SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

# Technical report on system sizing and optimised control strategies

IEA SHC TASK 53 | NEW GENERATION SOLAR COOLING & HEATING SYSTEMS (PV OR THERMALLY DRIVEN)

# Technical report on system sizing and optimised control strategies

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# 1 Introduction

This document reports on the sizing and control strategies used for the HVAC systems described in the deliverable B3. For each system, both reference and specific-case, there is a description of the different parts of the layout, the sizing process of each component and the management strategies.

For each component, the capacity or the procedure followed for the sizing is reported. Regarding the control rules, firstly the methodology for developing the control algorithm is reported, then all the working conditions and inputs to the devices are described.

The first example describes a reference system that, changing the components size or the number of distribution devices, can be adapted to different building typologies and climates conditions. The layout is composed of a generation system that primarily covers the DHW demand and then heats or cools a buffer for the space heating and cooling loads. In case of a PV system, there is not a special control for exploiting the solar production, but the energy production is accounted as self-consumption. On the contrary, in case of a solar thermal system, the DHW production by solar energy is fostered as well as solar heating when there is a big enough solar field area.

The second example consists of an energy plant with an adsorption chiller and CPC (Compound Parabolic Concentrator) collectors. The winter operation mode consists of exploiting the heating from the solar collectors for covering the heating uses, DHW and space heating. During summer instead, heating production from the collectors is used by the adsorption chiller for covering the cooling loads.

The third HVAC system consists of a geothermal heat pump with desuperheater and a PV system. The system control strategies aim to firstly cover the DHW demand and then to maximize the solar energy use for DHW production and space heating, and the self-consumption of PV production for the HVAC system. The heat pump can cover space heating demand by a buffer or directly.

The forth HVAC system includes three configurations: 1) a centralized heat pump and a tank per apartment for the DHW preparation; 2) one heat pump per apartment; 3) an electric system for each apartment for the DHW and heating production. The three configurations foresee a PV system. In the first two cases, the heat pump(s) have a schedule for feeding the DHW tank in a way that during the rest of the day it can be used for covering the space heating loads. In all three configurations, the control strategies aim at exploiting the self-consumption of the PV production. In the third case, the PV area is maximized in order to cover as much building loads as possible by solar energy.

# 2 HVAC system sizing and control for Single Family House and Multi Family House reference buildings from the iNSPiRe project

The layout configuration for the HVAC system follow the same characteristics for all the analysed cases despite the different building typologies and presence of solar technologies. This allows simplifying the numerical model implementation and running parametric analysis.

Figure 1 shows the architecture of the system. The system couples, in the **generation** side (red rectangle), solar energy source with other sources (such as fuel gas, pellet or electricity). This side of the system includes also **storages** (yellow part). The **distribution** side (light blue rectangle) covers the building and DHW thermal loads.

The differences between the two building typologies are reported in the following:

- Single Family House (SFH)

Zoning: The numerical model of the reference building consists in two thermal zones (around 48 $m^2$ each), one for the ground and one for the first floor. **Erreur ! Source du renvoi introuvable.** presents the schematic of the HVAC system simulated. A distinct distribution unit feeds each zone.

Solar thermal field: The generic solar thermal circuit is designed with an external heat exchanger, although in small solar thermal fields is not commonly used, because internal in the tank. Albeit the layout foresees an external heat exchanger, in SFH configurations the energy consumptions of the hydraulic pump positioned between the solar field and the heat exchanger is not accounted for. The solar circuit model is in this way easily handled in all combinations studied, while it is conservative in terms of thermal losses accounted for.

Domestic Hot Water: on the contrary, the heat exchanger on the DHW distribution side is to be considered also for SFHs, accounting for the most restringing legislations on the legionella disease prevention.

- Small Multi Family House (s-MFH)

Zoning: The numerical model simulates a three to seven floors Multi Family House. Each floor has two dwellings (50 $m^2$ each) which have been simulated using two thermal zones each, one per orientation (north/south). A distribution device feeds each of the two dwelling's zones. Furthermore, only three floors have been modelled: ground floor, top floor and middle floor. In fact, all the middle floors have been considered having identical thermal behaviour. Following this assumption, the distribution side has been modelled only for three floors. The generation side, instead, receives the loads as it would face the entire number of floors.

Domestic Hot Water: Normally, an HVAC system in s-MFH is designed with decentralized heat exchanger for DHW production (one heat exchanger per dwelling). In this case, we simulate the entire profile of DHW of the building as unique load acting only on one big heat exchanger. This follows the same configuration used for the SFH numerical model. This simplifies greatly the analysis, since only one demand file for the whole building is used. While the calculation is consistent in terms of energy flows and losses, the sizing of this component is purely theoretical.

Solar thermal field: The solar thermal circuit is designed with an external heat exchanger, as it usually is in medium to large solar thermal fields. Contrary to SFHs, in the sMFH configuration, energy consumption of the two pumps in the solar circuit are considered.

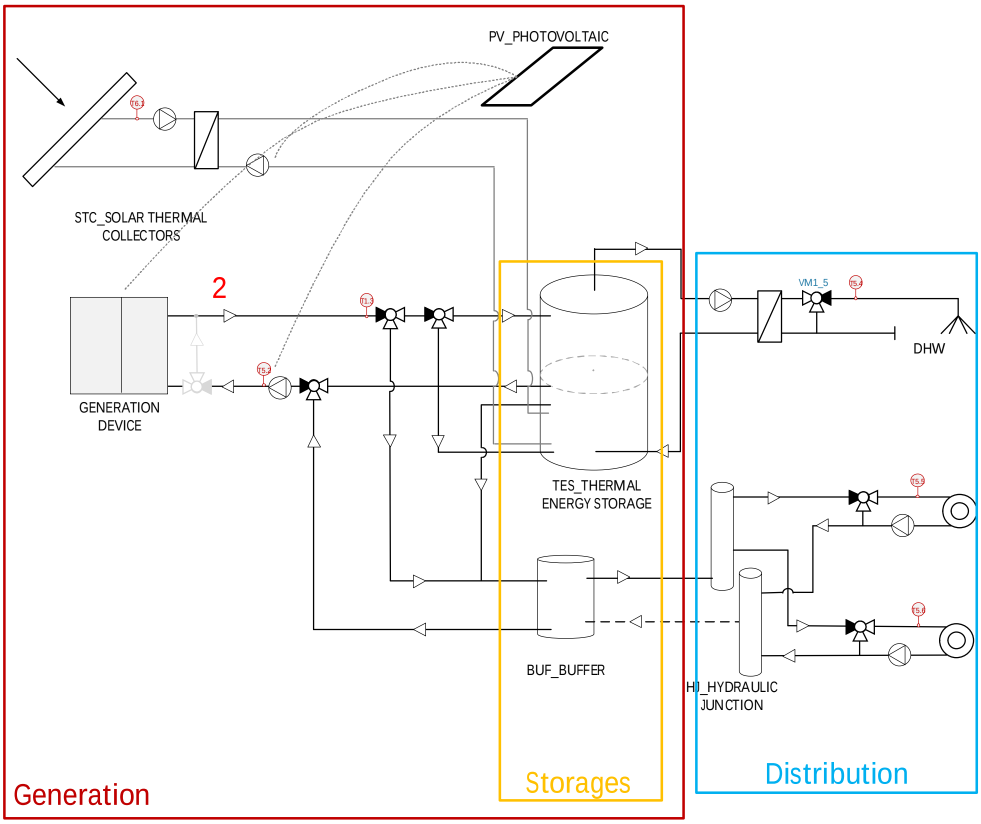

Figure 1 - Schematic of the HVAC system with the identification of the three main zones.

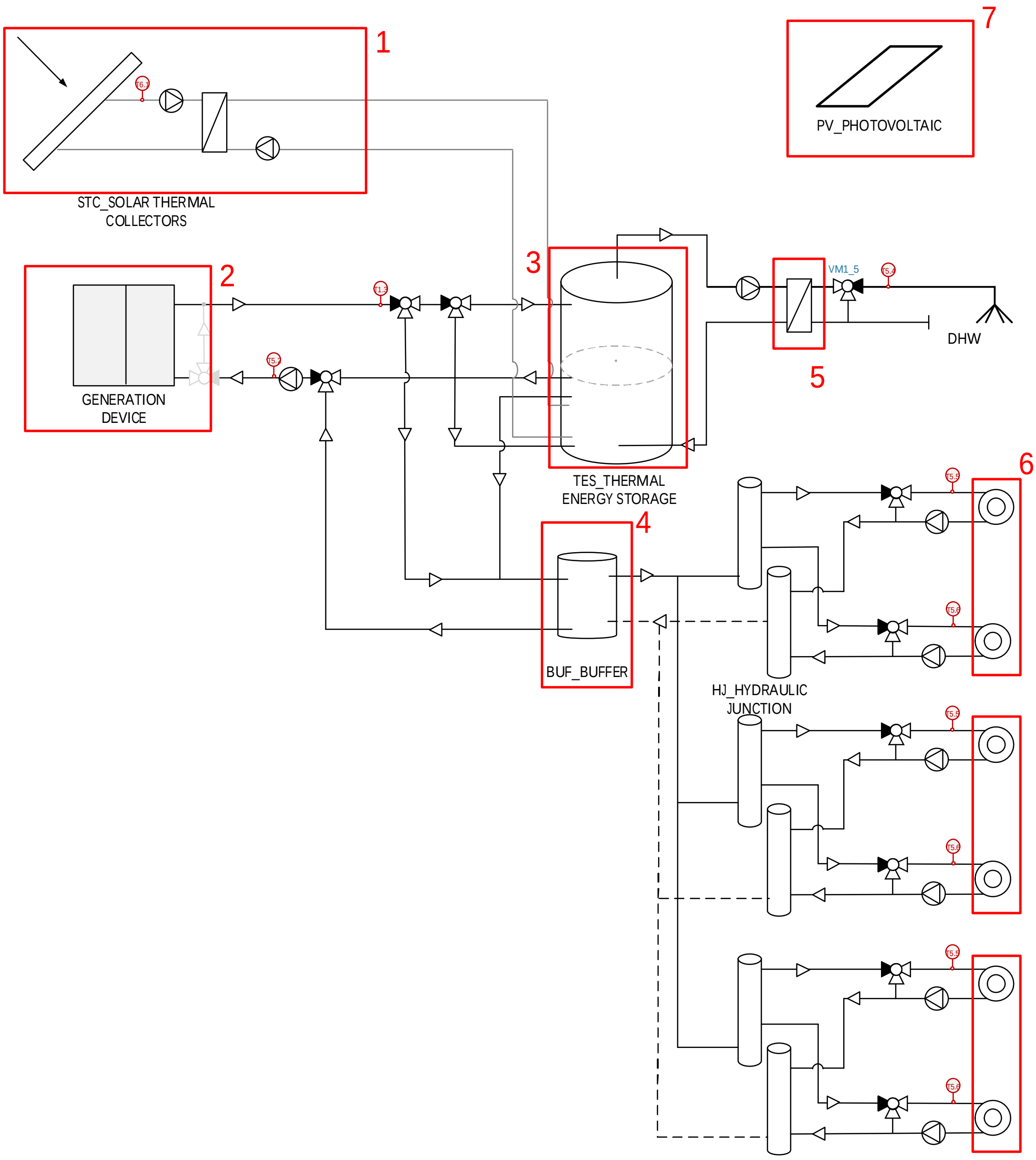

Figure 2 - Schematic of the plant used for the s-MFH.

Referring to Figure 2, the generation side is composed of the components 1, 2, 3, 4 and 7, while the distribution side by components 5 and 6. In the following, a description of each part of the plant is listed.

1. **Solar thermal field** (STC) refers to the solar thermal field that feeds the first tank, which is used as a thermal storage for DHW and solar heating purposes. The heat exchanger is a flat plate model; the modulating pumps keep a constant temperature difference between inlet and outlet of the solar field (15°C).
2. **Generation unit** represents the generation device for space heating and cooling, and for DHW preparation. In the studied cases, we have considered an Air to Water Heat Pump (AWHP), a Ground source Heat Pump (GWHP), a Gas condensing Boiler and a biomass Boiler (BOIL).
3. **Thermal Energy Storage** (TES) is a tank for the medium temperature level water to be used for the DHW preparation. Furthermore, this storage is used to store the energy from the solar field which can be used directly for the DHW preparation, or alternatively, to support the heating system.
4. **Buffer** (BUF) is a smaller storage designed for two main objectives. Firstly, this storage is useful to decouple hydraulically the generation side and the distribution side (working as hydraulic junction).

Secondly, it is used to provide thermal inertia (thermal flywheel, thermal mass) for the heat pump. Finally, during the de-icing cycle, the heat pump uses the energy stored in the buffer without taking from the building.

5. **DHW preparation** consists of a heat exchanger sized in a way to guarantee the instantaneous DHW production. On the user side, a thermostatic valve keeps the flow stream temperature to 45°C.
6. **Distribution system** can include different types of units: Radiators, Fan Coils and Radiant Ceilings. As already noticed, the number of devices per dwelling/office depends on the building thermal zoning.
7. **PV fields** is simulated as a field integrated in the available surface either onto the vertical south-oriented façade or tilted on the roof. The PV production aims to first cover the HVAC consumption and then the other uses: it drives appliances and the surplus is considered as fed into the grid.

## 2.1 Generation components sizing based on loads

As shown in Figure 1, the generation zone is composed by solar field, generation device for heating and cooling, the PV field and the storages.

The generation device has been sized according to the maximum load: building space heating and DHW loads have been considered for the residential cases. In the residential sector, the use of a storage (TES) reduces the simultaneity of the heating generation and DHW request. Accordingly, the peak of DHW has been reduced compared to a traditional DHW heater (instantaneous production of DHW). As a consequence, in SFH cases, the DHW load is higher than heating peak, while for s-MFH, the contrary is verified in general.

The procedure followed for calculating the Maximum Power requested (MPX) is presented in the following section. After that, there are paragraphs explaining the sizing rules applied to each HVAC system device.

The maximum heating/cooling load has been assessed using ideal loads calculated in TRNSYS for each building typology, retrofit measures adopted for the envelope and climate, while a standard procedure has been adopted for the DHW load evaluation.

### 2.1.1 Assessment of the maximum power for Heating/Cooling load

The building loads have been calculated assuming an ideal system with infinite capacity able to maintain the internal temperature at 20°C at wintertime, and 25°C in summer in the residential buildings. An average over 1 hour has been used to avoid selecting only peak loads at system start.

### 2.1.2 Assessment of the maximum power for DHW load.

For the DHW load, we considered a simplified numerical model, which has been retrieved from norms [1].

Firstly, the minimum required volume for the DHW is individuated and, secondly, the maximum power required to keep the water temperature within a specific range is calculated. The following tables show the calculation developed for a SFH and a 10-dwellings s-MFH. It is possible to note that the minimum volume for a SFH is a bit less than 140 litres while for s-MFH the volume increases to 425 litres. Power is double in s-MFHs reaching almost 11 kW, compared to around 5 kW for a SFH.

*Table 1 Calculation table for the DHW volume and Power.*

| | | SFH | s-MFH |
|---|---|---|---|
| **N dwellings** | | 1 | 10 |
| **Dwellings factor** | | 1.15 | 0.47 |
| **Rooms factor** | | 1.2 | 1.1 |
| **Area** | m² | 100 | 50 |
| $n_{person}$ | | 4 | 3 |
| $q_{mshower}$ | l/h | 745.2 | 2791.8 |
| $t_{shower}$ | min | 4 | 4 |

| | | | |
|---|---|---|---|
| $\boldsymbol{t_{peak}}$: | h | 0.27 | 0.20 |
| $\boldsymbol{t_{pr}}$ | h | 1.07 | 1.60 |
| $\boldsymbol{T_m}$ | °C | 40 | 40 |
| $\boldsymbol{T_f}$ | °C | 10 | 10 |
| $\boldsymbol{T_c}$ | °C | 45 | 45 |
| | | | |
| $\boldsymbol{V_{DHW}}$ | litres | 136 | 425 |
| $\boldsymbol{P_{DHW}}$ | W | 5200 | 10823 |
| **daily consump** | l/d/pers | 50 | 40 |

The “dwelling” and “room” factors are used to estimate the design shower mass flow rate (worst load in DHW usage). The factors account for wealth of households (Rooms factor) and contemporaneity of loads (Dwellings factor), and are fixed according to the standards.

The other parameters used for the calculation are:

- $t_{peak}$: represents the duration of the peak of DHW request (quantified as the minutes of a shower per number of inhabitants). The duration of the shower has been quantified in 4 minutes per person.
- $t_{pr}$: is the time of charging the storage when it reaches the minimum temperature allowed (40°C). This parameter depends by choice of experts, $t_{pr}$ was set four times $t_{peak}$ for the SFH and eight times for sMFH.
- $T_m$: is the temperature of supply water to the users (40°C).
- $T_c$: is the set point temperature for the storage (45°C).
- $T_f$: is the tap, cold water temperature (10°C for all climates in this analysis)
- $q_{mshower}$ is the nominal mass flow rate for a shower (700 l/h)
- *daily consump.* is the daily consumption per person
- $V_{DHW}$ is the size of the volume for DHW
- $P_{DHW}$ is the peak power to guarantee DHW preparation

For the peak loads time, the size of the storage guarantees internal water temperature at the temperature $\boldsymbol{T_m}$. The calculation of this volume is made as follows:

$$V_{DHW} = q_{mshower} * t_p * \frac{T_m - T_f}{t_p + t_{pr}} * t_{pr} * \left(T_c - T_f\right) \; [L]$$

The power of the generation device is calculated according to:

$$P_{DHW} = q_{mshower} * t_p * \left(T_m - T_f\right) * \frac{cp_w}{t_p + t_{pr}} \; [W]$$

### 2.1.3 DHW vs. space conditioning loads

Summarizing, in SFHs, the DHW power is around 5 kW, whereas in s-MFHs it ranges between 6.5 kW and 15.2 kW (depending by the number of floors). Space heating power varies from 6.2 to 38 kW all over the climates.

For the SFH cases, the DHW load is higher than heating peak, while for s-MFH, it is lower power for the majority of the cases.

## 2.2 Control Strategies

To integrate and run homogeneously all the components of the plant, an appropriate control strategy has been developed. For residential buildings, the control strategy is based on three main objectives:

- DHW priority on the other requests;
- Maximization of solar energy use for DHW production and space heating;
- Maximization of self-consumption of PV production for the HVAC system.

As already shown, the layout of the HVAC system uses storage as connection between generation and distribution devices. Following this, the control strategy has been developed keeping the control of generation and distribution separated. This approach makes the control strategy easy to be scalable and adaptable to different building typologies and system configurations.

The structure of the control rules consists of five elements listed in the following:

- **Feedback signal**: information acquired from the sensors;
- **Hysteresis**: elaboration of the acquisition signals in Boolean format. The hysteresis, in thermal systems, is useful to avoid continuous oscillation of the signal due to the nature of the system.
- **Schemes**: represent the working modes used by the HVAC system. The schemes are defined as logical phrase of hysteresis.
- **Modulation**: refers to pumps and valves and it is used to scale the control signal of the component. The modulation can be either a fixed value or a function of another independent variable (temperature or mass flow rate);
- **Control signal**: is the command given to the devices to be controlled; it is the combination of schemes and modulations.

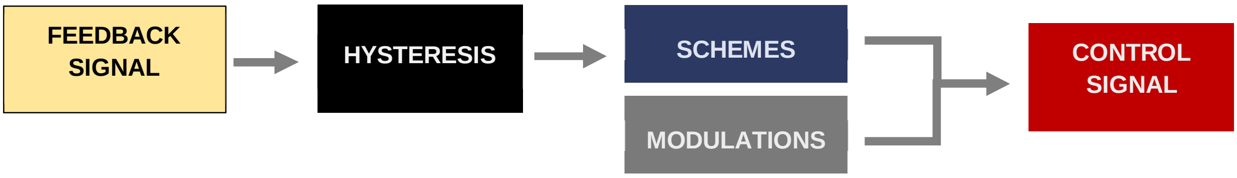

Figure 3 – Structure for the control signal.

### 2.2.1 Feedback signals

The measurements considered for the control of the plant refer to temperatures, mass flow rates and solar radiation on the horizontal plan. The position of the sensors is shown in the HVAC system layout in Figure 4. Hydronic elements have been grouped into Energy Hubs (EH), compact energy boxes that group valves, pumps and heat exchanger. In Figure 4 there are six Energy Hubs: EH1 for the hydronic components of the solar system, EH2 and EH3 for connecting the generation device with the TES and buffer, EH4 for the DHW pump and valve distribution, EH5 and EH6 for the heating and cooling distribution auxiliaries.

For the sake of clarity, Table 2 lists the nomenclature used in the following figure for the HVAC system equipment, while all the sensors name are reported here below.

- RAD: Horizontal radiation
- AMB: Ambient temperature
- T6.1: outlet temperature of the solar collectors

- T1.3: outlet temperature of the generation machine (Heat pump or boiler)
- T5.2: inlet temperature to the generation machine
- T1.BUF: sensor of the small storage (buffer)
- T5.4: temperature of DHW to the user
- T5.5: supply temperature to the distribution device – zone 1
- T5.6: supply temperature to the distribution device – zone 2
- Tzone1: internal temperature of the zone 1
- Tzone2: internal temperature of the zone 2
- MF: flow rate of the DHW demand

Sensors on the main storage:

- T1.TES: top sensor used to maintain the upper part of the tank at a certain temperature for the DHW production;
- T2.TES: middle sensor used for solar heating;
- T3.TES: bottom sensor used for the solar field circuit activation.

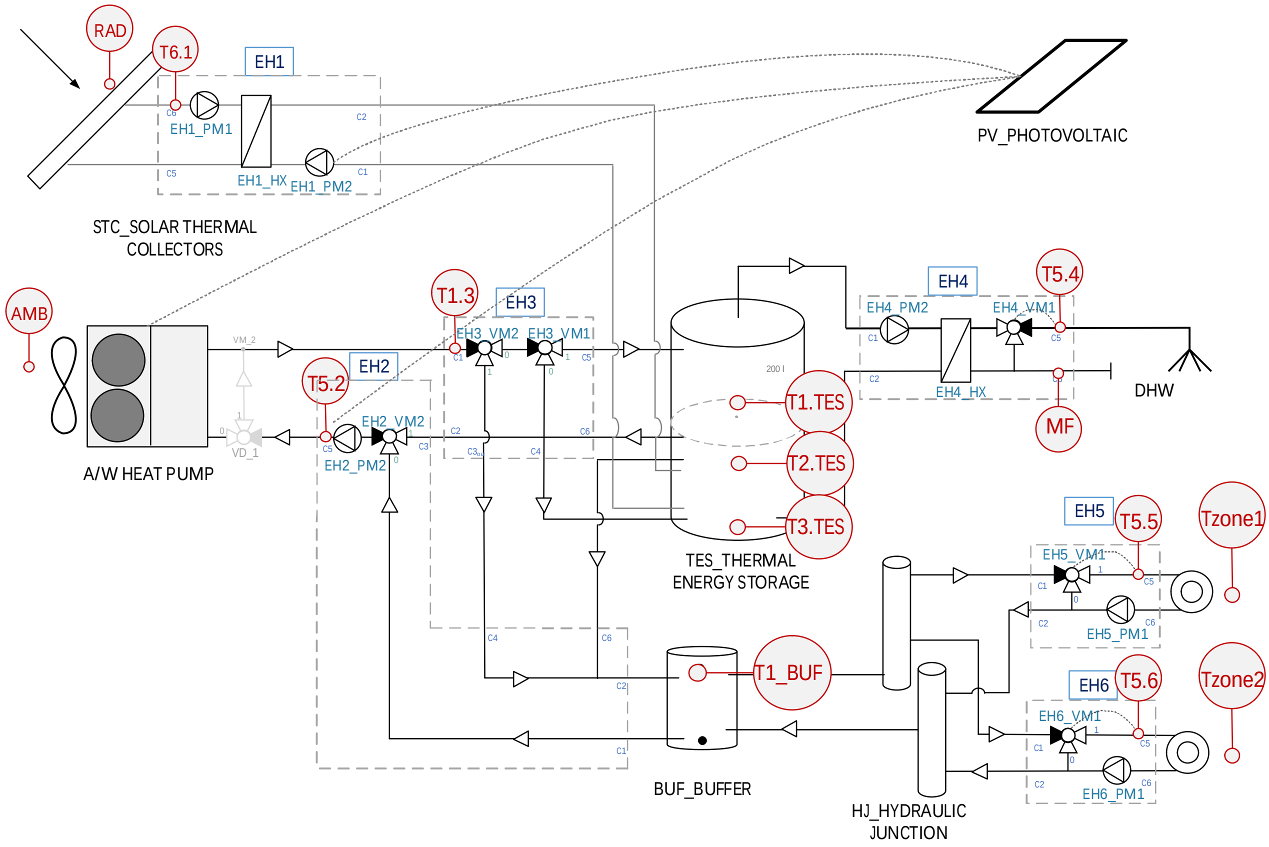

Figure 4 - Temperature and irradiation sensors.

The height of the sensors in the main storage depends on the different sizes of the storage. The minimum storage volume guarantees that DHW demand is covered, therefore that volume has to be kept always within the interval 40-45°C (red part in Figure 5). Visualising a fictive division line between the minimum DHW volume (whose height is indicated with H1) and the rest of the tank volume (which height is indicated with H2), the top sensor is located 20% of H1 above the division line. Sensor T2 is located below this fictive line in a distance equal to the 20% of H2. The bottom sensor is instead located at 10% of the overall height. H1 is maintained at the desired temperature by the generation device while the H2 volume is dedicated to solar energy.

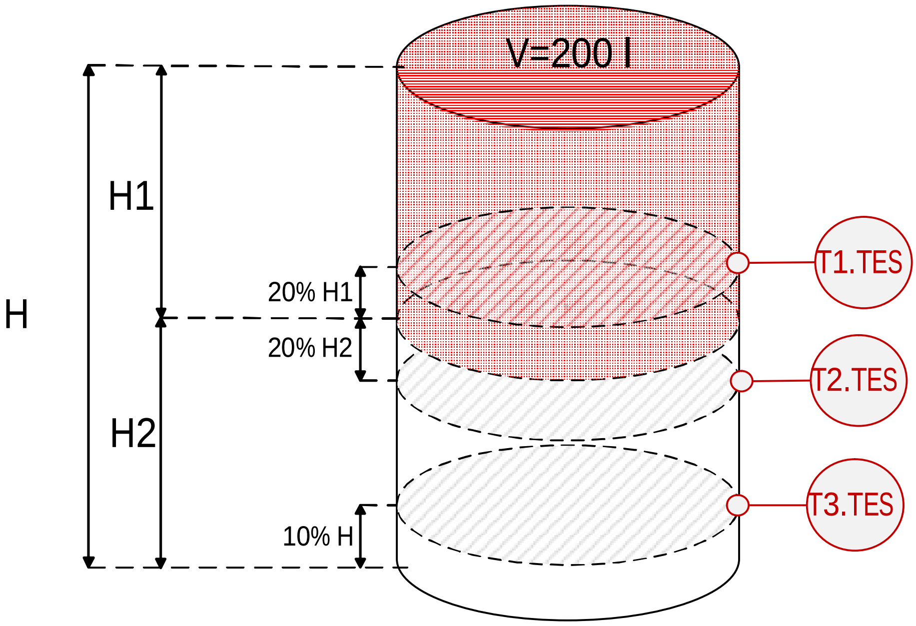

Figure 5 - Representation of the TES for DHW with height of temperature sensors.

Table 2 List of Hydraulic equipment of the HVAC system for a SFH.

| Energy Hub | Name | Description |
|---|---|---|
| **EH1** | EH1_PM1 | Circulation pump |
| | EH1_PM2 | Circulation pump |
| | EH1_HX | Heat exchanger |
| **EH2** | EH2_PM2 | Circulation pump |
| | EH2_VM2 | Mixing valve |
| **EH3** | EH3_VM2 | Diverter valve |
| | EH3_VM1 | Diverter valve |
| **EH4** | EH4_PM2 | Circulation pump |
| | EH4_VM1 | Thermostatic valve |
| | EH4_HX | Heat exchanger |
| **EH5** | EH5_PM1 | Circulation pump |
| | EH5_VM1 | Thermostatic valve |

### 2.2.2 Hysteresis

Hysteresis is useful to reduce continuous oscillation of the control signal around a set value. Table 3 summarizes the implemented hysteresis with the set values and dead bands.

The following signals refer to four group categories:

1. Signal group 1x. refers to hysteresis used for controlling the Solar Thermal Field

2. Signal group 2x. refers to hysteresis for controlling the Thermal Energy Storage use.
3. Signal group 3x. refers to the hysteresis for controlling the Buffer use.
4. Signal group 4x. refers to hysteresis used for controlling the DHW side.
5. Signal group 5x to 10x. refer to hysteresis used for controlling the distribution units. For the sake of simplicity, only signals for a single distribution unit (5A and 5B) have been reported below. For each further distribution unit, the approach is identical using a different nomenclature.

**Signal 1A**: Control of the temperature difference between the outlet of the Solar Thermal Collector field (STC) and the bottom of the main storage (T3.TES).

**Signal 1B**: Control of the temperature into the main storage to avoid stagnation (T1_TES).

**Signal 1C**: Control of the solar radiation on the horizontal plane for the solar field activation. If the irradiation is greater than 150 W/m$^2$ the signal is 1; when it drops below 100 W/m$^2$, it is 0.

**Signal 1D**: Control of the outlet temperature of the STC to avoid stagnation.

**Signal 2A**: Control of the T1.TES sensor of the main storage to charge the DHW volume. If the temperature is lower than 45°C the signal is 0; otherwise, if it is greater than 50°C the signal is 1.

**Signal 2B**: Control of the medium sensor temperature (T2.TES) of the main storage for activating the solar heating.

**Signal 3A**: Control of the temperature sensor in the small storage (T1.BUF). The signal is used to charge the small storage. Both in winter and summer, if the temperature is lower than the heating or cooling distribution set point of 3°C the signal is 0, otherwise, if the temperature is greater than this set point of 3°C the signal is 1.

**Signal 4A**: Control of the mass flow sensor (MF) to evaluate the user's DHW request. In the reality, this signal is provided by a pressure sensor which traduces the decrease of pressure as DHW request. For the sake of simplicity, in the simulation environment a profile of mass flow for the DHW request has been implemented.

**Signal 5A**: Control of the temperature for the indoor zone Tzone1 during winter. If the temperature of the room is lower than 19.5°C the signal is 1; otherwise, the signal is 0. In this case, the upper dead band is equal to 0.5°C while the lower is 0°C.

**Signal 5B**: Control of the temperature for the zone Tzone1 during summer. If the temperature of the room is greater than 25°C the signal is 1; otherwise, the signal is 0. In this case, the upper dead band is equal to 0.5°C while the lower is 0°C.

**WINTER**: Control of the mean indoor temperature over the previous 24h. If the mean temperature is lower than 22°C the signal is 1 otherwise it is 0.

**SUMMER**: Control of the mean indoor temperature over the previous 24h. If the mean temperature is higher than 22°C the signal is 0 otherwise it is 1.

Table 3 - Hysteresis implemented in the control strategy.

| Hysteresis name | Acquisition signal | Set Value | Upper dead band | Lower dead band |
|---|---|---|---|---|
| **Signal 1A** | Difference of temperature between the outlet of STC (T6.1) and the bottom of the storage (T3.TES) | 5°C | 2 °C | -2 °C |
| **Signal 1B** | Top temperature of the TES (T1.TES) | 95 | 3 | 0 |
| **Signal 1C** | Irradiation on the solar thermal collector panel (RAD) | 150 W/m$^2$ | 0 W/m2 | -50 W/m2 |
| **Signal 1D** | Outlet temperature of the STC (T6.1) | 95 | 3 | 0 |
| **Signal 2A** | TES Middle sensor temperature (T1.TES) | 45 | 5 | 0 |
| **Signal 2B** | TES bottom sensor temperature (T2.TES) | Heating set point | +3 | -3 |
| **Signal 3A** | BUF top sensor temperature (T1.BUF) | Heating (winter) and cooling (summer) set point | 3°C | -3°C |
| **Signal 5A** | Indoor zone sensor temperature (Tzone1) | 19.5 | 0.5 | 0 |
| **Signal 5B** | Indoor zone sensor temperature (Tzone1) | 25 | 0 | -0.5 |
| **Summer/Winter** | Mean temperature over 24 hours of the indoor zones temperature | 22 | 0 | 0 |

### 2.2.3 Functional schemes

The working schemes of the HVAC system identify which are the "operating state" of the plant based on the hysteresis generated. A scheme identifies the operation condition of each of the system components.

This paragraph describes the equations that define the combination of the hysteresis to individuate a scheme. The combination of hysteresis can be read in a logical way using the logic operator AND, OR and NOT.

The schemes 10w/s to 15w/s refer to the distribution heating and cooling units. For the sake of simplicity, only the scheme of a single distribution unit (10w/s) is reported below. The structure of schemes from 11w/s to 15w/s is identical of scheme 10 w/s.

Scheme 1 (SC1): Running solar field.

This scheme is designed to deliver energy from the solar field to the main storage. The scheme is defined using a logic representation as shown in the following equation:

$$SC2 = NOT(1D) * NOT(1B) * 1A * 1C$$

This equation is described by the following conditions:

- Temperature difference control: the outlet temperature of the solar field and the one at the bottom of the main storage (T3.TES) are compared. If the difference between the first and the second is positive and greater than 7K, signal 1A is 1. When the delta temperature falls below the value of 2K the signal 1A is 0.
- Solar radiation control: this condition is verified when the total radiation on the horizontal is greater than 150 W/m$^2$, while turns to 0 when the solar irradiation is 100 W/m$^2$ (Signal 1C).
- Stagnation control: two controls have been implemented to avoid stagnation phenomenon. The first controls the outlet temperature of the solar field avoiding that it overtakes 98°C (Signal 1B). The second controls the top temperature of the main storage (T1.TES) that is kept under the same limit adopted for the outer temperature of solar collector (Signal 1D).

Scheme 2 (SC2): Running generation machine for DHW.

This scheme has been developed to activate the generation unit (AWHP, GWHP, BOIL) when it is required to charge the upper part of the main storage. When the top tank sensor (T1.TES) measures a temperature below 45°C, the scheme is activated. The definition of the scheme using logic representation is the following equation:

$$SC2 = NOT(2A)$$

Scheme 3 (SC3): Running Generation device for distribution in winter.

This scheme is used to feed the buffer in winter. This scheme is activated when there is no need of DHW preparation (NOT(3A)) and the buffer temperature is lower than a specific set, dependent on the distribution system (2A).

In the cases where solar heating ($Y_{SC5}$) is foreseen because enough solar area is available, an additional condition (NOT(2B)) assures that the buffer is not fed from the TES during this operation. This avoids that 2 schemes operate contemporarily

$$SC3 = (Y_{SC5} * 2A * NOT(2B) * NOT(3A) + NOT(Y_{SC5}) * 2A * NOT(3A)) * WINTER$$

Scheme 4 (SC4): Running Generation device for distribution in summer.

This scheme is used to feed the buffer in summer only whether the generation device is able to provide cooling (reversible heat pump cases). If any other scheme for using the generation unit is activated (3A), and there is the need to cool down the BUF (2A), scheme 4 is ON:

$$SC4 = 2A * 3A * SUMMER$$

Scheme 5 (SC5): Running solar heating.

This scheme permits to exploit solar energy for space heating. We assume that the lowest part of the tank is heated by energy coming from the solar field. If the sensor of the buffer (T1.BUF) measures a temperature below the set point (NOT(3A)), there is no need of DHW preparation (2A), and there is enough energy in the bottom of TES for solar heating (signal 2B), scheme 5 is ON:

$$SC5 = 2A * 2B * NOT(3A) * WINTER$$

Scheme 6 (SC6): DHW request.

This scheme is structured to provide DHW to the user when required (Signal 4A). The light-blue circuit in the figure below takes the water from the top of the storage and returns with cooled water to the bottom of the tank. On the user side, tap water is heated up through the heat exchanger and a thermostatic valve modulates up to maintain a fixed supply temperature to the user (45°C). The definition of the scheme using logic representation is the following equation:

$$SC6 = 4A$$

Scheme 7 (SC7): DHW recirculation

Scheme 7 individuates the recirculation scheme on the DHW circuit in s-MFH only. Differently from scheme 6, this scheme involves only the source side of the DHW circuit pipes. This scheme is used to keep all the parts of the circuit warm when there is not request of DHW, allowing for a prompt delivery of HW on demand:

$$SC7 = NOT(4A)$$

Scheme 10w/s to Scheme 15w/s: distribution unit heating and cooling.

These schemes are used to run the distribution units of the plant. One valve and one pump per unit regulate the water distribution in order to maintain a comfort temperature in the zones associated at that particular distribution unit. When the internal temperature drops (winter) (signals NOT(5A)) or rises (summer) (signal 5B) across a set value, the scheme of each zone/dwelling is activated. The valve and pump modulations guarantee a fixed supply temperature to the distribution devices.

$$SC10w = NOT(5A) * WINTER$$

$$SC10s = 5B * SUMMER$$

PV control strategy.

Main objective of the control is to maximize the self-consumption of the PV electricity for the HVAC system, then use electricity for the other building uses and finally feed it into the grid.

In the numerical simulation this has been considered with an hourly balance between the PV energy production and the building energy consumptions. For each hour of the year the energy produced by the PV has been used to supply firstly the HVAC equipment, secondly appliances and finally fed into the grid.

### 2.2.4 Modulation

Schemes' signal can be either 0 or 1; for some components, this information is not enough. Modulation scales the Boolean signal according to component's requirements (Figure 3). In the following, the modulations description is reported, while **Erreur ! Source du renvoi introuvable.** summarizes the implemented logics. In Figure 4, the name of the controlled components can be found. The modulation name is composed by two parts:

- the name of the Energy Hub that groups the component;
- the name of the component (PM1/2 or VM1/2) added with the extension "MOD".

EH1_PM2_MOD

The modulation for the pump 2 of the EH1 aims at maintaining a temperature difference of 15°C between the inlet and outlet of the Solar Thermal Collectors field. When the scheme of recirculation is active, the pump runs with the minimum speed possible. The equation implemented in the numerical model modulates the mass flow defined between the minimum and the maximum reachable mass flow rate.

EH2_PM2_MOD

As in the previous case, the modulation for the pump 2 of the Energy Hub 2 is converted in mass flow rate signal. This signal is bounded between the minimum and the maximum reachable mass flow rate value. The modulation aims to maintain a temperature difference of 5°C (7°C for gas and pellet boiler) between the inlet and the outlet of the generation device.

EH4_PM2_MOD

The modulation for the pump 2 of the EH4 aims at maintaining a temperature difference of 30°C between the inlet and outlet of the heat exchanger of the DHW circuit. When the scheme of recirculation is active, the pump runs with the minimum speed (10% of the nominal mass flow).

The equation implemented in the numerical model gives the value of the mass flow rate defined between the minimum and the maximum reachable mass flow rate.

EH4_VM1_MOD

The modulation of the valve 1 of the EH1 is made according to the equation of a thermostatic valve. The idea is to keep the temperature to the user of the DHW load close to a set point temperature (DHW_TSET equal to 45°C) by mixing the cold flow from tap water and the hot flow (outlet of the DHW Heat exchanger).

EH6_VM1_MOD

The modulation of the valve 1 of the EH5 and 6 is made according to a thermostatic valve. The idea is to keep the distribution devices supply temperature as closer as possible to a set temperature for the winter period (the set point is the heating delivery set point, DIST_TSUPPLY), whereas in the summer period, this valve is fully open.

### 2.2.5 Control signals

The signal delivered to the components is the combination of schemes and modulations. For each element of the plant (pumps, valves, and generation device), there is a specific combination of schemes and modulation as shown here below. Table 4, Table 5 and Table 6 show the regulation for thr generation device, pumps and valves.

Generation unit

The generation device receives an input when there is the need of heating up the TES (SC2), the buffer during winter (SC3) or cooling it down during summer (SC4).

Solar field pumps - EH1_PM1, EH1_PM2

These pumps EH1_PM1 and EH1_PM2 belong to Energy Hub 1. They are activated only when scheme 2 is ON and the signal is modulated with EH1_PM2_MOD to limit the mass flow rate and maximize the temperature difference.

Pump of the generation unit – EH2_PM2

The pump of the generation side is activated whenever the generation device is on (SC2 or SC3 SC4) and also with the solar heating scheme (SC5) to transfer energy from the TES to the BUF.

Pump on the DHW distribution – EH4_PM1

This pump is activated both when DHW is requested (SC6) and when re-circulation is needed (SC7). The modulation, defined with EH4_PM2_MOD, regulates the flux in order to set the mass flow rate at the minimum value during recirculation.

Pumps on the space heating and cooling distribution - EH5_PM1

The pump of the distribution side is activated when the heating and cooling is required by the zone (SC10A+SC10B). It runs as fixed mass flow rate (PM1_5_MF) which is defined according to the distribution device characteristics.

Valve1 on the generation side - EH2_VM2

This is a mixing valve used for heating up or cooling down the buffer. This valve is directed to the TES in the scheme SC2, otherwise it is fully open through the buffer.

Valve2 on the generation side - EH3_VM1

This valve is oriented to the TES when there is the need of heating it up (position 1), otherwise it points to the buffer (SC3+SC4).

### Valve 3 on the generation side - EH3_VM2

This valve is an ON-OFF valve and connects the generation device to the top of the TES or to the bottom. This valve assumes the position 1, oriented to the top of the TES, when SC3 is verified.

Table 4 - Generation device regulation signal.

| Component | Regulation |
|---|---|
| **Generation Device** | SC2+SC3+SC4 |

Table 5 - Circulation pumps regulation signals.

| Circulation Pumps | Description | Regulation |
|---|---|---|
| **EH1_PM1** | Pump of the solar field | SC1*EH1_PM1_MOD |
| **EH1_PM2** | Pump of the solar field | SC1*EH1_PM2_MOD |
| **EH2_PM2** | Pump of the generation side | (SC2+SC3+SC4+SC5)*EH2_PM2_MOD |
| **EH4_PM2** | Pump for the DHW production | (SC6+SC7)*EH4_PM2_MOD |
| **EH5_PM1** | Pump of the distribution side zone 1 | (SC10A+SC10B)*PM1_5_MF |
| **EH6_PM1** | Pump of the distribution side zone 2 | (SC11A+SC11B)*PM1_6_MF |

Table 6 – Valves regulation signals.

| Valves | Description | Regulation |
|---|---|---|
| **EH2_VM2** | Mixing valve used for the buffer heating or cooling | SC3 |
| **EH3_VM1** | Diverter valve used for the solar heating | SC3 |
| **EH3_VM2** | Diverter valve used for the heating of the buffer | (SC3+SC4) |

# 3 HVAC system sizing and control for a Wooden Single-Family House (WRB)

Figure 6 shows the architecture of the system for summer operation. The system couples, in the **generation** side (red rectangle), solar energy and the gas heater together with the adsorption chiller. This side of the system includes also the **storage** (yellow part). The **distribution** side (light blue rectangle) covers the thermal loads of the building.

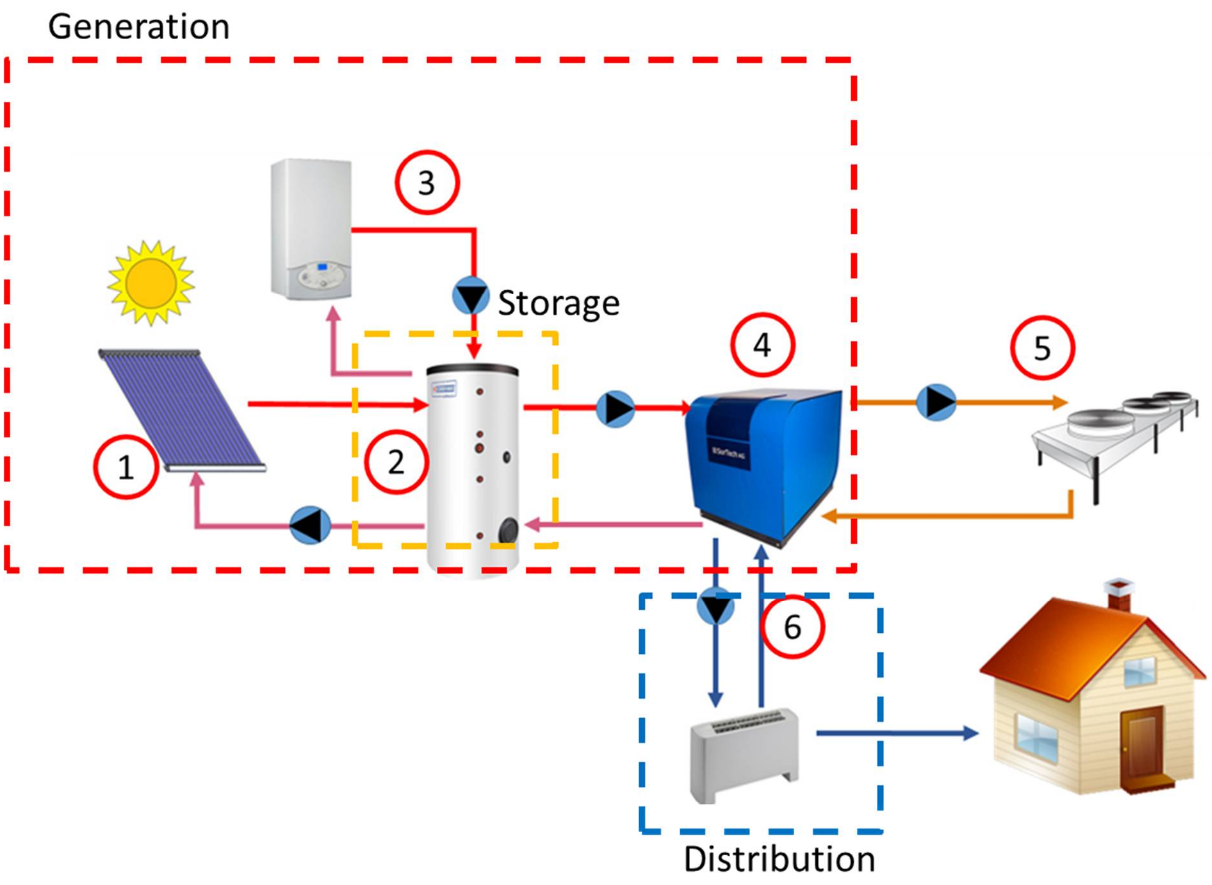

Figure 6 - layout of the system of WRB: summer operation.

Figure 7 shows instead the layout of the system for winter operation. In this case, the generation side includes solar panels and gas heater. The storage is also part of the layout. Heat is then delivered to the distribution system, bypassing the adsorption system.

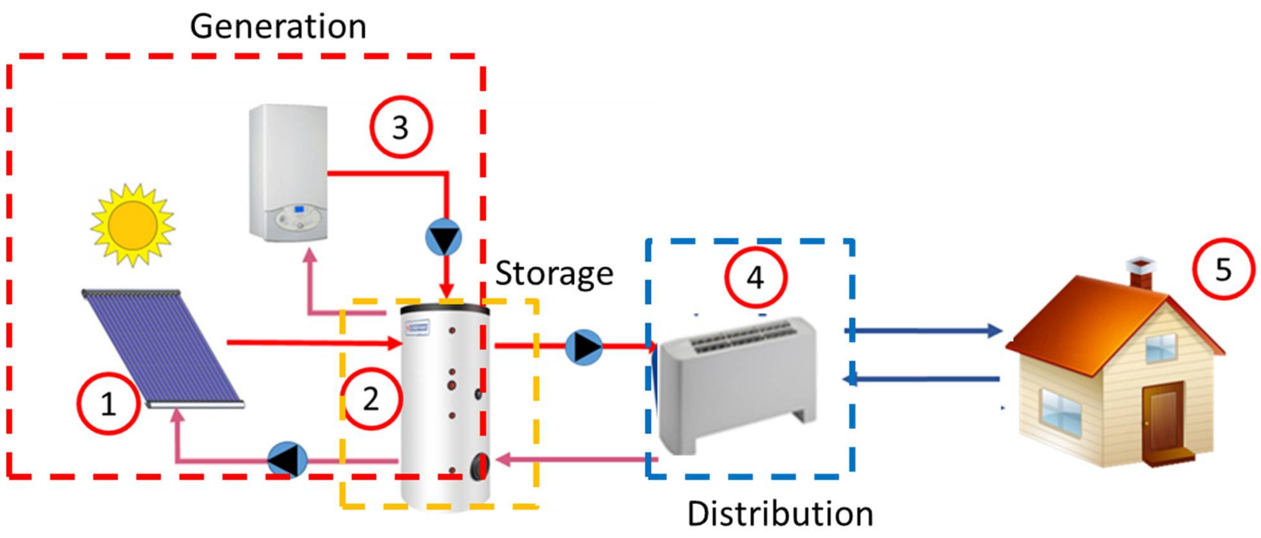

Figure 7 - layout of the system of WRB: winter operation.

## 3.1 Generation components sizing

In order to proper size the components of the system, the estimated loads have been calculated, according to the constraints reported in Deliverable B1. The core component in the sizing of the system is the adsorption system: indeed, since the units available on the market are mainly sold as chillers, coverage of space cooling demand was the leading criterion in the sizing process. The peak load required in the various investigated climates varied from 4 kW to 12 kW; considering the sizing for a coverage of 80% of the peak load, the required cooling power ranges from 3 kW to 10 kW. Since the smallest adsorption unit on the market has a nominal cooling power of 10 kW, this size was selected for all cases. The solar collector field was subsequently sized according to a rule of thumb that suggests 4 $m^2$ of solar collectors for each $kW_{cooling}$ to be produced. However, for each location, a sensitive analysis considering solar field areas between 24 $m^2$ and 40 $m^2$ was carried out. The storage volume was chosen equal to 1 $m^3$ on the basis of a sensitive analysis described in[1] , where it is shown that, for similar boundaries, selecting a higher storage volume decreases the solar fraction of the system. Finally, the dry cooler selected is the one suggested by the producer of the adsorption chiller, being optimised for such a component and equipped with variable speed fans controlled by the chiller itself.

### 3.1.1 Space Heating/Cooling load calculation

The building loads have been calculated assuming an ideal system with infinite capacity able to maintain the internal temperature at 20°C at wintertime, and 26°C in summer. An average over 1 hour has been used to avoid selecting only peak loads at system start.

## 3.2 Control Strategies

To integrate and run homogeneously all the components of the plant, an appropriate control strategy has been developed.

The structure of the control rules consists of the same five elements already described in par. 2.2.

### 3.2.1 Feedback signals

All the monitored parameters are reported in Figure 8 for summer operation and in Figure 9 for winter operation.

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[1] *S. Vasta, V. Palomba, A. Frazzica, G. Di Bella, A. Freni, Techno-Economic Analysis of Solar Cooling Systems for Residential Buildings in Italy, J. Sol. Energy Eng. Trans. ASME. 138 (2016). doi:10.1115/1.4032772.*

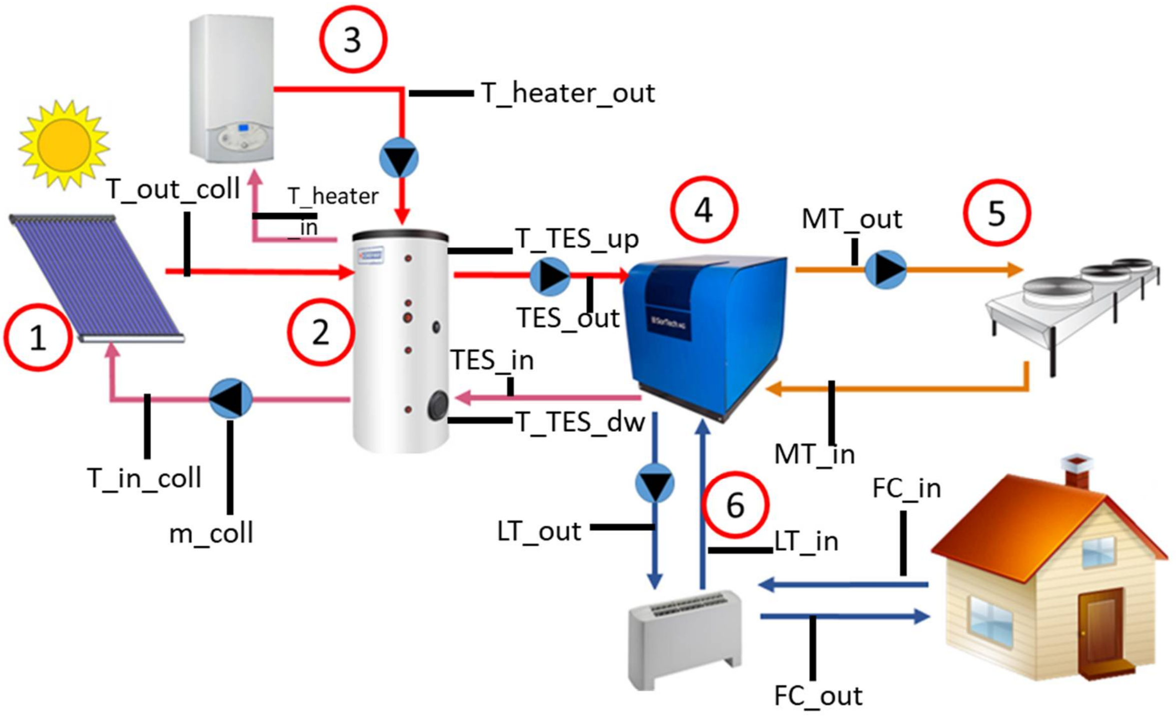


**Figure 8 - position of sensors for the WRB system, summer operation**

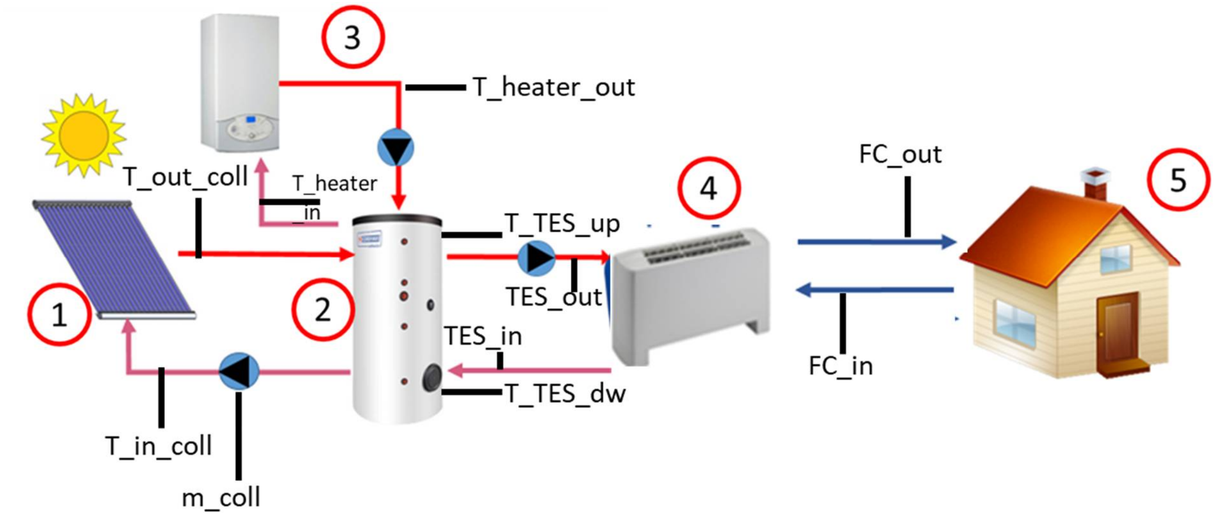


**Figure 9- position of sensors for the WRB system, winter operation.**

The data gathered and used for the control schemes are the following:

- T_in_coll: inlet temperature to solar field;
- T_out_coll: outlet temperature from solar field;
- m_coll: flow rate of the pump of the solar field;
- T_heater_in: inlet temperature to back-up heater;
- T_heater_out: outlet temperature from the heater:
- T_TES_dw: temperature at the bottom of the storage;
- T_TES_up: temperature in the upper part of the storage;
- TES_in: inlet temperature to the storage;
- TES_out: outlet temperature from the storage;
- FC_in: inlet temperature to fan-coil distribution system;

- FC_out: outlet temperature from fan-coil distribution system;
- AMB: ambient temperature;
- T_zone: internal temperature of the building.

### 3.2.2 Hysteresis functions

The following signals refer to four group categories:

1. Signal group 1x refers to hysteresis used for controlling the Solar Thermal Field
2. Signal group 2x refers to hysteresis for controlling the Heater use.
3. Signal group 3x refers to hysteresis for controlling the Thermal Energy Storage use.
4. Signal group 4x refers to hysteresis for controlling the Adsorption chiller use.
5. Signal group 5x refers to hysteresis used for controlling the Heat Rejection circuit.
6. Signal group 6x refers to hysteresis used for controlling the distribution units.

**Signal 1A**: Control of the temperature difference between the outlet of the Solar Thermal Collector field (T_coll_out) and the bottom of the main storage (T_TES_dw). If this value is higher than 2°C, the pump of the solar loop is activated.

**Signal 1B**: Control of the outlet temperature of the collectors to avoid stagnation.

**Signal 2A**: Control of the back-up heater. If the temperature in the storage is lower than 3°C of the set-point the signal is 1; otherwise, if it is greater than 3°C of the set-point the signal is 1.

**Signal 3A**: Control of the temperature of the tank to avoid stagnation.

**Signal 4A**: Control of the adsorption chiller. Adsorption chiller is switched on according to:

a) an hourly schedule, corresponding to the occupation profile of the house shown in Figure 10 (HOUR);

b) the actual existence of a cooling load, measured through the use of a thermostat inside the building.

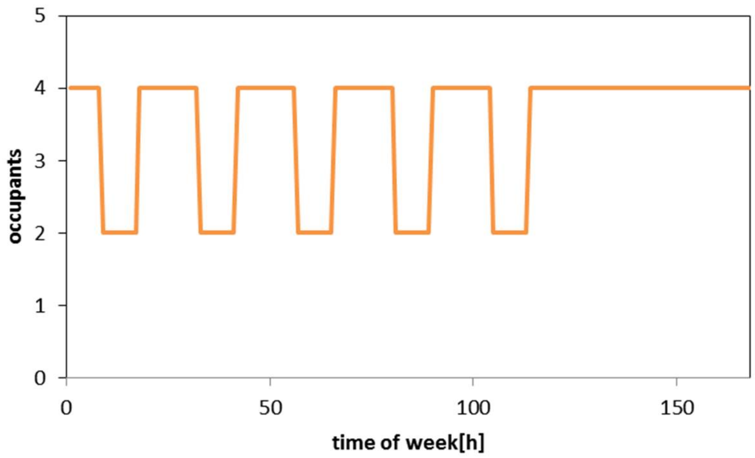


Figure 10 - occupation profile for WRB.

The adsorption chiller is equipped with 3 fixed speed pumps, turning on at the same time of the chiller and set to the nominal flow rates according to the datasheet of the component. During winter, the chiller is turned off.

**Signal 6A**: Control of the temperature for the indoor zone.

**SUMMER/WINTER**: Control of the space cooling/heating system for the indoor zone.

Table 7 - Hysteresis implemented in the control strategy of WRB system.

| Hysteresis name | Acquisition signal | Set Value | Upper dead band | Lower dead band |
|---|---|---|---|---|
| **Signal 1A** | Difference of temperature between the outlet of solar collectors (T_out_coll) and the bottom of the storage (T_TES_dw) | 2°C | 1°C | -1°C |
| **Signal 1B** | Outlet temperature of solar collectors (T_out_coll) | 97°C | 3°C | 0 |
| **Signal 2A** | Bottom temperature of the storage (T_TES_dw) | 60°C (winter operation), 85°C (summer operation) | 2°C | -2°C |
| **Signal 3A** | Top temperature of the TES (T_TES_up) | 95°C | 3°C | 0 |
| **Signal 4A** | Time of day, return temperature from fan coils (FC_out) | HOUR*GT(FC_OUT,12) | 3°C | -3°C |
| **Signal 6A** | Internal temperature inside the building (T_zone) | Heating (winter) and cooling (summer) set point | 3°C | -3°C |
| **Summer/Winter** | Mean temperature of the indoor zones temperature | 22 | 0 | 0 |

NOTE: GT: greater than; m_max: max flow rate of the pump of the solar field, fan_max: max speed of the fans in the dry cooler.

### 3.2.3 Functional schemes

The working schemes of the HVAC system identify which are the "operating state" of the plant based on the hysteresis generated. A scheme identifies the operation condition of each of the system components. This paragraph describes the equations that define the combination of the hysteresis to individuate a working condition - scheme. The combination of hysteresis can be read in a logical way using the logic operator AND, OR and NOT.

Scheme 1 (SC1): Running solar field.

This scheme is designed to deliver energy from the solar field to the main storage. The scheme is defined using a logic representation as shown in the following equation:

$$SC1 = NOT(1\mathrm{B}) * NOT(3A) * 1A$$

Scheme 2 (SC2): Running adsorption chiller for space cooling in summer

This scheme has been developed to activate the adsorption chiller.

$$SC2 = NOT(3A) * 4A$$

Scheme 3 (SC3): Running back-up heater

This scheme has been developed to activate the back-up heater when the temperature in the storage is lower than a certain set-point.

$$SC3 = NOT(3A) * 2A * SUMMER/WINTER$$

Scheme 4 (SC4): Control of heat rejection system

This scheme has been developed to turn the heat rejection system on when the adsorption chiller is on and regulate the speed of the fans according to external temperature:

$$SC4 = 4A + 5A$$

Scheme 5 (SC5): Running distribution system

This scheme has been developed to turn the distribution system when there is the need for a thermal load in the building:

$$SC5 = 6A * 4A * SUMMER/WINTER$$

### 3.2.4 Modulations

Modulations are here used for controlling the pump speed on the solar field circuit (PSOL) and the dry cooler (DCOO) fans speed.

**MOD_PSOL**

Control of the flow rate of the pump in the solar field, based on the temperature at the bottom of the main storage (T_TES_dw). The speed of the pump is regulated in order to maintain hot storage temperature to a set value suitable to drive the adsorption chiller, i.e. 85°C during summer and 60°C during winter. In this way, constant energy is supplied to the hot storage and high values of solar fraction can be reached.

**MOD_DCOO**

Control signal for the dry cooler. During summer, heat rejection is realised by means of a dry cooler: the speed of its fans is modulated in order to maintain the outlet temperature of the fluid equal to external temperature +3°C. During winter, the heat rejection circuit is not used.

### 3.2.5 Control signals

The signal delivered to the components is the combination of schemes and modulations. For each element of the plant (pumps, valves, and generation device), there is a specific combination of schemes and modulations. The control signals are reported in Table 8 and Table 9.

**Table 8 - Generation device regulation signal.**

| Component | Regulation |
|---|---|
| **Adsorption chiller (including pumps in the circuits of the chiller)** | SC2+SC5 |

**Table 9 – Pumps and fans regulation signal.**

| Component | Regulation |
|---|---|
| **Pump of solar circuit** | SC1*MOD_PSOL |
| **Pump of back-up heater** | SC3 |
| **Fans of dry-cooler** | (SC2+SC5)*MOD_DCOO |
| **Pump of cold distribution system** | SC5 |

# 4 HVAC system sizing and control for a Single-Family House - TheBat building

Figure 11 shows the architecture of the system. The system couples, in the **generation** side (red rectangle), a ground source heat pump with a solar energy source in form of PV-modules. This side of the system includes also a **storage tank** (yellow part). The **distribution** side (light blue rectangle) covers the building and DHW thermal loads.

The layout configuration of the HVAC system follows the same characteristics for all the cases analysed. Differences exist in form of different sizes for the thermal energy storage as well as installed PV area.

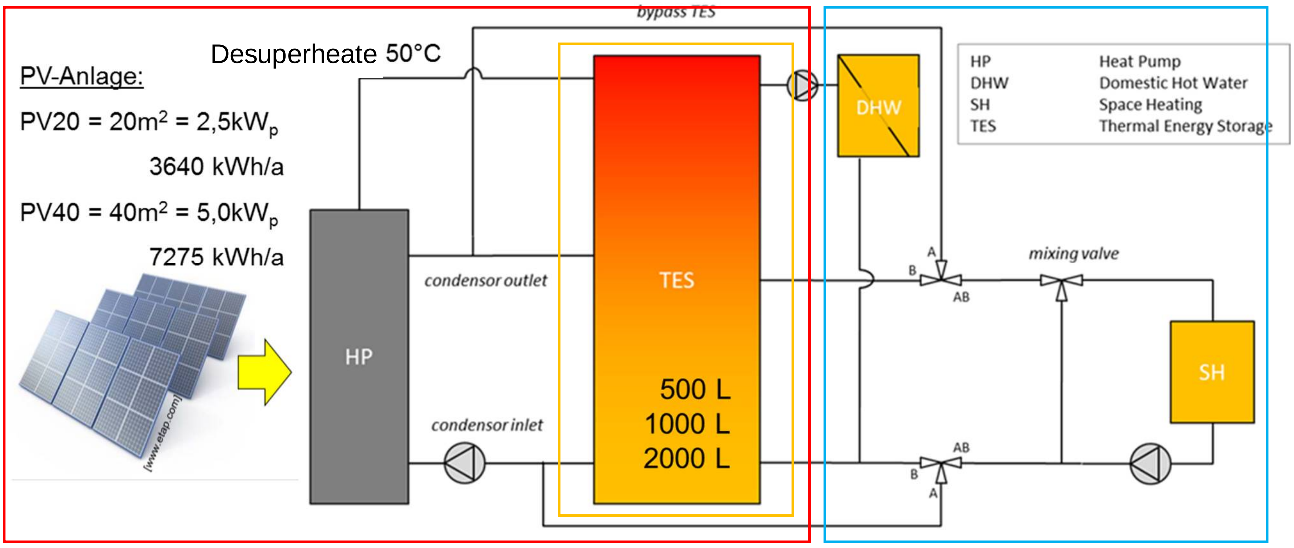


Figure 11 – Schematic of the HVAC system used for TheBat with the identification of the three main zones

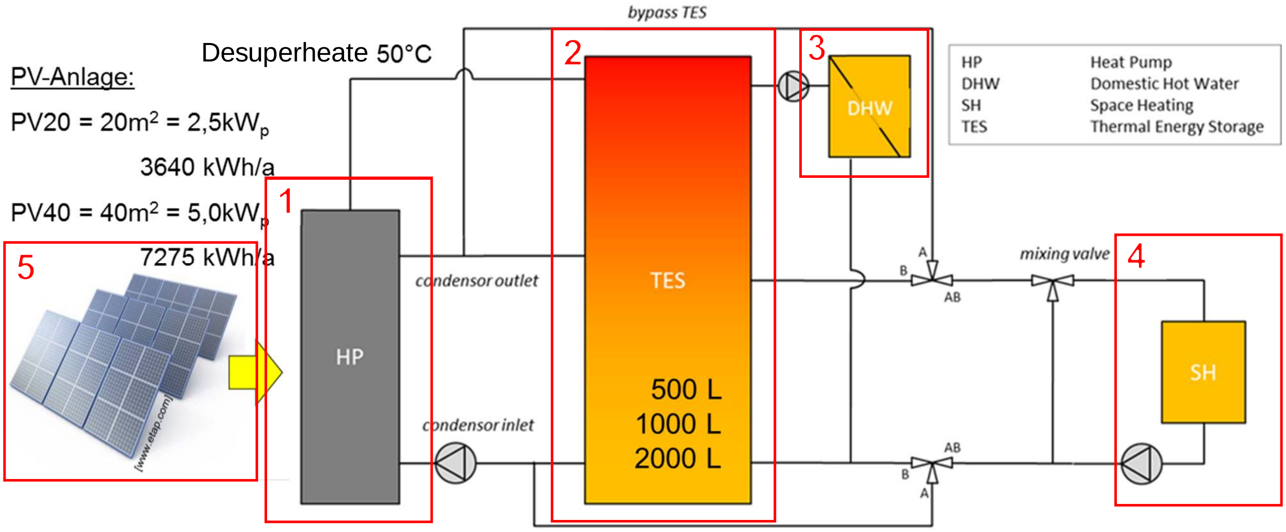


Figure 12 – Schematic of the HVAC system used for TheBat with the identification of the main components

1. **Heat pump** (HP), represents the ground source heat pump which is the only generation device for space heating and DHW preparation that was considered in all cases.
2. **Thermal Energy Storage** (TES) is a tank for the medium temperature level water to be used for the DHW preparation and as support for the heating system. In several considered cases this tank is also used to store excess energy from the PV system through overheating with the HP.
3. **DHW preparation** consists of a heat exchanger sized in a way to guarantee the instantaneous DHW production. The mass flow on the supply side controlled through a variable speed pump to achieve a return flow temperature of 27°C. This guarantees that the user side set temperature of 45°C is reached.
4. **Distribution system** (SH): In the considered cases, the building is equipped with floor heating as TABS. Each thermal zone (ground and first floor) is supplied by a distinct distribution unit feed.
5. **PV fields** is simulated as a field on the roof. The PV production aims to first cover the HVAC consumption. Based on the control strategy any additional energy produced is either use for overheating of the TES/Building or fed into the grid.

## 4.1 Generation components sizing

As shown in Figure 11, the generation side is composed of a ground source heat pump, a thermal storage tank and a PV system. The heat pump used in this model is designed for a thermal power output of about 10 $kW_{th}$ at B0W35 and is equipped with a desuperheater with a variable volume flow.

Given the available generation device, the goal of this model was an optimization of the self-use produced solar power to reduce the supply energy for space heating and DHWdemand. The size of the heat pump is sufficient and consequently not considered for this model.

### 4.1.1 Assessment of the maximum power for the TheBat model

For this model, the maximum heating load changes based on the different control concepts listed below. The respective loads are calculated in TRNSYS individually for each case, while a standard procedure has been adopted for the DHW load evaluation.

To evaluate the initial space heating load, a test was carried out using an ideal heating system with infinite capacity. Following this, the building loads for each case are calculated using the heat pump described in the deliverable B3 based on the respective conditions described below. For all cases, the minimum temperature of 20°C during the heating season is provided.

### 4.1.2 Assessment of the DHW load

For the DHW load, a reference demand created was used based on the data from Task 44

## 4.2 Control strategies

The control strategy for the model is based on the following main objectives:

- DHW priority to other requests;
- Maximization of solar energy use for DHW production and space heating;
- Maximization of self-consumption of PV production for the HVAC system.

The heat pump in this model is equipped with a desuperheater, which can be used to supply energy to the top volume of the TES.

As shown in Figure 11, the heat pump has three different states in which it interacts with the storage and demand side of the system:

1. Heating of the TES for DHW demand
2. Heating of the TES for space heating demand
3. Space heating directly by the heat pump

While the first can occur simultaneous with the other two, the second and third state is exclusive with each other. Therefor control rules are created for controlling the system based on the feedback signals and chosen concept.

The structure of the control rules consists of five elements listed in the following:

- **Feedback signal**: information acquired from the sensors;
- **Control functions**: elaboration of the signal acquisition.
- **Schemes**: represent the working modes used by the HVAC system. The schemes are defined as logical phrase of the control functions.
- **Control concept**: represents the strategy for increasing self-consumption of PV energy;
- **Control signal**: is the command given to the devices to be controlled; it is the combination of schemes and control concept.

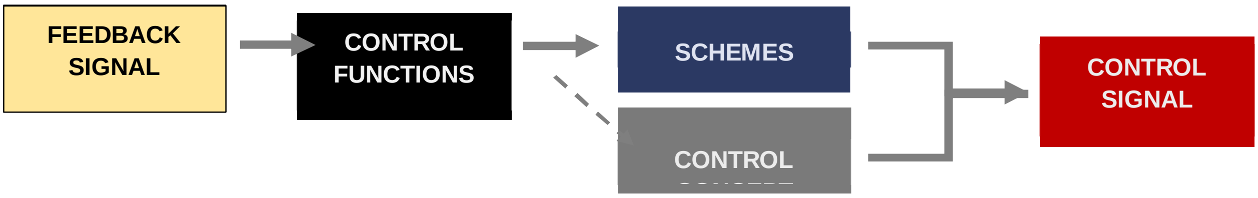


Figure 13 - Structure for the control signal

### 4.2.1 Measured parameters

The measurements considered for the control of the plant refer to temperatures, mass flow rates and irradiation on the horizontal plane.

The position of the corresponding sensors is shown in the HVAC system layout in Figure 14. A list of their respective information can be found below.

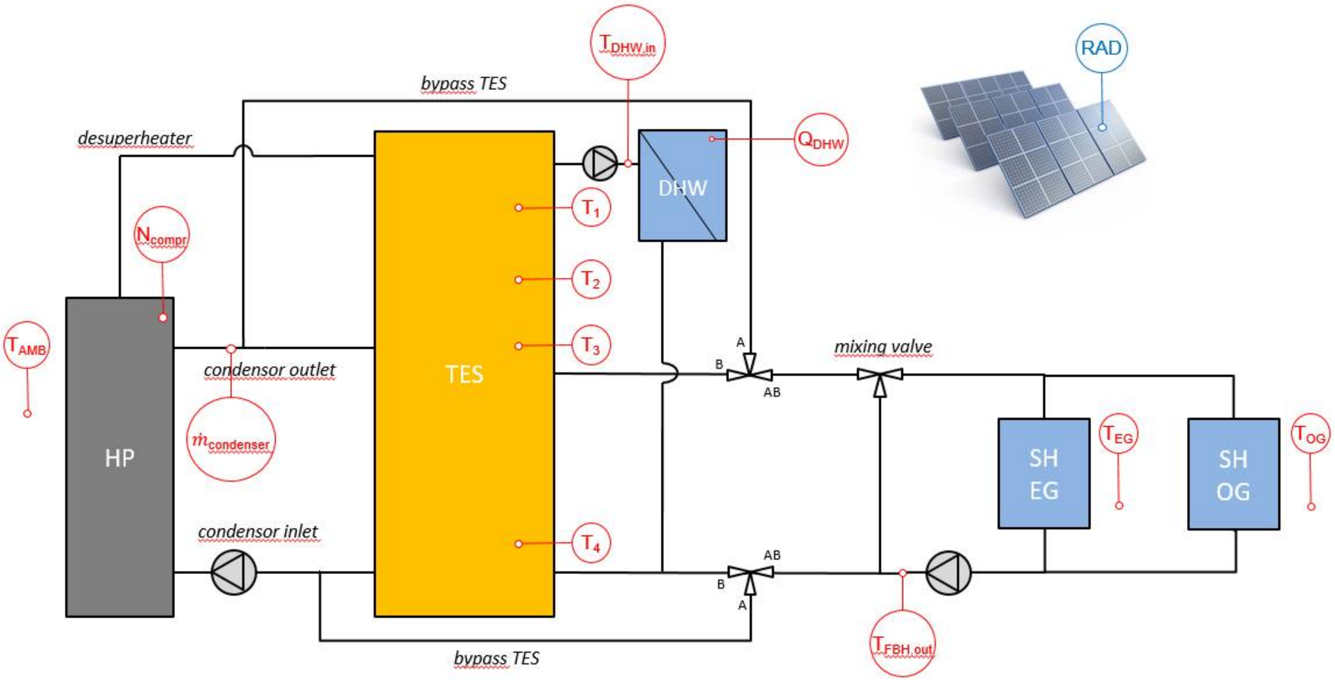
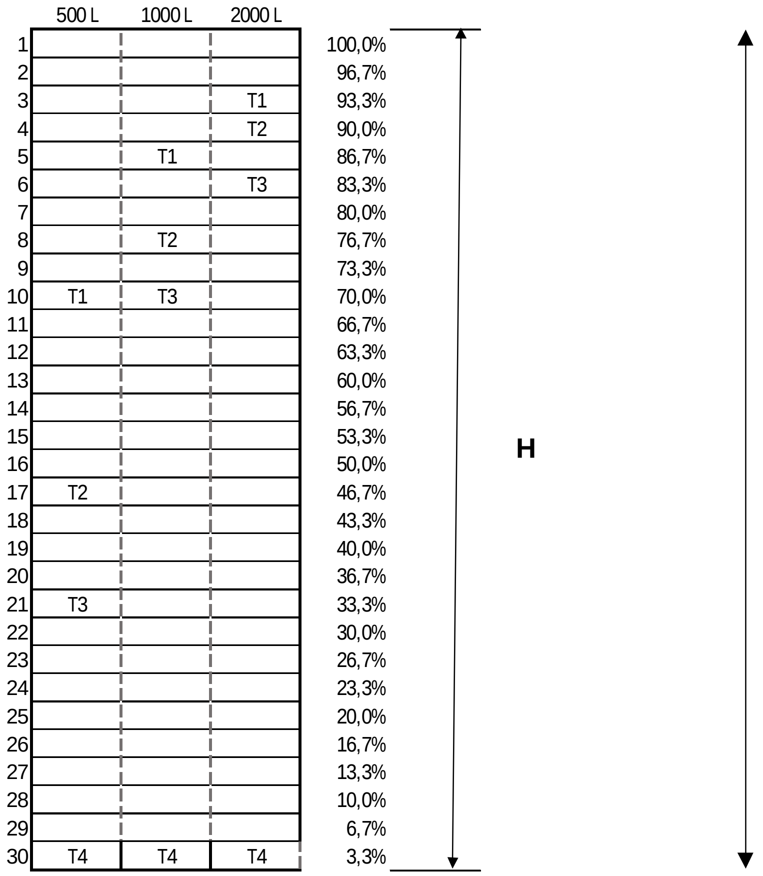


Figure 14 – Temperature and irradiation sensor locations

| | |
|---|---|
| $T_{AMB}$ | Ambient temperature [°C] |
| $T_{EG}$ | Temperature of air node in EG [°C] |
| $T_{OG}$ | Temperature of aid node in OG [°C] |
| RAD | Radiation on horizontal plane (split in beam and diffuse) [W/m²] |
| $T_1$ | Temperature in TES at Position 1 [°C] - used for DHW start condition |
| $T_2$ | Temperature in TES at Position 2 [°C] – used for DHW stop condition |
| $T_3$ | Temperature in TES at Position 3 [°C] – used for SH start condition |
| $T_4$ | Temperature in TES at Position 4 [°C] – used for SH stop condition |
| $T_{DHW,in}$ | outlet temperature of the TES towards the heat exchanger for DHW preparation [°C] |
| $Q_{DHW}$ | Energy demand for DHW preparation [kJ] |
| $\dot{m}_{condenser}$ | mass flow rate from the condenser [kg/h] |
| $N_{compr.HP}$ | rotational speed of the heat pump compressor [%] |

The height of the sensors in the main storage depends on the different sizes of the storage. In all cases the top ~300 l of the storage volume is reserved for DHW preparation. To guarantee that the demand can be fulfilled, the volume above sensor T1 is always kept above a temperature of 44°C. The location of sensor T2 marks a fictive division between the storage volume dedicated for DHW and the rest of the tank. The volume between sensor T3 and T4 is dedicated for space heating. The location for each of the sensors based on the different TES sizes can be found in Figure 15.



| | 500 L | 1000 L | 2000 L | |
|---|---|---|---|---|
| 1 | | | | 100,0% |
| 2 | | | | 96,7% |
| 3 | | | T1 | 93,3% |
| 4 | | | T2 | 90,0% |
| 5 | | T1 | | 86,7% |
| 6 | | | T3 | 83,3% |
| 7 | | | | 80,0% |
| 8 | | T2 | | 76,7% |
| 9 | | | | 73,3% |
| 10 | T1 | T3 | | 70,0% |
| 11 | | | | 66,7% |
| 12 | | | | 63,3% |
| 13 | | | | 60,0% |
| 14 | | | | 56,7% |
| 15 | | | | 53,3% |
| 16 | | | | 50,0% |
| 17 | T2 | | | 46,7% |
| 18 | | | | 43,3% |
| 19 | | | | 40,0% |
| 20 | | | | 36,7% |
| 21 | T3 | | | 33,3% |
| 22 | | | | 30,0% |
| 23 | | | | 26,7% |
| 24 | | | | 23,3% |
| 25 | | | | 20,0% |
| 26 | | | | 16,7% |
| 27 | | | | 13,3% |
| 28 | | | | 10,0% |
| 29 | | | | 6,7% |
| 30 | T4 | T4 | T4 | 3,3% |

Figure 15 – Representation of the temperature sensor positions based on different TES sizes

### 4.2.2 Control Functions

A list of the controls implemented in the model is summarized in Table 10.

The following signals refer to the different group categories:

1. Signal group 1x. It groups the hysteresis used for controlling the heating of the TES
2. Signal group 2x. It groups the hysteresis used for controlling the space heating
3. Signal group 3x. controller used for controlling the mass flow for DHW preparation
4. Signal group 4x to 8x. These groups contain the control signals that are used in the different control strategies to increase self-consumption of PV energy.

**Signal 1A**: Control of the T1 and T2 sensor of the TES to charge the DHW volume. If the temperature at T1 is lower than 44°C the signal is 1; otherwise, if the temperature at T2 is higher than 49°C the signal is 0.

**Signal 1B**: Control of the T3 and T4 sensor of the TES to charge the SH volume. The target temperature (Tset) lies between 32 and 37°C based on the ambient temperature. If the temperature at T3 is lower than Tset the signal is 1; otherwise, if the temperature at T4 is higher than Tset the signal is 0.

**Signal 2A**: Control of the space heating loop. If the minimal temperature at either of the sensors TEG or TOG is below 20.5°C the signal is 1, if the temperature is above 21.5°C the signal is 0.

**Signal 2B**: Control of the space heating loop based on the return flow temperature of the space heating loop. The target temperature varies based on the ambient temperature.

**Signal 3A**: Control of the mass flow for the variable speed pump at the DHW preparation loop.

**Signal 4A**: Signal to show minimum PV electricity production was exceeded

**Signal 4B**: Control for the heat pump that the PV electricity production exceeded the compressor electricity consumption.

**Signal 5A:** Control for the heat pump based on the ambient temperature

**Signal 6A**: Control for overheating of the TES with solar energy.

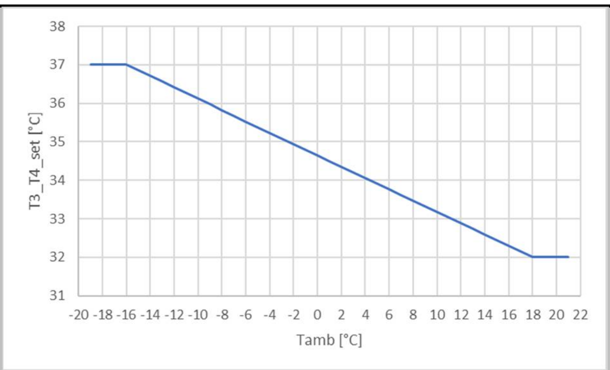
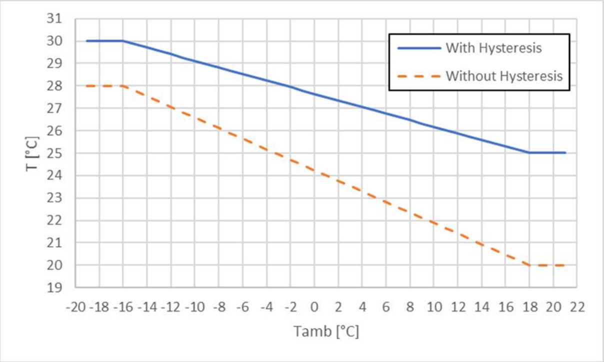
**Signal 7A**: Control for the heat pump based on the compressor speed needed

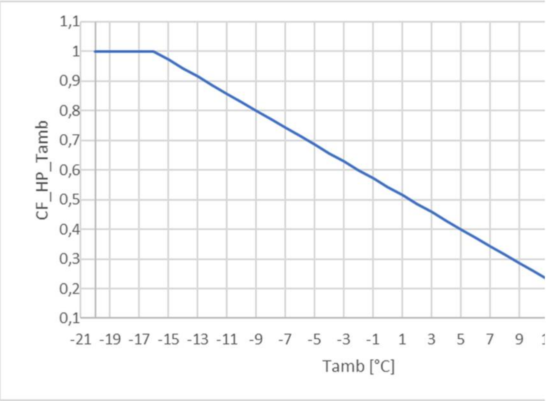
**Signal 8A**: Control for building overheating based on room temperature and overheating setpoint

**WINTER**: Control for the space heating system. For simplicities sake, a fixed start and end date was chosen for this.

Table 10 – Implemented control functions

| Control function name | Condition | Set value | Upper dead band | Lower dead band |
|---|---|---|---|---|
| **Signal 1A** | 1A*49°C+NOT(1A)*44°C – 1A*T2 – NOT(1A)*T1 | 44°C | 5°C | 0°C |
| **Signal 1B** | T3_T4_set – 1B*T4 – NOT(1B)*T3 | 32°C | 5°C | 0°C |
| | Because this hysteresis controls the space heating loop, the start/stop-condition is a function of the ambient temperature: The temperature setpoints vary therefore based on the ambient temperature based on the following conditions:<br>T3_T4_set = LT(Tamb,-16)*37+GT(Tamb, 18)*32 + GE(Tamb,-16)*LE(Tamb,18)* * 1/(-34)*(8*(Tamb-18)+3*(18-Tamb)+32) | | | |

| | | | | |
|---|---|---|---|---|
| |  | | | |
| **Signal 2A** | Hysteresis control for the space heating loop based on the minimum room temperature<br>Tmin = MIN($T_{EG}$,$T_{OG}$) | Tmin | 21.5°C | 20.5°C |
| **Signal 2B** | Hysteresis to control the space heating loop based on the return flow temperature. The start/stop condition is bound to the ambient temperature. | Tset_CTRL_upper – $T_{FBH,out}$ | 0°C | dTset_CTRL |
| | Tset_CTRL_upper = LT(Tamb,-16)*30+GT(Tamb, 18)*25 + GE(Tamb,-16) * LE(Tamb,18) * 1/(-34)*(8*(Tamb-18)+3*(18-Tamb)+25)<br>dTset_CTRL = LT(Tamb,-16)*2+GT(Tamb, 18)*5 + GE(Tamb,-16) * LE(Tamb,18) * (3/(-16-18)*(18-Tamb)+5)<br> | | | |
| **Signal 3A** | Control of the mass flow of the DHW preparation. The PID controller used for the heat exchanger was approximated by an ideal control. The mass flow is calculated to guarantee a return flow temperature of 27°C<br>mdot_DHW = Q_DHW/cp_water/(T_DHW_in – 27) [kg/h] | 0 | 0 | 0 |
| **Signal 4A** | This hysteresis control activates if the produced PV power surpasses a fixed value | RAD*PVArea – 1000W | 0 W | 0 W |
| **Signal 4B** | This signal uses the iterative feedback controller (Type22) to match the produced PV energy and the energy demand of the heat pump compressor.<br>Controlled Variable Compressor power | Produced PV Power = RAD*PVArea | | |
| **Signal 5A** | This signal uses a hysteresis control to control the heat pump based on the ambient temperature.<br>CF_HP_Tamb = LE(Tamb,NAT)*1 + | | | |

|  |  |  |  |  |
|---|---|---|---|---|
|  | +GT(Tamb,NAT)*LT(Tamb,12)*(Tamb*k+d) + + GE(Tamb,12)*0.2<br>k = 0.8/(NAT-12)<br>d = 0.2 - 0.8/(NAT-12)*12<br>NAT = -16<br> |  |  |  |
| **Signal 6A** | This hysteresis controls overheating of the TES. The concept uses higher setpoints for overheating purposes. (compare 4.3).<br>T3_set_OVERH = 50<br>T4_set_OVERH = 60 | 6A*T4_set_OVERH + NOT(6A)* T4_set_OVERH - 6B*T4 - NOT(6B)*T3 | 0°C | 0°C |
| **Signal 7A** | This signal controls the compressor based on the temperature difference between source and sink side and its characteristic map<br>Compressor_speed = 0.8*type581_output+0.2! |  |  |  |
| **Signal 8A** | This signal compares the minimum room temperature in the building with the overheating setpoint (compare 4.3).<br>8A = LT(MIN(TEG,TOG),TSET_BUI_OVERH) |  |  |  |
| **WINTER** | This signal fixates the heating season based on hours of the year.<br>CF_heating = LE(TIME,2880)) * GE(TIME,6528) |  |  |  |

### 4.2.3 Functional schemes

Based on the set objectives, five different requirement categories were created:

A) Category A (CF_A) - Heating demand TES for DHW
CF_A = 1A

B) Category B (CF_B) - Heating demand TES for space heating
CF_B = 1B

C) Category C (CF_C) - Demand DHW
CF_C = GT($Q_{DHW}$,0)

D) Category D (CF_D) - Space heating with the heat pump
CF_D = WINTER * LT(Tamb, 12)

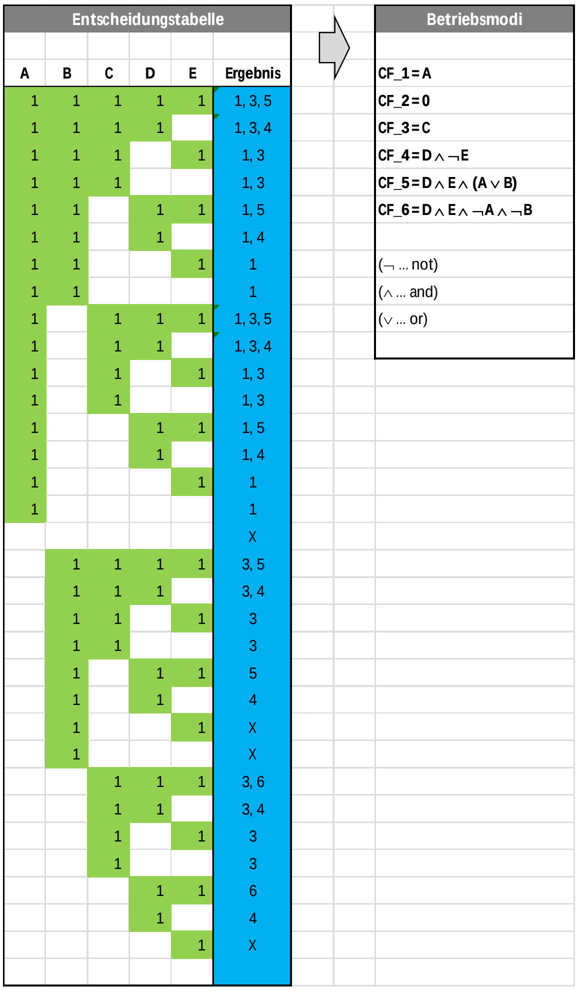
E) Category E (CF_E) - Demand Space heating
CF_E = 2B

a. Directly from the heat pump

b. from the TES

To decide on the functional schemes a decision table (as seen in Table 11) was created using these categories and the priority system outlined earlier.

Table 11 - Decision table for function schemes



**Entscheidungstabelle**

| A | B | C | D | E | Ergebnis |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1, 3, 5 |
| 1 | 1 | 1 | 1 |  | 1, 3, 4 |
| 1 | 1 | 1 |  | 1 | 1, 3 |
| 1 | 1 | 1 |  |  | 1, 3 |
| 1 | 1 |  | 1 | 1 | 1, 5 |
| 1 | 1 |  | 1 |  | 1, 4 |
| 1 | 1 |  |  | 1 | 1 |
| 1 | 1 |  |  |  | 1 |
| 1 |  | 1 | 1 | 1 | 1, 3, 5 |
| 1 |  | 1 | 1 |  | 1, 3, 4 |
| 1 |  | 1 |  | 1 | 1, 3 |
| 1 |  | 1 |  |  | 1, 3 |
| 1 |  |  | 1 | 1 | 1, 5 |
| 1 |  |  | 1 |  | 1, 4 |
| 1 |  |  |  | 1 | 1 |
| 1 |  |  |  |  | 1 |
|  |  |  |  |  | X |
|  | 1 | 1 | 1 | 1 | 3, 5 |
|  | 1 | 1 | 1 |  | 3, 4 |
|  | 1 | 1 |  | 1 | 3 |
|  | 1 | 1 |  |  | 3 |
|  | 1 |  | 1 | 1 | 5 |
|  | 1 |  | 1 |  | 4 |
|  | 1 |  |  | 1 | X |
|  | 1 |  |  |  | X |
|  |  | 1 | 1 | 1 | 3, 6 |
|  |  | 1 | 1 |  | 3, 4 |
|  |  | 1 |  | 1 | 3 |
|  |  | 1 |  |  | 3 |
|  |  |  | 1 | 1 | 6 |
|  |  |  | 1 |  | 4 |
|  |  |  |  | 1 | X |

**Betriebsmodi**

$CF\_1 = A$
$CF\_2 = 0$
$CF\_3 = C$
$CF\_4 = D \land \neg E$
$CF\_5 = D \land E \land (A \lor B)$
$CF\_6 = D \land E \land \neg A \land \neg B$

(¬ ... not)
(∧ ... and)
(∨ ... or)

Scheme 1 (CF_1) – Heating of the TES for DWH preparation

This scheme is designed to guarantee the DHW demand can be satisfied constantly. To guarantee this, Signal1A is used to control the scheme based on the following condition:

CF_1 = 1A

The equation is described by the following conditions:

- The temperature at sensor T1 falls below the setpoint of 44 °C, therefore the DHW demand can no longer be satisfied and heating of the TES commences.
- The temperature at sensor T2 exceeds the setpoint of 49 °C. The DHW reserve volume is sufficiently heated and the heat pump cycle switches of.

Because the heat pump used for this model is equipped with a desuperheater which allows heating of the DHW reserve volume while other schemes are active, this scheme can be superseded by several of the following schemes.

Because the heat pump is equipped with a desuperheater, energy is supplied to the top volume of the TES during energy generation for the other schemes. The appropriate control scheme in relation to the other schemes is presented below.

Scheme 2 (CF_2) – Heating of the TES as support for SH purposes

This scheme is designed to control the heating of the lower TES volume as energy storage to support the space heating cycle.

CF_2 = 0

For the reference schemes without PV interaction this scheme was excluded. Use in the control concepts listed below was changes to additions to other control schemes, therefore this scheme is not used for the model.

Scheme 3 (CF_3) – Satisfaction of DHW demand

This scheme is designed to signal a demand of DHW. The activation of the scheme is based on control signal 3A using the following control function:

CF_3 = GT(3A,0)

Scheme 4 (CF_4) – Space heating demand

This scheme is designed to control the space heating cycle. Activation is only possible during the heating season with an outside temperature below 12°C.

CF_4 = WINTER * LT(Tamb, 12)

Scheme 5 (CF_5) – Space heating demand satisfied directly from heat pump

The scheme is strictly speaking a sub-scheme of scheme 4 and is therefore only activating in case of activation of scheme 4. It is designed to control the space heating cycle while being fed directly from the heat pump.

CF_5 = NOT(2A)*CF_D*CF_E*GT(CF_A+CF_B,0)

Scheme 6 (CF_6) – Space heating demand satisfied from the TES storage

Like scheme 5, this scheme is a sub-scheme of scheme 4 and is therefore only activated if scheme 4 is activated. It is designed to control the space heating cycle while being fed with energy from the TES.

CF_6 = NOT(2A) * CF_D * CF_E * NOT(CF_A)

Desuperheater Control Strategy

As the heat pump is equipped with a desuperheater, an additional control strategy for the desuperheater loop is created:

CF_DS = GE(CF_1+CF_2+CF_5, 1)

The desuperheater is used to heat the uppermost volume of the TES and is therefore activated for the control schemes which activate the heat pump. When activating the control scheme, the type used in the model to simulate the heat pump (Type887) controls the mass flow through the desuperheater so that a temperature of 50°C is reached.

For the schemes in which CF_DS is not activated, a minimum flow rate of $\dot{m}_{ds} = 0.1 * \dot{m}_{condenser}$ is used.

## 4.3 Control concept

The goal of this model was the increase of self-consumption for the produced PV-energy. The PV electricity produced is primary used for the HVAC system, additional energy is fed into the grid. To incorporate the PV production into the control scheme, several different control strategies were created. These additions to the functional schemes described in 4.2.3 are highlighted in bold.

Control concept 0 (SELF) – Self-consumption of PV-energy

This control concept is used as a base for all other control concepts for PV-energy consumption. The functional schemes described in 4.2.3 contain no conditions for PV-energy production. To remedy this, this control concept is created to control the system based on availability of PV energy. The main condition is connection between heat pump and PV-system. This is controlled by the following condition:

Activation of PV-HP-coupling:

PV_COUPL_HP = 1

Coupling of the heat pump if produced PV electricity surpasses compressor electricity consumption:

CF_PV_HP = PV_COUPL_HP*(4A*GT(CF_HP_COUPL, MAX(CF_A*7A ,5A*7A*CF_D*2A)))

In addition to the PV-HP-connection, several of the functional schemes described above are used as inputs in the basic control concept of the heat pump. This control concept is described by the following equations:

CF_HP = ((CF_1*NOT(CF5)*1 + CF_2*NOT(CF_5)*1 +CF_5*5A)*7A)*NOT(CF_PV_HP)

To accommodate the different control concepts for overheating this control of the heat pump was further expanded with the following additions:

CF_HP = ((CF_1*NOT(CF_5)*1 + CF_2*NOT(CF_5)*1 +CF_5*5A)*7A)*NOT(CF_PV_HP) +

**+ TES_OVERHEAT*NOT((CF_D*8A*CF_PV_HP)*BUI_OVERHEAT)***

*** (CF_PV_HP*6A*4B) + (8A*BUI_OVERHEAT*CF_PV_HP*4B)**

The marked parts are activated based on the different control concepts described below.

To represent the changed conditions several schemes are extended by the following conditions:

CF_5 = NOT(2A)*CF_D*CF_E*GT(CF_A+CF_B,0) *NOT(4B)*
* NOT((CF_D*8A*CF_PV_HP)*BUI_OVERHEAT)*+
+ (CF_D*8A*CF_PV_HP)*BUI_OVERHEAT

CF_6 = NOT(2A) * CF_D * CF_E * NOT(CF_A) * NOT(MIN(CF_B, NOT(4B)) *
* NOT((CF_D*8A*CF_PV_HP)*BUI_OVERHEAT)

CF_DS = GE(CF_1+CF_2+CF_5**+CF_PV_HP**,1)

Because the consumption of PV-energy is a base condition, these changes apply for all the following control concepts.

<u>Control concept 1 (TES)</u> – Overheating of the TES

For this control concept, the TES is used as a storage for the surplus of PV energy. The control concept is activated by the following condition:

TES_OVERHEAT = 1

As the surplus of PV energy is used to run the heat pump and overheat the TES, and to accommodate these changes additional temperature limits are added. These setpoints are used for the hysteresis control signal 6A as described in 4.2.2:

T3_set_OVERH = 50! TES overheating restarts if T3 goes below T3_set_OVERH

T4_set_OVERH = 60! TES overheating STOPS if T4 goes above T4_set_OVERH

Activation of this control concept activates the following part of the addition to the heat pump control:

CF_HP = ((CF_1*NOT(CF_5)*1 + CF_2*NOT(CF_5)*1 +CF_5*5A)*7A)*NOT(CF_PV_HP) +
+ **TES_OVERHEAT*NOT((CF_D*8A*CF_PV_HP)*BUI_OVERHEAT)***
*** (CF_PV_HP*6A*4B)** + (8A*BUI_OVERHEAT*CF_PV_HP*4B)

If the TES temperature is below the setpoints, the marked part of the control concept activates overheating of the TES volume with PV energy. This condition appears only in cases in which overheating of the building is not possible or deactivated.

<u>Control concept 2 (BUI)</u> – Overheating of the TABS and air node

For this control concept, the TABS as well as the air nodes of the building are used to store the excess PV-energy. The control concept is activated via the control:

BUI_OVERHEAT = 1

Additional overheating setpoint, which was already mentioned in 4.2.2, is used to set the maximum allowed overheated room temperature. For most cases, this setpoint was set at 26 °C but additional cases with different setpoints were examined (compare deliverable B5).

TSET_BUI_OVERH = 26

Additional parts for this control concept activates of the heat pump control function are marked below.

CF_HP = ((CF_1*NOT(CF_5)*1 + CF_2*NOT(CF_5)*1 + CF_5*5A)*7A)*NOT(CF_PV_HP) +
+ TES_OVERHEAT*NOT((CF_D*8A*CF_PV_HP)*BUI_OVERHEAT)*
* (CF_PV_HP*6A*4B) **+ (8A*BUI_OVERHEAT*CF_PV_HP*4B)**

Overheating of the building with PV energy activates if the room temperature is below the setpoint described above (Signal 9A in 4.2.2).

In addition, the overheating conditions for CF_5 and CF_6, as shown above, are activated.

<u>Control concept 3 (BUI+TES)</u> – Overheating of the TABS and the TES

In this third control concept both, the TES and the building, can be overheated to store excess energy. The priority for this control scheme lies with overheating of the building over overheating of the TES. As this control concept is a combination of the previous two control concepts, all the conditions described above apply for this case.

## 4.4 Delivered signals

The signals delivered to the components of the model is a combination of the schemes and control functions shown above. Below is an account of the effects based on the different components.

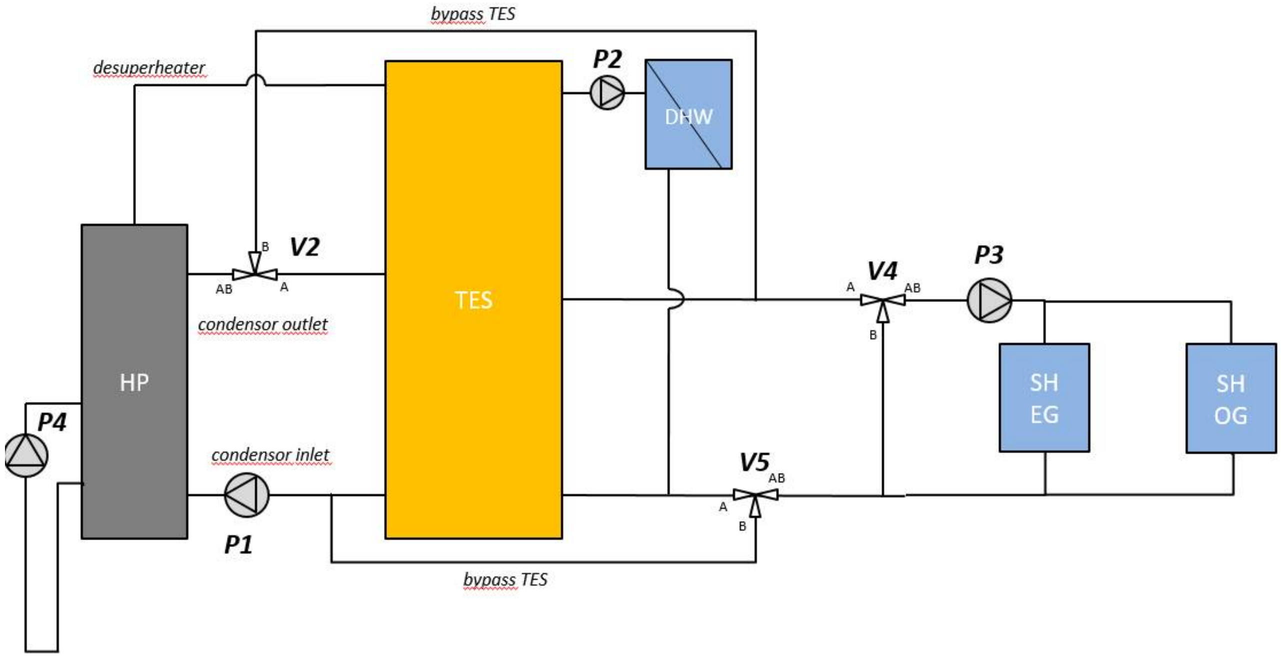


Figure 16 - Pumps and Valves for the TheBat-model

Pump of the heat pump loops – P1

This pump controls the mass flow of the heat pump loops and is therefore activated for every scheme and control concept which includes running the heat pump. The mass flow rate is controlled based on the relative compressor speed of the heat pump.

### Pump of the DHW preparation loop – P2

The pump P2 belongs to the DHW preparation loop and is only activated when scheme 3 is ON. The signal to the pump is modulated based on signal 3A to control the mass flow rate based on the target outflow temperature.

### Pump of the space heating loop – P3

The pump is activated when the space heating loop is activated based on scheme 4 and subsequently scheme 5 and 6. The pump uses an on-off-control without any mass flow control.

### Pump of the evaporator loop – P4

As this pump is used for the evaporator loop of the heat pump, it is activated based on every schemes and control concepts which includes running the heat pump. No mass flow rate control is implemented for this pump.

Valve V2 and V5

These valves control the bypass of the TES for space heating purposes. They are pointed towards A for all cases except scheme 5 in which case they point towards B.

Valve V4

This mixing valve controls the inlet temperature for the TABS. In case of scheme 5 the temperature is controlled by the heat pump and the valve takes 100% from A. For scheme 6 the valve setting is based on the ambient temperature. The mixing setting is based on the signal 6A, for which case the flow rate from A is based on the following condition:

CF_V4 = 6A

# 5 HVAC system sizing and control for a Reference Multi Family House from the Project HVACviaFaçade

This chapter describes the HVAC system for three different system concepts chosen for the MFH reference buildings of the Austrian national project HVAC via Façade. More details can be found in German language in [4].

## 5.1 System Concept #1: Central Heat Pump

The first system concept includes a central variable-speed outdoor air heat pump for domestic hot water and space heating. Auxiliary heaters work as back up for the two uses. Photovoltaic panels are included in the system (red rectangle in Figure 17). The heat pump heats a central buffer tank as well as separate domestic hot water tanks in each apartment. The heat for space heating is distributed using radiators in each room (green rectangle).

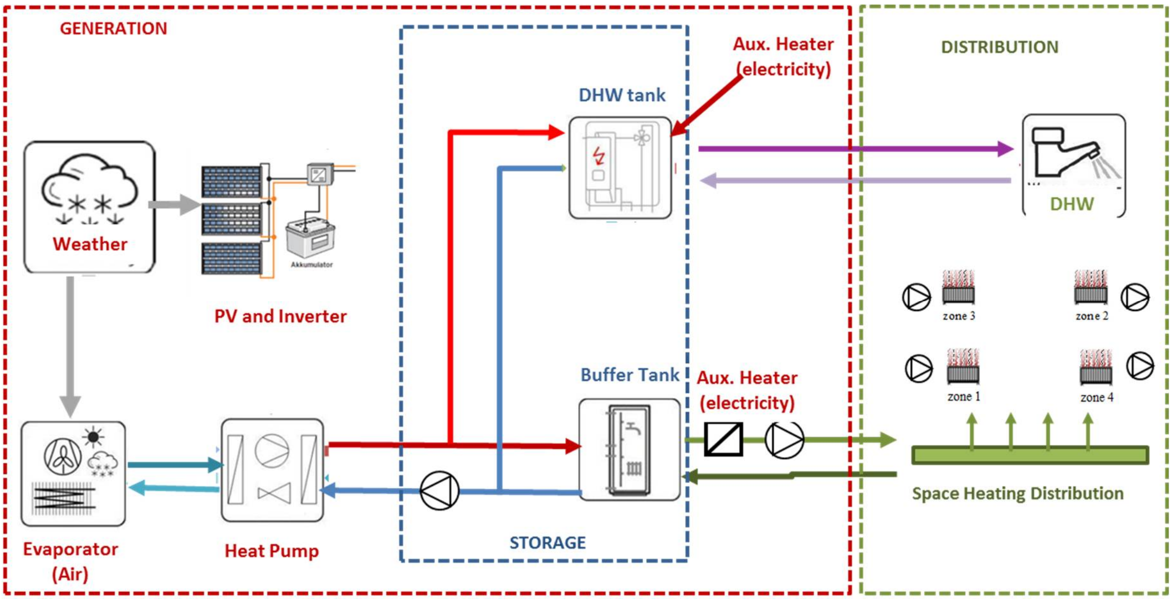


Figure 17 – Hydraulic scheme of concept with central heat pump and PV generation

### 5.1.1 Generation components sizing

Heat Pump

The heat pump for the system was dimensioned by means of a sensitivity analysis in order to minimize the use of auxiliary electricity for both space heating and domestic hot water. Only about 1-2 % of the total heating demand was covered by auxiliary electricity. The heat pump must be able to supply the heat needed for DHW during the specified time windows. During the rest of the day, it covers the SH demand directly and charges the buffer tank if there is excess PV power available.

PV

The size of the PV array is limited by the available area on the building façade and roof excluding the window areas. In a first step, only the south façade was covered with PV modules. This led only to a small reduction of primary energy demand. Adding the west and east façades, the primary energy reduces significantly. In addition, the east and west roof would be available for PV modules although simulations showed that this would not reduce the primary energy demand enough to justify such a large PV area.

South, east and west façades excluding windows sum up to roughly 190 m² of PV area.

Tanks

The DHW tanks were sized in order to satisfy the daily hot water demand for one apartment.

The buffer tank was chosen based on a sensitivity analysis minimizing the overall electricity consumption of the system.

### 5.1.2 Control strategies

Heat Pump

The heat pump is generally only allowed to operate between 6 a.m. and 1 a.m. at night. During the night hours when there is very little DHW demand and night setback for space heating, the heat pump is turned off.

To minimize the operating temperature of the heat pump, the DHW tanks in the apartments are only charged during time windows twice a day (9:30 h-11:30 h and 15 – 17 h). During these time windows, the heat pump is operated at maximum speed until a set temperature (52°C) in the DHW stores is reached. Only if the heat demand for DHW is satisfied, the heat pump is allowed to operate in space heating mode.

During the rest of the day, the heat pump charges the buffer tank if the set temperature of the tank is not reached. The tank set temperature is always two degrees higher than the flow temperature that is currently necessary in the space heating loop.

To maximize the self-consumption of PV electricity, there is a second set of set temperatures which are higher than the first ones. Until the first set temperatures are reached, the heat pump always operates at full load. Afterwards, the storage tanks can be heated up to the second set temperature only if PV electricity is currently available. Depending on the available PV electricity, the heat pump can then operate at part-load or full-load respectively. The second set temperature was chosen 4 K higher for the DHW tanks and 8 K higher for the buffer tank. It should be avoided that the tanks are heated too far which would lead to even lower coefficients of performance of the heat pump, more tank losses and thereby more energy consumption.

This control strategy leads to slightly lower seasonal coefficients of performance (due to part-load operation and higher operating temperatures) but increases self-consumption of PV electricity.

Auxiliary Heaters

The auxiliary heater for DHW is located in the top part of the DHW tank. It has to be avoided that the auxiliary heater turns on even if the heat pump would have been able to heat the tank. Therefore, a lower value than for the heat pump is chosen as the set temperature of the auxiliary heater (45°C). This way, it can be ensured that 45°C are always available in the tank to cover the load.

The auxiliary heater for space heating is positioned in the flow line of the space heating loop. It heats the flow line always to the necessary flow temperature even if the temperature in the buffer tank is not sufficient.

## Measured parameters

**Signal 1A**: schedule for heat pump activation, from 6 am to 1 am

**Signal 1B**: schedule for DHW tank charging: during this period the tank for the DHW is maintained at 52°C while for the rest of the day, the tank is heated up for maintaining 45°C.

**Signal 2A**: this signal is used for the DHW tank charging; the value of this signal is compared with the set temperature (Tset_DHW) that varies according to the time of the day. Tset_DHW is 52°C during the schedule time of Signal 1B while it is 45°C during the rest of the day.

**Signal 2B**: compares the DHW tank temperature with another set point (Tset_DHW_PV) that is 4°C higher than Tset_DHW because exploits the PV availability.

**Signal 3A**: this signal is used for the buffer used for space heating charging; the value of this signal is compared with the set temperature (Tset_SH). The Tset_SH is the 2°C higher than the supply temperature to the distribution devices.

**Signal 3B**: compares the buffer tank temperature with another set point (Tset_SH_PV) that is 8°C higher than Tset_SH for exploiting the PV availability.

**Signal 4A**: this signal communicates when there is PV availability in a way that the tanks are charged up to higher temperatures exploiting the solar availability for driving the heat pump.

**Signal 5A**: this signal activates the auxiliary heater when the temperature in the DHW tank is below 45°C and the set temperature in the buffer is not reached.

Table 12 - Hysteresis implemented in the control strategy of concept #1.

| Hysteresis name | Acquisition signal | Set Value | Upper dead band | Lower dead band |
|---|---|---|---|---|
| **Signal 1A** | Time of the day | 6 am to 1 am | - | - |
| **Signal 1B** | Time of the day | From 9:30 to 11:30<br>From 15 to 17 | - | - |
| **Signal 2A** | DHW tank top temperature | Tset_DHW | 2°C | 0 |
| **Signal 2B** | DHW tank top temperature when PV availability | Tset_DHW_PV | 2°C | 0°C |
| **Signal 3A** | Buffer tank top temperature (Tset_BUFF) | Tset_SH | 2°C | 0°C |
| **Signal 3B** | Buffer tank top temperature when PV availability | Tset_SH_PV | 3°C | 0 |
| **Signal 4A** | PV production | PV_min | - | - |
| **Signal 5A** | Top temperature in the tank and buffer | 45°C for the tank<br>Tset_SH for the buffer | | |

## Functional schemes

The above described signals are combined for defining the working modes in which the devices have to be activated. Three main schemes are individuated, for the charging of the DHW tank (SC1), for the charging of the buffer for space heating (SC2) and for activating the auxiliary heater.

SCHEME 1 Working mode for charging the DHW tank.

This scheme regulates the charging of the DHW tank.

$$SC1 = 1A * (NOT(2A) * \mathrm{NOT}(4\mathrm{A}) + NOT(2\mathrm{B}) * 4A)$$

SCHEME 2: Working mode for charging the buffer.

This scheme regulates the charging of the tank used for space heating.

$$SC2 = \mathrm{1A} * \mathrm{2A} * (\mathrm{NOT}(\mathrm{3A}) * \mathrm{NOT}(\mathrm{4A}) + \mathrm{NOT}(\mathrm{3B}) * \mathrm{4A})$$

SCHEME 3: Working mode for activating the auxiliary heater.

This scheme refers to the activation of the auxiliary heater when the heat pump is not enough.

$$SC3 = NOT(\mathrm{5A})$$

## Modulations

The set point for the DHW tank depends on the time of the day. Accordingly, the set point to be maintained is defined as follows:

$$Tset_{DHW} = 52 * \mathrm{1B} + 45 * NOT(\mathrm{1B})$$

## Control signals

In the system, the two main components that need a control signal are the heat pump and the auxiliary heater.

The heat pump is activated when the working modes for charging the DHW tank or the buffer are verified, while the auxiliary heater activates with the working mode SC3.

Table 13 – Pumps and fans regulation signal.

| Component | Regulation |
|---|---|
| **Heat Pump** | OR(SC1,SC2) |
| **Auxiliary heater** | SC3 |

## 5.2 System Concept #2: Separate Heat Pump for Each Apartment

The second system concept is very similar to the first one. The main difference is that there is a separate system for each apartment. In addition, there is no buffer tank for space heating so the heat pump feeds directly into the radiator system.

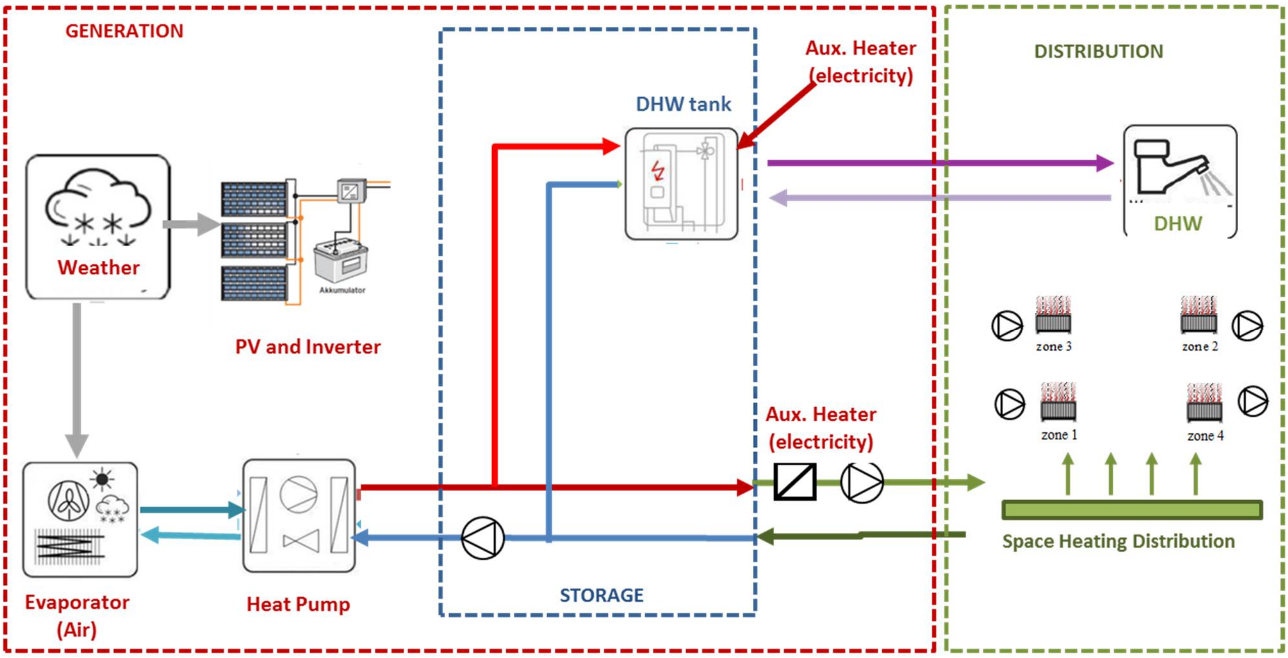


Figure 18 – Hydraulic scheme of concept with separate heat pumps for each apartment

Just like for the central heat pump system, there are PV panels integrated into the south, east and west facades.

### 5.2.1 Generation components sizing

Heat Pump

For the dimensioning of the heat pump for the individual apartment, the DHW demand was the most important factor than the space heating demand. Because there is no buffer tank for space heating available in this system concept, the time window for charging of the DHW tank was reduced to 1.5 hours compared to 2 hours for the central system. Therefore, the same heating capacity of the heat pump (2 kW at 0°C and 45°C) was chosen for both energy levels.

PV

In this case, each apartment has a certain number of PV panels in each façade dedicated to cover the electricity demand of that apartment. Because of the module sizes, the total PV surface is slightly lower than for the central system: 14.6 m² for each apartment or 176 m² for the whole building.

Tanks

The DHW tanks were sized in order to satisfy the daily hot water demand for one apartment.

No buffer tank was chosen in order to minimize the size of the components that have to be integrated into the apartment of façade.

### 5.2.2 Control strategies

Apart from the reduced time window for charging of the DHW tank, the control strategies are the same as for the central system concept (#1).

## 5.3 System Concept #3: Direct Electrical Heating

The third system concept uses direct electrical heating elements for both space heating and DHW preparation. For space heating, infrared heating panels are used. For DHW preparation an electric water heater with a 150 L tank was included.

The system is designed as a de-centralized system. That means there is a separate system for each apartment including PV panels dedicated to each apartment.

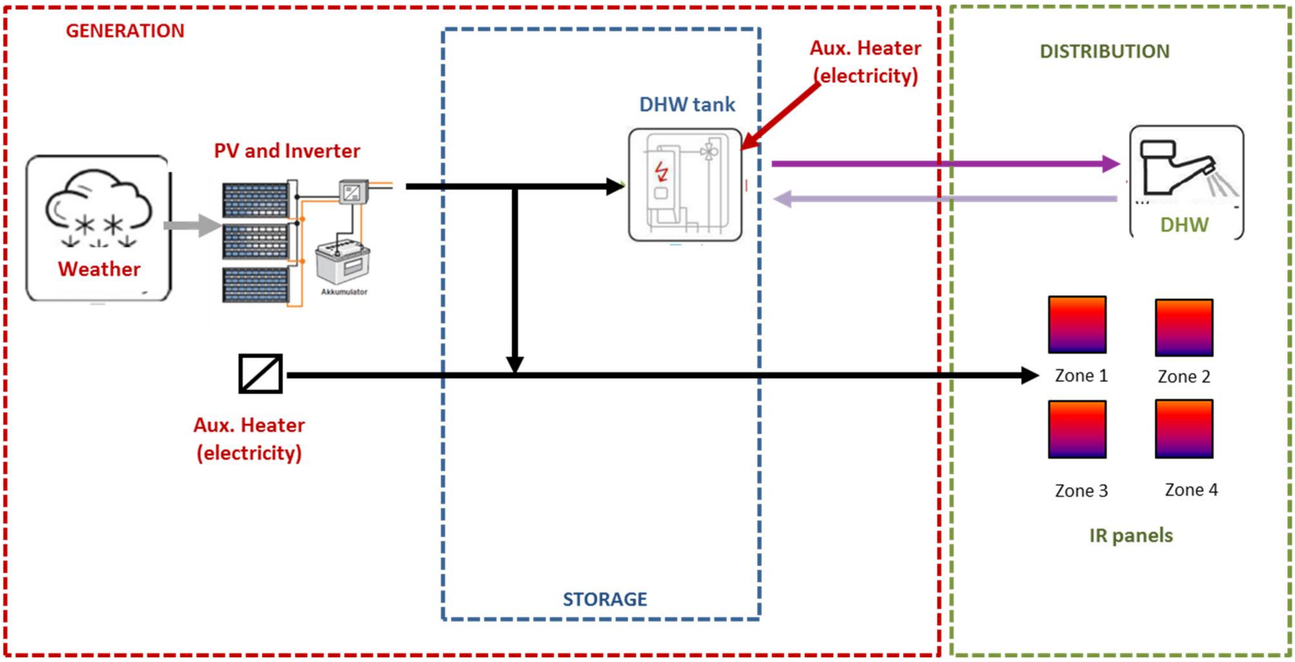


Figure 19 – Scheme of concept using direct electrical heating at apartment level

### 5.3.1 Generation components sizing

The final energy consumption of the direct electrical heating system is significantly higher than for the heat pump systems. Therefore, the PV surface area used for system #2 is not sufficient to reach low primary energy consumptions. The same surface area was simulated anyway to have a good comparison to the other two system concepts.

In addition, the system was simulated also with the maximum possible PV area which is limited by the available surface area on the façades and the roof.

These sum up to 34.9 m² for each apartment or a total of 419 m² for the whole building. The PV areas are the same for both energy levels although for energy level 30 even more PV area would have been necessary.

### 5.3.2 Control strategies

The control strategy for the DHW tank gives priority to electricity produced by PV. Just like for the heat pump systems, there are two set temperatures. When there is more PV electricity available than needed for space heating, the tank can be heated by PV to a maximum of 90°C. Otherwise, 50°C is used as the set temperature.

# 6 References

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