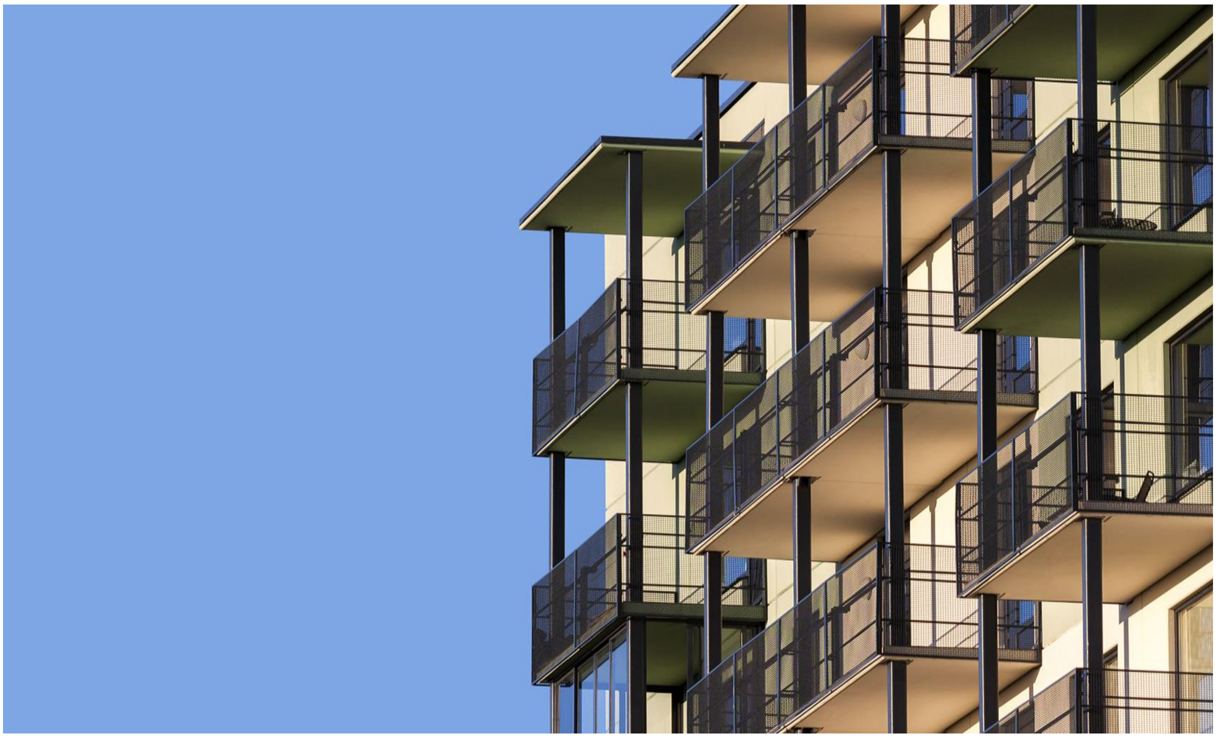
D2.10a - Suitable H&C layouts at building and district level, including monitoring, control strategy and energy performance



Standardised approaches and products for the systemic retrofit of residential BUILDings, focusing on HEATing and cooling consumption attenuations

BuildHeat

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1 Summary

The design of a HVAC system of multiapartment buildings needs to tackle a range of needs including energy efficiency, installation cost, installation feasibility, comfort, building architecture, building regulations, systems monitoring and control typology, user/customer expectations.

Distributed or decentralized systems are suited in buildings where the installation of a centralized system results too complex or expensive, when running costs need to be easily split among the users or when there is disagreement among the dwelling owners on renovating the building. One of the main advantages of decentralized systems is very low thermal losses and consumption for auxiliaries.

Centralized systems involve the installation of a communal generation unit. A wise design of a centralized system allows to install smaller generation units by exploiting the non-contemporaneity of the loads, therefore reducing installation costs. Maintenance costs are lower than in decentralized systems as the system is one and located in the technical room (i.e. the single apartments do not need to be accessed).

Mixed configurations have decentralized generation units connected ne to another through a main control system and/or hydraulic circuit, supporting (source or sink) the dwelling generation units.

Energy efficiency of HVAC systems can be improved by using thermal storages at building or dwelling level, reducing and shifting peak loads to “convenient” periods of the day, reducing devices’ on-off cycles, reducing distribution losses and increasing overall system resiliency.

The choice of an efficient generation device and a proper layout configuration does not guarantee good performance of the whole system. For this reason, the control system plays a key role for a good and integrated operation of all the system parts.

In an HVAC system configuration with efficient generation devices, thermal storages, renewable energy technologies, effective control strategies need to be implemented to improve the use of renewable energies, act on peak shaving, exploit the most convenient energy tariffs, reduce the generation unit on-off cycles and reduce thermal losses.

This document analyses possible heating and cooling system configurations for multifamily houses, their sizing principles and expected performance with respect to three of the BuildHEAT demonstration cases.

The analysis conducted on different layout configurations, decentralized, centralized and mixed, applied to different building typologies located in four European climates shows as effective HVAC systems can reduce Primary Energy consumption of all thermal uses of around 30 to 50% for given thermal demand. Coupling of these systems with technologies that exploit renewable energies contributes to an additional reduction Primary Energy consumption of up to 27%.

2 H&C systems layouts

Heating and cooling (H&C) system layouts can be classified as centralized or decentralized, depending on the production of heating and cooling energy being managed either at building or dwelling level. In cases where the production is distributed through the dwellings, but they interact through the control system or a "driving" hydraulic circuit, the system layout is defined Mixed.

Conventional centralized systems are usually composed by a generation device that directly provides space heating or DHW to the user. A general representation of the layout of this kind of systems is reported in Figure 1. In these systems, the generation device is continuously switched on for covering any DHW or space heating need. To guarantee a comfort temperature for DHW in multi-family houses, warm water continues circulating in a recirculation circuit. As a consequence, normally high thermal losses occur, while electricity consumption of the circulation pump cannot be neglected.

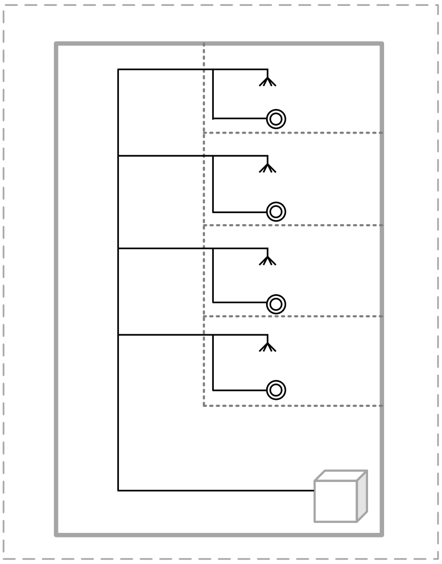

Figure 1 – Layout of a general traditional heating and cooling system

Conventional decentralized systems are instead composed by a generation unit located in each dwelling that covers space heating and DHW needs. Commonly, these systems have low efficiency devices installed, such as electric or gas boilers. Space cooling in both cases is traditionally covered by split units at dwelling level.

In light of a building renovation and reduction of energy consumption in the residential sector, existing H&C systems need to be replaced with more efficient ones. Depending on the building typology, dwelling ownership, available space in the technical room and management of the renovation works, different H&C solutions can be implemented.

In the following, different HVAC systems layouts for centralized, decentralized or mixed systems are assessed. All these configurations have some elements that help to reduce thermal losses, on-off cycles of the generation device allowing a longer lifespan, electricity consumption of the auxiliaries, use of renewable sources.

2.1 De-centralized and mixed systems

2.1.1 De-centralized systems

With distributed systems, we refer to a collection of multiple independent units placed in each dwelling working in isolation. Each dwelling therefore provides space heating (SH) and cooling (SC) and Domestic Hot Water (DHW) by means of its own system.

In the retrofit of multi-family houses, decentralized systems are appropriate if:

- the existing system is also a decentralized system and the installation of pipes through the building results too complicated or expensive;
- the dwellings owners do not agree to retrofit the building simultaneously;
- the dwellings of a building are often empty or tenants change frequently;
- the energy bills and maintenance costs need to be easily split among the inhabitants;
- the building typology is not suitable for the implementation of a centralized system, i.e. the extension of the building in vertical, high number of floors, or horizontally causes excessive thermal losses and head losses.

Main advantages of this kind of systems can be identified in:

- installation of H&C devices only in some dwellings is possible;
- reduced thermal losses and auxiliaries' electricity consumption due to the absence of pipes outside the dwelling;
- easy management of the system;
- flexibility of operation around different dwelling needs.

Together with this systems advantages, there are also some disadvantages such as:

- intrusive installation works;
- higher overall maintenance costs compared to a centralized system;
- higher overall installation costs, since the generation device is sized for covering the single dwelling peak loads;
- not optimal working conditions due to the difference between device size and dwelling loads;
- occupation of a portion of the dwelling by the technical room.

A schematic representation of this kind of system is reported in Figure 2 (left).

Adopting a thermal storage can contribute to the increase of the system efficiency as it reduces the generation device on-off cycles and the time of space heating stop for covering DHW load. Moreover, it can help shifting peak loads towards favourable periods of the day (Figure 2 right).

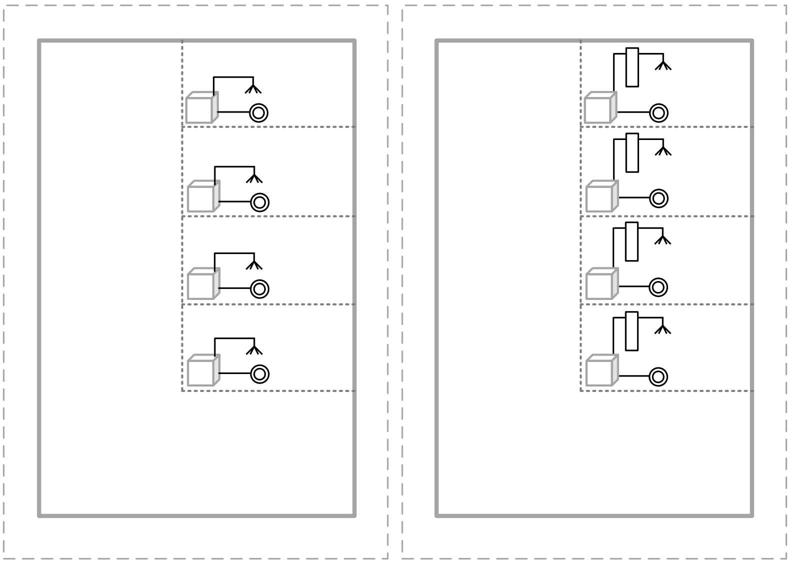

Figure 2 – De-centralized systems layouts

2.1.2 Mixed systems

Mixed configurations have decentralized generation units connected ne to another through a main control system and/or hydraulic circuit, supporting (source or sink) the dwelling generation units.

An example of this system is a multifamily house with dwelling water-to-water heat pumps that are connected through a communal water loop driven by a borehole field (Figure 3 left). In this case, each dwelling is independently managed for heating and eventually cooling production but interacts with the other apartments as the temperature at heat pump source side depends on the total load insisting on the borehole field.

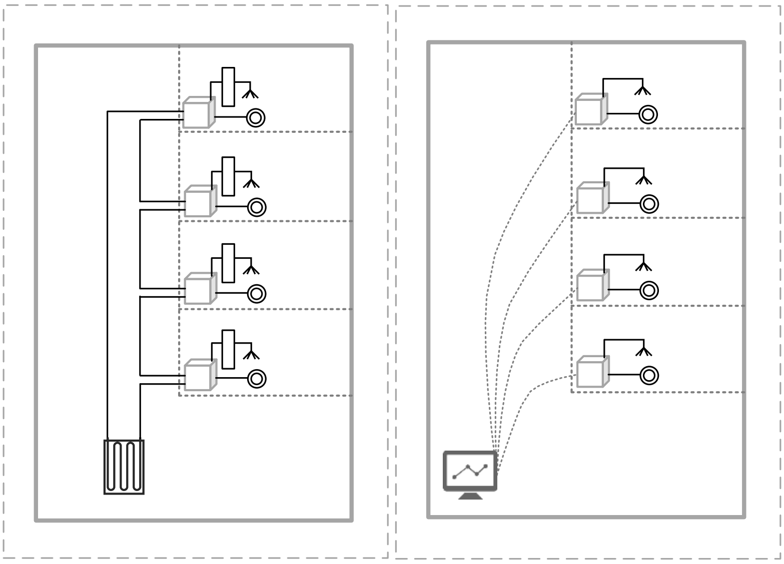

Figure 3 – Mixed systems layout with a common control system (left) or water loop (right)

In this kind of solutions, control strategies at building level can improve the overall system efficiency by regulating the heat pumps operation in order to reduce the number of devices simultaneously requiring or rejecting heat from/to the ground, to reduce electricity consumption of the water loop distribution pump and to optimise the exploitation of renewable energy available. A thermal storage in each apartment eases the flexible management of the mixed system.

Mixed systems also include decentralized heating and cooling solutions that are connected under a common high-level control. This configuration is favourable for electricity peak shaving, for fostering the use of renewable energy and for reducing energy costs by exploiting advantageous energy tariffs (Figure 3 right).

2.2 Centralized systems

Centralized H&C systems for multi-family houses are particularly proper when:

- The building is owned by one entity that can decide for a renovation of the building as a whole;
- The number of floors is not too high (< 10÷12) for maintaining pressure drops and thermal losses under certain limits;
- Retrofit works involve also the envelope in a way that new piping can be integrated in the façade;
- There is a suitable technical room in the basement or on the roof.

For buildings with more than one staircase, one H&C system for each staircase can be installed in order to reduce thermal losses and head losses.

This system typology is very flexible and suitable for several cases. Main advantages of installing a centralized system for heating and cooling production in a multi-family house are:

- Non-intrusive renovation works as they mainly occur in communal spaces, on the basement or on the roof;
- Placement of the equipment in a common technical room;
- Easier and cheaper maintenance as all the operating components are grouped together;
- Optimized equipment sizing thanks to the non-contemporaneity of the load;
- Use of building management system with possible overall electric consumption reduction and peak shaving.

Despite the advantages that centralized systems can bring, some disadvantages should also be considered. The main drawbacks are:

- thermal losses through the distribution piping due to the distance between the heat generation and the user;
- Electric consumption of auxiliaries of the distribution circuits.

2.2.1 District/building level

A centralized system can serve more than one building or staircase. In this case, the generation device produces heating at high or low temperature that is distributed to the single buildings/staircases. T

he solution with high temperatures can foresee a thermal storage for each building/staircase where heat is accumulated and then used according to the needs (Figure 4, right building).

In the case heating is produced at low temperatures a communal storage is not suitable, while dwelling heat pumps can increase the temperature at the desired level. This solution reduces thermal losses through the distribution and energy use in each dwelling for the production of heating or cooling (Figure 4, left building).

The advantages of having a unique generation device at district level is i) reduced installation and maintenance costs as only one device is used; ii) exploitation of the non-contemporaneity of the load with a consequent lower than the total peak installed capacity; iii) higher working efficiency as the generation device works mainly at full load.

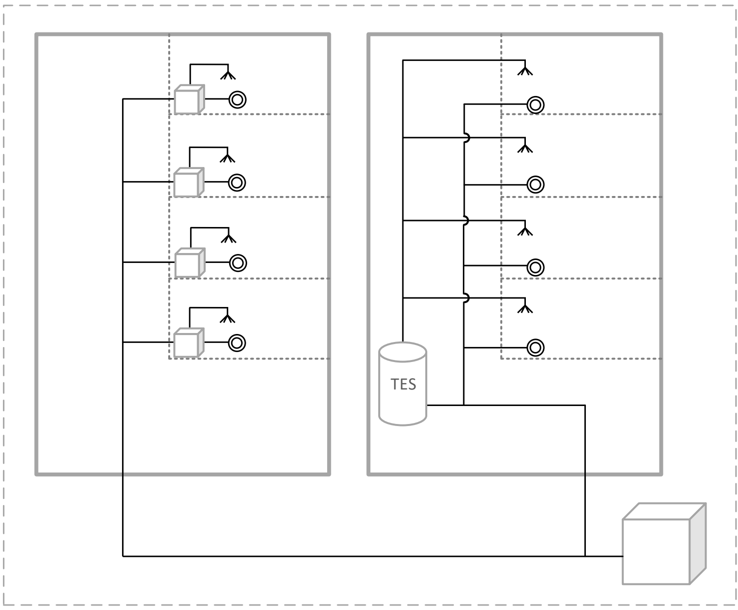

Figure 4 – Configuration of a generation device at district level for a production at low (left) or high (right) temperature

2.2.2 Thermal storage at building or dwelling level

As previously mentioned, one of the disadvantages of centralized systems is thermal losses. A solution that helps at reducing these and also limits the generation device on-off cycles is the use of a thermal storage (TES). This can be used at building and/or dwelling level.

Figure 5 shows two different distribution solutions, with 4 or 2 pipes. The 2-pipes distribution on the right provides alternatively DHW and space heating or space cooling. The main advantages of installing a 2-pipes system are the lower installation costs and the occupied space. However, this system is less capable to handle the loads variation and the process to switch from heating to cooling load to the other implies thermal losses due to the water capacity contained in the pipes. For reducing discomfort due to the interruption of space heating for DHW production and thermal losses when moving from DHW to cooling and vice versa, thermal storages for DHW at dwelling level are needed.

The 4-pipes solution (on the left in the figure) allows providing DHW and space heating or cooling at the same time, as two different pipes are allocated to hot and cold fluids. Although this configuration allows to simultaneously manage different demands, it shows high installation costs due to the doubling of pipelines, and therefore valves and pumps. On the contrary, comfort and continuity of the service.

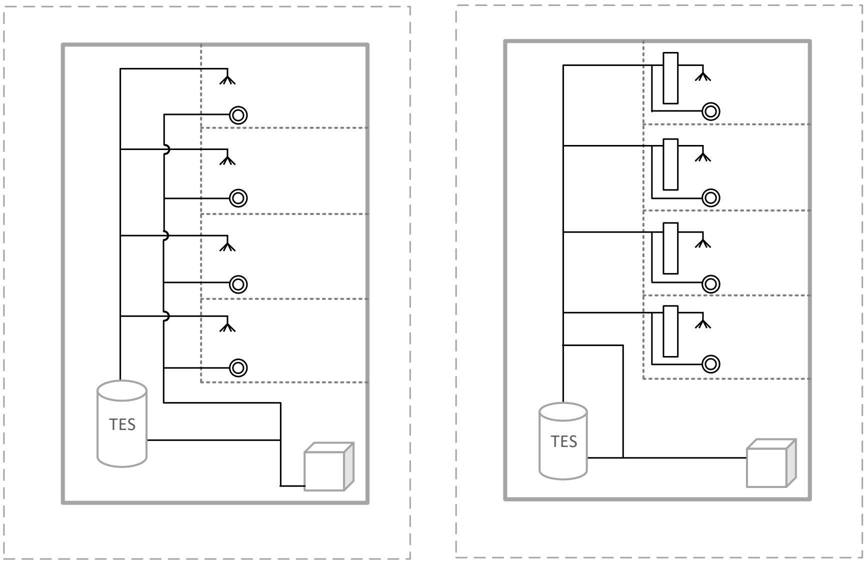

Figure 5 – Heating and cooling system and DHW production with 4-pipes configuration (left) and 2-pipes configuration (right)

In addition or as an alternative to the thermal tank at building level, it can be adopted a small storage at apartment level. The advantage of this solution lies in the possibility to install a smaller storage tank at building level and dislocate the domestic hot water storability in the apartments. In addition, this configuration allows playing with charging strategies in order to facilitate peak shaving, following the most convenient energy tariff along the day and reducing thermal losses, by eventually removing the DHW recirculation circuit and charging the small dwelling DHW storages during specific periods of the day.

The adoption of thermal storages at apartment level applies to both 2- or 4-pipes systems (Figure 6 left and middle). For a better management of the DHW and space conditioning production, an additional buffer can be used in the space heating/cooling circuit (Figure 6 right). This configuration allows full flexibility of the storages charging and management of the generation device operation.

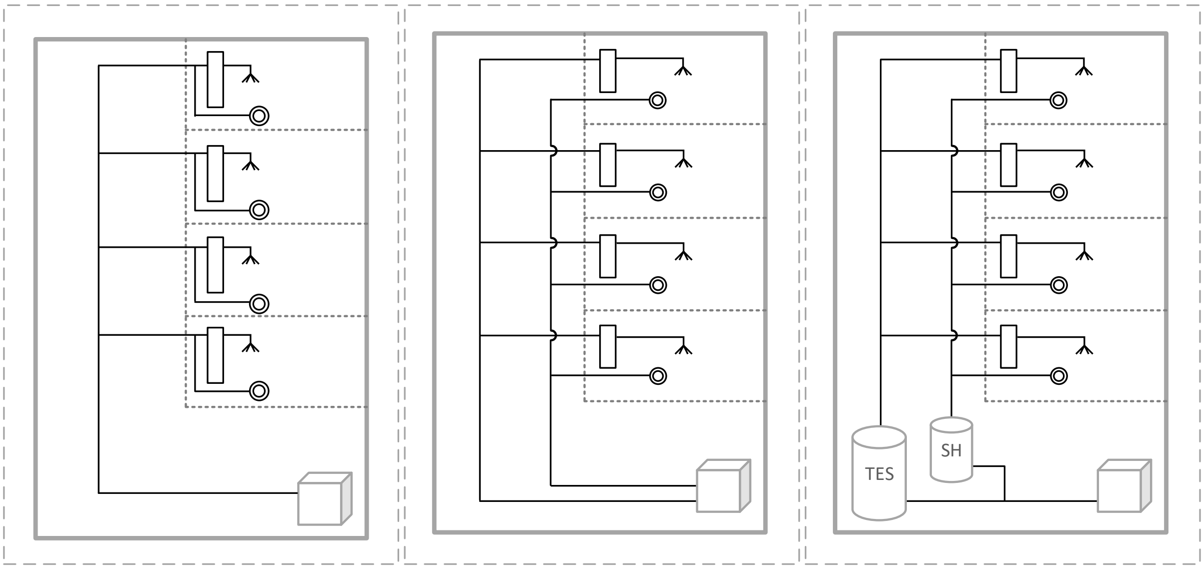

Figure 6 – Distributed thermal storages at apartment level in 2-pipes (a) and 4-pipes (b) systems and with centralized tanks for DHW uses and space heating/cooling

2.2.3 Solar Thermal System integration

The integration of solar thermal systems in multi-family houses can contribute to the DHW production only or to space heating too, with a consequent reduction of energy consumption. Depending on the operating modes, the layout takes different configurations.

Integrating solar thermal collectors can happen at building or dwelling level, depending on the available surface in the building and energy management between the tenants/owners. In case each dwelling is equipped with its own solar thermal collectors, a tank is needed in each dwelling for storing the harvested solar energy (Figure 7 left). If the solar thermal field is at building level, harvested energy can be stored in a dedicated central solar storage tank (Figure 7 middle) or in the lower part of the stratified tank used for the DHW storage purposes (Figure 7 right).

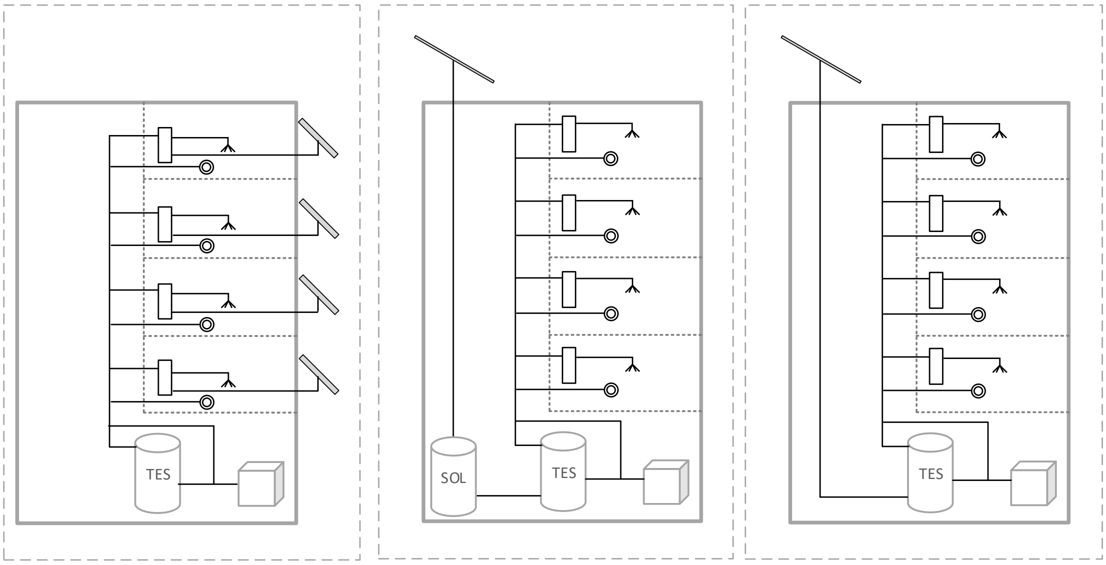

Figure 7 – Solar thermal collectors integration at apartment level (left), and at building level with separated tanks for solar energy and back up production (middle) or with stratified tank (right)

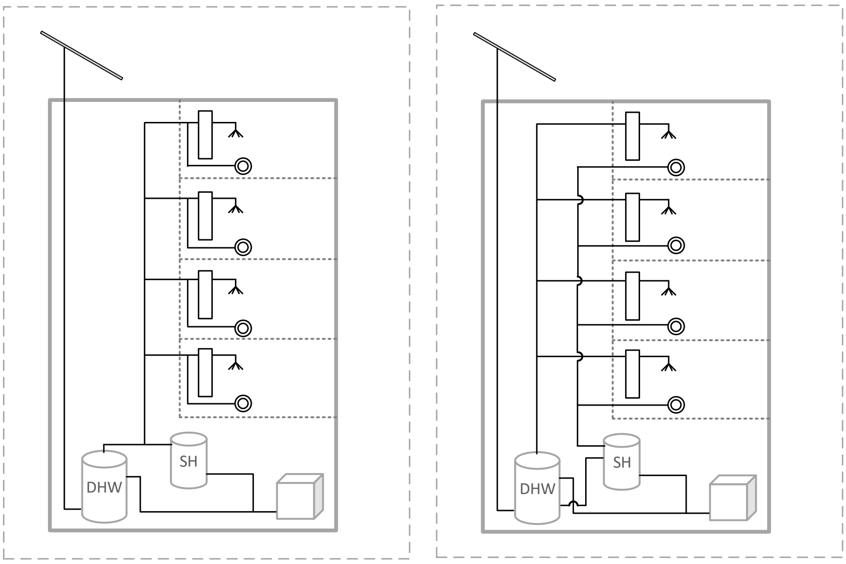

Figure 8 – Use of solar energy for DHW preparation only (left) or for space heating too (right)

The solar thermal system can be exploited for space heating too. All the mentioned configurations, 2-pipes, 4-pipes, with buffer for space heating (Figure 8) or with only one tank for solar energy, DHW and space heating allow this configuration.

Besides the different layout configurations, in this kind of systems control strategies become crucial. In fact, the presence of thermal storages allows to play with the charging cycles based not only on the user needs, but also on the energy tariffs, loads contemporaneity, supply water temperature and renewable energy availability.

3 H&C systems sizing

Systems sizing is key to ensure a high efficiency of the system. For decentralized configurations, the choice of the components size is usually linked to the smallest available unit size despite the dwelling area or the location. In centralized systems instead, the size of thermal storages or of the heat pump can influence the harvested and distributed energy from solar collectors, the device working efficiency or the internal comfort.

In the following, two parametric studies on thermal storages for solar energy and DHW production and for heat pump sizing are reported.

3.1 Thermal storages in solar thermal systems

The study here reported is focused on the investigation of the most suitable solar thermal tank and DHW tank volumes for enhancing the solar energy harvesting by reducing stagnation hours. The system is supposed to be installed in the Rome demo case (see description in [2]).

The solar collector field is connected to a solar tank following the scheme in Figure 7-central. The solar collector field and solar collector panel characteristics are summarized in Table 1.

Table 1 - Solar field circuit characteristics

Solar collector characteristics	Value
Model	VIESSMANN Vitosol 100-FM
Collector aperture area	2.3 m^2
Collector slope	90°C
Collector Azimuth	-13°
Collector linear loss coeff.	3.792 W/m^2K
Collector quadratic loss coeff.	0.021 W/m^2K
Optical efficiency	0.824
Solar field characteristic	Value
Number of single modules in series	6
Number of single modules in parallel	11
Field total area	151 m^2

Parametric simulations have been performed for different combinations of solar and DHW storages sizes. The study refers to the summer season only as it aims at studying the contribution of the solar collectors to DHW production. The yearly DHW demand has been assumed to be 14 kWh/m^2 that represents a very low use. Parameters investigated and their ranges in the parametric analysis are reported in Table 2.

Table 2 - Parametric values for the sizing of a solar and DHW tanks

Parameter	Values
Maximum temperature allowed in the storage tank	95°C – 105°C
Solar storage Volume	300 – 600 – 900 litres
DHW storage Volume	300 – 600 litres

Simulation results highlight some significant behaviours. First, despite of parametric values configuration, both TES volume and DHW volume do not affect significantly the total stored and supplied solar energy as well as stagnation hours for the solar collector field. In fact through the different configurations and considering the same DHW energy demand, the harvested solar energy ranges in all the cases between 17500 and 19000 kWh (see Table 3).

The number of stagnation hours mainly depends by the DHW demand, higher for lower demand, and by the setpoint for stopping the circuit. As expected, increasing TES and DHW storages volume helps to raise system capacity to store thermal energy implicating stagnation hour reduction.

Table 3 – Performance analysis of different thermal storages sizes

		Solar thermal storage / DHW storage				
95°C / 14 kWh/m²y	Units	300 l/300 l	600 l/300 l	300 l/600 l	900 l/300 l	600 l/600 l
Harvested solar energy	kWh	17847	18247	18137	18558	18507
Exchanged energy	kWh	15795	16150	16056	16430	16388
Stagnation hours	h	124	108	110	99	98
105°C / 14 kWh/m²y						
Harvested solar energy	kWh	18223	18649	18548	18963	18922
Exchanged energy	kWh	16145	16534	16442	15822	16786
Stagnation hours	h	33	24	25	16	16

3.2 Heat pump sizing study

The size of the heat pump depends on the maximum heating capacity required for covering the user needs. In this study, considerations refer to the heating production aimed at covering space heating and DHW demand. The analysis has been focused on the Rome demo case [2], however some considerations can be extended to a wider set of cases.

The approach proposed here starts from the calculation of the building loads throughout one year where weather conditions, occupancy habits and DHW use are considered on a hourly. As a consequence, a profile of the building heating is individuated.

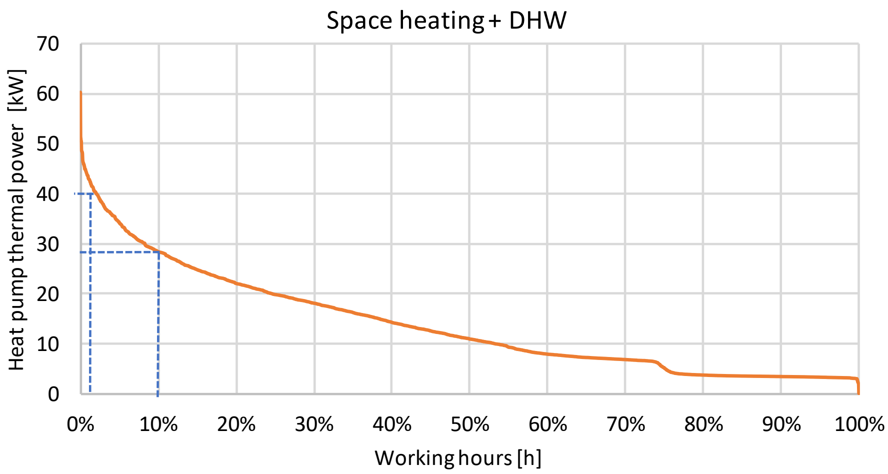

Figure 9 – Cumulative thermal power for space heating and DHW required by the building

In the study, three different HP sizes are compared in terms of delivered energy, daily on-off cycles and comfort conditions provided. Starting from the building cumulative required thermal power for space heating and DHW (Figure 9), the peak load is 60 kW and occurs less than 1% of the total operating hours. For 2% of the working hours the required thermal power is one third lower than the peak while for 90% of the working hours the required peak is half of the peak power.

Despite this consideration and assuming that the installed heat pump is the only generation device, the heat pump size needs to be higher than the peak power for considering working condition out of the nominal conditions. For this reason, three different sizes of 85, 67 and 50 kW have been compared in terms of electricity consumption, thermal comfort and heat pump operation conditions.

Reducing the HP size, there is not an appreciable energy saving in the simulation scenario. This is because inverter-driven heat pumps, even if oversized within some ranges, are capable to adapt their capacity to the demand. The benefit of a correctly sized heat pump, however, is mainly in the improved operation and in the investment costs.

Adopting a heat pump size 40% and 10% higher than the heating building peak, the daily average number of on-off cycles is reduced from 28 to 21 with a consequent increase of the heat pump efficiency and life duration expectation. If the size of the heat pump is reduced up to 50 kW, the daily number of on-off is almost halved as the heat pump stays on for longer periods (Figure 10).

If from one side the reduction of the heat pump size increases the component efficiency and life expectancy, on the other side there could be discomfort in the internal ambient. Dynamic simulations of the building and energy plant have shown as the case with 50 kW leads a weighted discomfort time[1] (WDT) of 3.2 hK. This can be interpreted as if the indoor temperature is one degree below the setpoint that around three hours during the year (here setpoint is maintained 24 hours a day without night setback). In the case of 67 kW, the WDT is 0.6 hK, value that is considered as acceptable.

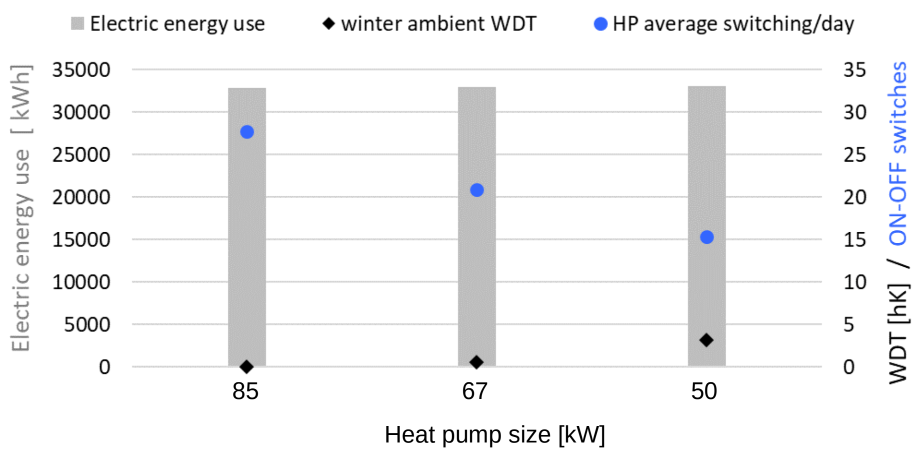

Figure 10 – Impact of the HP size on the energy consumption, the discomfort time, and the number on ON-OFF switches of the HP

[1] The weighted discomfort time (WDT) is here defined following the EN 15251, i.e. a time integral of the difference between the ambient temperature and the comfort temperature (setpoint). Adaptive comfort is not considered here.

As a consequence, for the specific case a heat pump with a size 10% higher than the heating peak load is suitable for covering the building demands, by guaranteeing an appropriate comfort and device operation conditions. On the other hand, if investment costs and minimisation of on-off cycles are pursued, an undersized heat pump with electric backup can provide same comfort and equivalent energy performance. The maximum size of an electric backup is hardly stated, since national regulations can hinder the adoption of electric rods covering loads larger than 50 to 100 kW.

4 Energy performance of different HVAC systems configurations

The affordability of a H&C system depends on different factors as comfort, energy and economics. However, in the following a focus on the energy aspects only will be reported for investigating the energy performance of different H&C systems configurations.

4.1 Energy indicators and system performance

The energy indicators used for the evaluation of energy performance are here presented and explained.

Useful energy - UE

The Useful Energy (UE) is the energy required by the inhabitants for maintaining the set internal temperature and relative humidity. The UE can be also meant as the building demand both in terms of space heating or cooling.

Final Energy - FE

For electricity driven systems, FE equals the electricity used to drive the HVAC systems, while for gas or biomass driven ones, the FE equals the Higher Calorific Value (HCV) of the used fuel by its mass consumption.

Primary Energy - PE

In order to compare systems and technologies in terms of their environmental impact, the use of the Primary energy concept is recommended in this report. The PE use gives information on the consumption of non-renewable energy sources for the provision of useful energy output of the system. This indicator helps to compare systems and technologies that use different energy sources.

For the calculation of this figure, the CEDNRE – Cumulative Energy Demand (CED), non-renewable – is used: it quantifies the non-renewable primary energy used to provide the final energy, including the energy used for construction of the electric grid and power plants. This indicator accounts for the primary energy from fossil, nuclear and primary forest resources (i.e. original forests that are destroyed and replaced by farmland) defined in terms of primary energy to final energy - kWh_{PE}/kWh_{FE}.

$$PE = FE * \mathrm{PEF}$$

Since the provenance of the electrical energy at the plug varies widely from country to country due to their power generation and import mixes, the adopted values are reported in Table 4 and refer to the “Primary Energy Factors and Members States Energy Regulations” document [3].

Table 4 – Values of PEF

	PEF [kWh_{PE}/kWh_{FE}]
Electricity	2.3
Mains gas	1.1

Seasonal Performance Factor - SPF

The performance of the H&C generation units are reported in terms of Seasonal Performance Factor (SPF) that can be intended as a sort of efficiency of the system. In fact, this indicator is calculated as the fraction of the useful energy provided to the final user over the energy used to cover that demand. The SPF can be calculated for DHW production, space heating or space cooling only or for the total amount of energy demanded/consumed. According to the definition, the SPF is referred to a specific energy source. If not specified, it is calculated for electricity.

$$SPF_{el} = {}^{UE}/_{FE_{tot,el}}$$

$FE_{tot,el}$ is the total electric energy used by the heating and cooling system for covering the demands, including pumps, valves backup solutions and any axiliaries.

Seasonal Coefficient of Performance and Energy Efficient Ratio – SCOP, SEER

The efficiency of a generation device – gas boiler, heat pump, electric resistance or split unit – is calculated through the year and an average of the hourly values is reported. For each generation device, the seasonal efficiency is calculated as the ratio between thermal energy produced by the device over the consumed energy:

$$SCOP, SEER, \eta = \sum_{year} \frac{Produced\ thermal\ energy}{Consumed\ energy}$$

The control volume this quantity refers to is the device itself as η, SCOP, SEER represents the efficiency of the generation device under working conditions (see Figure 11).

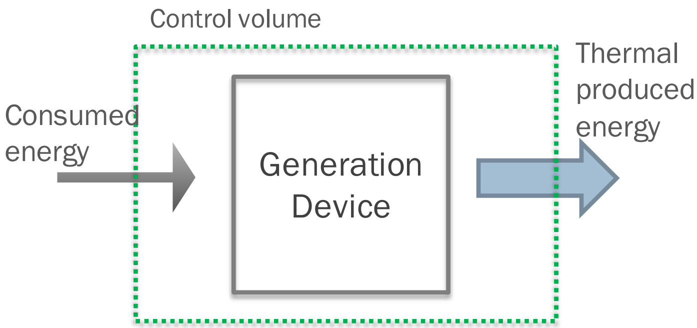

Figure 11 – Control volume for the definition of boiler efficiency, SCOP, SEER

4.2 Energy performance of different system layouts

In the following sections, it is shown what levels of system SPF can be reached and how much primary energy is reduced thanks to adopting different system architectures. The focus here is on the heating and cooling system, while the effect of the envelope retrofit is not highlighted; the envelope performance considered with respect to both initial/reference system (before H&C system retrofit) and new/innovative solutions is distinctive of a retrofitted one.

Dynamic simulations have been run in the TRNSYS environment [4] for four climates conditions throughout Europe: London representing the Oceanic climate Stuttgart for the Continental climate, Rome for the Mediterranean climate and Madrid for the Southern Dry climate.

Figure 12 to Figure 14 show results in terms of Primary Energy consumption for the range of solutions and climates addressed. The light green column (REFERENCE) represents the

Primary Energy consumption of the reference system; the green column (NEW) represents the Primary Energy use of the new system installed without accounting for the support of PV and/or solar thermal systems; the dark green column (NEW+SOLAR) represents the Primary Energy consumption of the system accounting for the PV and/or solar thermal systems contributions, hence deriving from the overall, net, yearly energy exchanged with the electric grid.

4.2.1 Fully decentralized system

As mentioned, the new case for a fully decentralized system is a decentralized heat pump that covers space heating, cooling, DHW and ventilation. In the specific, the considered device is the Elfo Pack, provided by Clivet. The Elfo pack is connected to a PV field of around 1kWp that provides electricity whenever available. In case of PV overproduction, an electric resistance for DHW production is switched on (see Deliverables 4.4 and 5.3 for more details on the demonstration case of Zaragoza).

The Elfo pack is an air-to-air heat pump able to also produce DHW. A minimum fresh air flow rate is always guaranteed. In case of heating or cooling demand, fresh air is mixed with recirculation air and conditioned by the compressor. DHW is produced together with space heating, from heat recovery during space cooling, through the compressor as DHW production only or by an electric resistance.

The Elfo Pack has been modelled following technical data and performance simulated under dynamic conditions of the four climates. Simulations results shows as SCOP for space heating ranges between 4.0 and 4.3 from the coldest to the warmest climates. For DHW production, SCOP is around 3.5 for the colder climates both in winter and in summer, while in warmer climates the SCOP achieves 5.6-5.9 in summer as it benefits of the heat recovery from cooling. SEER for cooling ranges around 3.5 for all the climates (Figure 15).

The efficiency of the whole system, auxiliaries consumption and thermal losses included, in this case is higher than the SCOP/SEER. Thermal losses in this case are limited because there is no piping as it is an air-driven system and eventual losses occur in the ambient to be conditioned. In addition, heat recovery form air recirculation contributes to a higher SPF than SCOP/SEER because air is pre-treated without additional energy consumption. The calculation of SPF also considers the contribution of PV on the total electricity consumption. For the coldest climates, the total SPF is around 4.8, while in the warmest ones it reaches 6-7 thanks to the contribution of the PV system (Figure 16).

To understand the savings that can be achieved with such a system, it is analyzed the primary energy consumption that the replacement of the H&C system and the implementation of a renewable energy system can save with respect to a reference system. For this case, the H&C system before intervention is supposed to be a decentralized gas boiler for heating production (space heating and DHW) and a split unit for space cooling. Energy efficiency of the gas boiler is assumed equal to 0.85 while EER of a non-efficient split unit equal to 2.5.

The consequence of the higher component efficiency is observed in the reduction of primary energy consumed for covering each use. Despite the climatic conditions, the use of the considered decentralized system is able to reduce the consumption for space heating of around 60% with respect to a gas boiler. Savings for space cooling is not representative in Northern climates as the demand is low, while in the warmer climates the use of the Elfo Pack is able to reduce primary energy for space cooling of 56% in the Mediterranean climate and 42% in the Southern Dry. In all the climates, savings related to the production of DHW is between 30-40% (see Figure 12).

Coupling of the heat pump with a PV system helps to additionally reduce energy drawn from the grid. The contribution of a 1 kWp per apartment of PV is in terms of 34-38% for DHW production in northern climates of the remaining energy after the replacement of the H&C

system. In warmer climates, PV helps to reduce the remaining Primary Energy consumption of 58% for space cooling and almost 60% for DHW production.

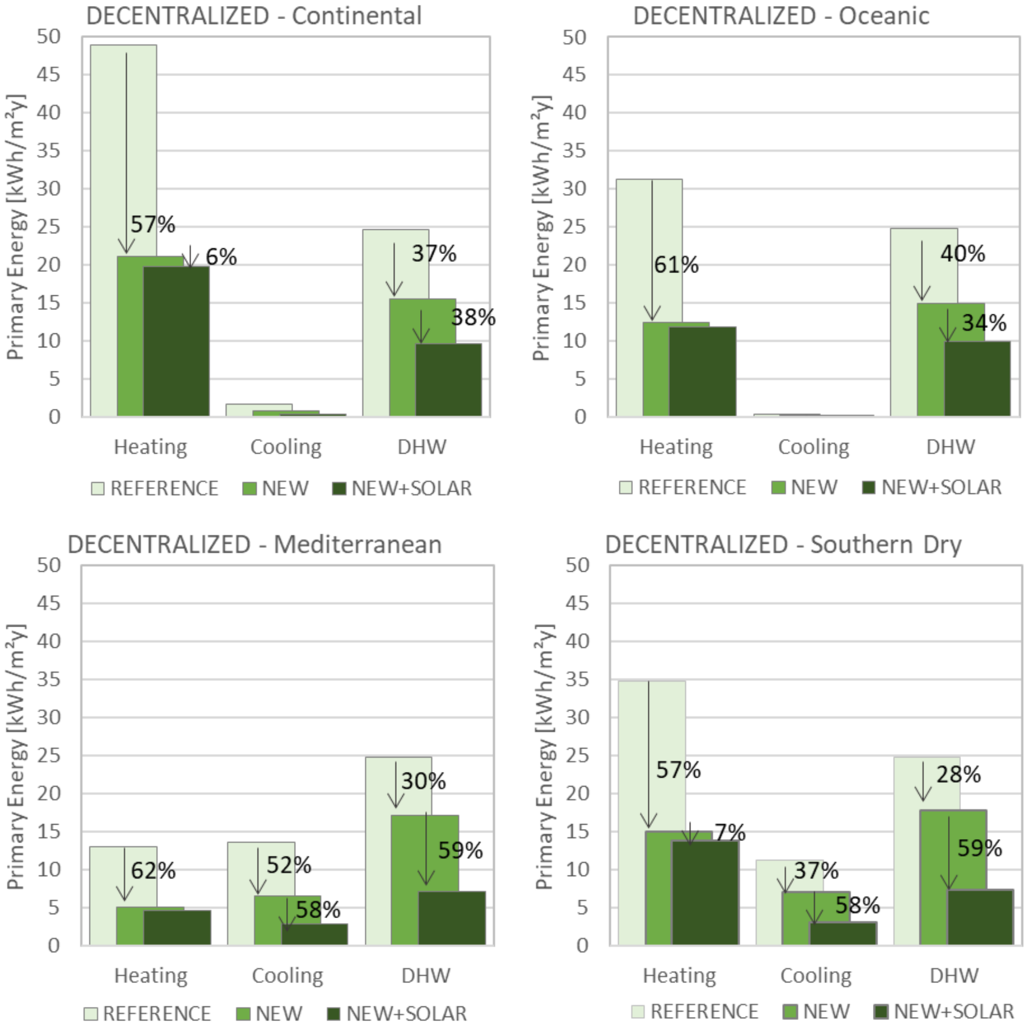

Figure 12 – Primary energy consumption and percentage savings for different energy uses of a reference case (REFERENCE), of a new fully decentralized H&C system (NEW) and of the new system with the contribution of solar technologies (NEW+SOLAR) in different climates

4.2.2 Mixed system

The Mixed system studied is made out of decentralized ground source heat pumps that cover space heating, cooling and DHW demands of each building apartment. Thermal storages installed in each apartment are charged by the heat pumps and used to cover DHW loads. Space heating and cooling is instead provided directly through the heat pump. The source side of each heat pump is connected to a communal water loop heading into a geothermal field. Each apartment is provided with a PV field of around 0.8 kW installed on the roof or on the South façade of the building to partly cover the energy use of the heat pump. The heating system of the refence case is a centralized gas boiler system with thermal efficiency of 0.8, while space cooling is covered through split units with low EER, estimated in 2.5.

Loads simultaneity influences the water loop temperature and consequently the heat pumps performance. An optimal control of the water loop hydraulic pump can significantly reduce auxiliaries' electric consumption and therefore increase the system efficiency. Dynamic simulations run in the TRNSYS (more details in D4.5 [5]) report that SCOP for space heating ranges between 4.3 and 5.5, from the coldest to the warmest climate. This value mainly depends on the supply temperature for space heating that is around 45°C and on the ground temperature, partially influenced by the seasonal air temperature. Supply temperature for DHW is around 52°C, therefore the COP of the heat pump is lower and in the range of 2.8 (Figure 15).

Looking at the efficiency of the whole system, SPF differs from SCOP/SEER for thermal losses through the water loop and energy consumption of the water loop pump. For the impact of thermal losses to the system efficiency, these depends on the building height and pipes insulation. In this case, the considered building is a 17-storeys multi-family house. For the hydraulic pump, four raisers have been considered for reducing the maximum flow rate and therefore the pressure drops.

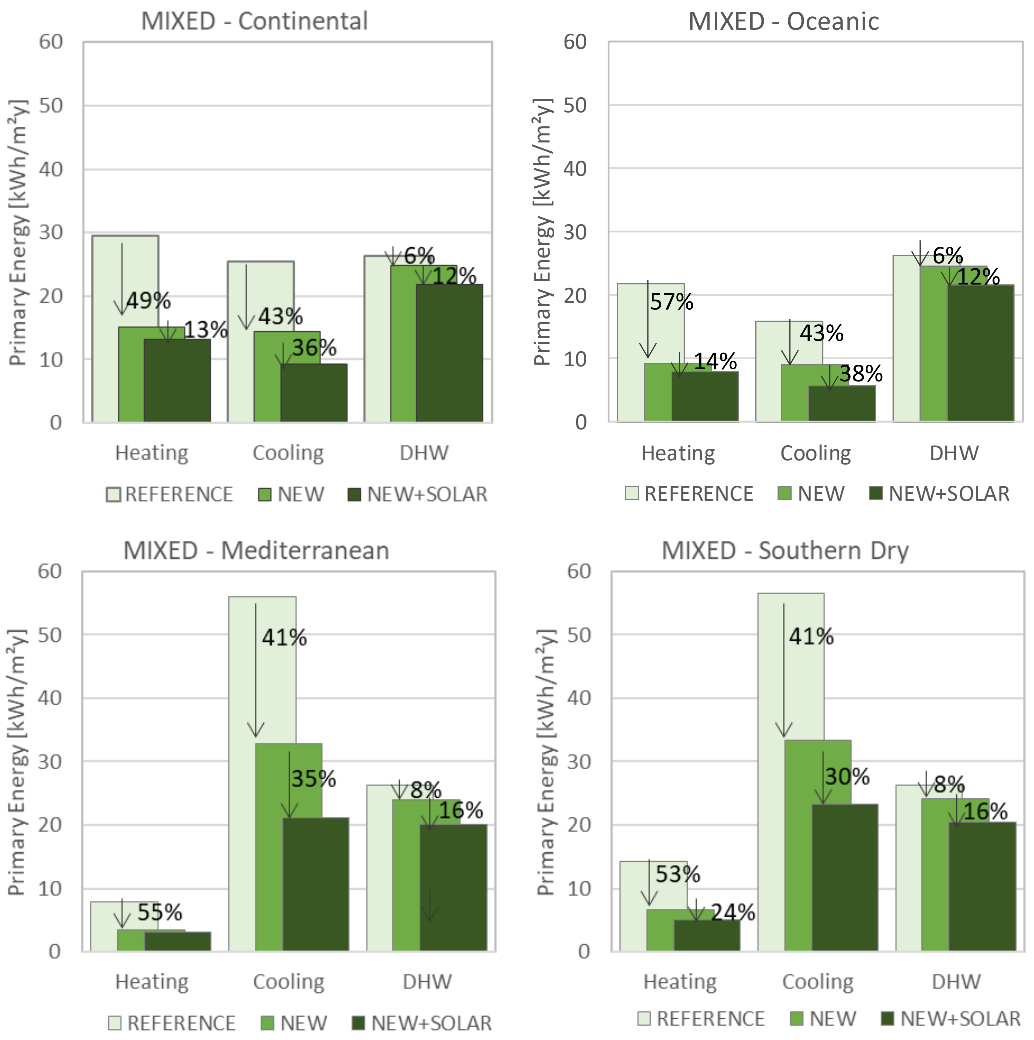

Figure 13 - Primary energy consumption and percentage savings for different energy uses of a reference case (REFERENCE), of a new mixed H&C system (NEW) and of the new system with the contribution of solar technologies (NEW+SOLAR) in different climates

Following these considerations, system SPF for space heating is around 3.7, for space cooling 4.3 and for DHW 2.4. Along the different climates, the system performance does not vary significantly as the ground temperature changes slightly from country to country (Figure 16).

Despite the high electricity consumption due to the hydraulic pump of the communal water loop and thermal losses through the pipeline, the suggested mixed system halves heating and cooling consumptions in all climates with respect to the centralized gas boiler system. Primary energy consumption for DHW production is reduced with a lower impact than for space heating and cooling.

The presence of a PV system helps to reduce the Primary Energy consumption, especially for space cooling and DHW uses. Primary Energy for space cooling is reduced by 35-38% with respect to the energy used by the new system, while for DHW the reduction is in the range of 12-15% (Figure 13).

4.2.3 Centralized system

The building assessed is composed of 5 staircases, 16 apartments per staircase distributed over 8 floors. The reference space heating system (before retrofit) is a centralized gas boiler with efficiency equal to 0.80; space cooling loads are covered by split units with low EER of 2.5, while DHW is produced by means of electric boilers (see Deliverables 4.4 and 5.3 for more details on the demonstration case of Rome).

The newly installed heating and cooling system includes a centralized system at each staircase and is driven by air-to-water, 4-pipes heat pumps covering space heating, cooling and DHW loads. Each staircase has its centralized system. Only the south faced staircase has a solar thermal system, while a PV field is installed and used by the whole building.

As in the previous case, each apartment is provided with a thermal storage for DHW uses. As in the mixed system, thermal losses through the pipes and pump consumption of the main circuit influence the efficiency of the whole system.

Looking at the results obtained through dynamic simulations (for more details on the model definition and boundary conditions, see D4.5 [5]), SCOP for space heating varies between 3.6 in the coldest climates and 4.0 in the warmest ones, while SEER results around 5 in all the climates. The slightly lower SCOP compared to the Mixed system is due to the wider range of outdoor temperatures at the source side of the heat pump. For the SEER, the more efficient behavior is given by the heat pump capability to largely modulate the compressor speed, hence the delivered power, to follow the building loads. This allows to operate with optimal EER, since the required cooling load is most often lower than the nominal one (Figure 16).

In the centralized system, the overall system SPF for space heating ranges between 3.0 to 3.2, for space cooling is assessed around 3.8 and for DHW it results in the range of 3.5 during winter time, while it achieves more than 5.5 during summertime thanks to the heat recovery mode from space cooling production (see Figure 16)

The replacement of a gas boiler system and electric boiler for DHW with a centralized air-to-water system can reduce primary energy consumption for space heating and space cooling by 40-45% in all the studied climates. Primary Energy consumption for DHW production is instead reduced of around 60% in the northern climates and 70% in the southern ones.

Being the building managed as a whole and not divided by staircase, the contribution of the solar thermal and PV systems is distributed over the loads of the whole building. The available surface of solar thermal system on the south façade and the PV installed on the roof correspond to a small percentage on the total heated area. For this reason, their contribution is small, still not negligible. In the northern countries, Primary Energy consumed with the centralized system is reduced by around 10% for DHW uses and almost 30% for space cooling in the warmer climates (see Figure 14).

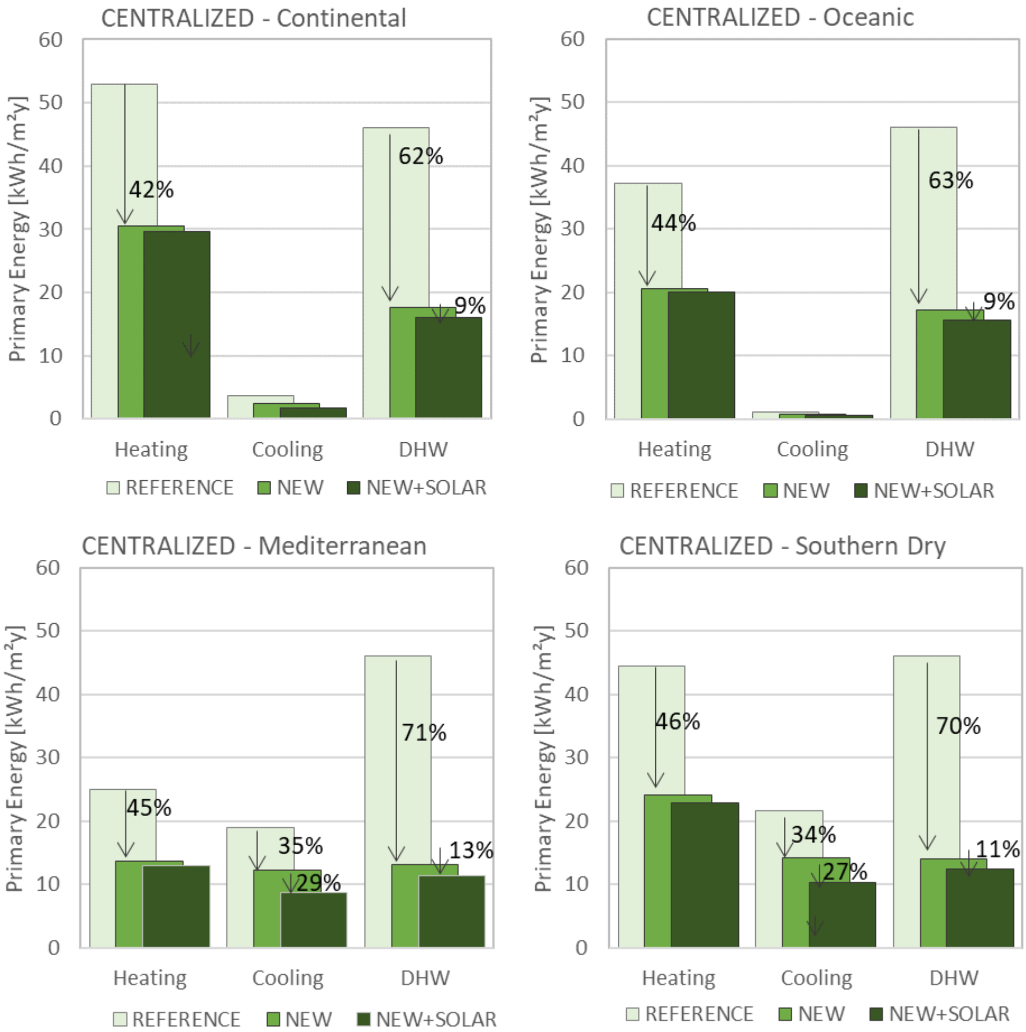

Figure 14 - Primary energy consumption and percentage savings for different energy uses of a reference case (REFERENCE), of a new centralized H&C system (NEW) and of the new system with the contribution of solar technologies (NEW+SOLAR) in different climates

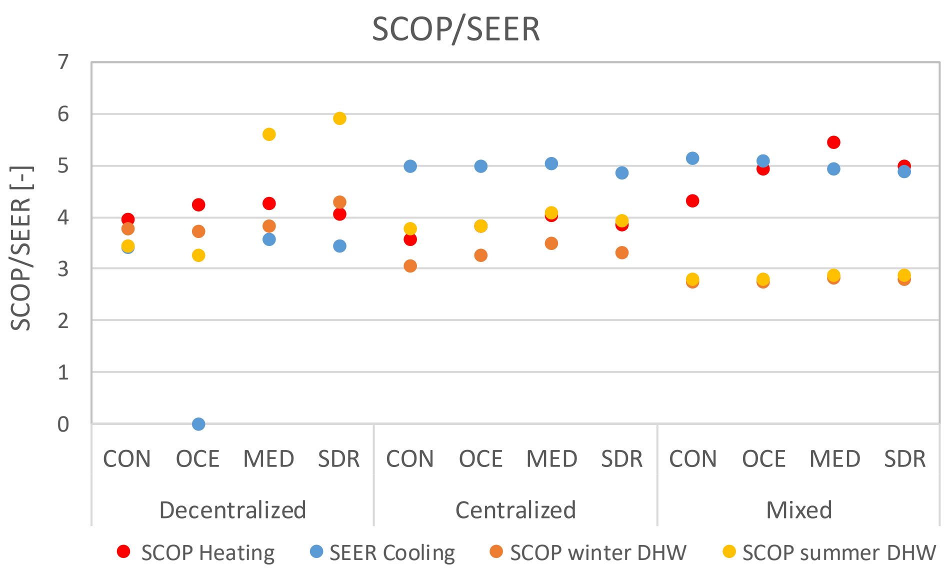

Figure 15 – SCOP and SEER values for each energy use, building typology and climate

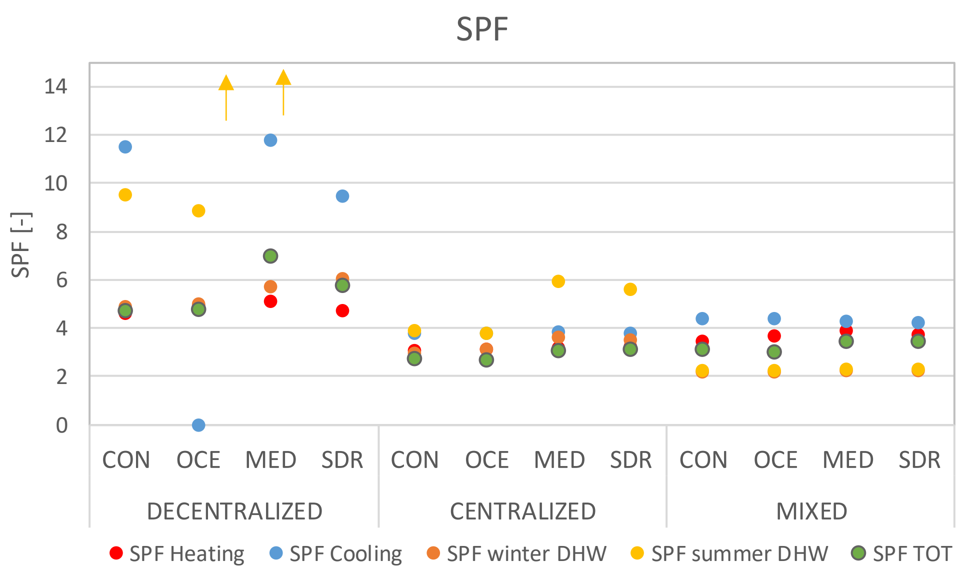

Figure 16 – SPF values for each energy use and of the whole system (SPF TOT), for each H&C system typology and climate

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