Residential buildings retrofit: the role of solar technologies

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Abstract

In line with the last European directives that boost actions for reducing the energy consumption in the residential sector, buildings refurbishment becomes key. On one hand, a deep building retrofit concerns actions aimed at reducing the building demands and the final energy consumption. In particular, the replacement of existing windows, the addition of an insulation layer on the external surfaces and the installation of a mechanical ventilation system with heat recovery (MVHR) help to drastically reduce the building demands. On the other hand, the installation of a system with improved performance can additionally decrease the final energy used for space heating and cooling (H&C) and Domestic Hot Water (DHW) preparation with respect to a traditional system. Once the retrofit measures have acted on improving the energy efficiency of both building envelope and HVAC system, an additional contribution can be given by solar technologies integrated in the building.

In this context, this paper wants to show the amount of final and primary energy consumption reduction through a deep renovation on existing buildings and the contribution that solar technologies gives in this perspective.

Keywords: Building retrofit, solar technologies, simulation-based analysis, residential buildings

1. Introduction

In line with the last European directives that boost actions for reducing the energy consumption in the residential sector, buildings refurbishment becomes key. The construction period of half of the existing European residential building stock dates back to before 1970. The average heating demand of these buildings over Europe is higher than 200 kWh/(m²y) (Birchall et al., 2014). This means a big potential for buildings refurbishment although up to now the yearly retrofit ratio is around 1-2%. For achieving high energy savings, what is needed is a deep building retrofit that involves both the envelope and the HVAC system of a building. The integration of solar technologies can even increase the reduction of energy consumption due to space Heating & Cooling (H&C) and Domestic Hot Water (DHW) preparation.

Deep building retrofit concerns actions aimed at reducing building demands and final energy consumption. On one hand, the replacement of existing windows, the addition of an insulation layer on the external surfaces and the installation of a mechanical ventilation system with heat recovery (MVHR) help drastically to reduce the building demands. On the other hand, the installation of a system with improved performance can contribute additionally to decrease the final energy needed for covering the building uses. Intervention on the envelope, in fact, are effective only if also the HVAC system is performing. The effect that one solution could have on another one and the contribution that solar thermal panels (ST) and photovoltaics (PV) without battery can have on the final energy consumption are not easy to be estimated during the design phase. For this purpose, dynamic simulations could help for accounting for the loads to be covered and production contemporaneity.

For the abovementioned reasons, this paper aims to present simulation-based results of renovation packages solutions applied to residential existing buildings. In particular, the paper reports building demands reduction due to envelope solutions, final energy consumption and HVAC system performance, solar fraction obtained with the integration of STC and PV production, self-consumption and energy fed into the grid. Simulations are carried out in the TRNSYS environment (Klein et al., 2011).

The paper presents results collected in an online database (iNSPiRe, 2016) useful in a pre-design phase for giving an idea about energy and economic performance of market-available renovation packages solutions. The validity of this database concerns the possibility to consult easily renovation measures performance obtained through detailed models. The numerical models of the analysed cases take also into account the contemporaneity of available solar energy and building loads (thermal or electrical), the presence of thermal storages and the implementation of the system control. The analysis has been performed through seven European climates, seven building construction periods, four heating demand levels and five building typologies. Moreover, the database reports results on the investment, maintenance and running costs of each solution. For the scope of the paper, only a selection of these results is commented.

In this paper, in particular, the authors want to underline the impact that solar technologies have in a retrofit process for the reduction of the final and primary energy consumption. Additionally, the paper provides suggestions on the optimal solar field size to match the building needs and reduce stagnation hours in solar thermal field and fed-into-the-grid energy in PV installations.

2. Retrofit packages for residential buildings

The study refers to reference buildings individuated in a previous study developed within the iNSPiRe FP7 project (Birchall et al., 2014). Based on an extensive literature review through national statistics, public papers, other sources and previous European projects, two main building typologies, Single Family Houses (SFHs) and Multi Family Houses (MFHs) are identified. In addition, some variations of surface over volume (S/V) ratio through detached/row houses for SFHs and number of floors for MFHs, it was possible to have models that covered around 70% of the existing residential building stock in Europe.

Building typologies are classified based on information collected through the study: geometric and physic characteristics are defined by building typology, construction period and climate (Birchall et al., 2014). In particular, the SFH reference building is a two-storeys building with a total heated area of 96 m². Glazing ratio in the north façade is 10%, 12% in the east and west facades and 20% in the south façade. The building covering is a pitched roof; the ground floor bounds with a cellar. In order to enlarge the cases availability, together with the detached SFH, also row-houses are considered: east and west facades of the detached ones are taken as adiabatic surfaces instead of external. From detached to row-houses, the S/V ratio reduces from 0.87 to 0.58.

The MFH reference building here considered is a small MFH (s-MFH) composed by ten apartments distributed through five floors. Each dwelling is 50 m²; the staircase is embedded in the building between the two apartments. In this case, the roof is flat and the cellar is not present. In MFHs, the number of floors varied from three to seven in order to cover cases with S/V ratio from 0.48 to 0.61.

In the study, numerical models of the reference buildings were therefore developed and in particular, one model per building typology, construction period and climate were created. For each of these, the assessed heating and cooling demands were benchmarked with statistics data in order to prove the models validity (Dipasquale et al., 2014).

For the reference cases, energy consumption was calculated assuming that heating and DHW were provided by a gas boiler with efficiency of 0.8, while cooling demand was covered by a split unit with EER equal to 2.5. For the Primary Energy (PE) consumption calculation, conversion factors of 2.878 kWh_{PE}/kWh_{FE} for electricity and 1.194 kWh_{PE}/kWh_{FE} for gas are used (Malenkovic et al., 2012).

The abovementioned buildings models represent the reference cases for the retrofit solutions to be investigated.

The studied retrofit packages are defined with market-available products. In this way, the final user of the database, that could be the decision maker or a technician of the residential sector, can find in it a generic building similar to the specific case.

In this paper, the interventions of a deep renovation are studied in three steps: measures on the envelope, improvement of the HVAC system performance and integration of solar technologies.

The retrofit measures for the envelope concern the replacement of the existing windows with double or glazed windows, the installation of a mechanical ventilation machine with heat recovery (MVHR) with efficiency of 0.85 and the insulation of the external surfaces. The specific measure or insulation thickness are decided based on the climate (one of the seven, Nordic, Northern Continental, Continental, Oceanic, Southern Continental, Southern Dry and Mediterranean) and the heating demand energy level (EL) to be achieved, 15, 25, 45 and 70 kWh/(m²y).

Once defined the window quality, the presence of the MVHR system and, consequently, the new infiltration rate, the insulation thickness is calculated for achieving the targeted EL. For this study the insulation layer is an EPS (expanse polystyrene) with conductivity 0.039 W/(mK).
Details on the envelope renovation measures are reported in (Fedrizzi et al., 2016a) for SFHs and in (Fedrizzi et al., 2016b) for s-MFHs.

In the study, the existing generation and distribution system is supposed to be replaced with a more efficient HVAC system. Different configurations are studied with a modular approach that allows to investigate the performance of different devices for the energy generation and terminals using the same energy plant layout and working modes. Also for the HVAC system, the choice of the renovation solutions moves on the most common and promising market-available solutions. In particular, the investigated generation systems are: air-to-water heat pump, ground-source heat pump, condensing boiler and pellet boiler.
With regard to the distribution system, the different behavior and energy consumption of radiant panels, fan coils and radiators is taken into account.

Finally, the contribution of solar technologies is considered for even reducing the energy consumption. In the study, solar thermal collectors (STC) and photovoltaics (PV) fields were analysed accounting for the effect of either one of them or both together. Three different areas and two slopes, 30° on the roof and 90° on the façade, were studied. The below tables report the solar fields size for STC and PV.

Table 1: Solar thermal collectors field size

	Unit	SFH	s-MFH
STC_1	*m²*	4.6	18.4
STC_2	*m²*	9.2	27.6
STC_3	*m²*	13.8	36.8

Table 2: PV field size

	Unit	SFH	s-MFH
PV_1	*kWp*	1	3
PV_2	*kWp*	2	4
PV_3	*kWp*	3	5

3. Results and discussion

The abovementioned renovation measures aim at reducing the total energy consumption of the existing residential building stock keeping thermal comfort inside the dwellings. Each measure contributes differently: envelope solutions decrease the building demands, an efficient HVAC system reduce the final energy consumption and solar technologies contribute to the energy savings with the use of renewable energy.

Within all the cases presented in the database (iNSPiRe, 2016), in the following paragraphs only a selection of these will be reported. For the sake of clarity, extreme climates will be showed, that is Nordic, with reference weather conditions of Stockholm (STO), and Mediterranean – Rome (ROM). These two cases in fact represent a heating and a cooling dominated climates. For the generation systems, air-to-water heat pump (AWHP) only is chosen as one of the most common and innovative solution. Performance of this generation system is compared with the reference one. In terms of final energy consumption, ground-source heat pump differs from AWHP for a higher electricity consumption due to the hydraulic pump used in the source/sink side of the heat pump. However, exchanging with the ground instead of external air, the heat pump performance improves and consequently final energy consumption decreases keeping the same delivered thermal energy. A condensing boiler has higher efficiency than a normal boiler. The pellet boiler, since it has a smaller primary energy factor, outperforms the condensing boiler in terms of primary energy despite its performance is lower.

With regard to the distribution system, results refer to a system with radiant ceilings working with a supply temperature of 35°C. These units better suit the possibility to deliver heating and cooling with the same generation device working at low temperatures. Differently from the radiant panels, radiators and fan coils distribute heating/cooling with a lower radiative fraction. This means that with radiant panels the operative temperature in the zone is closer to the sensible temperature that is used by the thermostat. Consequently, more thermal energy, in a range of 3-5%, is required for keeping the internal set temperature and therefore balance the extra transmission losses due to surfaces higher temperature. However, fan coils consume additional electricity required by the fan embedded in the device, while radiators, instead, cannot deliver cooling needing, therefore, another device for that purpose. In the case of boilers and radiators, space cooling is covered by split units.

3.1. Envelope renovation measures

The improvement of the envelope energy performance can allow important heating demand reductions.
In SFHs despite the different weather conditions of the Nordic and Mediterranean climates, the average heating demand for buildings built between 1945-1970 in both climates is around 170 kWh/(m²y). This behaviour is due to a better wall constructions adopted in the northern climates for the existing buildings. In the here reported case, the envelope measure aims at achieving a fixed heating demand of around 50 kWh/(m²y). For this energy level (EL) target, in the Nordic it is necessary to install a triple glazed window, a MVHR system, 8 cm of insulation on the external façade, 5 cm on the ground floor and 15 cm on the roof. In the Mediterranean, instead, the EL is reached by installing double glazed windows, 12 cm of insulation on the façade and 18 cm on the roof. These interventions on the envelope allow reducing the building heating demand of around 70% in both cases. A better quality window and the use of external shadings for both climates bring also a reduction of the cooling demand of 55% in Rome and 44% in Stockholm.
s-MFHs with same construction period as SFHs have heating demand around 86 and 95 kWh/(m²y) respectively in the warmer and colder climate. The lower demand is due to the lower S/V ratio. For this building typology for both climates, the EL target is achieved without the need of a MVHR system neither triple glazed windows. Regarding insulation, while in Rome only 5 cm are needed on the façade, in Stockholm it is required 10 cm on the façade and 10 cm on the roof. As shown, a small intervention on the envelope allows to reduce the heating demand of 40-45%. Differently with SFHs, the cooling demand in s-MFH slightly reduces (see Table 3).

Table 3: Heating and cooling demand before and after envelope renovation

Building	Space Heating [kWh/(m²y)]		Demand	Space cooling [kWh/(m²y)]		Demand
	Existing case	Post renovation	reduction [%]	Existing case	Post renovation	Reduction [%]
SFH_ Rome	171.2	53.7	68.6%	44.7	25.7	42.6%
SFH_Stockholm	173.9	51.3	70.5%	16.8	7.4	55.8%
sMFH_ Rome	86.3	55.1	36.2%	42.1	40.4	4.0%
sMFH_Stockholm	95.4	49.7	47.9%	14.7	14.5	1.4%

3.2. HVAC system renovation measures

A building with a good performance envelope is not enough for achieving important energy savings if also the HVAC system is not efficient. The replacement of the existing system with a more efficient one is able to bring relevant savings on the final energy consumption. Starting from the demands obtained after renovation (Table 3), Primary Energy consumption for space heating (SH) and space cooling (SC) is calculated considering the reference system (Reference) and the AWHP system (AWHP). The reference system is the one used for calculating the final energy for the existing buildings (see Par.2). Final energy consumption obtained after retrofit are instead calculated through simulations and are available on the database. The results reported in Table 4 show as an improvement of the HVAC system performance allows a PE reduction for SH of 44%-46% in Rome and 36-37% in Stockholm respectively for the SFH and s-MFH buildings. For SC the savings depend on a better EER of the cooling device bringing for Rome and Stockholm 23-27% of PE consumption in the SFHs and 33-36% in s-MFHs.

Table 4: Primary Energy consumption before and after HVAC system renovation

Building	PE heating [kWh/(m²y)]		PE for SH	PE cooling [kWh/(m²y)]		PE for SC
	Reference	AWHP	reduction [%]	Reference	AWHP	reduction [%]
SFH_ Rome	80.0	44.9	43.9%	29.6	21.6	27.0%
SFH_Stockholm	76.4	49.3	35.5%	8.5	6.5	23.4%
sMFH_ Rome	82.1	44.2	46.2%	46.5	31.2	32.9%
sMFH_Stockholm	74.0	46.3	37.4%	16.7	10.7	35.7%

Comparing the PE consumption for the cases before retrofit and the ones with the envelope renovation measures and the more efficient HVAC system, the energy savings that can be achieved amount to around 80% for the SH of the SFH and 66% for the SH of s-MFHs (regardless the climate). For the SC the percentage is lower due to also to the lower demand, but even not negligible: in the SFH, PE for SC is reduced of 58% in Rome and 66% in Stockholm, while in the s-MFH the reduction is of around 36% in both climates (see Fig 1).

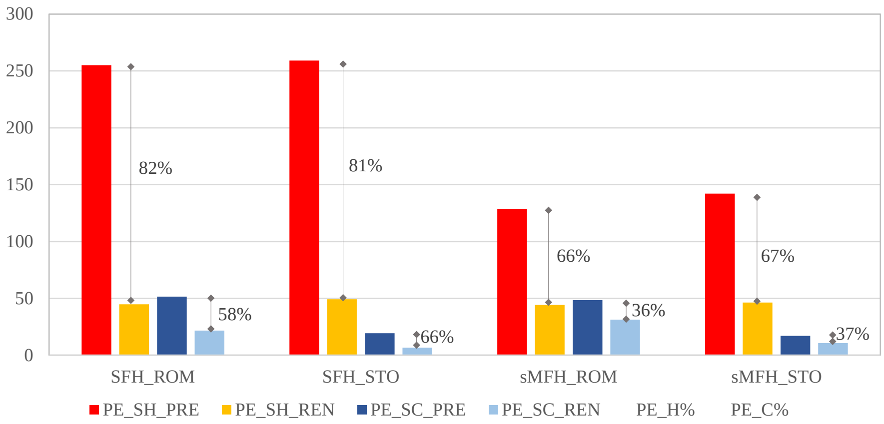

Fig 1 Primary Energy consumption of the two buildings typologies in the two climates before renovation (PRE) and after the envelope and HVAC system renovation (REN)

3.3 Solar technologies contribution

In a deep renovation process, a strongly reduction of the energy consumption is favoured by the installation of solar technologies as solar thermal panels (STC) and photovoltaics (PV). Depending on the building loads and climate, one or the other technology can have a higher impact on the total final consumption. However, even a small solar field can bring important savings against a small investment cost, with respect to the cost of the whole renovation.

Solar thermal collectors

In the following, results for cases STC_1 and STC_3 (see table 1) referred to SFHs and s-MFHs are reported.

In SFHs, a solar field of 4.6 m² installed on the roof is able to cover around 74% of the DHW load in the Mediterranean climate and 40% in the Nordic one. If the panels are installed on the façade (90°), the production is reduced respectively in the two climates of 18%-10%. This difference amounts to only 3 % if calculated over the whole heating production.

In the Mediterranean, a three times bigger solar field can double the solar fraction for the heating production (DHW demand and space heating) but the number of hours where the stagnation phenomena can occur drastically increases. To reduce this effect or even eliminate it, solar collectors can be installed on the façade with only 4% of solar fraction reduction with respect to the installation on the roof.

In a Nordic climate, the behavior is similar, moving from STC_1 to STC_3 the solar fraction for heating production almost double, but also stagnation hours occur. The installation of solar panels on the façade strongly limits the stagnation hours with only 1% less of solar fraction.

Accordingly, similar trend is observed also in the s-MFHs (see Table 5). The percentage of solar collectors over living are is smaller in s-MFH with respect to SFH because of the lower available surface. Despite this, a solar field of almost 37 m² on the roof causes the stagnation phenomena both in the Mediterranean and in the Nordic climate. Again in this case, stagnation disappears if the panels are installed on the façade with a solar fraction reduction of 3% (see Table 5).

Table 5: Solar fraction for heat production

AREA	Slope	ROM_SFH		STO_SFH		ROM_s-MFH		STO_s-MFH	
		SF [%]	[hr]	SF [%]	[hr]	SF [%]	[hr]	SF [%]	[hr]
no ST	0	0%	0	0%	0	0%	0	0%	0

STC_1	*30°*	21%	101	12%	0	22%	37	13%	0
STC_3	*30°*	44%	1985	21%	374	34%	624	20%	68
STC_1	*90°*	17%	0	9%	0	17%	0	11%	0
STC_3	*90°*	40%	30	20%	0	31%	0	18%	0

In terms of final energy consumed for covering heating and DHW demands, the savings of using STC_1 amount to 26% in Rome – SFH and 12% in Stockholm - SFH. Despite the lower ratio of solar panels area over living area, same behavior is observed in the s-MFH. The STC_3 instead, that corresponds to around one fourth of the SFH roof surface, in the warmer climate can cover 43% of the heating production while in the colder one 20%. For the s-MFHs the final energy for heating production reduction with STC_3 amounts to 34% and 18% respectively in Rome and Stockholm (Fig. 2).

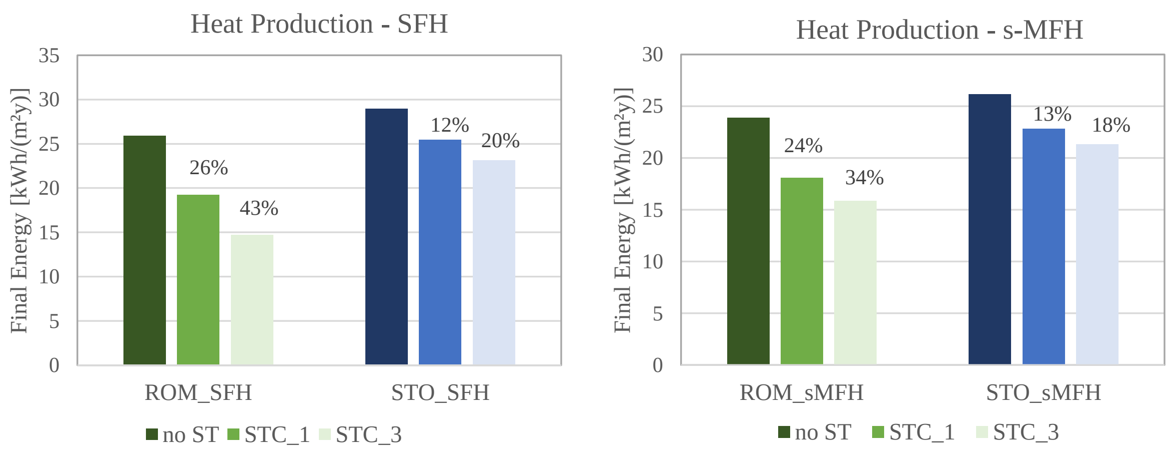

Fig 2 Final Energy consumption for heating production for two solar thermal fields in comparison with the case without thermal panels in SFH (left) and s-MFH (right)

In addition to two panels slope, the database contains also results for two different solar tank sizes, 50 l/m² and 100 l/m² of solar area. With respect to the final energy consumption for heating purposes, a slightly better performance is observed with the bigger storage, in the order of 2-3%.

Solar thermal panels influence only the consumption due to space heating and DHW consumption, so their contribution on the total building consumption depends on the share between the different uses. In particular for the cases here analysed, these quantities on the total energy consumption of a SFH for STC_1 and STC_3 fields amount to 20% and 33% in the Mediterranean, and 10% and 16% in the Nordic. In a s-MFH instead, the energy reduction due to the installation of a solar thermal field can achieve 23% in Rome and 16% in Stockholm if the biggest studied area is installed.

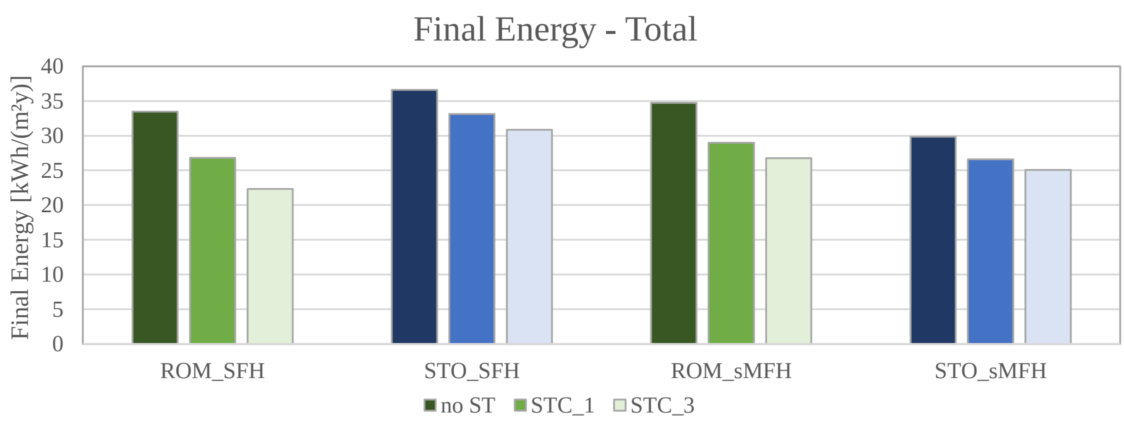

Fig. 3 Total Final Energy consumption for two solar thermal fields in comparison with the case without thermal panels

Photovoltaics

The analysis on the contribution that a photovoltaic field could give on the total energy consumption of a building focuses first on the share between self-consumption versus fed-into-the grid and then on the savings that this technology can bring to the building total final consumption.

Fig. 4 shows the share options of PV production between the energy used by the HVAC system (red bar), by other building uses like appliances (orange bar) and fed into the grid (yellow bar). The following comments do not consider any feed-in-tariff for the latter share option as every country has its own regulation that often changes.

In this contest, a solution that maximizes the auto-consumption is considered more favorable. Looking at the left graph of Fig. 4, the solution with only 1 kWp installed represents the best compromise between production and consumption. Most of renewable energy production is in fact used by the HVAC system itself or by other uses. Installing 3 kWp, instead, around 60% of the produced energy is not consumed by the building. This scenario becomes favorable only if convenient fees are foreseen. On the total PV production, the installation of the PV panels on the façade in place of on the roof brings less energy production of 24% in Rome and 13% in Stockholm. In the following it will be shown as the lower energy production has a minor effect on the single uses.

Different behavior is observed for the s-MFHs where, as for the STC, the percentage of PV area on the living area is lower than in the SFH. Electricity production of a 3 kWp PV field is used for 95% from the building uses. If instead 5 kWp of PV is installed, that means covering 6.5% of the roof area, the self-consumption amounts to around 85-90% both in the northern and in the southern climate.

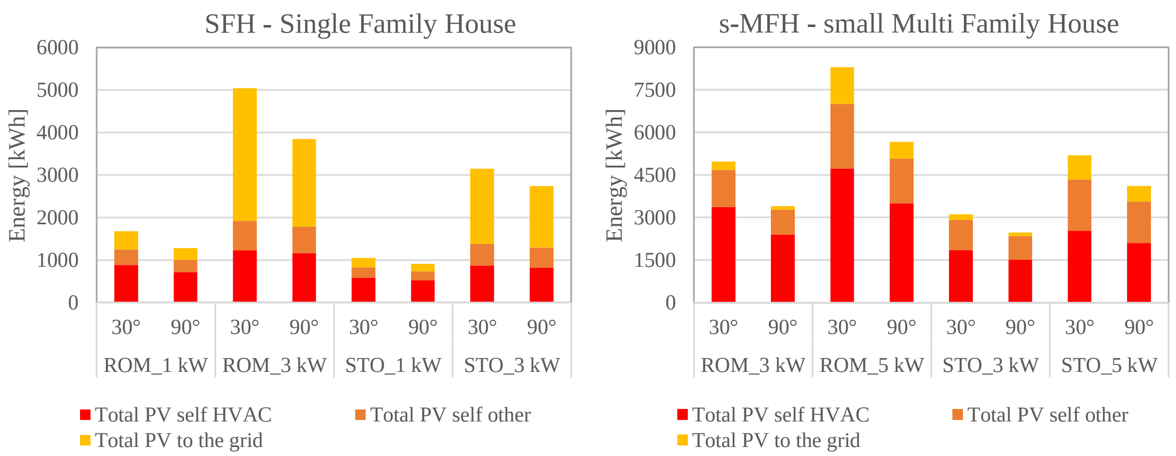

Fig.4 PV production and self-consumption for SFHs (left) and s-MFH (right) for two climates and two field sizes

Looking at the savings that the analysed solar fields bring on the different energy uses consumption, 1 kWp of PV in a SFH is able to reduce space heating consumption of 7% in Rome and 3% in Stockholm. If instead 3 kWp are installed, the reduction is respectively of 12% and 7%. The advantage in this case seems to be not relevant, but doing the same consideration for the cooling load, the reduction is higher than 80% in both climates. Together with the space heating and cooling, PV contributes also in the decrease of DHW preparation energy need. Looking at the total building consumption, we can observe that 1 kWp of PV field in a SFH reduces 27% of the total electricity in the southern climate and 16% in the northern one. A three times bigger field helps in achieving 38% and 24% lower electricity consumption respectively in the two climates (Fig. 5).

The above considerations refer to a PV field installed on the roof. If it is positioned on the south façade, the winter harvesting slightly decreases, in the order of 1-2%, but the summer harvesting increases. The yearly electricity reduction therefore amounts to 36% in the Mediterranean and 23% in the Nordic climate.

Although in s-MFHs the share of PV field over living area is lower than in SFHs, the higher percentage of self-consumed electricity makes the electricity savings similar in both building typologies. In particular, the bigger PV field – 5 kWp – brings 16% and 7% of energy reduction in winter for the two climates, Mediterranean and Nordic, while for the cooling the reduction amounts to 34% and 46%. Accounting for also the DHW production and the yearly behavior, the PV_3 field (Table 2) is able to reduce the total final consumption for the HVAC system of 30% in the Southern climate and almost 20% in the Northern one. If the PV field is installed on the façade, the total energy savings for the two climates reach respectively 23% and 16%.

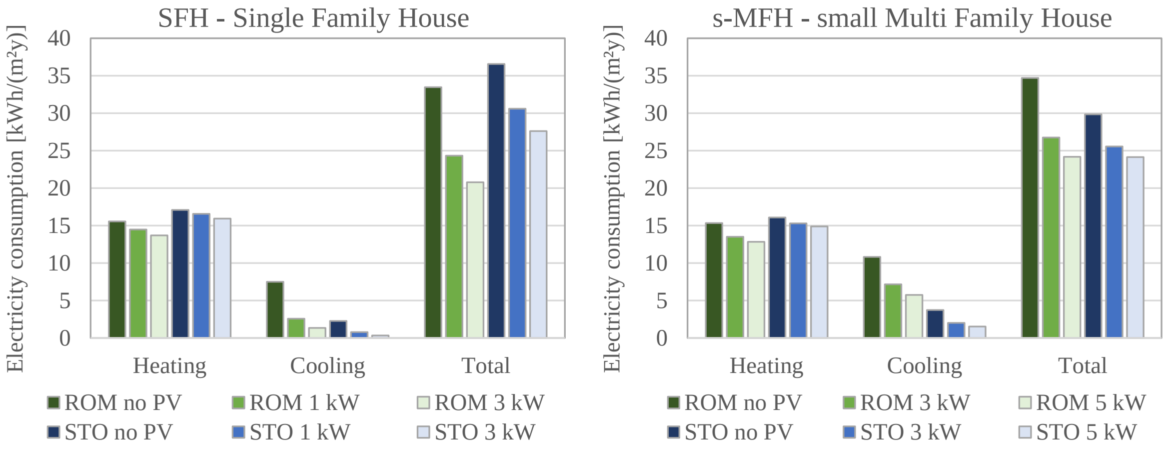

Fig.5 Final energy consumption for space heating, space cooling and total for SFH (left) and s-MFH (right) in two climates by different PV field sizes.

3.4 Retrofit solutions total savings

In the previous paragraphs, each retrofit measure has been analysed separately. In Fig.6 the initial PE consumption for space heating, space cooling and DHW preparation is compared with the PE savings that each measure gives to the total energy consumption. For the solar technologies, it has been considered the contribution of STC and PV together, considering the PV_3 size on the roof and STC_3 on the façade.

Table 6 summarizes the savings in percentage on the initial total primary energy consumption by each retrofit solution. The last line instead indicates the percentage of PE consumption after retrofit on the one before retrofit.

In the study, the retrofit measures for the envelope were decided once fixed the heating demand energy level. Consequently, depending on the initial building demand, the savings obtained by the envelope are larger where the initial building demand is higher. Buildings with same external surfaces thermal characteristics but different S/V ratio, i.e. SFH and s-MFH, can have heating demand one the double of the other. As a consequence for the studied cases, especially in SFH, the retrofit measures applied to the envelope are the ones that mostly contribute on the primary energy consumption reduction. An efficient HVAC system has a major impact on the heating production consumption than on the consumption for cooling because of the performance of the reference case. With this regard, the savings due to the HVAC system only amount to 32% and 23% in SFH respectively southern and northern climate and 38% and 31% in s-MFHs. This means that with respect to a boiler with 0.8 efficiency and split units with 2.5 EER, the final primary energy consumption can be reduced by around one third thanks to the use of a more efficient system composed by an air-to-water heat pump.

Additionally, even small surfaces of solar technologies as PV and thermal collectors, have an important impact on the total energy consumption. In fact in Southern climates as Rome, the combination of 3 kWp of PV and 6 panels in STC can almost halve the final consumption in SFHs. 5 kWp of PV and 16 panels of STC in s-MFH instead allow 43% of the total primary energy reduction. Due to climate conditions in the Northern climate the contribution of solar technologies on the total energy consumption is slightly lower, but still 34% in SFH and 29% in s-MFHs.

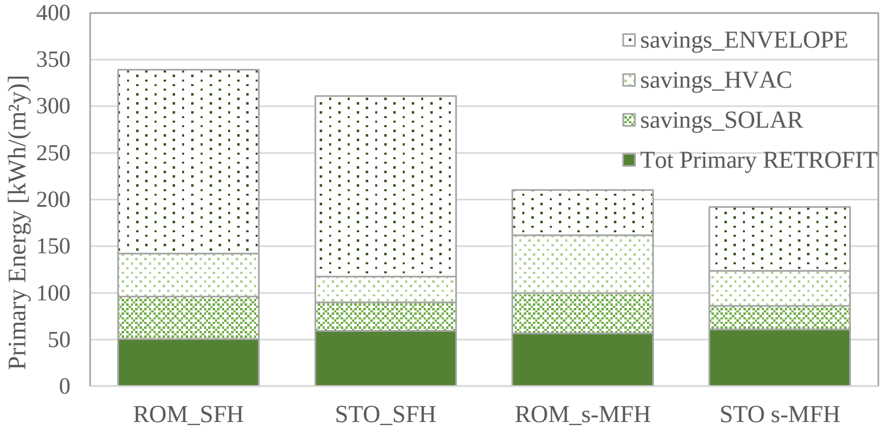

Fig. 6 Primary energy savings due to the retrofit solutions

Table 6: Energy savings of each retrofit solution on the total PE consumption pre-retrofit

Primary Energy	*Units*	SFH Mediterranean	SFH Nordic	s-MFH Mediterranean	s-MFH Nordic
savings_envelope	*kWh/(m²y)*	58%	62%	23%	36%
savings_HVAC syst	*kWh/(m²y)*	14%	9%	29%	20%
savings_PV+STC	*kWh/(m²y)*	13%	10%	21%	13%
Total PE retrofit	***kWh/(m²y)***	**15%**	**19%**	**27%**	**32%**

Finally, thanks to the interventions on the building envelope, HVAC system and use of renewable energies, primary energy consumption for space heating, cooling and DHW preparation of a SFH located in the Mediterranean climate is reduced up to 15% of the consumption before retrofit. Similarly, if the building is located in the Nordic climate, the PE consumption after retrofit amounts to 19%.

Due to the lower PE consumption already pre-retrofit of s-MFHs with respect to SFHs, the application of the renovation measures in this case reduces the primary energy consumption up to 27% in the southern climate and 32% in the northern one.

4. Conclusion

The large share of European residential buildings built before 1970 with high energy consumption requires measures that can contribute to the reduction of the final energy consumption. In this contest, this work wants to show how market-available solutions can drastically reduce the energy consumption for space heating, cooling and DHW of a building. In particular, the paper focuses on the contribution that solar technologies, e.g. photovoltaic and solar thermal collectors, gives on the final energy consumption reduction. In this contest, considerations are given with respect to the influence of each technology on the final uses, the installation position on the building and solar field size.

Regarding the panel position, both for PV and STC the installation on the façade obviously reduces the solar energy harvesting, but this does not mean a relevant difference on the final energy consumption. In fact, thanks to the solar radiation direction through the year, thermal panels vertically positioned become advantageous in reducing the stagnation hours in summer and in maximizing the winter harvesting. On the contrary, the PV contribution is mostly exploited during summer period due to the cooling demand that is covered by electricity. In this case, the difference on the solar radiation harvesting between the two positions is higher for the summer period. Despite that, even in the southern climate, the impact of the vertical position instead of on the roof on the total energy consumption is less than 10%.

Another important achievement of the study is that even small ratios of solar fields on living area can help on achieving relevant energy savings. In fact, looking at SFHs, solar thermal collectors of 2 to 6 panels can reduce the heating production (space heating and DHW preparation) of 26-43% in the southern climate and 12-20% in the northern. In s-MFHs due to the lower ratio between solar field versus living area, 8 to 16 panels contribute with 24-34% in the southern climate and 13-18% in the northern climate for the heating production reduction.

Regarding the PV, especially if it is not foreseen a feed-in-tariff policy, the solar field should be sized with the self-consumption capacity. From the study, 1 kWp for SFH and 3 kWp for s-MFH use respectively 80% and 95% of the PV production for self-consumption.

Concluding, in a deep renovation process of a residential building, in addition to retrofit measures on the envelope and HVAC system, even limited solar fields areas of PV and/or STC can contribute on an additional final energy consumption reduction. In fact, with respect to the case without solar technologies, these can allow additional energy savings of around 45% in the Mediterranean climate and 30% in the Nordic climate.

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