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Performance of the main technologies demonstrated in the ENVISION project

Paolo Finocchi[1], *Diego* Rattazzi[1], *Fabrizio* Tavaroli[1], *Giorgia* Spigliantini[1]

[1]RINA Consulting S.p.A., via Cecchi 6, Genova (Italy)

Abstract. Within the context of ENVISION project, different technologies have been developed aiming to harvest energy being integrated into the building façade. These technologies have been tested in different demosites with a monitoring phase of around one year in order to assess their performances on-field. The technologies developed within ENVISION and reported in this article are solar façade collectors coupled with Heat Pumps and PV windows. The present paper reports the assessment of the performance of the ENVISION technologies in the different demos. This analysis is carried out through the calculation of normalized KPIs related to four different domains (energy, social, economic, and environmental) and the aggregation of these KPIs in domain scores to understand the strengths and weaknesses of each demo. In all the different demosites, the monitored data have been collected and processed to calculate the most valuable KPIs, which are compared with state-of-the-art values found in the literature to calculate a normalized KPI. Depending on the obtained value of the normalized KPIs a score from 0 (worst performance) to 5 (best performance) is assigned, considering that a score of 3/5 has been assigned to the State-Of-the-Art. Some KPIs are specific for the single demo (e.g. the SCOP of the heat pump), while others are common to all the demos and were used to carry on a direct comparison between the technologies. All the demos showed promising results in the social, energy, and environmental domains. For the last domain, in particular, the best results are obtained, as each technology leads to significant savings in GHG emissions. There is room for improvement on the economic side, which can be filled by progressively lowering the cost of technology over the years.

Nomenclature & Symbols

BIPV	Building Integrated PhotoVoltaics
CHP	Combined Heat and Power
COP	Coefficient of Performance
DHN	District Heating Network
ENVISION	ENergy harVesting by Invisible Solar IntegratiON in building skins
FSC	Façade Solar Collectors
GHG	GreenHouse Gases
HP	Heat Pump
KPI	Key Performance Indicator

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mGT	micro Gas Turbine
NG	Natural Gas
NIR	Near InfraRed
NKPI	Normalized Key Performance Indicator
RES	Renewable Energy Source
SCOP	Seasonal Coefficient of Performance
TES	Thermal Energy Storage
η_{Coll}	Solar Collectors' Efficiency
E'_{Coll}	Solar Collectors Specific Production
$E_{consumption}$	Primary Energy Consumption

1 Introduction

ENVISION [1] is an H2020 EU funded project that aims to develop technologies for harvesting energy using all the available surfaces of a building. In particular, the ones not commonly used such as building façades. Different technologies have been designed, developed, and tested in demo sites located all around Europe, with the aim of evaluating the performances of the systems on field.

A dedicated methodology has been performed to properly assess the performances of these systems. The KPIs are the basis for the development of the methodology implemented in this paper that aims to evaluate in an objective way the performances of ENVISION technologies, comparing them with state of the art and/or competitors.

The considered KPIs can be grouped in different categories as reported in **Fig. 1**.

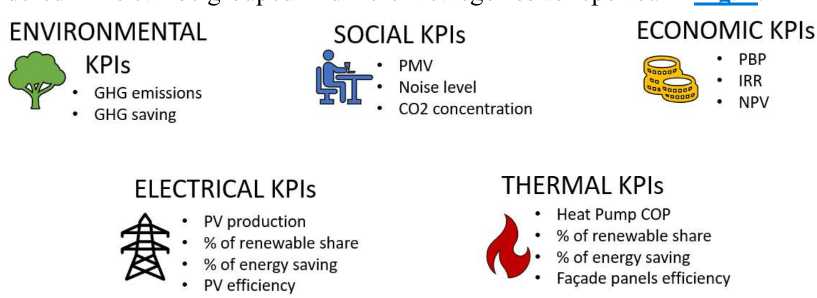

Fig. 1. List of KPIs

In particular, the main ENVISION technologies are:

- Façade solar collectors (FSC) coupled with a Heat Pump (HP)
- Building Integrated PV (BIPV) windows
- Smart ventilated window

This paper will be focused on the analysis of the performance of the FSC+HP system in two different demo sites with different climate conditions, while a detailed analysis of the two other technologies can be found in the project's deliverables [2].

The FSC+HP system consists of the use of solar thermal collectors to be installed on the façade of the building. These collectors produce heat then used by a water-water HP to produce hot water with high COP. The Façade solar collectors are produced by EMERGO, using a particular coating produced by AKZO NOBEL that makes possible the exploitation of the solar radiation also in the Near Infrared (NIR) area. The overall system is then managed

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and assembled by TNO. The collaboration of EMERGO and TNO led to the birth of a Spin-off company named Calosol [3], this can be assumed as a good result of ENVISION project. This system has been installed in Savona (Italy) and Enschede and Helmond (Netherlands).

2 Methodology

The core of the analysis described in this document is the Key Performance Indicators (KPIs). Starting from the KPIs, it is possible to understand numerically how the technology is performing in the two different scenarios. The steps of the work conducted by RINA have been:

- **Definition of the Needed Variables**. The first step is the definition of the variables that must be collected for each demosites (Temperatures, mass flow rates, energy flows, etc.). The list of required variables has been registered and shared with the demosite responsibles to ensure that it would have been possible to collect the needed data.
- **Data Collection**. Once defined the variables to be collected in agreement with the demo responsible, the demo responsible has been in charge of installing the proper sensors and measuring the variables for the collection of the data required. These data are collected mainly referring to monitored data (directly acquired with sensors installed by demo responsibles), and questionnaires submitted to building occupants for collecting their feedbacks on social/comfort aspects.
- **Data Analysis**. Starting from the variables collected in the demosites, the proper KPIs has been calculated. With this aim, specific spreadsheets have been produced by RINA for the automated calculation of the KPIs.
- **Results Report**. This can be highlighted as the crucial phase for the proper development of the proposed assessment methodology. Considering that the KPIs have different ranges of values, it is necessary to normalize them. This normalization is done by referring to standards and state-of-the-art values. These reference values are obtained through literature review and research on the market With this process, then, the KPIs are transformed into Normalized KPIs (NKPIs). Once obtained the different N-KPIs, a rate ($R_{KPI}i$) is assigned to the respective i-th KPI depending on the range of values of the i-th N-KPI, as reported in Fig. 2

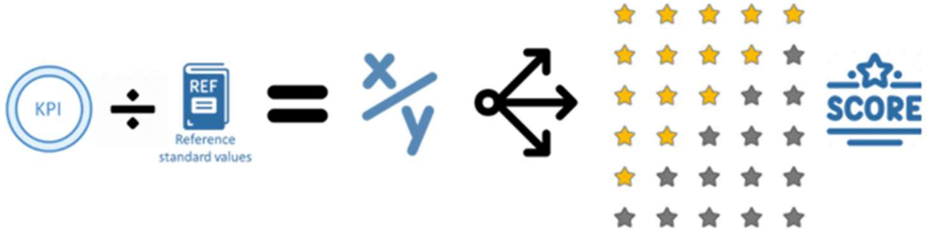

Fig. 2: KPIs normalization process and rating assignment

- **Final conclusions.** Making accurate considerations and conclusions on the score results could indicate very well the market potential for future applications. This analysis could, therefore, suggest to the supplier on which aspect investing effort in order to reach the aspiring position on the market.

Fig. 3 summarizes the methodology previously explained

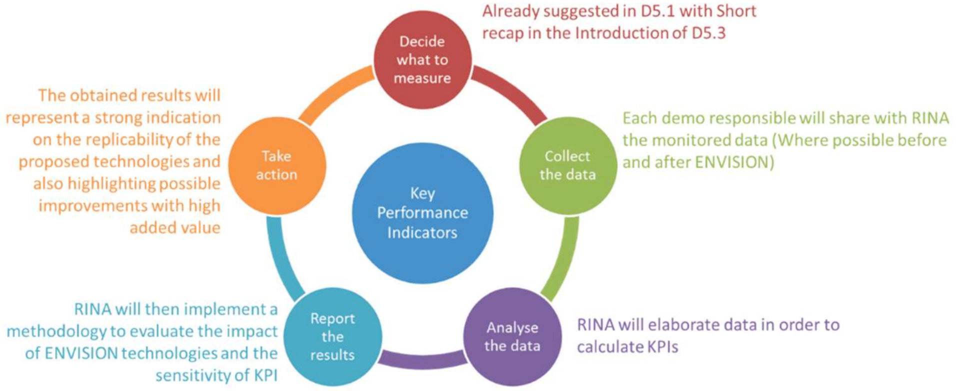

Fig. 3 : Concept of the presented methodology

3 Demo description

3.1 Northern demo (Netherlands)

In the area of Eindhoven, two social housing corporations that can make houses available for the demonstration of the ENVISION heat collection technology have been found. The names of these social housing corporations are Trudo located in Eindhoven and Compaen located in Helmond.
Trudo's proposal is to renovate 3 different houses of the same type located in the neighbourhood Mensfort in Eindhoven:

- 1 row dwelling north-south oriented
- 1 row dwelling south-north oriented
- 1 row dwelling at the end of the row (more energy loss)

Compaen's proposal is to renovate 3 different types of houses in 2 different neighbourhoods with different renovation approaches. In Table 1 an overview of the row dwelling characteristics is presented. The monitoring period is slightly different among the different houses because of the different timing of installation and the presence or absence of the tenants. Generally, the start of the data collection phase has been in November or December 2022 and the end in September 2023 and the data has been taken continuously to evaluate the performance in a real-life scenario.

Table 1: Overview of the TNO houses characteristics

House	Approach	A_{Tot} $[m^2]$	City	Facades	HP	Buffer	Radiators	Tenant
1	Panels on facade	15.60	Helmond	East, West	IthoDaalder op WPU65-COE	Cold, 500l	New	No
2	Panels on façade	13.70	Helmond	South-East	Nibe S1255-PC	Cold, 400l	New	No
3	Panels on prefab element	19.20	Helmond	South	EcoGeo B2 1-9	Cold, 500l	New	No

4	Panels on façade	15.70	Eindhoven	North, South	EcoGeo B2 1-6	Hot, 300l	Existing	Yes
5	Panels on façade	15.70	Eindhoven	South, North	EcoGeo B2 1-6	Hot, 300l	Existing	Yes
6	Panels on shed	16.00	Eindhoven	Façades, roof	EcoGeo C2 1-6	Hot, 300l	New	No

Each of the six houses has differences regarding orientation and behaviours in energy use by the tenant and the size of the PV installed on the roof. Since this paper is focused mainly on the comparison the potential of the solution in Northern vs Southern countries, an average of the six houses have been used to calculate the KPIs; further details about how each house is performing can be found in [2].

3.2 Southern demo (Italy)

The Southern Demo system integrates the ENVISION harvesting collectors with a 100kWe CHP-mGT, an innovative high-efficiency prototype heat pump, and two thermal energy storages with the aim of testing the performance of the ENVISION harvesting solutions and their integration with other devices in a smart polygeneration microgrid which was already present at the Savona Campus. The integrated system configuration requires the solar façade collectors to be connected to the heat pump that works as a temperature booster in order to guarantee the temperature required by the DHN. A low-temperature thermal energy storage is installed between the façade collectors' circuits and the HP to mitigate temperature fluctuations due to the solar availabilities on the heat pump. The CHP unit (100 kWe/160kWth micro–Gas Turbine) is also integrated into the system providing both electric and thermal energy. A high-temperature thermal energy storage is installed in order to guarantee one more degree of freedom in the management of both thermal and electric demand. Moreover, thermal dissipators are present to allow tests to be conducted independently of the DHN requirement and also to simulate different thermal demand profiles. The monitoring campaign has been conducted from May to July, during 20 different days to test the operation of the panels during different environmental conditions
Therefore, the FSC+HP system is installed in two different conditions in the two demos. In Table 2 a summary of the main differences is reported.

Table 2: Summary of the main differences between the two demos

	Northern demo (NL)	Southern demo (ITA)
Climate conditions	Cold, sub-oceanic	Warm, Mediterranean
Type of installation	Row dwellings,	Test rig
Monitoring phase	Continuous use by tenants, aggregated monthly energy use	Intermittent operation phase, punctual measures of temperature
Maximum temperature at the condenser side	40-45 °C (space heating)	65-70 °C (DHN)
Other energy system	PV modules on the roof	mGT + DHN+TES

4 Results

The results and the scores obtained for the **northern demo** (average between the 6 houses) and for the *southern demo* are reported below regarding the energy ratings:

Table 3: Results

	unit	ENVISION value	Reference value	Ref. number	NKPI	RATING
η_{Coll}	%	**30** *29*	75	**Error! Reference source not found.**	**0.406** *0.387*	☆☆☆☆☆ ☆☆☆☆☆
E'_{Coll}	kWh/m^2 per day	**0.77** *1.87*	2.01	**Error! Reference source not found.**	**0.382** *0.929*	☆☆☆☆☆ ★★☆☆☆
$SCOP_{HP}$	-	**3.06** *2.32*	2.73	**Error! Reference source not found.**	**1.12** *0.85*	★★★☆☆ ★☆☆☆☆
$E_{consumption}$	kWh/day	**2.19** *0.90*	**20.98** *1.11*		**0.1** *0.81*	★★★★★ ★★★★★
$GHG_{emissions}$	kgCO2/kWth	*0.09*	*0.23*		*0.40*	★★★★★ ★★★★★

From the performances reported Table 3, it can be observed that the performances of the overall system are very promising. Indeed, the SCOP values are higher than the HP state of the art. Looking at the Primary Energy consumption, the impact of this system is even more evident, considering also the additional benefits related to the local production of electricity with the local PV system that makes the houses equipped with this ENVISION solution very close to Net Zero Energy Balance. For the calculation of the GHG emissions, a natural gas boiler has been used as a reference. Only the southern demo results are reported since for the northern demo the calculation has been done considering also the renewable energy production from PV, and therefore the two demos are not comparable for this KPI. Further details are presented in [2].

When considering the performances of the collectors the situation becomes quite different. The efficiency of the collectors is generally far below the state of the art (75%). This is because a low operating temperature higher their efficiency, while looking at the system level, the impact of having higher temperatures helps in having better COPs. Anyway, it is worth mentioning that the main gap between the monitored values and the reference one can be due to the real operation of the system, while the reference value is obtained from a literature review. Therefore, possible shadings or other effects could affect the calculation of the efficiency.

From the economic point of view the results in terms of payback sorted out to be not as promising due to the high cost of installation. It is worth mentioning that ENVISION project is focused on building renovation and therefore the marginal cost of the system is sensibly reduced if compared with a "traditional" envelop renovation. To evaluate the social aspect a questionnaire has been distributed to the tenants and good results have been collected; this is an indication of the fact that this system has no drawback from a comfort perspective.

Looking at the performances of the whole system, the obtained SCOP is competitive with the state-of-the-art solutions, despite the fact that, connecting to a DHN, the temperature gap between Evaporator and Condenser is relevant (this aspect leads to lower SCOP values). Consequently, the savings in terms of primary energy are very promising. It is worth mentioning that the transition from the use of Natural Gas to electrical energy to a Heat Pump leads to other benefits such as avoiding the local production of pollutants due to NG combustion in residential areas. Furthermore, the use of electricity can be easily coupled with

other RES such as PV. Furthermore, during the test phase, a lot of start-up and shut-down processes have been carried on, reducing the performance of the system.
Then we can conclude that thanks to ENVISION technology is possible to couple local HPs with DHN maintaining competitive energy performances. As a reference for the daily energy consumption, the amount of primary energy used in a traditional gas boiler to obtain the same useful energy has been considered.
Figure 4 summarizes the performance of the two demosites in the 4 categories (Energy, Environmental, Social and Economic). In this paper, the focus has been put only on the first two because of the limited length of the paper. The environmental category is by far the category that shows the best results because this technology allows both an energy consumption reduction and the shift from fossil-fueled technologies to electrical systems, which has a lower emission factor.

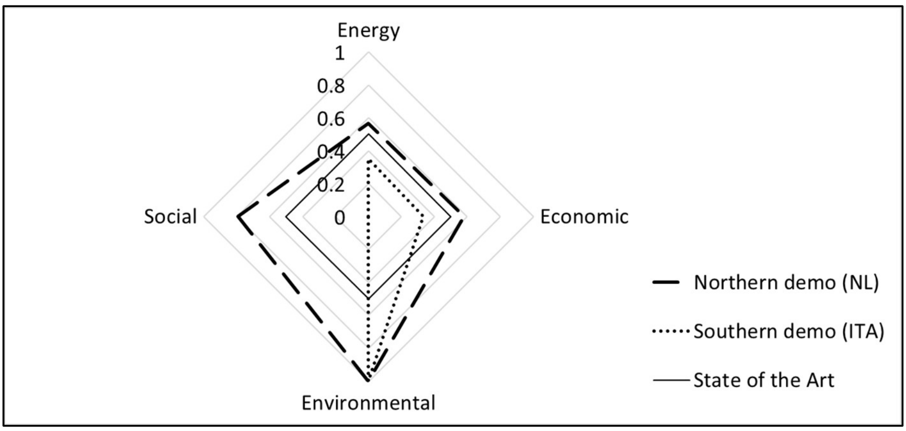

Fig. 4: Summary of the performance of the two demos

5 Conclusions

In conclusion, it is possible to state that the SFC+HP system performed better in the row dwelling application because of the continuous operation (that avoided frequent start and stop procedure) and the lower temperature at the condenser. Despite this, the Savona demo site gave an important indication of the possible integration between this system and a DHN and a CHP unit. It is worth mentioning that the transition from the use of Natural Gas to the use of electrical energy to a Heat Pump combines the benefits of reduced energy consumption and the absence of any local production of pollutants due to NG combustion in residential areas. Furthermore, the use of electricity can be easily coupled with other RES such as PV.
The methodology applied to this project was sorted out to be very effective to have a general framework of the performance of the ENVISION technologies in the different categories; in the picture below the final graphical results of the two demos presented in this paper are reported. These good results suggest the idea of using this methodology in other projects in the future

Acknowledgments

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References

[1] https://cordis.europa.eu/project/id/767180/it
[2] ENVISION Project: D5.8 - Methodology for energy efficiency assessment of the ENVISION technologies – Lead partner: RINA (2022)
[3] https://www.emergo.nl/producten-en-oplossingen/energiesystemen/calosol
[4] Ion Visa, Macedon Moldovan, Mihai Comsit, Mircea Neagoe, Anca Duta, Facades Integrated Solar-thermal Collectors – Challenges and Solutions, Energy Procedia, Volume 112, 2017, Pages 176-185, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2017.03.1080.
[5] Michael Chesser, Pádraig Lyons, Padraic O'Reilly, Paula Carroll, Air source heat pump in-situ performance, Energy and Buildings, Volume 251, 2021, 111365, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2021.111365.