Techno-economic analysis of an air conditioning heat pump powered by photovoltaic panels and the grid

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Abstract

This work presents an environmental and techno-economic study of an inverter air conditioner powered by photovoltaic panels and the grid simultaneously and without batteries. The unit provides the thermal demand to an office in an administrative building located in Alicante (South East Spain).

In comparison with other systems which also use renewable energy for air conditioning, this one presents significant advantages. It is comparatively simple, reliable, has low maintenance needs and its renewable energy production is entirely self-consumed, which avoids problematic interaction with the grid.

The system has been monitored during one year to measure the thermal energy provided to the room, the electrical consumption of the device, the photovoltaic and grid contribution to it and the solar irradiation.

Experimental results of the Key Performance Indicators are presented as a result of a one year data collection campaign. The measurements show a solar contribution of 54% to the electricity consumed by the system. As a result, the ratio between the thermal energy and grid electricity consumption during one year is SPF = 9.6. Consequently, the primary non–renewable energy consumption is drastically reduced to a 26% of the reference system.

Furthermore, the techno-economic study concludes that in spite of requiring a higher initial investment in the system, the saving produced by the lower electricity consumption, results in an annualized cost of 84% of the reference system cost.

Keywords: photovoltaic panel, solar energy, air conditioning, building sector.

Nomenclature

$PnRE$ Primary non renewable energy

PEF_{EL} Primary energy factor for electricity

$E_{sun,PV}$ Energy of the sun which reaches the PV panels

$E_{PV,max}$ Maximum electrical energy that could be produced by the three PV panels

$E_{PV,unit}$ Electrical energy produced by the three PV panels connected to the air conditioning unit

$E_{GD,unit}$ Electrical energy consumed by the air conditioning unit from the grid

$E_{TOT,unit}$ Total electrical energy consumed by the air conditioning unit

Q Thermal energy provided by the air conditioning, including cooling and heating

Key Performance Indicators

SPF_{unit} Seasonal performance factor for the air conditioning unit: ratio of useful heat and/or cold in relation to the electricity consumption needed.

SPF_{EQU} Equivalent seasonal performance Factor for the whole system. It indicates the grid electricity needed for supplying the thermal energy demand.

PER_{nRE} Primary non–renewable energy ratio. Relation between the non-renewable primary energy employed by the analysed system and by the reference system for the same energy demand.

PF Performance factor of the PV panels connected to the air conditioning unit.

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$FSAV$	Fraction savings of non-renewable primary energy.
SF	Solar fraction or solar contribution to the electricity consumed by the air conditioning unit.
CR	Cost ratio. Ratio between the total annualized cost of the analysed system and that of the reference system for the same space heating and cooling provided.

<u>Subindex</u>

ref	Refers to the reference system.

1. Introduction

In 2015 in Paris, the United Nations Framework Convention on Climate Change agreed to keep the increase in global average temperature to well below 2°C above pre-industrial levels, in order to reduce risks and the impacts of climate change. Consequently, the European Union has established the objective of a drastic cut of 80% of CO_2 emissions (referred to 1990) by 2050 . Besides, individual goals and pathways have been set for the different energy consuming sectors, the goal for the building sector being a 90% reduction, which includes the total decarbonization of this sector. With this aim, the use of renewable energy and electricity is proposed as substitution for fossil fuels in heating and cooling, which in developed countries accounts for half the energy use in buildings and one fifth of the total national energy use [1]. Furthermore, the European Union has defined an intermediate general goal for 2030 of a 40% cut in CO_2 emissions, with at least a 32% share of renewable energy.

Under these circumstances, there is significant research activity focused on reliable and environmental friendly solutions for HVAC systems. Back in 2007, Balaras et al. [2] made a review of solar air conditioning systems in Europe and Henning [3] drew a picture about general issues for using solar thermal energy for the air conditioning of buildings. More recently, Al-Alili et al. [4], Zouaoui et al. [5] focused their works on solar activated solid desiccant cooling technologies. Several authors [6, 7, 8, 9] studied the economic feasibility of different types of solar air conditioning systems.

Through a systematic literature research, Sampaio and González [10] analysed the current situation of photovoltaic solar energy, and pointed out the main advantages which make it a good solution for use in buildings: high reliability, availability, low maintenance needs and its potential to mitigate emissions of greenhouse gases. In fact, solar cooling and heating systems are increasing consistently in number and available technologies [11]. Among them, the use of photovoltaic panels is actively studied. Li et al. [12] demonstrated that consistent and reliable heating and cooling could be achieved by a solar photovoltaic air conditioner in the cold winter as well as in the hot summer of Shanghai (China). They also pointed out that this system could be a good solution to reduce the peak loads in the electrical grid during such periods. Huang et al. [13] studied six different air conditioning devices powered only by PV panels. Liu et al. [14] investigated an air conditioner driven by a quasi grid–connected photovoltaic (PV) system in Beijing (China) and found potential energy savings of more than 67% and 77% during summer daytime and nighttime. Varga et al. [15] reported their first experimental results with a small scale solar driven ejector cooling system installed in Porto, Portugal. Xu et al. [16] applied ice thermal storage air-conditioning and photovoltaic air-conditioning in the refrigeration field. Their analysis showed that it is feasible to use ice thermal storage instead of a battery bank to store solar energy in the field of distributed photovoltaic refrigeration.

A previous work by the authors [17] tested a heat pump in cooling mode powered by photovoltaic panels and the electrical grid during the hot season in Spain. The cooling system was installed in an office and the solar contribution and the production factor were found to be both 65%. Recently, Opoku et al. [18] studied the performance of a hybrid solar PV(with batteries)-grid powered air-conditioner for daytime office cooling in hot humid climates (Kumasi, Ghana) during one year.

Our literature search has yielded only one experimental work dealing with PV powered air conditioning devices which has been tested throughout one year [18]. However, the study is particular to the hot humid climate in Ghana, as the device only works in cooling mode throughout the year and with a very high demand throughout the day. This situation is very different to the one in an office in Europe, where there are cooling and heating demands throughout the year and the demand varies significantly throughout the day. Furthermore, the lack of knowledge and economic reasons are pointed out as the main obstacles for a wider spread of this technology [11].

In view of this situation the present study was undertaken. It presents an experimental study in a real situation, which uses solar energy and grid electricity to provide an office with cooling and heating for one year. By the use of solar energy and an efficient heat pump,

Table 1: Air conditioner technical data

Midea Solar 3D	Unit	Nom.
Cooling capacity	kW	3.52
Cooling power supply	kW	0.86
EER	—	4.09
Heating capacity	kW	3.81
Cooling power supply	kW	0.99
COP	—	3.83
Refrigerant	R410A	

the use of primary energy and CO_2 emissions are drastically reduced and, at the same time, the direct use of fossil fuels is avoided. The office is located in Alicante, in the south east of the Iberian Peninsula (Spain), where the climate is Mediterranean, which is characterised by moderate winters and hot summers. The study, focused on the annual performance of the system, is aligned with the European objective of CO_2 emission reduction, the use of renewable energies, decarbonization and the objective of developing solutions towards nearly zero energy buildings (nZEB). The work analyses parameters such as the solar contribution, the grid electricity savings, the use of non–renewable primary energy and the CO_2 emissions. Besides, the annual cost of the system during its lifetime is quantified and compared to a reference system.

2. Experimental setup

A 35 m^2 office in an administrative building has been provided with cooling and heating during one year by using a highly efficient heat pump. The characteristics of the air conditioning unit are detailed in Table 1. For the study, the temperature was set to 23°C in summer and 21 in winter within the office. The system control is configured to meet the demand. A sketch of the experimental setup is shown in Figure 1. As can be observed, the air conditioning unit is powered by three photovoltaic panels each of 230 Wp, connected in parallel and the electrical grid. If the PV panels do not provide enough energy, the heat pump consumes the rest from the grid. The PV panels provide 24 VDC electricity directly to the device, while the direct grid connection is 230 VAC. The panels are located on the roof of the building, with an inclination of 30° (with a latitude of 38°) and their azimuth deviates 15° from south.

As can be observed in Figure 2, three additional and identical PV panels have been connected directly to the electrical grid. The purpose is to measure the potential maximum production of the panels. Consequently, the influence of the air-conditioning equipment on the PV panels production can be evaluated. The figure also shows details of the data collection carried out by an Agilent 34972A data-logger with a 5 minute time step. The room and outside ambient temperatures are measured with type-K thermocouples. The refrigerant cycle parameters are measured by four thermocouples and two manometers. Two shunt resistances are used to evaluate the current consumed by the air conditioning device both from the grid and from the PV panels, while a third one is used for the PV panels which are connected to the grid. A network analyser Chauvin Arnoux CA 8334 is in charge of registering power consumption from the compressor. Furthermore, a meteorological station registers Humidity, wind, wind direction and solar irradiance.

Further details of this experimental setup and procedure can be found in [17], where detailed results in cooling mode are provided.

3. Results

The results of the system performance throughout one year are analysed in this section. The heat pump has been working in heating mode from November to April and in cooling mode from May to October, the system control being configured to meet the thermal demand.

Figure 3 shows the total electricity absorbed by the air conditioning unit month by month. The thermal energy (heat or cold) provided to the office is shown in the figure as well. Out of this data, the *seasonal performance factor* of the AC unit can be obtained. It calculates the ratio of useful heat and/or cold in relation to the electricity consumption needed.

$$SPF_{unit} = \frac{Q}{E_{TOT,unit}} \quad (1)$$

The results show that the demand is higher during December and January in heating mode and July and August in cooling mode, as is expected for this climate. The resulting SPF_{unit} of the air conditioning unit for the year has been 4.44. Better performance of the unit is observed for months with lower demand, when the machine is working at partial loads and the climate conditions are moderate. Besides, the obtained SPF_{unit} of 5.34 in cooling mode is higher than the one in heating mode, 3.84.

The contribution of the PV panels is evaluated next. The total solar energy which reaches the surface of three

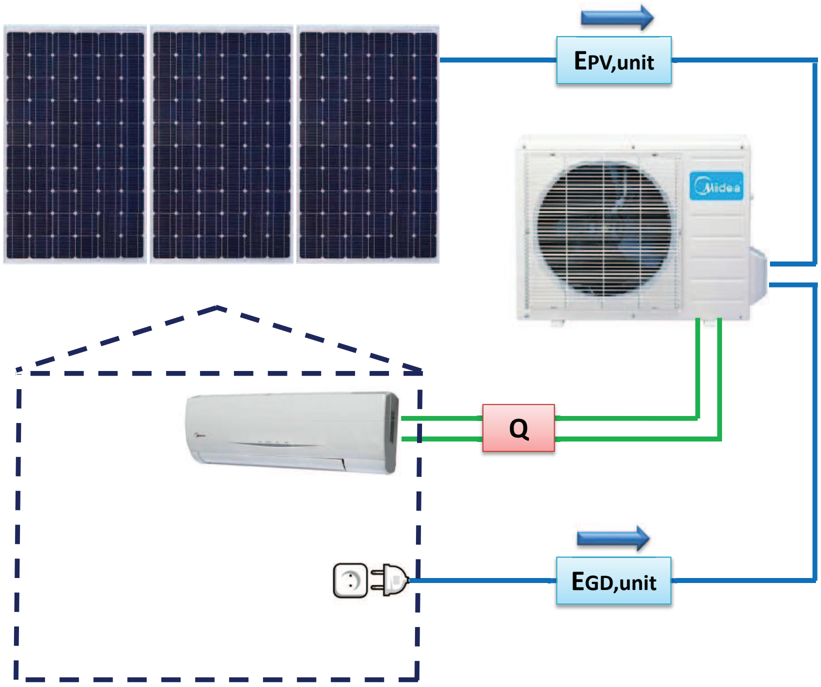


Figure 1: Sketch of the experimental setup.

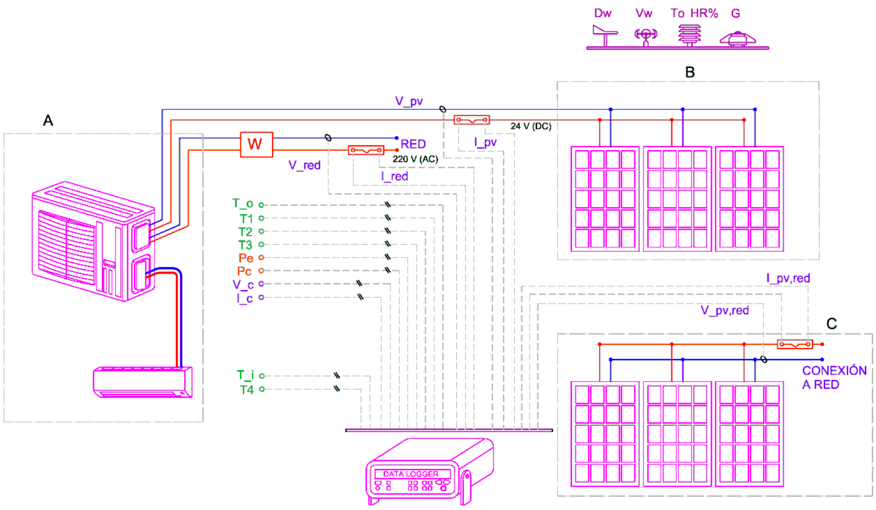


Figure 2: Experimental setup. Monitorization details.

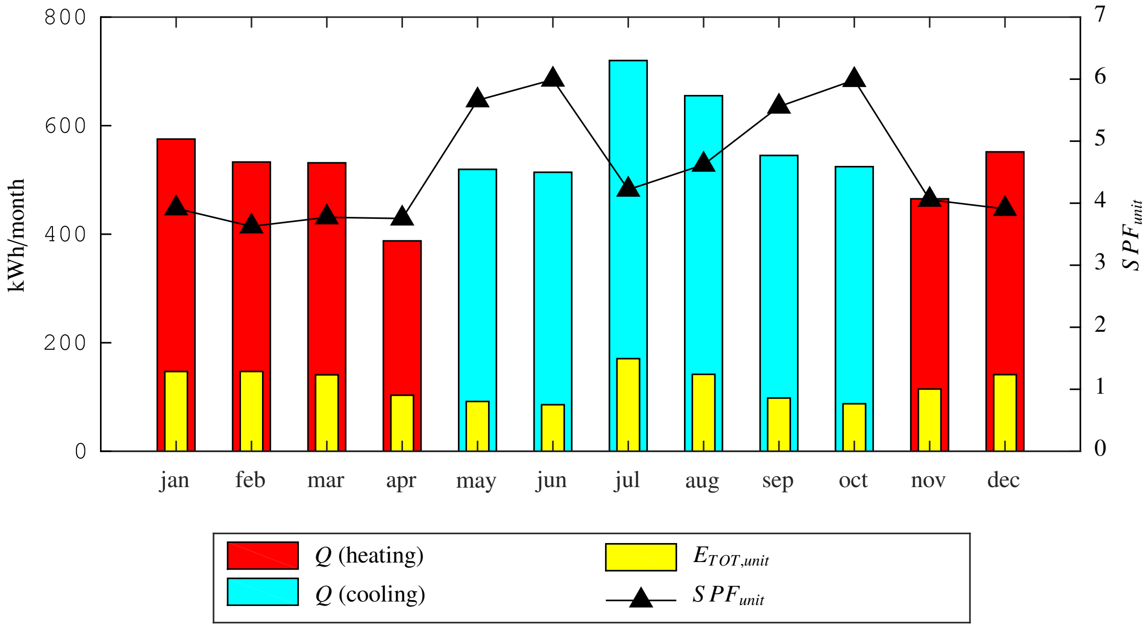


Figure 3: Total energy consumed $E_{TOT,unit}$ (electrical) and produced Q (thermal) by the air conditioning unit. Seasonal performance factor of the unit (right axis).

solar panels ($E_{sun,PV}$) has been calculated directly from irradiance measurements. When the electricity provided by the PV panels is not enough to feed the AC unit, the rest is taken from the grid. Electricity consumptions from the PV panels and the grid are obtained from voltage and current measurements. The solar fraction is defined as the ratio of the electricity produced by the PV panels and the total consumed by the air conditioner.

$$SF\ (\%) = \frac{E_{PV,unit}}{E_{TOT,unit}} \tag{2}$$

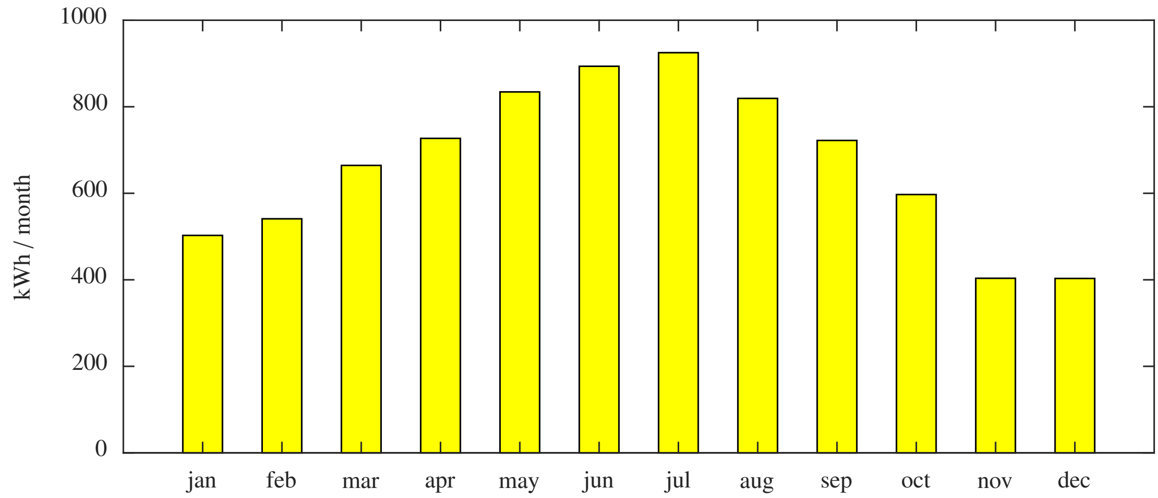
The solar irranciance on the panels is shown in Figure 4(a), while Figure 4(b) shows the electricity consumed by the air conditioning unit from the PV panels ($E_{PV,unit}$) and from the grid ($E_{GD,unit}$), as well as the corresponding solar fraction. The measurements show a growing irradiation from January to July, with a maximum of 925.0 kWh and a decreasing one afterwards, with a minimum of 403.5 kWh in December. This should result in higher electricity production in months with more irradiation, but this is not always the case. In months like June, where thermal needs are lower, the electricity needs decrease and a greater portion of PV potential production is wasted.

Being the lowest solar irradiation in winter and the highest in summer, the solar factor SF varies along the year. The low demand in spring and autumn and moderate solar resource result in solar fractions up to 78%. During the hottest months of the year, July and August, the solar fraction drops to 56%-59% despite being two of the months with highest solar irradiation (see Figure 4(a)), due to the great cooling demand. Lower values of the solar contribution are found from December to March where the thermal demand is also significant (heating) and, besides, the solar irradiation reaches its minimum.

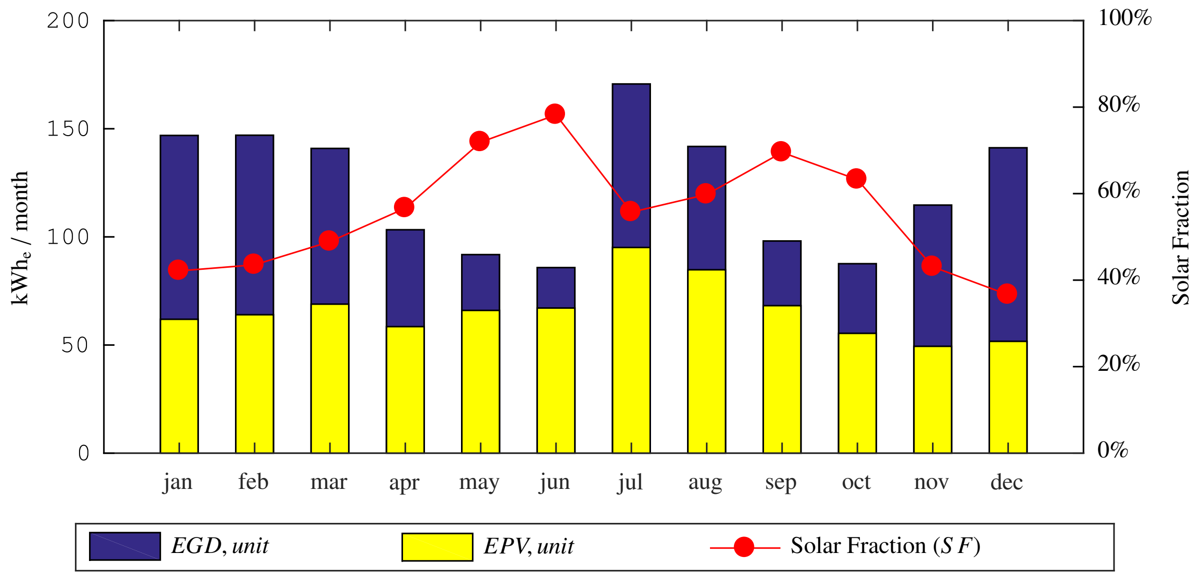
The SPF_{unit} represents the performance in the working conditions, of the air conditioning unit only. In order to evaluate the performance of the whole system, including the panels, the equivalent seasonal performance factor for the system has been obtained.

$$SPF_{sys} = \frac{Q}{E_{GD,unit}} \tag{3}$$

So defined, the SPF_{sys} indicates the grid electricity needed for supplying the energy demand. This parameter can be considered like a mean COP or EER of the system, but in working conditions. The overall SPF_{sys} for the year is 9.61. The results in Figure 5 show better ratios during months with moderate climate, where the working conditions for the unit are more favourable and the solar fraction is higher. Besides, the SPF_{sys}



(a) Solar irrandiance on the PV panels surface.



(b) Electrical consumption ($E_{TOT,unit}$) broken down according to the energy source: the grid ($E_{GD,unit}$) or the PV panels ($E_{PV,unit}$)

Figure 4: Performance of the PV panels connected to the grid/to the air conditioner.

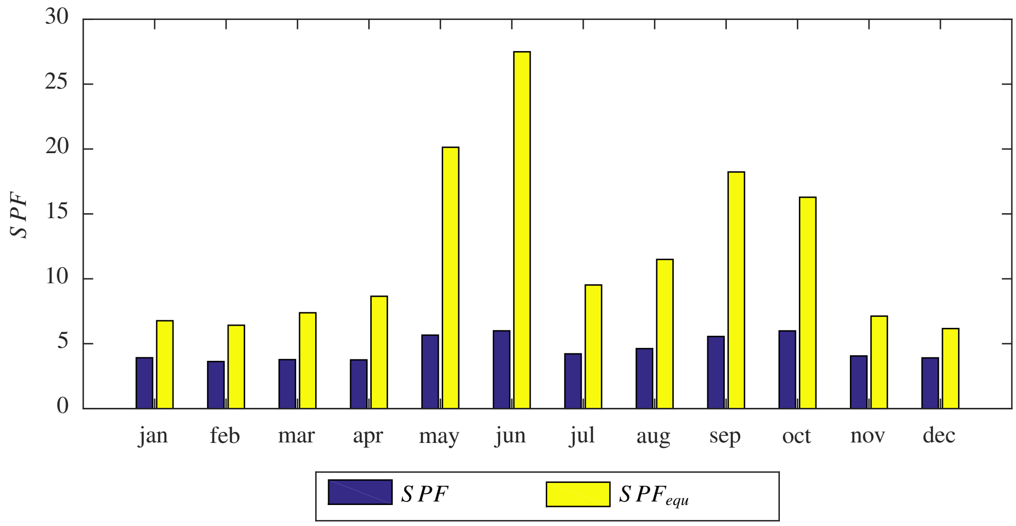


Figure 5: Seasonal performance factor for the unit (SPF_{unit}) and the system (SPF_{sys}).

in heating conditions is 6.93 on average, while in cooling conditions it is 14.54, 110% higher. This difference is partly explained due to the better SPF_{unit} in cooling mode, but also due to the higher solar irradiation available during the hot months, which results in lower grid electricity demand.

As has been commented before, the PV panels connected to the air conditioner do not produce as much energy as if they where connected to the grid. The reason is that if there is solar resource available, but no thermal demand on the air conditioner, then no electricity is produced by the panels. In order to evaluate this effect, three PV panels, identical to the ones connected to the AC unit, are connected directly to the grid. A performance factor of PV panels has been defined as the ratio between their energy production and their maximum production if they were connected to the grid.

$$PF\ (\%) = \frac{E_{PV,unit}}{E_{PV,max}} \tag{4}$$

The results are shown in Fig. 6. The best performance factor values are obtained from November to February (up to 92%). During this period, irradiation is low and the thermal needs are high enough to make the most of it. In July and August, the thermal needs are high as well, but more irradiation is available during longer periods each day, which results in a higher waste of energy (PF between 73% and 74%). However, the highest waste takes place during months with low thermal needs: April (cooling) and May, June and October (heating). The result for the year is an average performance of 70%.

The results which have been commented in this section are summarized in Table 2.

4. Environmental benefits

In this section the environmental benefits of the PV powered air conditioning system are evaluated. With that aim, two different system configurations are studied. For both of them the unit consist of a very efficient heat pump, but in one of them the unit is powered by three PV panels and the grid and in the other it is powered only by the grid. The results will be compared to those of a reference system. Usually, a gas boiler for space heating and an air conditioning unit for space cooling are considered as the reference system. However, this is an expensive solution, which is not often used for offices in the Mediterranean region. Therefore, in this study, the reference system consist in a reversible air conditioner for heating and cooling, which is a very common solution for this climate. The unit is considered to have a seasonal efficiency of 2.5 (cooling and heating). The proposed comparison allows us to evaluate separately the effect of installing a more efficient heat pump and the one of installing the PV panels as well.

Firstly, the environmental benefits of the analysed systems are evaluated in terms of primary energy consumption and CO_2 emissions reduction.

Nomenc.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Heating	Cooling	Year
$E_{sun,PV}$	502.6	541	664.4	726.9	834.3	893.6	925	819.3	722.1	597.1	403.5	403.1	3241.5	4791.4	8032.9
$E_{PV,max}$	70.4	75.7	93	101.8	116.8	125.1	129.5	114.7	101.1	83.6	56.5	56.4	453.8	670.8	1124.6
$E_{PV,unit}$	61.9	64	68.9	58.5	66	67.1	95.1	84.8	68.2	55.4	49.4	51.7	354.4	436.6	791
$E_{GD,unit}$	85	83	72	44.8	25.8	18.7	75.6	57	29.9	32.2	65.3	89.5	439.6	239.2	678.8
$E_{TOT,unit}$	146.9	147	140.9	103.3	91.8	85.8	170.7	141.8	98.1	87.6	114.7	141.2	794	675.8	1469.7
Q	575.3	533	531.5	387.7	519.5	514.1	720	655.2	545.1	524.4	465.2	551.7	3044.4	3478.3	6522.6
SPF_{unit}	3.92	3.63	3.77	3.75	5.66	5.99	4.22	4.62	5.56	5.99	4.06	3.91	3.83	5.15	4.44
SF (%)	42.1	43.5	48.9	56.6	71.9	78.2	55.7	59.8	69.5	63.2	43.1	36.6	44.6	64.6	53.8
SPF_{sys}	6.77	6.42	7.38	8.65	20.1	27.5	9.52	11.5	18.2	16.3	7.12	6.16	6.93	14.5	9.61
PF (%)	87.9	84.5	74.1	57.5	56.5	53.6	73.4	73.9	67.5	66.3	87.4	91.7	78.1	65.1	70.3

Table 2: Annual and monthly energy flow data of the HVAC system. All energy values are given in kWh. The unit provides cooling from May to October and heating from November to April.

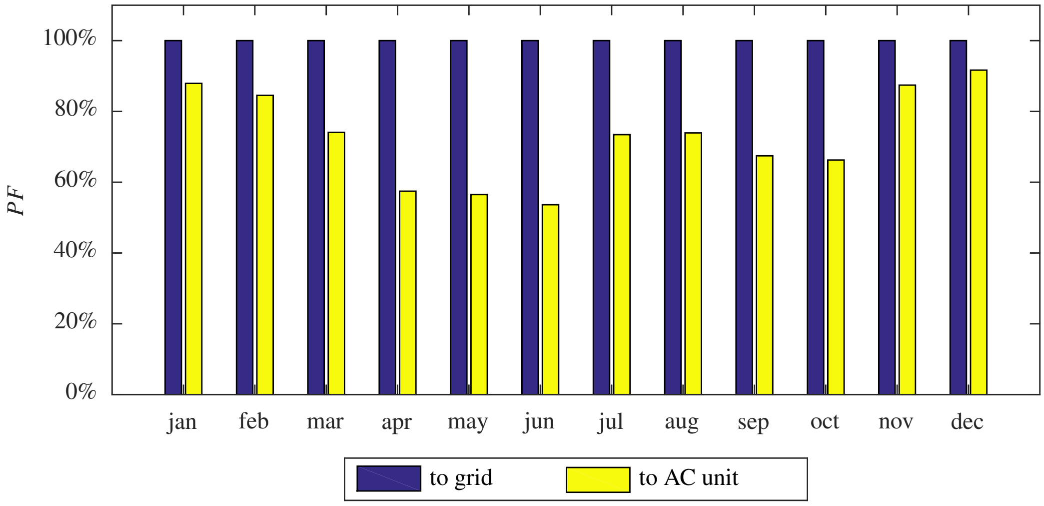


Figure 6: Performance factor of the PV panels connected to the grid or to the air conditioning unit.

Table 3: Reference system efficiency and energy conversion factors

	value	units
SPF_{ref}	2.5	
PEF_{EL}	2.5	kWh_{PnRE}/kWh_e
Emissions factor	0.351	gCO_2/kWh_e

As electricity is the final energy consumed by all the systems under consideration, their primary non–renewable energy is computed by using the conversion factor for this type of final energy (PEF_{EL} in Table 3):

$$PnRE = \frac{Q}{SPF} PEF_{EL} \tag{5}$$

The *primary energy ratio*, indicates the relation between the non-renewable primary energy employed by the analysed system and by the reference for the same energy demand. For this case, where the final energy consumed by the system and the reference is electricity, the ratio is reduced to the following

$$PER_{nRE} = \frac{PnRE_{ref}}{PnRE_{sys}} = \frac{SPF_{sys}}{SPF_{ref}} \tag{6}$$

The *savings fraction* of non-renewable primary energy, indicates the percentage of non-renewable primary energy consumption.

$$FSAV\ (\%) = \frac{PnRE_{ref} - PnRE_{sys}}{PnRE_{ref}} \tag{7}$$

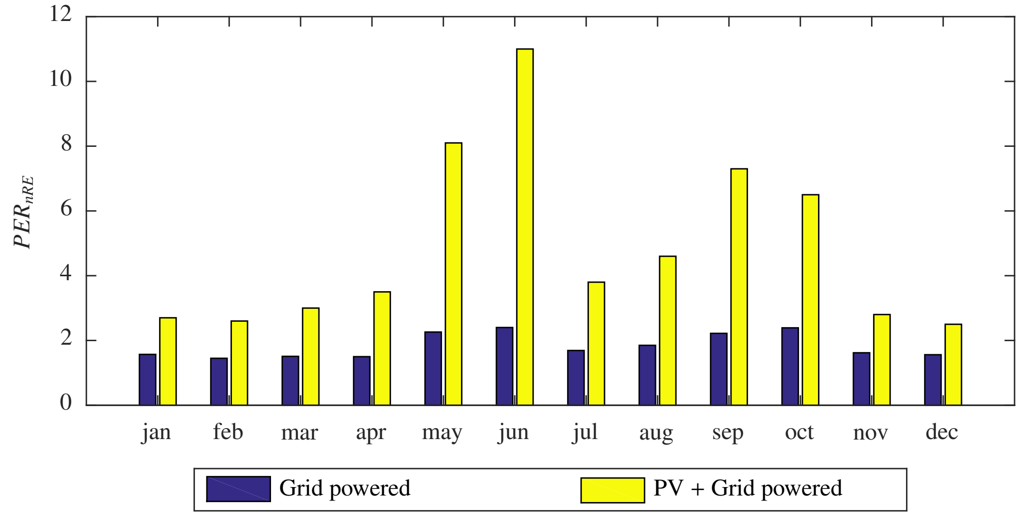
The results plotted in Figure 7 show the convenience of using an efficient heat pump instead of the reference system. The annual primary energy ratio for the system without PV panels is 1.78, meaning that the reference consumes 1.78 times more non–renewable primary energy than this system. This results in annual savings of 44% of the primary non–renewable energy. Furthermore, the use of the PV panels boost the savings of primary non–renewable energy. With a *PER* of 3.84, the system powered with PV panels achieves an annual saving of 74%, which is 30% more savings than the system without the PV panels.

Due to the use of the same final energy for the two systems and the reference, the CO_2 emissions savings in percentage is the same as primary energy: 44% and 74% of the emissions along a year for the systems without the PV panels and with them, respectively. The absolute figures for the CO_2 emissions are shown in Table 4 and they have been calculated with an emission factor for electricity production in Spain (detailed in Table 3).

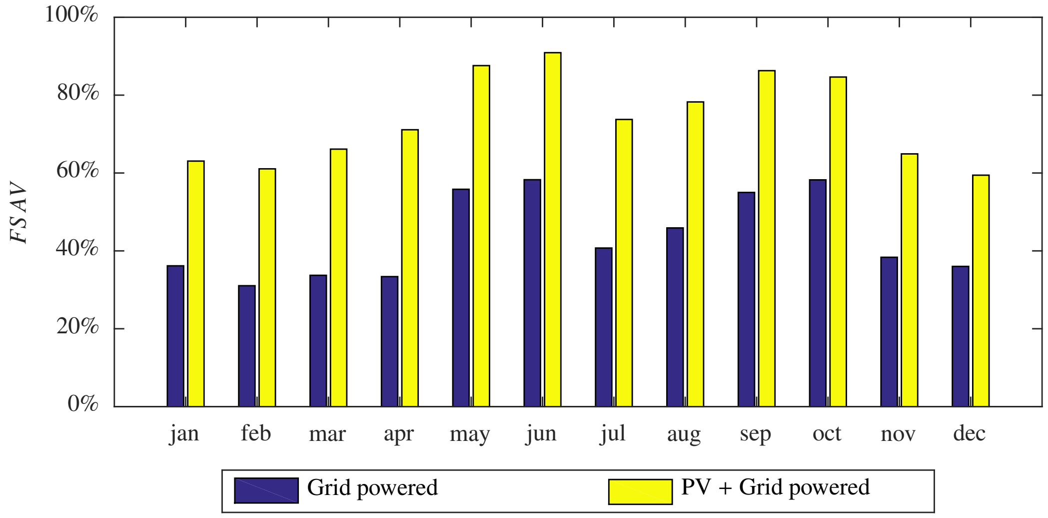
5. Techno-economic analysis

Once the energy savings of both systems have been detailed in the previous section, the cost of the improvements is quantified. Consequently, the systems under study are the same as in the previous section.

The economic analysis takes into account the annual costs for investment, maintenance, residual value, replacement and energy cost during the system lifetime.



(a) Primary energy ratio.



(b) Fraction savings.

Figure 7: Comparison of non–renewable primary energy ratios for the systems under study.

Table 4: Primary non–renewable energy consumption and CO_2 emissions for the systems under consideration.

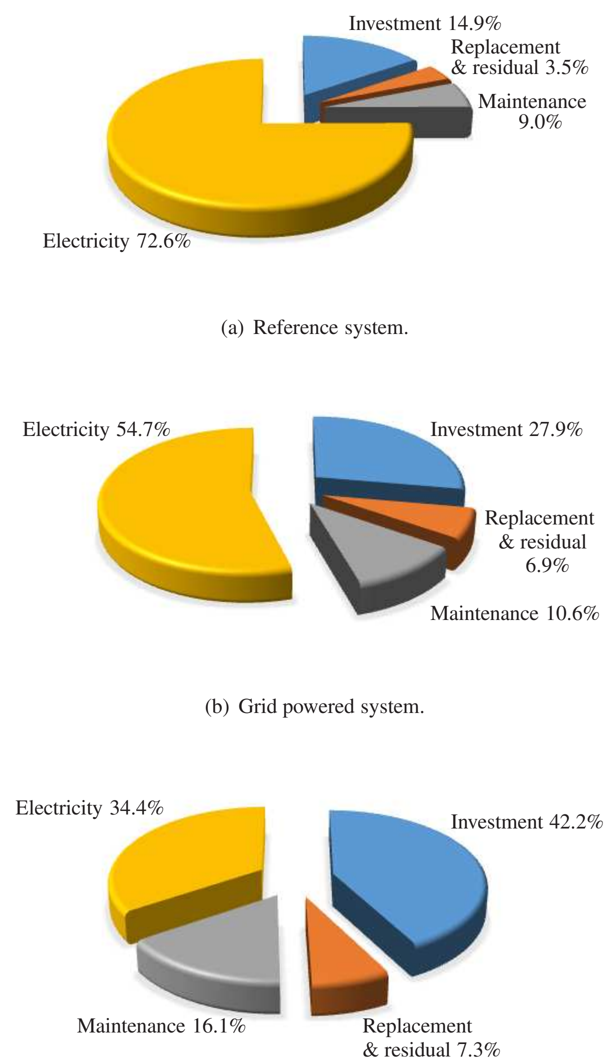
	PV + Grid powered	Grid powered	Ref.	Units
Produced thermal energy, Q	6523	6523	6523	kWh/year
Electricity consumed, $E_{Tot,Unit}$	679	1470	2609	kWh/year
Seasonal Performance Factor, SPF	9.61	4.44	2.5	-
Primary non–renewable energy, $PnRE$	1697	3674.3	6523	kWh/year
CO_2 emissions	606	1312	2329	kg/year
Primary non–renewable energy ratio, PER	3.84	1.78	-	-
PnRE Savings factor, $FSAV$	73.98%	43.67%	-	-

The annualized costs for the entire system are calculated by means of the annuity method. For each component the estimated lifetime, costs for investment and maintenance are calculated from real prices provided by three companies that work at local level (see Table 5). The maintenance cost for the PV panels has been quantified as 30 €/year, while 60 €/year is considered for the air conditioning unit, both for the reference model and the more efficient one used by the system. The period under consideration is 25 years, which is also the lifetime of the PV panels, while the air conditioning unit is considered to last for 18 years only. An inflation rate of 3% and a market discount rate of 3% have been also considered. Besides, the unit is paid with a 5 years credit with an interest rate of 5%. The energy cost of electricity is 0.15 €/kWh and the power cost 90 €/kW.

Figure 8 shows the contribution of different concepts to the global cost of a system during its lifetime. For the reference system (less efficient), the highest cost is for the electricity (72.6%), while the investment is 14.9% because the unit is cheaper. An efficient heat pump would require higher investment, which increases investment cost to 27.9% and replacement and residual cost to 6.9% of the total, while the electricity cost is reduced to 54.7% due to lower consumption. If an investment is made to purchase the PV panels, the electricity consumption decreases, but the investment cost and replacement and residual cost raise to 42.2% and 7.3% respectively. The total cost and individual cost contributions for the three systems are depicted in Figure 9. As can be observed, the total annual cost for the two systems under study is quite similar, the cost of the reference system being about 17-18% higher than them.

Even if there were no economic savings, the investment in the efficient heat pump and the PV panels would be interesting due to the reductions in primary non–renewable energy consumption and CO_2 emissions. Then, the economic savings reinforce this conclusion.

However, the result of the former analysis depends strongly on the electricity price. To overcome this inconvenience, the same study has been carried out for electricity prices ranging from 0.10 €/kWh to 0.3 €/kWh. Figure 10 shows the total cost of the three systems under consideration versus the electricity cost. Obviously, interest in the reference system increases for low electricity prices, as its higher energy consumption would be cheaper. This can be better observed if the cost ratio, *CR*, is used. It is calculated by comparing the total annualized cost of the system and that of the reference system for the same space heating and cooling energy provided to the room:



(c) PV + Grid powered system.

Figure 8: Total life system cost contributions.

Table 5: techno-economic study results for a 25 years lifetime (Energy cost 0.15 €/kWh).

	PV + Grid powered	Grid powered	Reference
INVESTMENT	€	€	€
PV panels	1200	0	0
Air Conditioner	2600	2500	1500
INVESTMENT MATERIAL	3800	2500	1500
Design, planning and commissioning	200	200	200
General costs associated to works	760	500	300
Indirect costs and industrial benefits	190	125	75
TOTAL INVESTMENT COST	4950	3325	2075
REPLACEMENT COST	€/year	€/year	€/year
PV panels (25 years lifetime)	0	0	0
Air Conditioner (18 years lifetime)	39.27	37.76	22.65
TOTAL REPLACEMENT COST	39.27	37.76	22.65
MAINTENANCE	€/year	€/year	€/year
PV panels (30 €/year)	30	0	0
Air Conditioner (60 €/year)	60	60	60
TOTAL MAINTENANCE COST	90	60	60
OPERATION-ENERGY	€/year	€/year	€/year
Energy Cost of Electricity	101.81	220.46	391.36
Power Cost of Electricity	90	90	90
TOTAL ENERGY COST	191.81	310.46	481.36
ANNUALIZED COSTS	€/year	€/year	€/year
Investment	228.67	153.60	95.85
Replacement	39.27	37.76	22.65
Maintenance	87.38	58.25	58.25
Electricity	186.23	301.41	467.34
TOTAL ANNUALIZED COST	541.54	551.02	644.10
Cost ratio	0.84	0.86	-

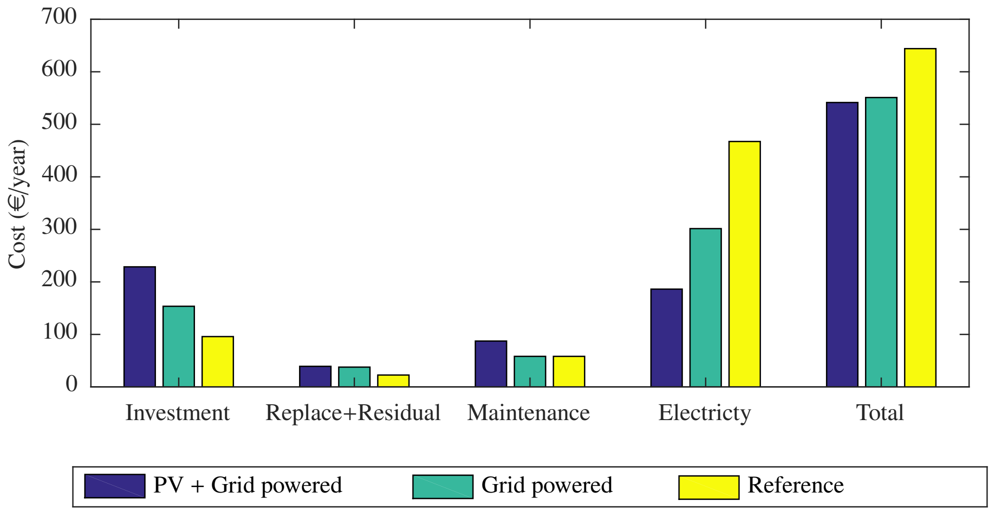


Figure 9: Individual annual cost contributions and total cost of the systems.

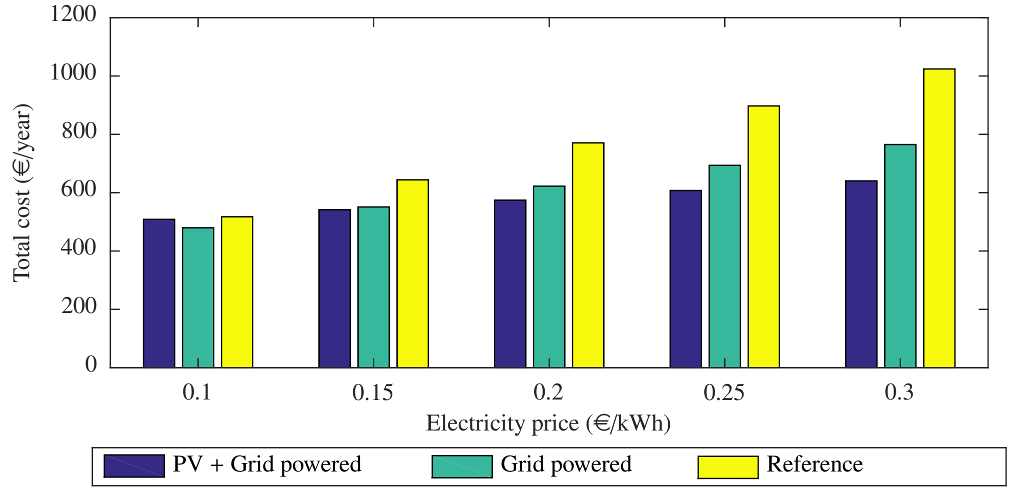


Figure 10: Influence of the electricity price on the total cost.

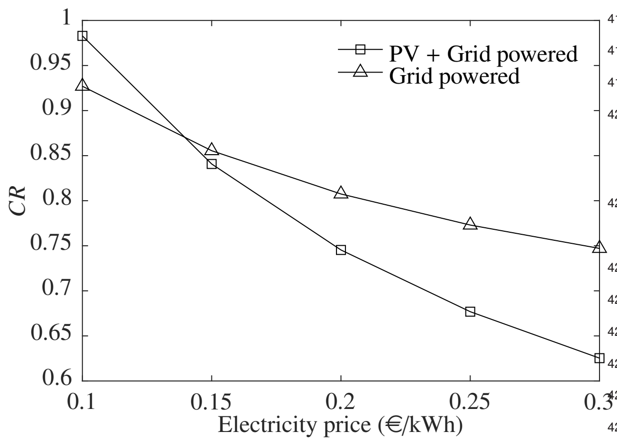


Figure 11: Cost ratio of the systems as a function of electricity price.

$$CR = C_{AN}/C_{AN,Ref} \tag{8}$$

As can be observed in Figure 11, almost no savings are achieved for the lowest energy price by the PV powered efficient heat pump in comparison with the reference. However, for 0.15 €/kWh$_e$, the annual cost of the system is only 84% of the reference system cost, being the more interesting, the higher the energy price.

By comparing the cost ratio for the efficient heat pump with and without the PV panels, their influence is evaluated. As shown in the figure, from the economic point of view, for low energy prices (below 0.15 €/kWh$_e$) the cost of the PV panels becomes slightly higher than the economic savings they produce. Nonetheless, as stated before, the environmental benefits are significant enough to justify this investment for all the prices in the range considered.

6. Conclusions

The work presents an air conditioning solution, consisting of an inverter heat pump powered by PV panels and the electrical grid. The system has been used to meet the thermal demand of an office during one year in a European city in the Mediterranean basin (Alicante, Spain).

Experimental measurements have been carried out during one year. Out of this data, the following working parameters have been quantified for such a period: solar irradiation, PV panels electricity production, PV panels maximum production, electricity consumption of the air conditioning unit from the grid and its thermal production. The results have been summarized as key performance indicators.

The PV panels directly connected to the AC unit have been found to produce 70% of its potential electricity production in comparison to the same model of PV panels connected to the grid. However, this solution does not increase the complexity of the building connection to the grid and avoids potential conflicts with local regulation, by not supplying electricity to it.

The combined use of an efficient inverter heat pump with photovoltaic panels result in a significant reduction of the grid consumption during one year. The seasonal performance factor obtained for the system indicates that for each electrical energy unit consumed from the grid, 9.6 thermal energy units are produced within the office. The solar contribution of the PV panels to the electricity consumption of the AC unit has been quantified as 53.8%.

Environmental and techno-economic studies have been carried out in order to quantify the environmental benefits and to evaluate the feasibility of the system. It has been found to reduce 74% of the primary non–renewable energy consumption and CO_2 emissions in comparison with the reference system. Furthermore its annual cost is 84% of the reference system cost, due to the reduction in electricity consumption.

Moreover, the system provides a simple, feasible, safe and reliable solution based on renewable energy to drastically reduce CO_2 emissions and allow decarbonization within buildings, which is in agreement with the European and international roadmaps to stop the increase in the average Earth temperature.

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