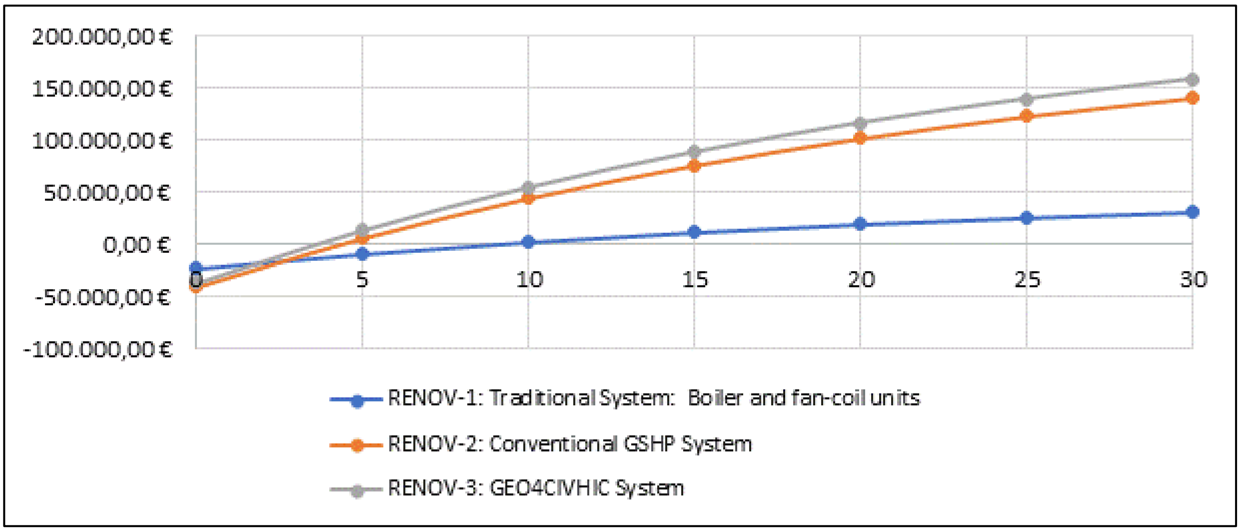


Figure 4.7 VDC2-VALE NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.7 – VDC2-VALE non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	81297	73167	0	0
Price of gas €/kwh	0,16 €	0,16 €	- €	- €
Total electricity consumption of building (kwh/yr)	7476	6230	25577	22093
Price of electricity €/kwh	0,241 €	0,24 €	0,24 €	0,24 €
Maintenance cost [€/Yr]	4.000,00 €	2.500,00 €	2.500,00 €	2.500,00 €
Energy savings (€/Yr)	N/A	1.632,42 €	8.967,63 €	9.806,23 €
Maintenance loss or savings (€/Yr)	N/A	1.500,00 €	1.500,00 €	1.500,00 €
Total savings (€/Yr)	N/A	3.132,42 €	10.467,63 €	11.306,23 €

Payback and return on investment:

Table 4.8 – VDC2-VALE Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	8	5	4
Discounted ROI (30 year)	115,54%	276,07%	327,58%

— VDC3-AVAN economic performance

30 year NPV results:

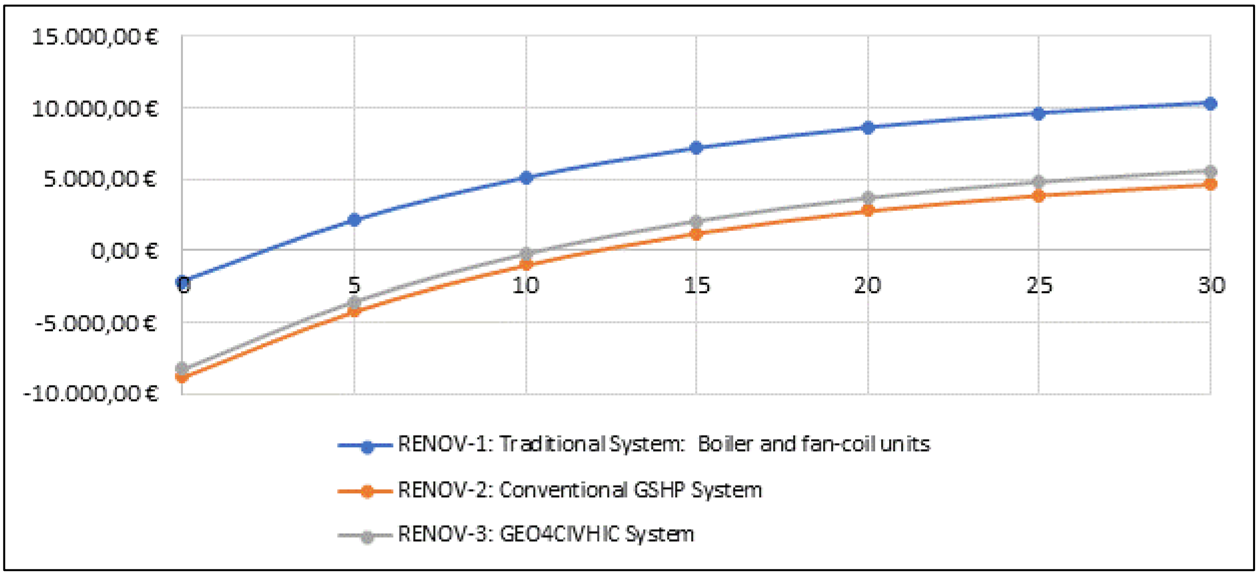


Figure 4.8 VDC3-AVAN NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.9 – VDC3-AVAN non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	6366	5730	0	0
Price of gas €/kwh	0,06 €	0,06 €	- €	- €
Total electricity consumption of building (kwh/yr)	477	397	2148	1953
Price of electricity €/kwh	0,163 €	0,16 €	0,16 €	0,16 €
Maintenance cost [€/Yr]	2.000,00 €	1.000,00 €	1.000,00 €	1.000,00 €
Energy savings (€/Yr)	N/A	53,65 €	135,08 €	166,79 €
Maintenance loss or savings (€/Yr)	N/A	1.000,00 €	1.000,00 €	1.000,00 €
Total savings (€/Yr)	N/A	1.053,65 €	1.135,08 €	1.166,79 €

Payback and return on investment:

Table 4.10 – VDC3-AVAN Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	3	9	8
Discounted ROI (30 year)	318,09%	46,53%	58,55%

— VDC4-BUCH economic performance

30 year NPV results:

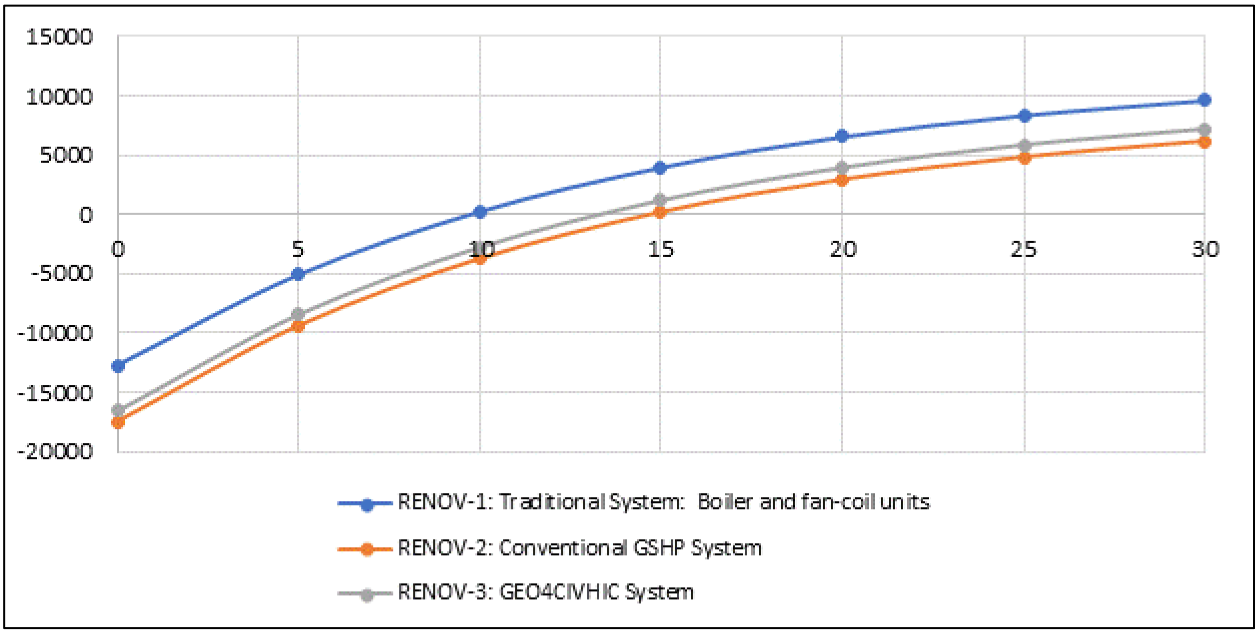


Figure 4.9 VDC4-BUCH NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.11 – VDC4-BUCH non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	17553	3627	0	0
Price of gas €/kwh	0,06 €	0,06 €	0,06 €	0,06 €
Total electricity consumption of building (kwh/yr)	237	198	962	951
Price of electricity €/kwh	0,163 €	0,16 €	0,16 €	0,16 €
Maintenance cost [€/Yr]	2.500,00 €	1.500,00 €	1.500,00 €	1.500,00 €
Energy savings (€/Yr)	N/A	896,21 €	1.003,75 €	1.005,54 €
Maintenance loss or savings (€/Yr)	N/A	1.000,00 €	1.000,00 €	1.000,00 €
Total savings (€/Yr)	N/A	1.896,21 €	2.003,75 €	2.005,54 €

Payback and return on investment:

Table 4.12 – VDC4-BUCH Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	8	10	9
Discounted ROI (30 year)	65,48%	31,48%	38,52%

— VDC5-OSPE economic performance

30 year NPV results:

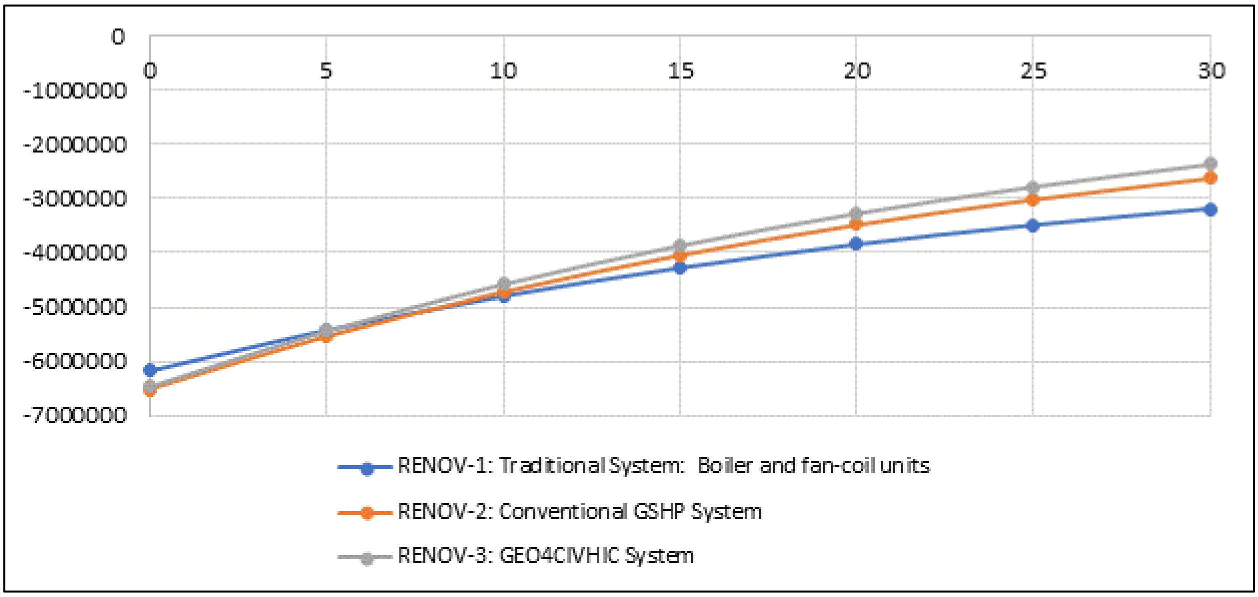


Figure 4.10 VDC5-OSPE NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.13 – VDC5-OSPE non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	960708	285026	0	0
Price of gas €/kwh	0,23 €	0,23 €	0,23 €	0,23 €
Total electricity consumption of building (kwh/yr)	151719	164333	190992	169857
Price of electricity €/kwh	0,480 €	0,48 €	0,48 €	0,48 €
Maintenance cost [€/Yr]	45.000,00 €	25.000,00 €	25.000,00 €	25.000,00 €
Energy savings (€/Yr)	N/A	146.918,42 €	198.649,32 €	208.796,24 €
Maintenance loss or savings (€/Yr)	N/A	20.000,00 €	20.000,00 €	20.000,00 €
Total savings (€/Yr)	N/A	166.918,42 €	218.649,32 €	228.796,24 €

Payback and return on investment:

Table 4.14 – VDC5-OSPE Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	38	31	29
Discounted ROI (30 year)	-50,30%	-38,78%	-35,47%

— VDC6-SPLI economic performance

30 year NPV results:

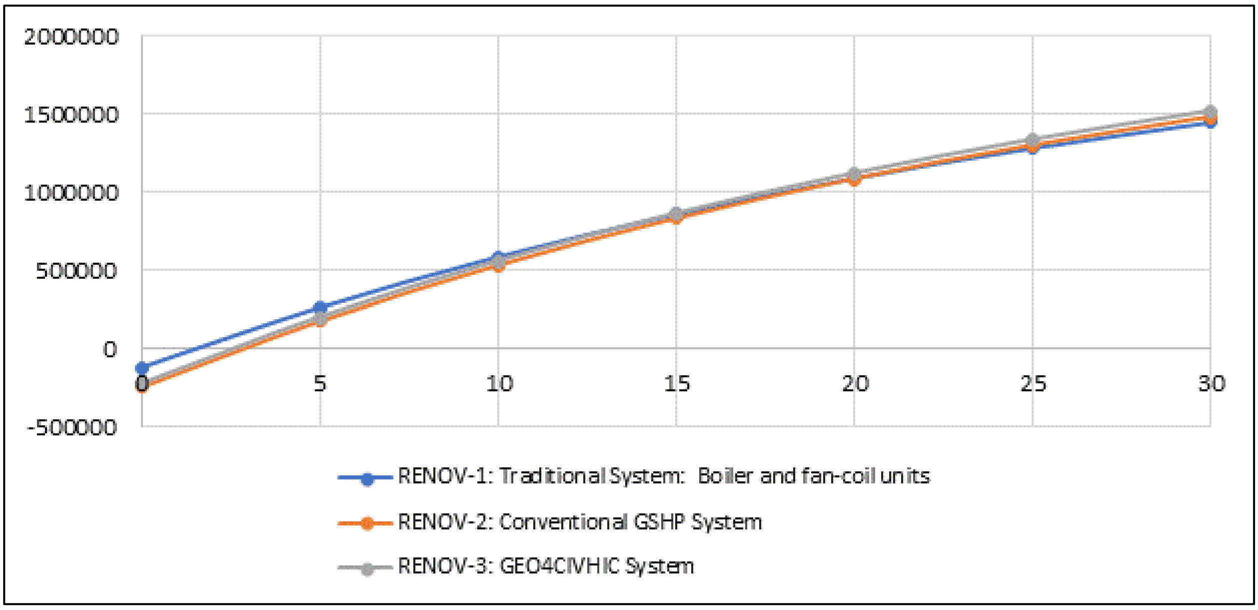


Figure 4.11 VDC6-SPLI NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30-year NPV.

Table 4.15 – VDC6-SPLI non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	296936,6031	267242,9428	0	0
Price of gas €/kwh	0,05 €	0,05 €	0,05 €	0,05 €
Total electricity consumption of building (kwh/yr)	651030,7724	86804,10298	131914	124252
Price of electricity €/kwh	0,144 €	0,14 €	0,14 €	0,14 €
Maintenance cost [€/Yr]	7.000,00 €	5.000,00 €	4.000,00 €	4.000,00 €
Energy savings (€/Yr)	N/A	82.748,17 €	90.260,41 €	91.362,91 €
Maintenance loss or savings (€/Yr)	N/A	2.000,00 €	3.000,00 €	3.000,00 €
Total savings (€/Yr)	N/A	84.748,17 €	93.260,41 €	94.362,91 €

Payback and return on investment:

Table 4.16 – VDC6-SPLI Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	2	4	3
Discounted ROI (30 year)	694,36%	432,69%	467,35%

— VDC7-ERLA economic performance

30 year NPV results:

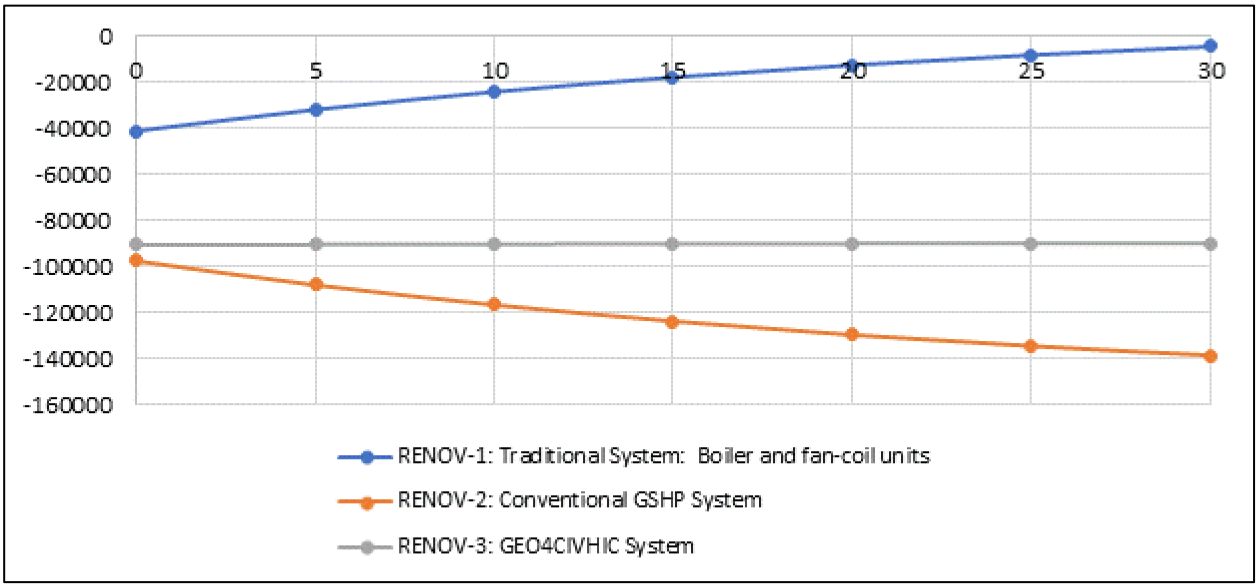


Figure 4.12 VDC7-ERLA NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.17 – VDC7-ERLA non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	76978,80424	69280,92381	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	0	0	32991	27712
Price of electricity €/kwh	0,447 €	0,45 €	0,45 €	0,45 €
Maintenance cost [€/Yr]	3.500,00 €	2.500,00 €	2.000,00 €	2.000,00 €
Energy savings (€/Yr)	N/A	1.092,33 €	- 3.830,25 €	- 1.469,68 €
Maintenance loss or savings (€/Yr)	N/A	1.000,00 €	1.500,00 €	1.500,00 €
Total savings (€/Yr)	N/A	2.092,33 €	- 2.330,25 €	30,32 €

Payback and return on investment:

Table 4.18 – VDC7-ERLA Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	21	-41	2982
Discounted ROI (30 year)	-10,16%	-145,52%	-99,38%

— **VDC8-ATTR economic performance**

30 year NPV results:

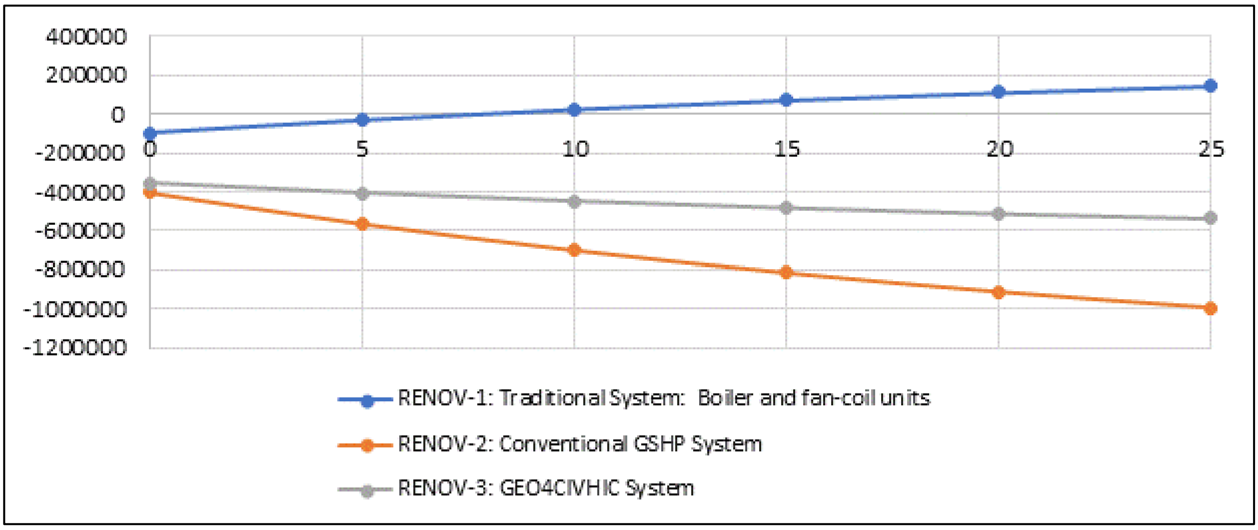


Figure 4.13 VDC8-ATTR NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.19 – VDC8-ATTR non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	829458,94	737296,8356	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	0	0	351094	294919
Price of electricity €/kwh	0,447 €	0,45 €	0,45 €	0,45 €
Maintenance cost [€/Yr]	6.000,00 €	4.500,00 €	2.500,00 €	2.500,00 €
Energy savings (€/Yr)	N/A	13.077,80 €	- 39.308,89 €	- 14.187,43 €
Maintenance loss or savings (€/Yr)	N/A	1.500,00 €	3.500,00 €	3.500,00 €
Total savings (€/Yr)	N/A	14.577,80 €	- 35.808,89 €	- 10.687,43 €

Payback and return on investment:

Table 4.20 – VDC8-ATTR Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	8	-10	-33
Discounted ROI (30 year)	151,38%	-291,38%	-160,13%

— VDC9-DUBL economic performance

30 year NPV results:

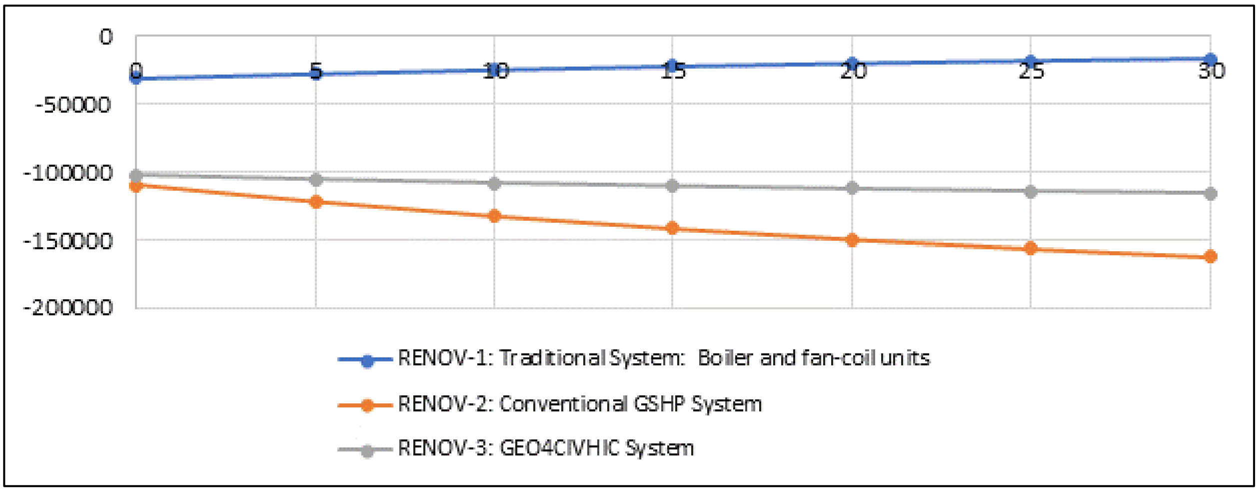


Figure 4.14 VDC9-DUBL NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.21 – VDC9-DUBL non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	65000	58444,44444	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	0	0	27831	23378
Price of electricity €/kwh	0,447 €	0,45 €	0,45 €	0,45 €
Maintenance cost [€/Yr]	698,00 €	898,00 €	150,00 €	150,00 €
Energy savings (€/Yr)	N/A	930,23 €	- 3.222,38 €	- 1.231,04 €
Maintenance loss or savings (€/Yr)	N/A	- 200,00 €	548,00 €	548,00 €
Total savings (€/Yr)	N/A	730,23 €	- 2.674,38 €	- 683,04 €

Payback and return on investment:

Table 4.22 – VDC9-DUBL Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	44	-40	-149
Discounted ROI (30 year)	-52,88%	-151,37%	-113,81%

— VDC10-AIL economic performance

30 year NPV results:

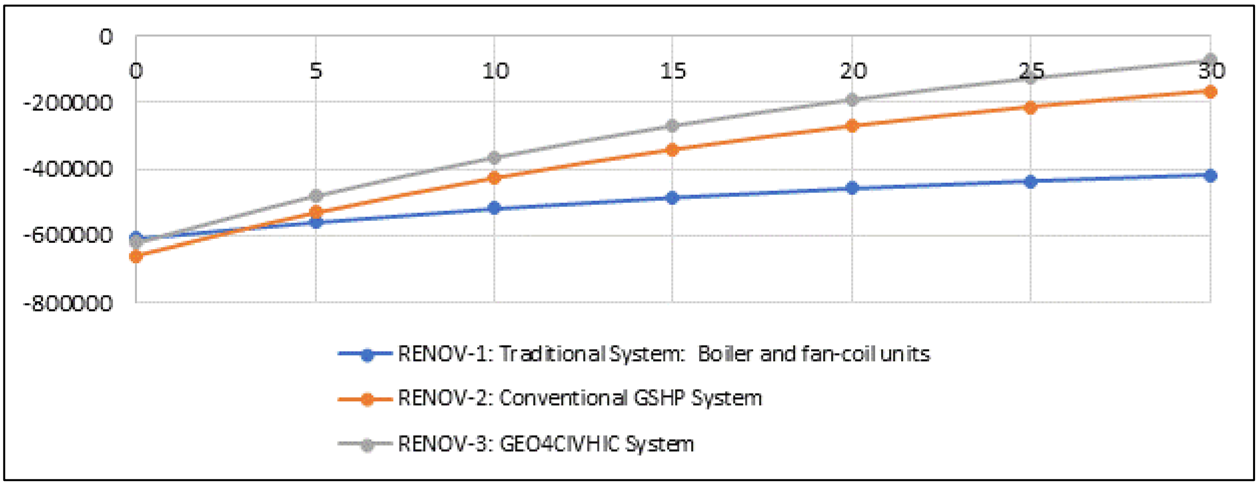


Figure 4.15 VDC10-AIL NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.23 – VDC10-AIL non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	272209	244988	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	62000	51666,66667	92247	85156
Price of electricity €/kwh	0,447 €	0,45 €	0,45 €	0,45 €
Maintenance cost [€/Yr]	8.500,00 €	6.000,00 €	5.000,00 €	5.000,00 €
Energy savings (€/Yr)	N/A	8.483,73 €	25.100,00 €	28.271,20 €
Maintenance loss or savings (€/Yr)	N/A	2.500,00 €	3.500,00 €	3.500,00 €
Total savings (€/Yr)	N/A	10.983,73 €	28.600,00 €	31.771,20 €

Payback and return on investment:

Table 4.24 – VDC10-AIL Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	56	24	21
Discounted ROI (30 year)	-67,57%	-23,95%	-11,07%

— VDC11-SOES economic performance

30 year NPV results:

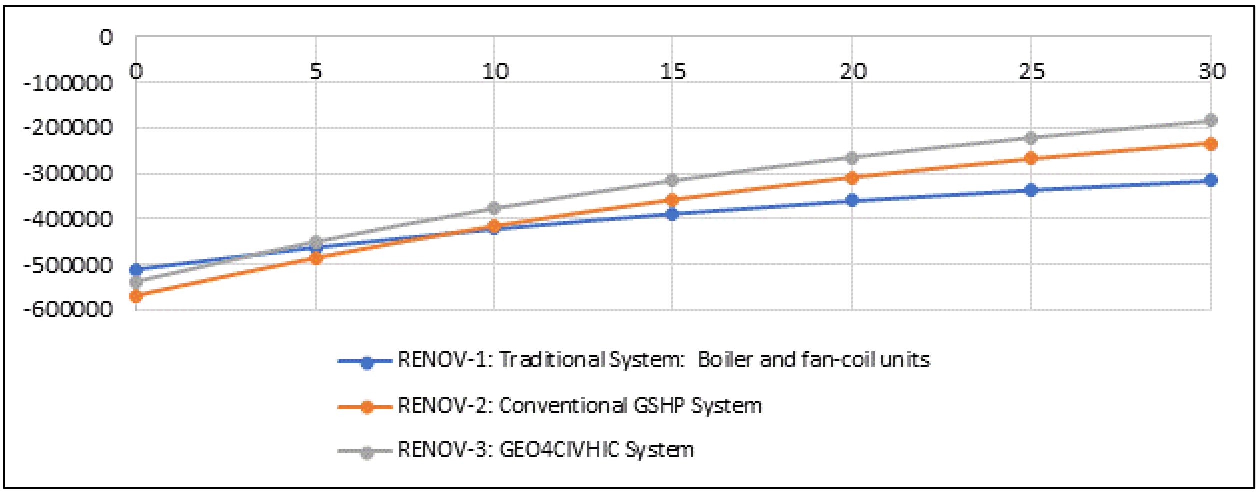


Figure 4.16 VDC11-SOES NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.25 – VDC11-SOES non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	158490	82205	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	0	0	24911	24911
Price of electricity €/kwh	0,447 €	0,45 €	0,45 €	0,45 €
Maintenance cost [€/Yr]	15.000,00 €	15.000,00 €	8.000,00 €	7.000,00 €
Energy savings (€/Yr)	N/A	10.824,84 €	11.349,71 €	11.349,71 €
Maintenance loss or savings (€/Yr)	N/A	- €	7.000,00 €	8.000,00 €
Total savings (€/Yr)	N/A	10.824,84 €	18.349,71 €	19.349,71 €

Payback and return on investment:

Table 4.26 – VDC11-SOES Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	48	32	29
Discounted ROI (30 year)	-60,26%	-39,89%	-33,28%

— VDC12-LLEI economic performance

30 year NPV results:

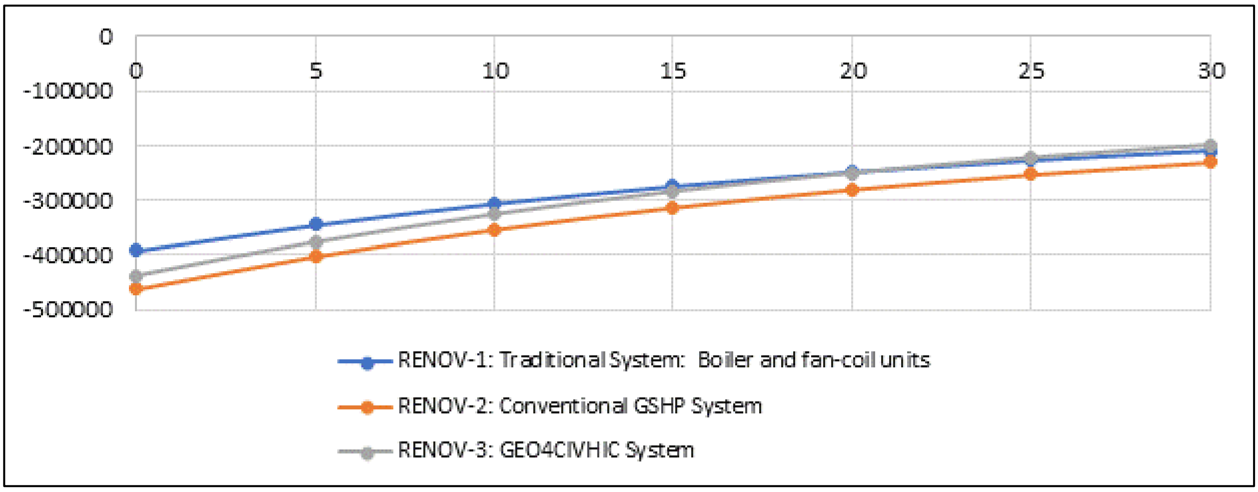


Figure 4.17 VDC12-LLEI NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.27 – VDC12-LLEI non-discounted annual savings for retrofit options

	Pre-retrofit	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	104632	30129	0	0
Price of gas €/kwh	0,14 €	0,14 €	0,14 €	0,14 €
Total electricity consumption of building (kwh/yr)	0	4600	12181	11444
Price of electricity €/kwh	0,447 €	0,45 €	0,45 €	0,45 €
Maintenance cost [€/Yr]	8.000,00 €	6.000,00 €	4.000,00 €	4.000,00 €
Energy savings (€/Yr)	N/A	8.514,86 €	9.400,01 €	9.729,49 €
Maintenance loss or savings (€/Yr)	N/A	2.000,00 €	4.000,00 €	4.000,00 €
Total savings (€/Yr)	N/A	10.514,86 €	13.400,01 €	13.729,49 €

Payback and return on investment:

Table 4.28 – VDC12-LLEI Simple payback periods and discounted ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	38	35	33
Discounted ROI (30 year)	-52,13%	-48,37%	-44,32%

— RDC1-VALL economic performance

30 year NPV results:

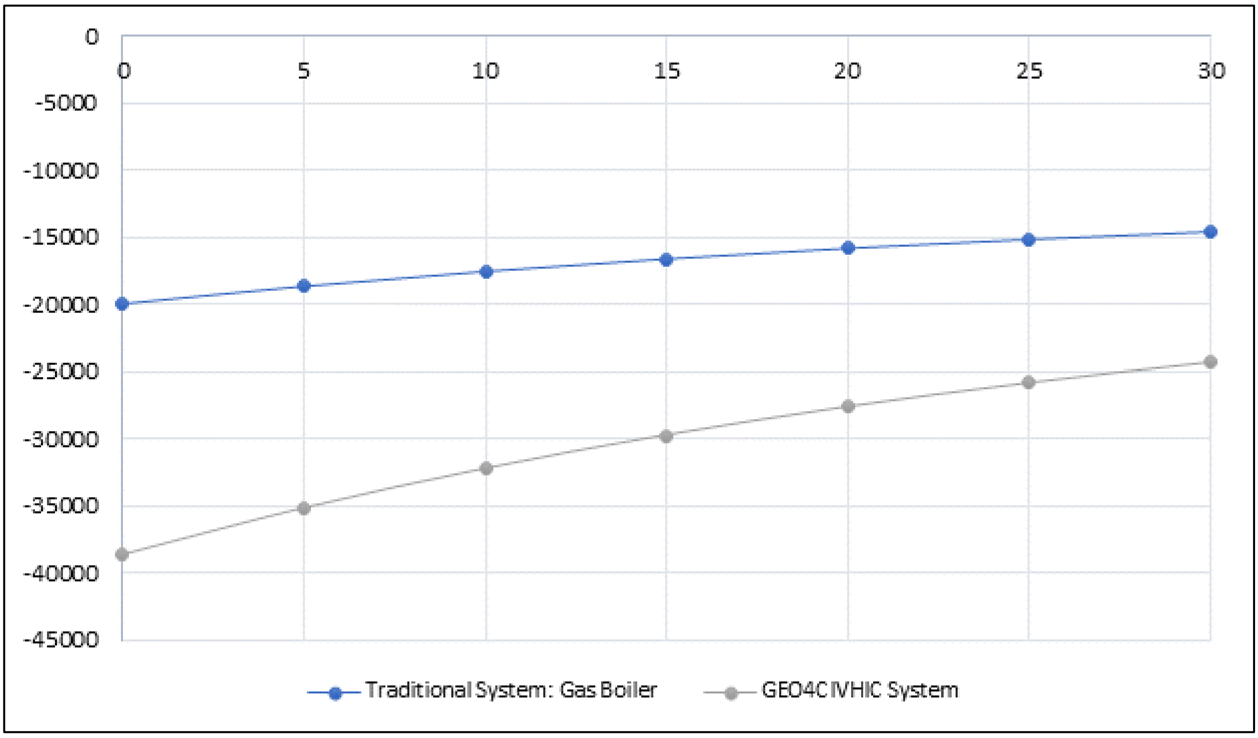


Figure 4.18 RDC1-VALL NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.29 – RDC1-VALL non-discounted annual savings for retrofit options

	Pre-retrofit	Traditional System: Gas Boiler	GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	6357,14	4784,95	N/A
Price of gas €/kwh	0,12 €	0,12 €	N/A
Total electricity consumption of building (kwh/yr)	3580,00	2864,00	3978,95
Price of electricity €/kwh	0,12 €	0,12 €	0,12 €
Maintenance cost [€/Yr]	120,00 €	100,00 €	40,00 €
Energy savings (€/Yr)	N/A	271,53 €	692,09 €
Maintenance loss or savings (€/Yr)	N/A	20,00 €	80,00 €
Total savings (€/Yr)	N/A	291,53 €	772,09 €

Payback and return on investment:

Table 4.30 – RDC1-VALL Simple payback periods and discounted ROI

	Traditional System: Boiler and fan-coil units	GEO4CIVHIC System
Calculated PP (Yr)	70	51
Discounted ROI (30 year)	-71,87%	-61,72%

— **RDC2-FERR economic performance**

30 year NPV results:

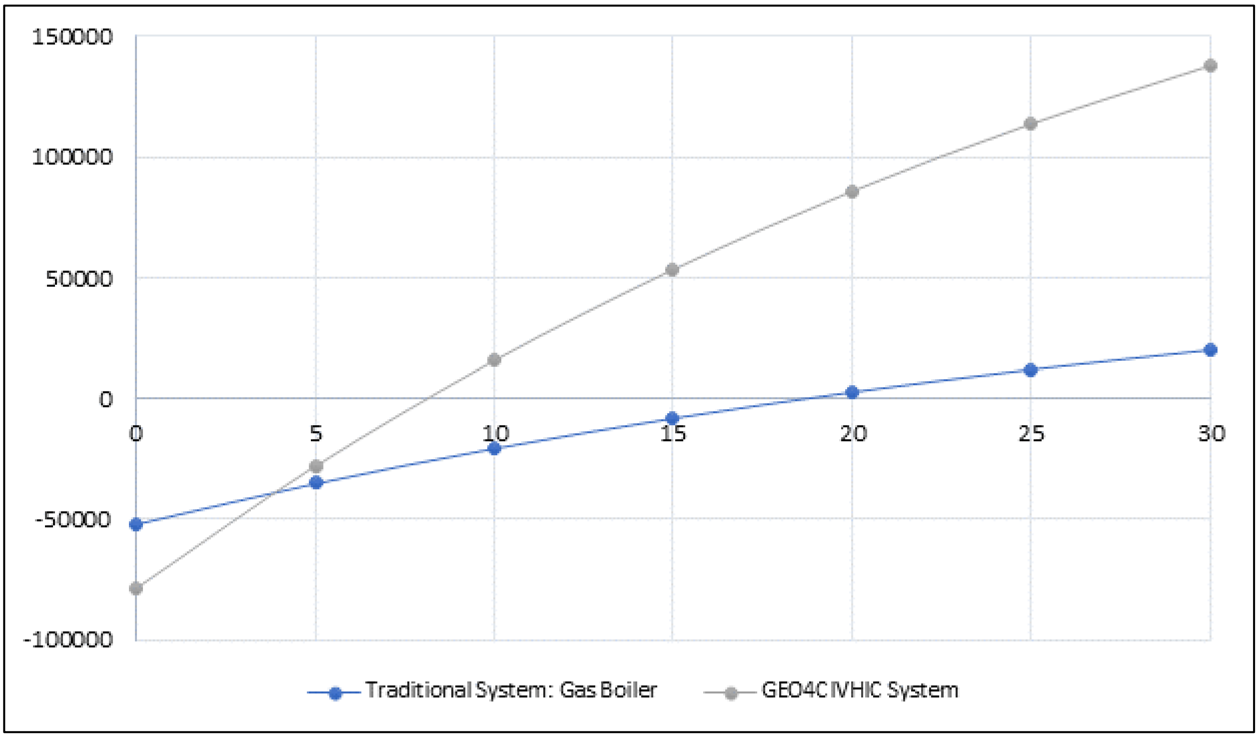


Figure 4.19 RDC2-FERR NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.31 – RDC2-FERR non-discounted annual savings for retrofit options

	Pre-retrofit	**Traditional System: Gas Boiler**	**GEO4CIVHIC System**
Total gas consumption of building (kwh/yr)	93916,67	72709,68	N/A
Price of gas €/kwh	0,16 €	0,16 €	N/A
Total electricity consumption of building (kwh/yr)	3202,50	2562,00	13894,48
Price of electricity €/kwh	0,39 €	0,39 €	0,39 €
Maintenance cost [€/Yr]	280,00 €	280,00 €	122,50 €
Energy savings (€/Yr)	N/A	3.669,96 €	10.942,76 €
Maintenance loss or savings (€/Yr)	N/A	- €	157,50 €
Total savings (€/Yr)	N/A	3.669,96 €	11.100,26 €

Payback and return on investment:

Table 4.32 – RDC2-FERR Simple payback periods and discounted ROI

	Traditional System: Boiler and fan-coil units	**GEO4CIVHIC System**
Calculated PP (Yr)	15	8
Discounted ROI (30 year)	35,88%	153,44%

— RDC3-MECH economic performance

30 year NPV results:

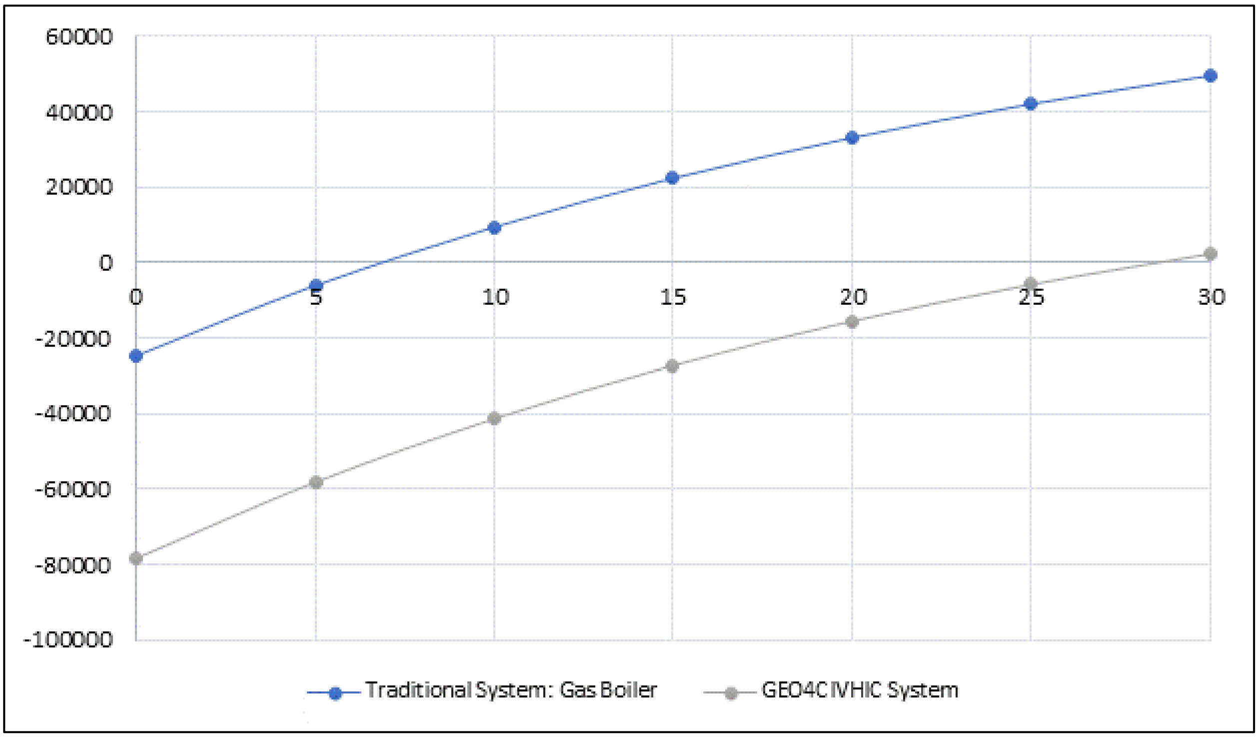


Figure 4.20 RDC3-MECH NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.33 – RDC3-MECH non-discounted annual savings for retrofit options

	Pre-retrofit	Traditional System: Gas Boiler	GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	43531,43	18244,09	N/A
Price of gas €/kwh	0,16 €	0,16 €	N/A
Total electricity consumption of building (kwh/yr)	0,00	0,00	6712,64
Price of electricity €/kwh	- €	0,39 €	0,39 €
Maintenance cost [€/Yr]	150,00 €	60,00 €	40,00 €
Energy savings (€/Yr)	N/A	4.076,32 €	4.382,56 €
Maintenance loss or savings (€/Yr)	N/A	90,00 €	110,00 €
Total savings (€/Yr)	N/A	4.166,32 €	4.492,56 €

Payback and return on investment:

Table 4.34 – RDC3-MECH Simple payback periods and discounted ROI

	Traditional System: Boiler and fan-coil units	GEO4CIVHIC System
Calculated PP (Yr)	7	18
Discounted ROI (30 year)	171,38%	2,62%

— RDC4-WICK economic performance

30 year NPV results:

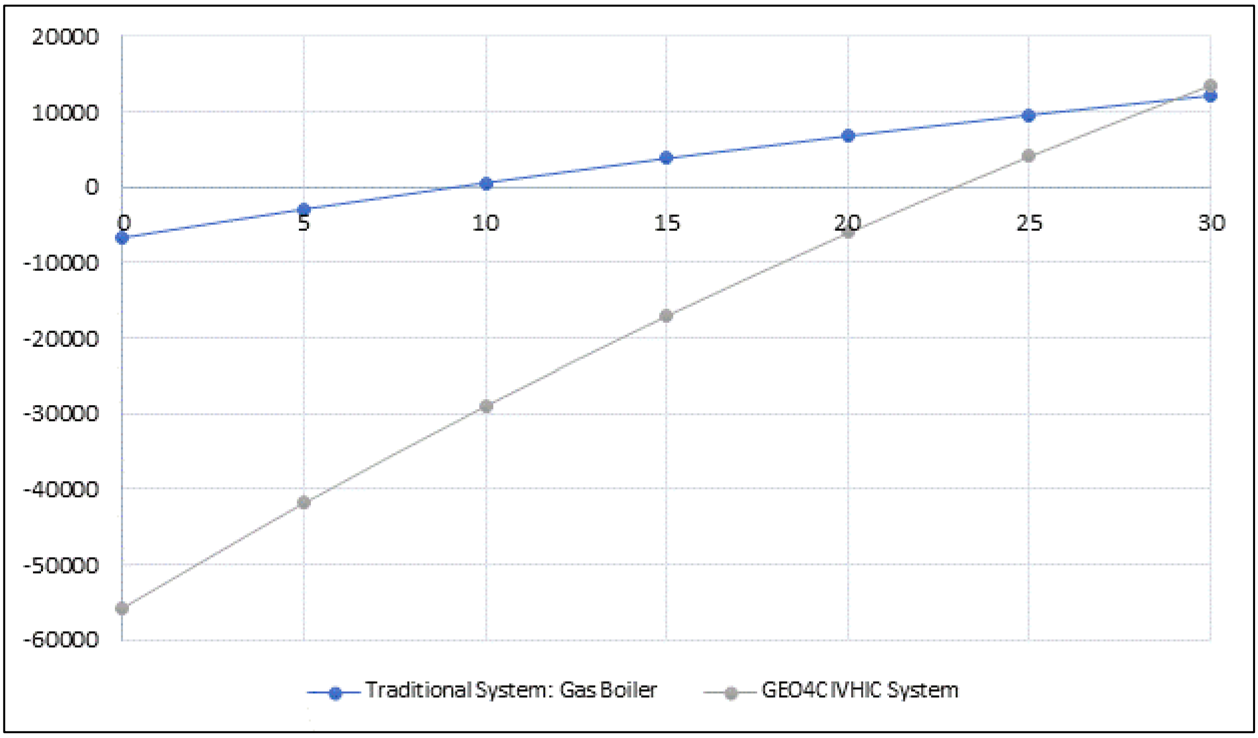


Figure 4.21 RDC4-WICK NPVs for retrofit options

The following projections and savings have been simulated or obtained in order to compute the above 30 year NPV.

Table 4.35 – RDC4-WICK non-discounted annual savings for retrofit options

	Pre-retrofit	Traditional System: Gas Boiler	GEO4CIVHIC System
Total gas consumption of building (kwh/yr)	22445,00	38838,71	N/A
Price of gas €/kwh	0,16 €	0,16 €	N/A
Total electricity consumption of building (kwh/yr)	6744,00	0,00	8059,00
Price of electricity €/kwh	0,50 €	- €	0,50 €
Maintenance cost [€/Yr]	189,00 €	180,00 €	150,00 €
Energy savings (€/Yr)	N/A	783,15 €	2.875,07 €
Maintenance loss or savings (€/Yr)	N/A	9,00 €	39,00 €
Total savings (€/Yr)	N/A	792,15 €	2.914,07 €

Payback and return on investment:

Table 4.36 – RDC4-WICK Simple payback periods and discounted ROI

	Traditional System: Boiler and fan-coil units	GEO4CIVHIC System
Calculated PP (Yr)	9	20
Discounted ROI (30 year)	160,57%	23,07%

4.1.3 Overview of building economic performance

The economic performance of buildings has become an increasingly significant focal point in the modern era, driven by a global emphasis on sustainability, energy efficiency, and cost optimization. In this context, the integration of innovative geothermal systems for heating and cooling has emerged as a transformative solution with the potential to reshape how buildings operate and economize their energy consumption. This section delves into the profound impact that such pioneering geothermal systems can exert on the economic dynamics of buildings, assessing their potential benefits and addressing the challenges that may influence their overall financial performance. By examining the intricate interplay between innovative geothermal technology, operational efficiency, initial investment, ongoing maintenance, and long-term savings, we navigate the intricate landscape that underpins the economic outcomes of integrating geothermal systems into building infrastructure. Through this exploration, we shed light on the multifaceted considerations that stakeholders must weigh as they strive to strike an optimal balance between environmental responsibility and financial viability in the realm of building management.

- **Civil building demo cases**

Figure 4.22 depicts three economic indicators (simple payback period, 30 years NPV and discounted ROI). These indicators show encouraging economic performance of the GEO4CIVHIC solution when compared to conventional GSHP implementations for the real demo case in Belgium (RDC3), for the virtual demo cases in Alexandroupolis, Greece (VDC1) and in the two others in Bucharest, Romania (VDC3 and VDC4).

The lower economic performance of the building subsequent to the installation of a GEO4CIVHIC system (Figure 4.23) can be attributed to a combination of factors that have influenced its operational and financial outcomes. These factors need to be considered in order to understand the challenges faced by the building's economic performance:

- **Initial Capital Investment:** Despite their energy efficiency, the payback period for geothermal systems can be longer than initially projected. Besides the costs of development and installation of the GEO4CIVHIC system correspond to a prototype configuration (TRL7). It means the costs considered in this analysis are not the industrialized ones. This extended period might delay the realization of financial benefits, affecting the building's economic performance.
- **Energy Price Volatility:** While geothermal systems are generally more energy-efficient, they are not immune to energy price fluctuations. If electricity prices rise significantly, the operating cost advantages of geothermal systems might be eroded, impacting the anticipated cost savings. Also, the high differentials between gas prices and electricity prices such as VDC10, VDC11 and VDC12 plays an important role on the lower economic performance of the system.
- **Enhanced Tenant Satisfaction and Retention:** A change in use habits pre and post retrofit has been observed in VDC11 and VDC12. It means the existing system did not cover any cooling demands. GEO4CIVHIC system increases the comfortability and consistent indoor temperatures. This improved comfort contributes to tenant satisfaction, potentially reducing tenant turnover and associated costs.

While the initial pilot conditions resulted in comparatively low economic efficiencies for all three systems, it is noteworthy that the GEO4CIVHIC system exhibits a superior performance when compared to alternative solutions, as illustrated in Figure 4.23.

However, it is crucial to acknowledge that the analysis conducted thus far does not encompass various factors that might hold significance when considering the implementation of the geothermal system developed as part of the GEO4CIVHIC project. These elements, although not quantified in the current evaluation, could substantially influence the decision-making process regarding the adoption of this innovative geothermal solution.

- **Increased Property Value:** Buildings equipped with energy-efficient geothermal systems often experience increased property values due to their appeal to environmentally conscious buyers and tenants. The long-term cost savings associated with these systems can enhance a building's overall attractiveness.
- **Future-Proofing:** As regulations and standards increasingly prioritize energy efficiency, buildings equipped with geothermal systems are better positioned to meet evolving requirements, avoiding costly retrofitting in the future.
- **Tax Incentives and Rebates:** Many jurisdictions offer tax incentives, rebates, or grants for the installation of energy-efficient systems like geothermal. These financial benefits can help offset the initial investment, making the technology more accessible and financially appealing (see section 4.1.4 and Table 4.37).

High economic performance

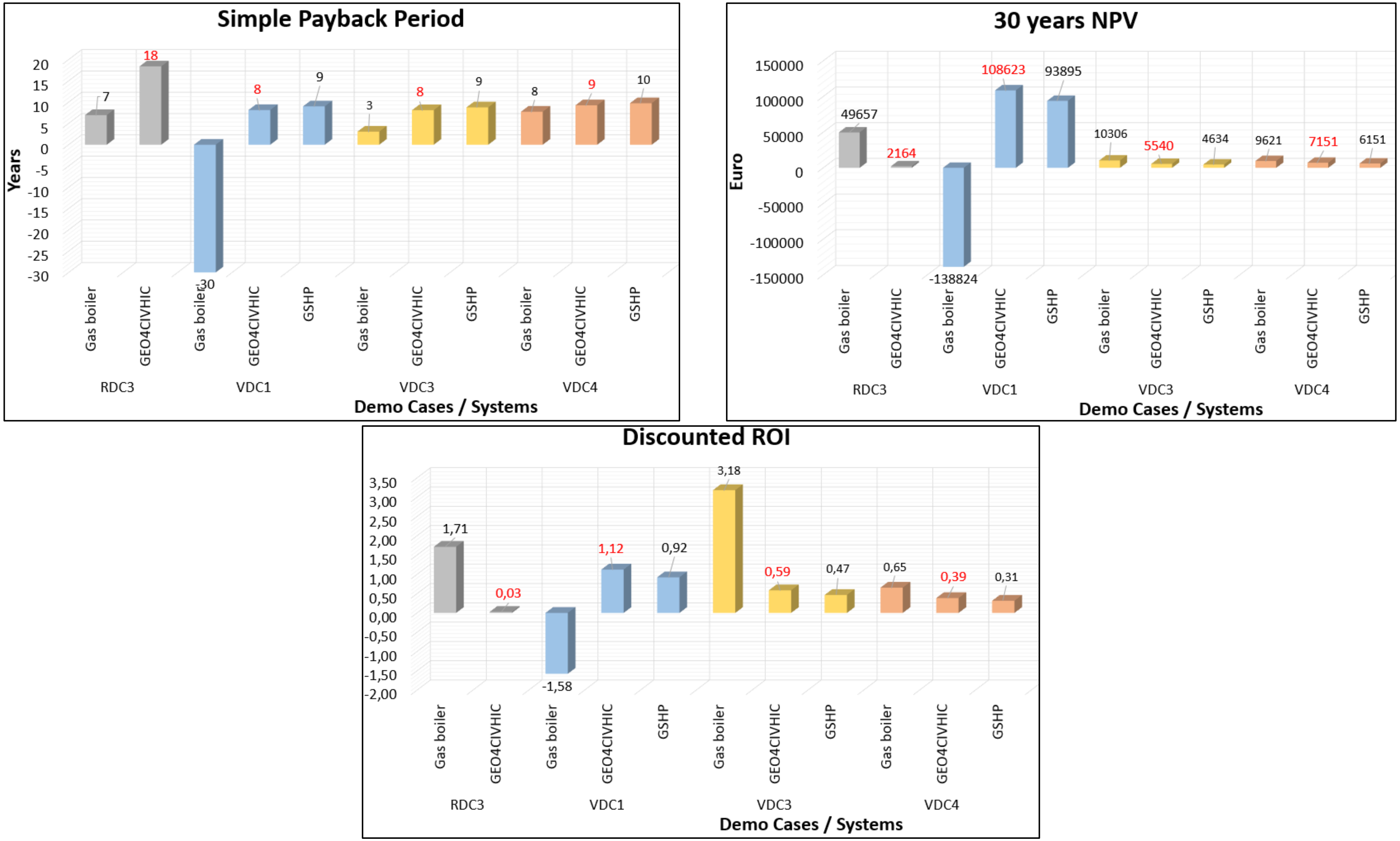


Figure 4.22 Civil building high performance

Low economic performance

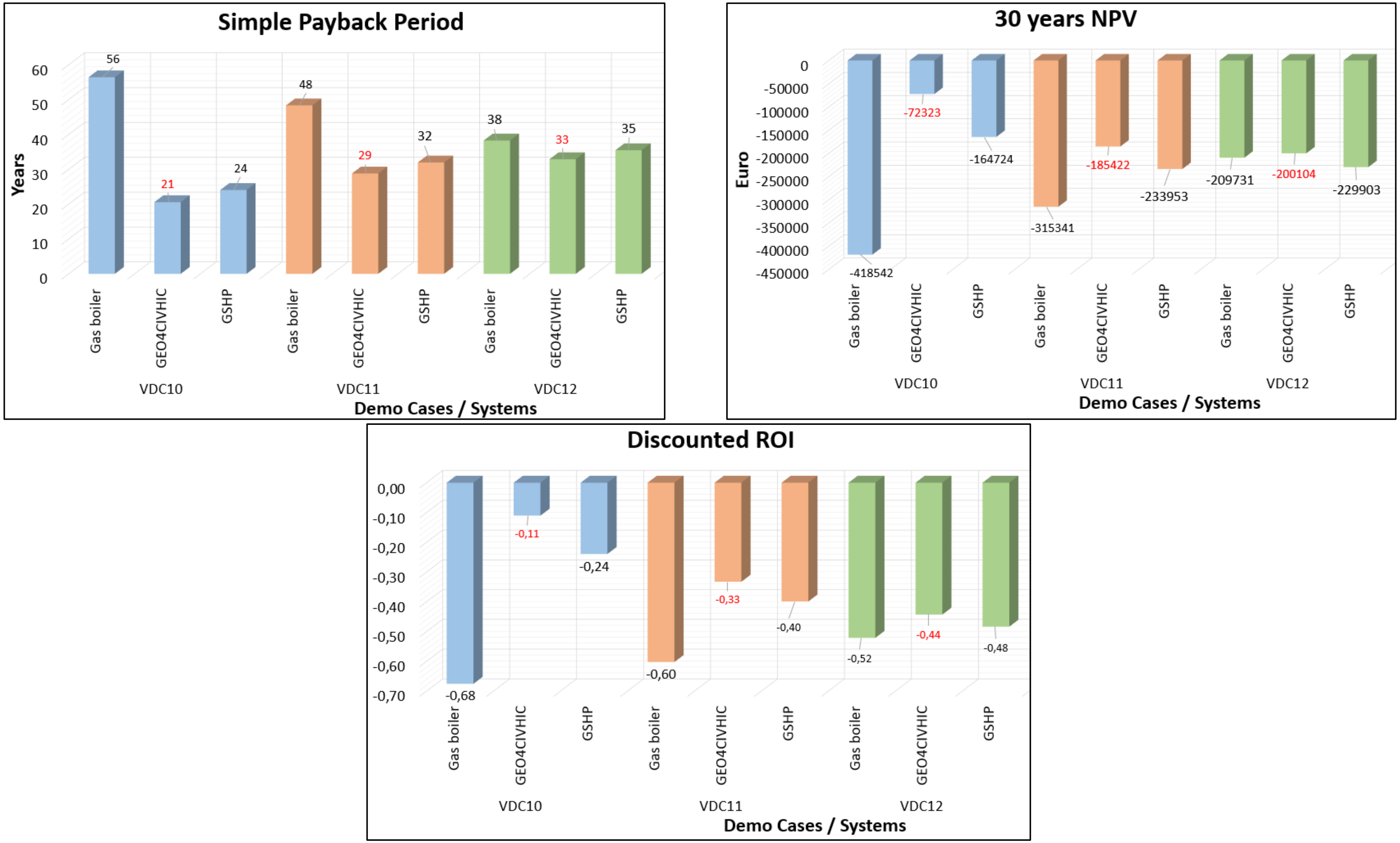


Figure 4.23 Civil building low performance

- **Historical building demo cases**

The introduction of a new geothermal system into historical buildings can often result in challenges that could lead to a lower economic performance. These challenges stem from the unique characteristics and preservation concerns of historical structures.

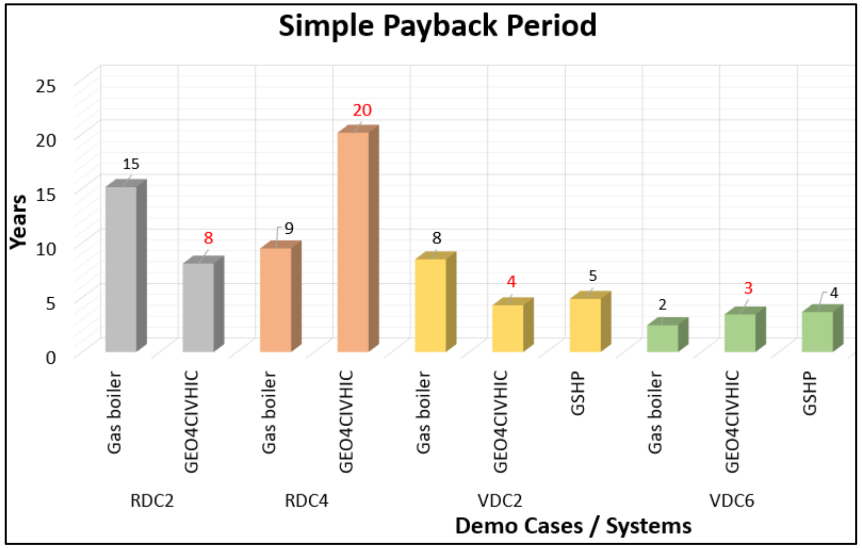
Figure 4.24 depicts three economic indicators (simple payback period, 30 years NPV and discounted ROI). These indicators have shown a high economic performance of the GEO4CIVHIC solution for the real demo case in Italy and Ireland (RDC2 and RDC4), for the virtual demo cases in Valencia, Spain (VDC2) and in the Spit, Croatia, (VDC6).

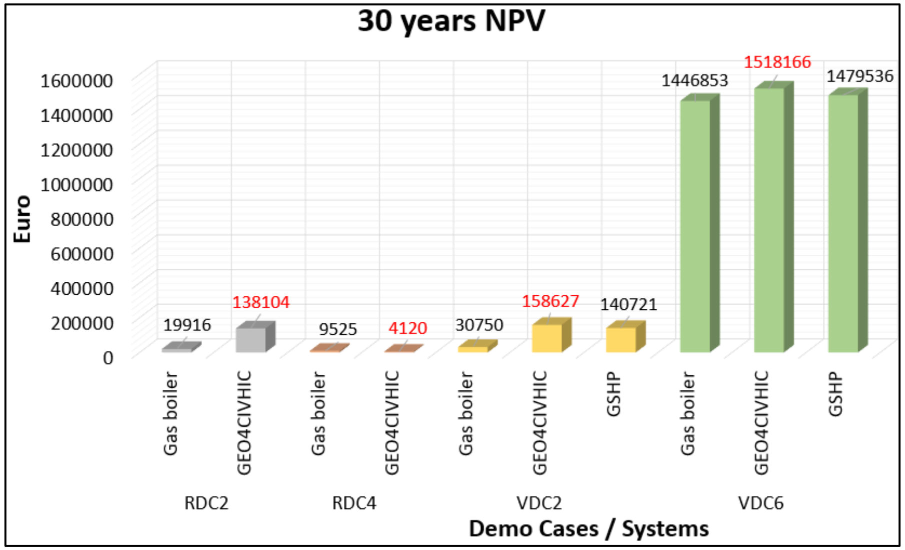
The lower economic performance of the building subsequent to the installation of a GEO4CIVHIC system (Figure 4.25) can be attributed to a combination of factors (additionally to those identified for civil buildings in the section above pp.47) that have influenced its operational and financial outcomes. Understanding these factors is essential to justifying the potential impact on economic performance:

- **Preservation Requirements**: Historical buildings are subject to strict preservation regulations to maintain their authenticity and cultural value. The installation of a new geothermal system may conflict with these regulations, requiring careful planning and approvals as such in the case of RDC1. This compliance with preservation guidelines added complexity and costs to the project.
- **Higher Installation Costs:** Tailoring a geothermal system to the specific requirements of a historic building can lead to higher installation costs, as realised for the virtual cases in Italy (VDC5), Germany (VDC7), Belgium (VDC8) and Ireland (VDC9). The need for customisation and specialised expertise has strained budgets and reduced economic benefits.
- **Complex Approval Processes:** Obtaining the necessary approvals and permits for installing a geothermal system in a historical building can be time-consuming and bureaucratic such as been realized for the real demo cases in Malta (RDC1) as well as in Italy (RDC2) and Ireland (RDC4). Delays in approval processes have impacted project timelines and escalate costs.

In addition of the factors above the lower economic performance has also been affected by the **high differentials between gas prices and electricity prices** such as Italy (VDC5), Belgium (VDC8) and notably in Germany (VDC7) and Ireland (VDC9) as is depicted in Figure 4.1. The Figure 4.25 shows that these differentials play an important role on the lower economic performance of the system.

High economic performance





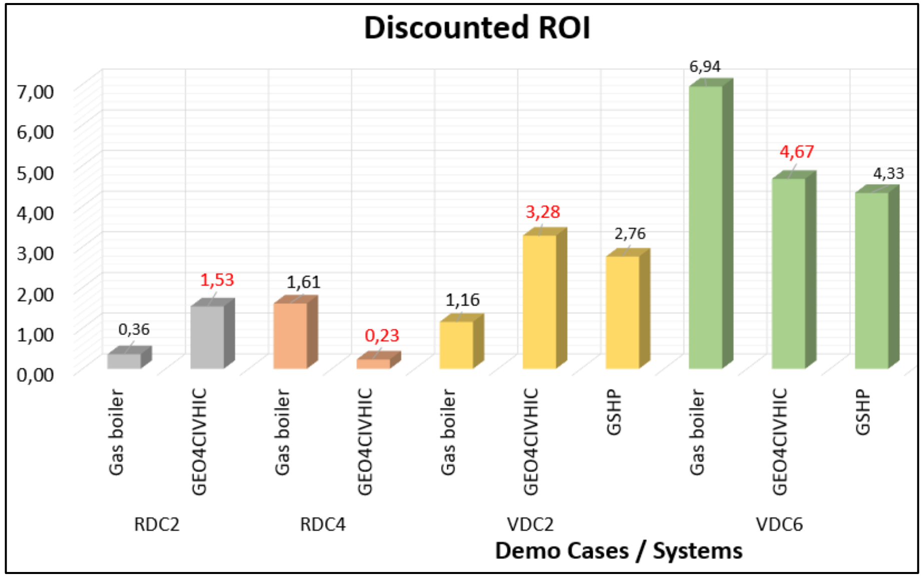


Figure 4.24 Historical building high performance

Low economic performance

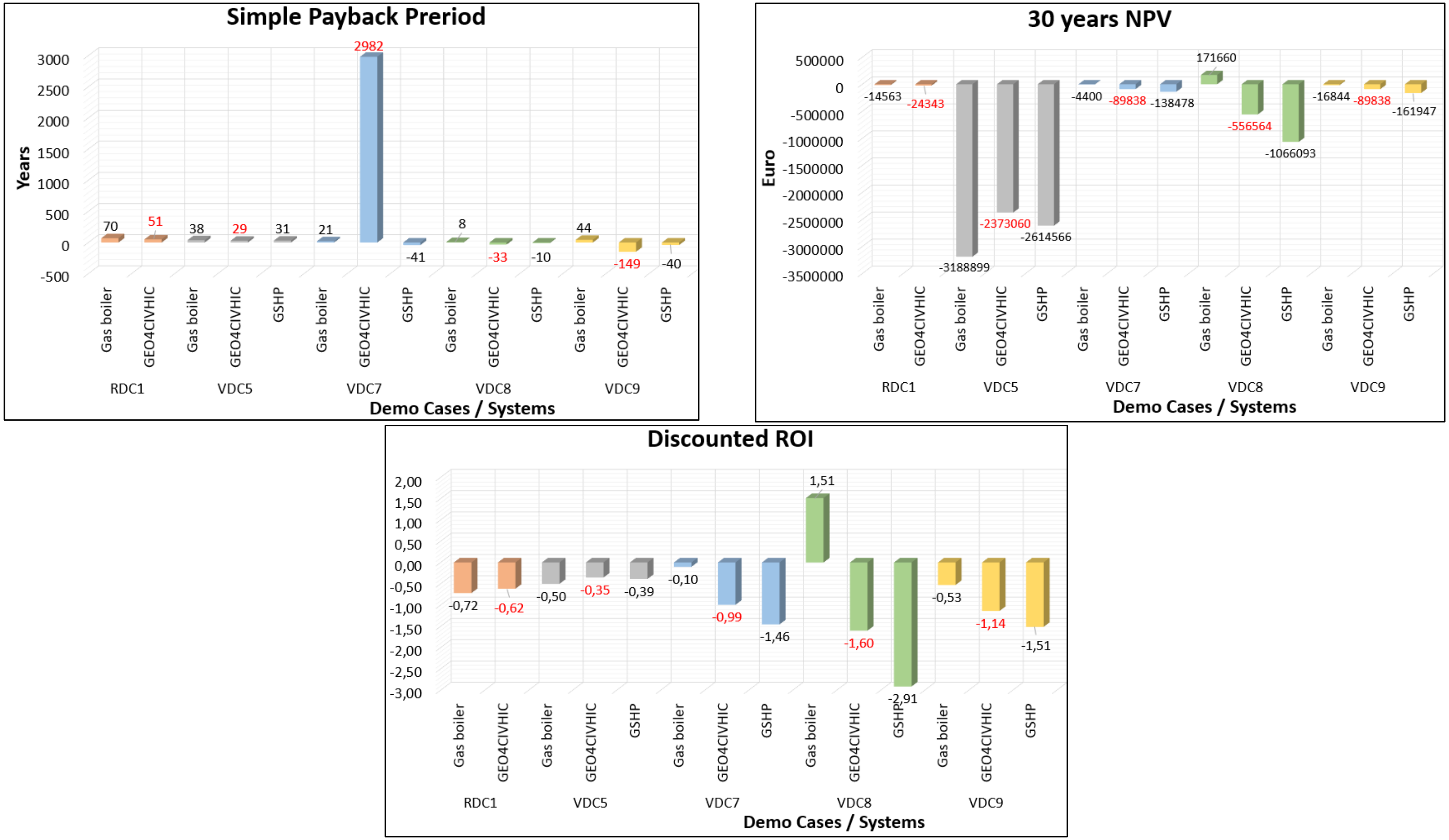


Figure 4.25 Historical building low performance

4.1.4 Subsidies for residential heat pump – details per country

Because the costs of investing in low-carbon heating and cooling systems, like heat pumps, are still higher compared to traditional fossil fuel-based heating devices, there remains a need for financial support programs to eliminate investment barriers. These financial incentives encompass options such as offering low-interest loans, implementing grant initiatives, and providing tax rebates. These measures often vary for households with lower and higher incomes. Concurrently, the REPowerEU plan of the European Union, which strives to eliminate fossil gas usage, mandates that Member States cease promoting fossil fuel boilers. Instead, they should redirect these subsidies towards bolstering heat pump adoption.

The following Table 4.37 presents an outline of diverse heat pump subsidy arrangements within EU Member States (where the demo cases have been deployed) as of early 2023.

Table 4.37 – Subsidies for residential heat pumps details segmented per country

Name of subsidy		Type of subsidy	Single family house	Type of heat pump & grant (€)	Extra info on subsidy	Are other measures or schemes in place that indirectly support heat pump deployment?	Dates of subsidy
Belgium	Flanders: Mijn Verbouw Premie [1]	Grants	Renovation	ATA - € 300-480 ATW - €3000-4800 **GSHP - €4000-6400** HHP - €2000-3200 SHW - €300-540	N/A	VAT reduced to 6% (from standard 21%) for heat pumps. In Belgium. In Wallonia, the Primes Habitation scheme covers up to 70% of the installation costs for a heat pump. A one-earner-couple with two children could take less than 4 years to recover the installation costs. — Energy efficiency subsidy scheme — Building codes and standards	From 1 October 2022
	Brussels: RENOLUTION Bonuses [2]	Grants	Renovation	ATW - €4250-4750 **GSHP - €4250-4750** SHW - €400-1600	Depends on income categories		Since 1 January 2022
	Wallonia: Prime temporaire – Appareil de chauffage et d'eau chaude sanitaire [3]	Grants	Renovation	ATW - €1000-6000 SHW - €500-3000	Depending on household income and max. 70% of the bill		From 1 June 2022
Croatia	Public call for the use of renewable energy systems in family buildings [4]	Grants	Renovation	ATW, SHW and **GSHP – Max of €4250 up to 40% subsidised.**	In less developed regions, subsidy is increased up to 60% (max. €6,375) or up to 80% (max. €8,500).	— Energy efficiency subsidy scheme — Building codes and standards	Given periodically (1-2 times a rear)
Germany	Die bisherige Förderung des Bundesamtes für Wirtschaft und Ausfuhrkontrolle (BAFA) [5]	Grants	Renovation	ATA - €15000 ATW - €15000 **GSHP - €18000**	Up to 25% for heat pump. 5% bonus for GHSP. 10% for replacement of fossil fuel boiler.	— Energy efficiency subsidy scheme — Carbon price — Existing ban on fossil fuel heating	From 2023 to 2030

[1] https://www.vlaanderen.be/bouwen-wonen-en-energie/bouwen-en-verbouwen/premies-en-belastingvoordelen/mijn-verbouwpremie/mijn-verbouwpremie-voor-warmtepomp
[2] https://environnement.brussels/citoyen/services-et-demandes/primes-et-aides-financieres/les-primes-renolution
[3] https://energie.wallonie.be/fr/primes-temporaires-appareil-de-chauffage-et-d-eau-chaude-sanitaire-jusqu-au-30-juin-2023.html?IDC=10306
[4] https://www.fzoeu.hr/hr/nacionalni-javni-pozivi-i-natjecaji/1367
[5] https://www.waermepumpe.de/waermepumpe/foerderung/

Name of subsidy		Type of subsidy	Single family house	Type of heat pump & grant (€)	Extra info on subsidy	Are other measures or schemes in place that indirectly support heat pump deployment?	Dates of subsidy
Ireland	Heat Pump system grant [6]	Grant	Renovation	ATA - €3500 (all house type) ATW and **GSHP** - **€4500** (Apartment) **€6500** (all other house types)	Under building regulations for new buildings, 20% of energy must come from renewable sources.in practical terms this has made heat pumps the default choice – heat pumps now feature in 80 to 90% of new homes, for instance.	— Building codes and standards — Carbon price	Current grant scheme for retrofitting heat in place since 2021
Italy	Fiscal bonus scheme [7]	Tax deductions	Renovation	ATA - ATW - **GSHP -** HHP – SHW -	**Bonus Casa:** 50% covered by tax breaks (A). **Ecobonus:** from 50% to 85% covered by tax breaks (B). **Superbonus:** 110% conditional to several primary renovation measures (B).	— Energy efficiency subsidy scheme (B) — Building codes and standards (A)	Last until: Superbonus:2025. Ecobonus: 2024. Bonus casa: 2024
Spain	Direct Subsidies for HPs (amounts in column 6) Real Decreto 477/2021 Real Decreto 1124/2021 Orden TED/707/2022 Other Schemes (Energy reduction program, etc., (amounts not specified in this document)	Grants	New Building	ATW – residential, up to €3000 **GSHP – Residential €13500. New DH (100% HP), €2,070/kW and up to 70% of the investment for Energy communities (nonprofit).** SHW – same as ATW	Must comply with the Do No Significant Harm, always.	— Energy efficiency subsidy scheme — Building codes and standards — Other scheme tax reduction	Not specified

[6] https://www.seai.ie/grants/home-energy-grants/heat-pump-systems/
[7] https://www.enea.it/it/cittadini/superbonus-sito-enea-detrazioni-fiscali

	Name of subsidy	Type of subsidy	Single family house	Type of heat pump & grant (€)	Extra info on subsidy	Are other measures or schemes in place that indirectly support heat pump deployment?	Dates of subsidy
	Real Decreto 853/2021 Real Decreto 691/2021 & 692/2021 Income tax retrofit Ley 10/2022, de 14 de Junio [8]		Renovation	ATW – for DH (100% HPs) €570/kW instead **GSHP – DH (100% HP), €1620/kW instead of €2070/kW** SHW – same as new building			
Switzerland	MyClimate and subsidies per Canton VAUD	Grants	New Building And Renovation	ATW – If replacing a gas/oil boiler: Power < 20kW: €5,076. Power > 20kW: 250/kW. If replacing an electric heater: Power< 20kW: €7,615. Power> 20kW: 375/kW **GSHP - for replacing a gas/oil boiler**: Power < **20kW: €15,229**. Power> 20kW: €3,045 + 600/kW. **If replacing an electric heater**: Power<20kW: **€22,335**. Power> 20kW €4,061 + 900/kW.		— Energy efficiency subsidy scheme — Building codes and standards — Carbon price — Existing ban on fossil fuel heating — Other scheme	Not specified
	MyClimate and subsidies per Canton GENEVA	Grants	New Building And Renovation	ATW - 3,043 + €405/ kW (Power ≤ 50kW individual housing). €13,187+ €202 >50kW or collective. + Bonus for the first instal of a heat distribution system: €3,042 + €405/kW.		— Energy efficiency subsidy scheme — Building codes and standards — Carbon price — Existing ban on fossil fuel heating — Other scheme	Not specified

[8] https://www.idae.es/ayudas-y-financiacion

	Name of subsidy	Type of subsidy	Single family house	Type of heat pump & grant (€)	Extra info on subsidy	Are other measures or schemes in place that indirectly support heat pump deployment?	Dates of subsidy
				GSHP - €3,042.60+ €811.15/kW (≤50kW or single-family house). €23,329 + €405/kW (>50kW for collective housing). + Bonus (first instal of a heat distribution system): €3,042 + €405/kW.			
	MyClimate and subsidies per Canton FRIBOURG	Grants	New Building and Renovation	ATW - For heat production: Heating: €3,545.03. For heat distribution or heating circuit: First instal of heat distribution: €8,104.51. €5,065.90 per apartment. **GSHP** - For heat production: Heating: up to 100 kWth: €5,065 + €300/ kWth. From 100 to 250 kWth : €27,000. From 250 to 500 kWth: €2,431. From 500 kWth: €42,957. Hot water: €1,013. For heat distribution: First heat distribution instal: €8,104 + 500/kW. €5,066- per apartment.		— Energy efficiency subsidy scheme — Building codes and standards — Carbon price — Existing ban on fossil fuel heating — Other scheme	Not specified

4.2 Threshold pricing analysis for GEO4CIVHIC applications in demo-sites

The following section will explore important market considerations and expectations of future buyers which can be used as inputs for evaluating the future pricing strategy of GEO4CIVHIC systems and solutions.

4.2.1 Threshold price function for the GEO4CIVHIC solution in demo sites

In order to do this, we will observe payback periods for conventional competing systems and solutions in all virtual and real demo sites, and determine the maximum CAPEX or initial investment for the GEO4CIVHIC solution implementation that would yield similar paybacks and return on investment in order to be competitive with conventional solutions and provide equivalent utility to final end users and building owners. As stated previously, the current initial investments having been used reflect basic manufacturing and estimated implementation costs of the project and are not commercial prices. We will only be providing this preliminary analysis for the cost competitive cases we have identified previously and listed below:

Civil buildings:

- RDC3-MECH: Residential building in Battel, Belgium
- VDC1-ALEX: Museum of natural history in Alexandroupolis, Greece
- VDC3-AVAN: Residential building Avangarde Forest, Romania
- VDC4-BUCH: Residential building in Bucharest, Romania

Historical buildings:

- RDC2-FERR: Angel's gate, historical building in Ferrara, Italy
- RDC4-WICK: Historical residential building in Wicklow, Ireland
- VDC2-VALE: Palacete de la Cruz Roja en Valencia, Spain
- VDC6-SPLI: Historical building, Museum of Croatia Arch. Monuments in Split, Croatia

An analysis from the point of view of end users (whether it be public or private) implementing the solution whereby a "reservation price", known in economic theory as the maximum amount they are ready to pay for a set of goods and services (On the demand side, it is the highest price that a buyer is willing to pay; on the supply side, it is the lowest price a seller is willing to accept for a good or service), will be established conditioned by the derived expected utility that should accompany such an investment which in turn is defined in our analysis in terms of threshold payback periods and return on investment to which the prior competitive analysis should provide insights.

As observed in the graphs above for the cost competitive cases, payback periods of 2-15 years are observed for alternate commercial offerings. Of course, these payback periods are conditioned by different building typologies and uses as well as energy prices being applied. Therefore, conclusions on threshold prices for GEO4CIVHIC solutions are case specific. Partners are in charge of their own pricing strategy and most KERs are integrated within existing business activities with different exploitation approaches. In this way, this short study will give an indicative measure of the total threshold implementation costs for GEO4CIVHIC systems to be competitive within the market and this can then be leveraged by the partners with the aforementioned competitive assessments in order to optimize their pricing policies.

As mentioned earlier, the focus of this study is set on the demo case nations of Italy, Greece, Romania, Germany, Belgium, Croatia, Ireland, Switzerland, Netherlands, Malta and Spain, representing different electricity prices.

By using all of the previously collected information in our solutions assessments, we are able to compute the threshold costs for implementing systems according to different targeted payback periods using the simple payback period equation.

$$Payback\ period = \frac{Initial\ Investment}{€\ Savings}$$

Our dependent variable becomes initial investment or what is paid by end users for technologies and installation (Y) and our independent variables become savings obtained in the pilot and payback periods targeted by the project. Therefore, we can derive the following equation.

$$€\ Savings * PP = Y$$

With:

$€savings$= Obtained yearly savings in pilot as calculated in previous sections characterizing the economic performance of solutions in different demo sites.

PP= targeted payback period

Y = Reservation price

Moreover, the same type of assessment can be performed using target 30-year discounted ROIs. The interest in performing such an assessment is that payback periods for certain investments may be shorter but may not offer the same level of returns over the same period.

The following discounted ROI equation is used:

$$discounted\ ROI = \frac{\sum_{t=1}^{n} \frac{\Delta E_t}{(1+r)^t} - Initial\ Investment}{Initial\ Investment}$$

Which then becomes the following when Initial investment is set as the dependent variable:

$$Initial\ Investment = \frac{\sum_{t=1}^{n} \frac{\Delta E_t}{(1+r)^t}}{discounted\ ROI + 1}$$

$$\Delta E_t = yearly\ cash\ flows$$
$$r = discount\ rate\ (opportunity\ cost)$$

4.2.2 Contextualizing threshold and competitor pricing analysis for GEO4CIVHIC

The following section provides an overview of computed results for the selected demonstration cases at payback levels of 5, 10 and 15 years as well as discounted 30 year ROIs of 20%, 30% and 35% reflecting industry and competitor levels. Please keep in mind, the GEO4CIVHIC system is mainly to be benchmarked to the GSHP simulations. This final analysis which takes the outputs of the past sections to contextualize them in terms of possible pricing policies given upper limits imposed by reservation price and competitor pricing as well as lower limits imposed by basic consolidated manufacturing and implementation costs for the whole system found during the project is offered below. As a conclusion to the results, cases VDC1,3,4,2 and 6 and RDC2 already present reservation threshold prices that seem to offer promising perspectives for margins. Unsurprisingly, these pilots correspond to some of the regions with smaller gaps between gas and electricity prices. Moreover, given CAPEX prices used in the prior cost effectiveness analysis do not reflect commercial or industrialized costs or prices but rather developments costs of the solutions, these results would automatically improve upon increasing to TRL 9 and full fledge commercial implementations and costs.

— **Civil demonstration cases:**

i. RDC3-MECH

The following table presents original modelling results from prior sections.

Table 4.38 – RDC3-MECH original payback and ROI

	Traditional System: Gas Boiler	Conventional GSHP System	GEO4CIVHIC System
Calculated PP (Yr)	7,0	n/a	18,4
Discounted ROI (30 year)	171%	n/a	3%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

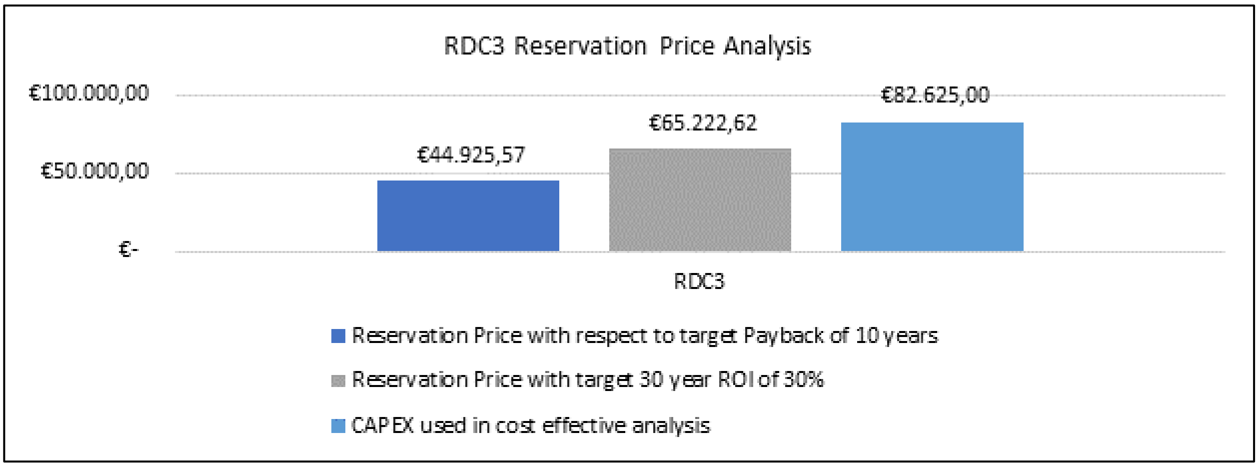


Figure 4.26 RCD3-MECH Reservation price analysis

Table 4.39 – RDC3-MECH Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	4.492,56 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	22.462,78 €	44.925,57 €	67.388,35 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	70.657,84 €	65.222,62 €	62.806,97 €
CAPEX used in cost effective analysis	82.625,00 €		

ii. VDC1-ALEX

The following table presents original modelling results from prior sections.

Table 4.40 – VDC1-ALEX original payback and ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	n/a	9,0	8,1
Discounted ROI (30 years)	n/a	92%	112%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

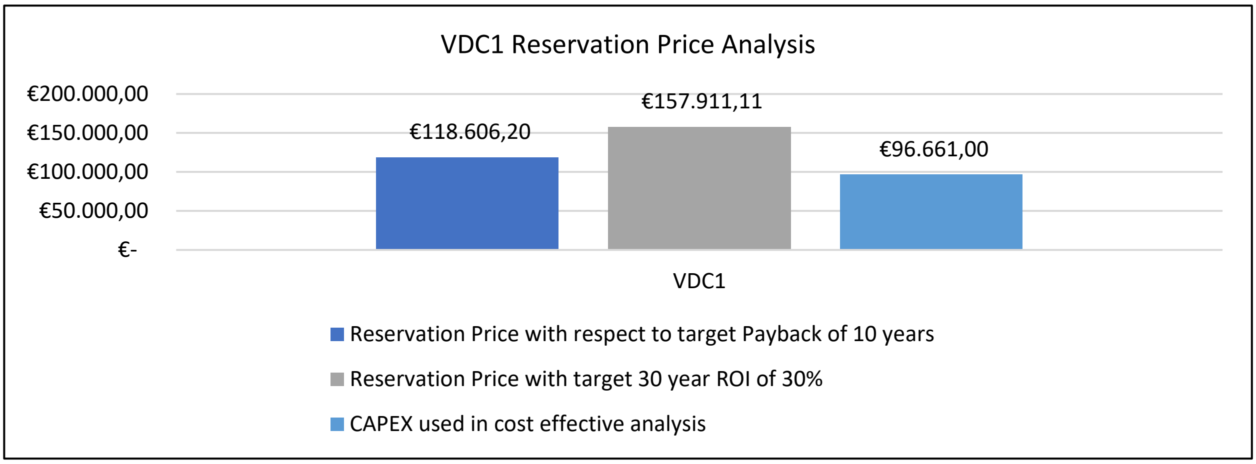


Figure 4.27 VDC1-ALEX Reservation price analysis

Table 4.41 – VDC1-ALEX Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	11.860,62 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	59.303,10 €	118.606,20 €	177.909,30 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	171.070,37 €	157.911,11 €	152.062,55 €
CAPEX used in cost effective analysis	96.661,00 €		

iii. VDC3-AVAN

The following table presents original modelling results from prior sections.

Table 4.42 – VDC3-AVAN original payback and ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	3,1	8,8	8,1
Discounted ROI (30 years)	318%	47%	59%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

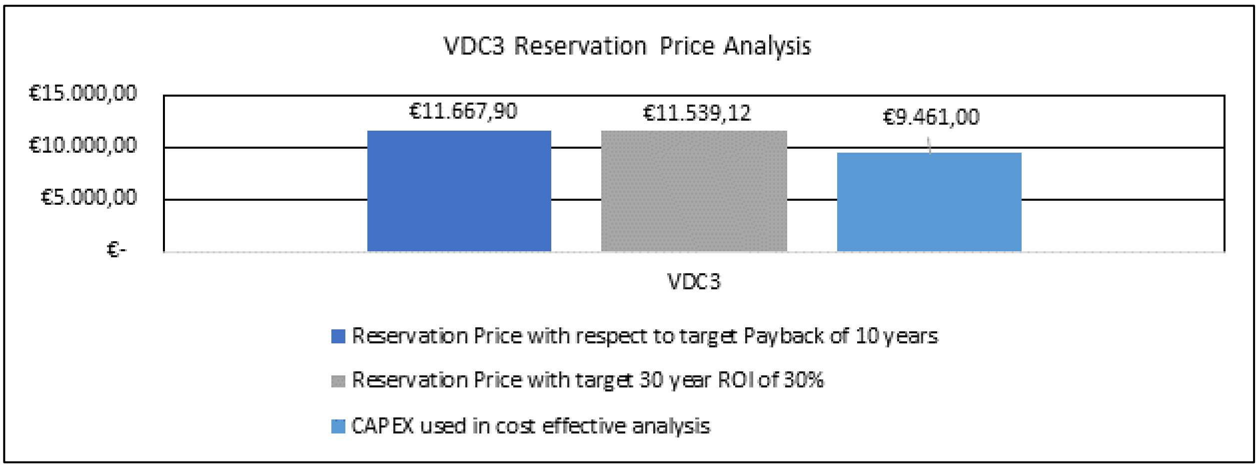


Figure 4.28 VCD3-AVAN Reservation price analysis

Table 4.43 – VDC3-AVAN Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	1.166,79 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	5.833,95 €	11.667,90 €	17.501,85 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	12.500,72 €	11.539,12 €	11.111,75 €
CAPEX used in cost effective analysis	9.461,00 €		

iv. VDC4- BUCH

The following table presents original modelling results from prior sections.

Table 4.44 – VDC4- BUCH original payback and ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	7,7	9,8	9,3
Discounted ROI (30 years)	65%	31%	39%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

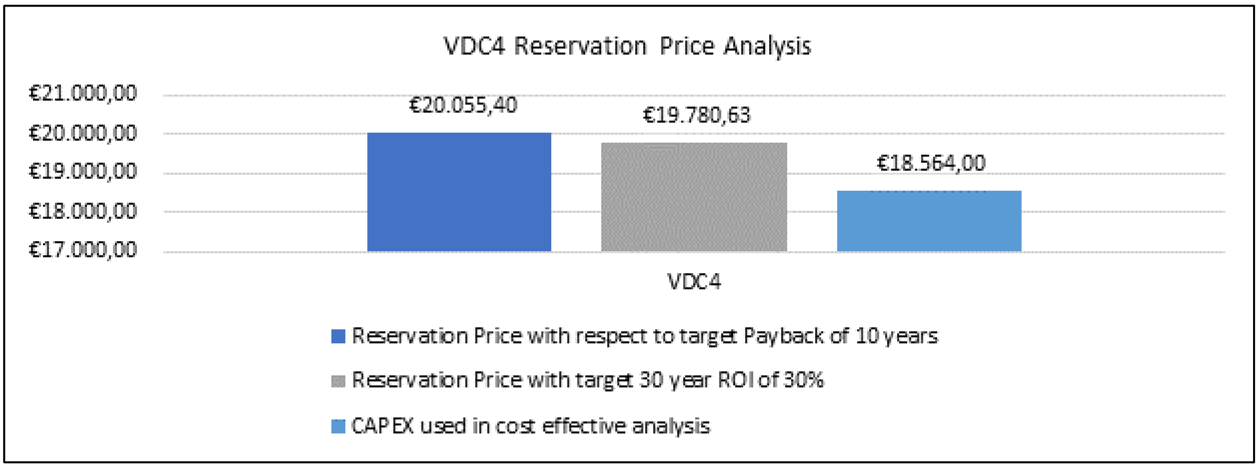


Figure 4.29 VDC4- BUCH Reservation price analysis

Table 4.45 – VDC4-BUCH Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	2.005,54 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	10.027,70 €	20.055,40 €	30.083,10 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	21.429,02 €	19.780,63 €	19.048,02 €
CAPEX used in cost effective analysis	18.564,00 €		

— **Historical demonstration cases:**

i. RDC2-FERR

The following table presents original modelling results from prior sections.

Table 4.46 – RDC2- FERR original payback and ROI

	Traditional System: Gas Boiler	Conventional GSHP System	GEO4CIVHIC System
Calculated PP (Yr)	15,1	n/a	8,1
Discounted ROI (30 years)	36%	n/a	153%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

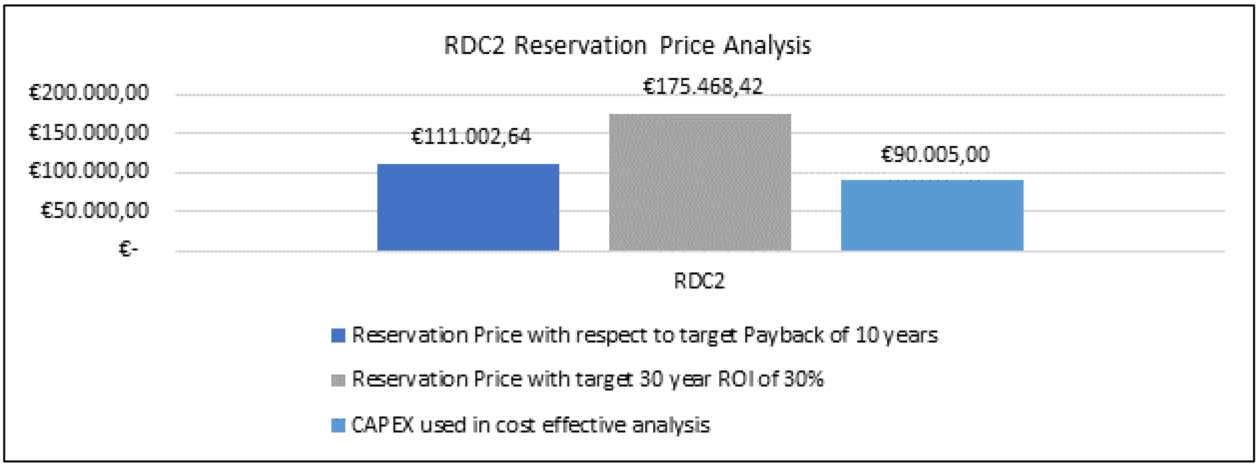


Figure 4.30 RDC2- FERR Reservation price analysis

Table 4.47 – RDC2-FERR Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	11.100,26 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	55.501,32 €	111.002,64 €	166.503,96 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	190.090,79 €	175.468,42 €	168.969,59 €
CAPEX used in cost effective analysis	90.005,00 €		

ii. RDC4-WICK

The following table presents original modelling results from prior sections.

Table 4.48 – RDC4- WICK original payback and ROI

	Traditional System: Gas Boiler	Conventional GSHP System	GEO4CIVHIC System
Calculated PP (Yr)	9,5	n/a	20,1
Discounted ROI (30 years)	161%	n/a	23%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

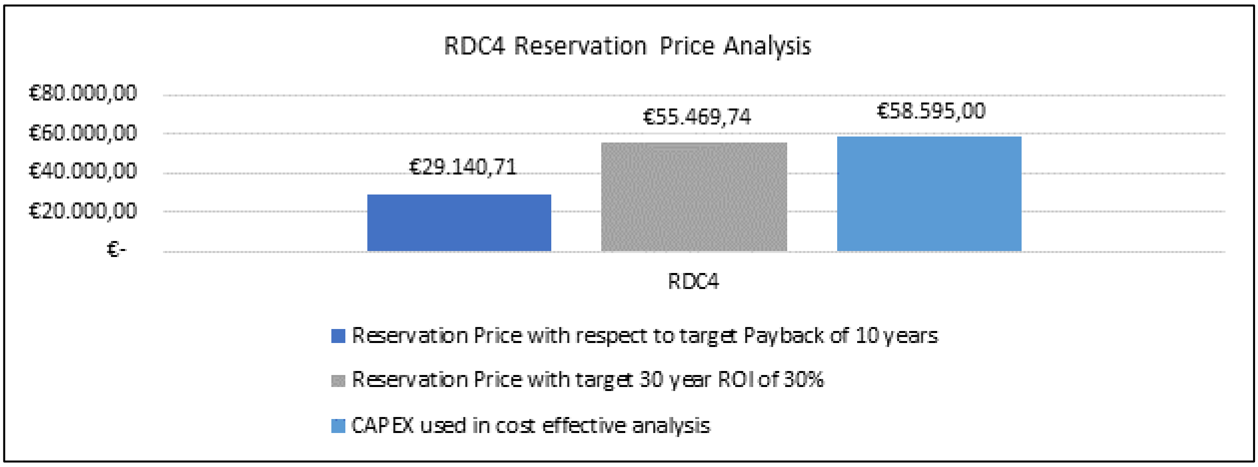


Figure 4.31 RDC4- WICK Reservation price analysis

Table 4.49 – RDC4-WICK Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	2.914,07 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	14.570,36 €	29.140,71 €	43.711,07 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	60.092,22 €	55.469,74 €	53.415,30 €
CAPEX used in cost effective analysis	58.595,00 €		

iii. VDC2-VALE

The following table presents original modelling results from prior sections.

Table 4.50 – VDC2- VALE original payback and ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	8,5	4,9	4,3
Discounted ROI (30 years)	116%	276%	328%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

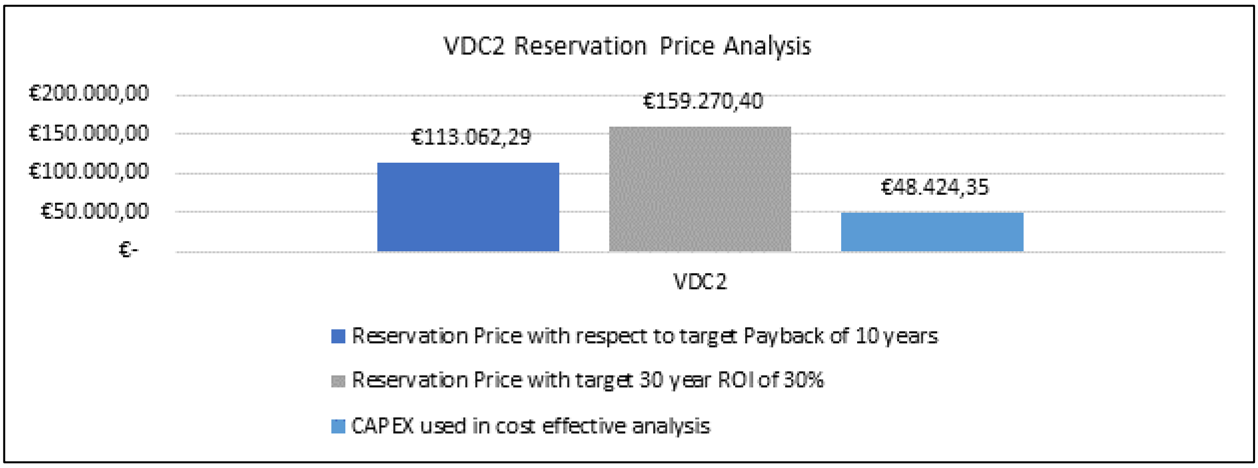


Figure 4.32 VDC2- VALE Reservation price analysis

Table 4.51 – VDC2-VALE Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	11.306,23 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	56.531,15 €	113.062,29 €	169.593,44 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	172.542,94 €	159.270,40 €	153.371,50 €
CAPEX used in cost effective analysis	48.424,35 €		

iv. VDC6-SPLI

The following table presents original modelling results from prior sections.

Table 4.52 – VDC6- SPLI original payback and ROI

	RENOV-1: Traditional System: Boiler and fan-coil units	RENOV-2: Conventional GSHP System	RENOV-3: GEO4CIVHIC System
Calculated PP (Yr)	2,458710012	3,666522212	3,442499709
Discounted ROI (30 years)	694%	433%	467%

The following table presents the reservation price analysis at the stipulated Payback and ROI levels.

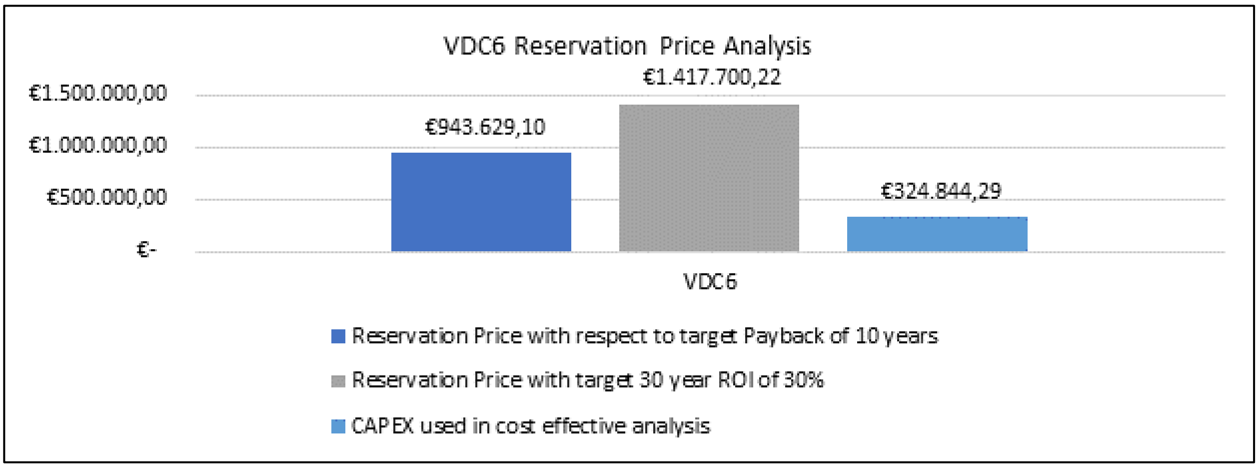


Figure 4.33 VDC6- SPLI Reservation price analysis

Table 4.53 – VDC6-SPLI Reservation price analysis

Total annual cashflow savings GEO4CIVHIC system	94.362,91 €		
Target PP (yr) for GEO4CIVHIC System	5	10	15
Reservation Price with respect to target PP	471.814,55 €	943.629,10 €	1.415.443,65 €
Target Discounted ROI (30 years)	20%	30%	35%
Reservation Price with respect to target ROI	1.535.841,91 €	1.417.700,22 €	1.365.192,81 €
CAPEX used in cost effective analysis	324.844,29 €		

5 Conclusions

Predictably, some of the driving factors towards higher economic performance of the GEO4CIVHIC solutions are low electricity prices and high gas prices, areas with high heating and cooling demand and the scale of the building where it is being implemented.

The solutions, despite higher initial investment costs offer substantially improved economic KPIs than traditional retrofits such as gas boilers in terms of discounted ROIs and NPVs. Of course, these results would see substantial improvement if further inflation on gas prices, either driven by the general economic environment or by policy measures, takes place.

An analysis from the point of view of end users implementing the solution and a “reservation price” has been stablished conditioned by the derived expected utility that should accompany such an investment which in turn is defined in our analysis in terms of threshold payback periods and return on investment to which the prior competitive analysis has provided insights. As observed in that analysis payback periods of 2-15 years are observed for alternate commercial offerings. Of course, these payback periods are conditioned by different building typologies and uses as well as energy prices being applied.

Moreover, it is important to take into consideration that in line with the EPBD, it is likely that incentives are put in place or already exist for the implementation of such systems when performing a thermal system retrofit which have not been taken into consideration.

6 References

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