Heat4Cool – Task 8.3 Education and training.

TRAINING MATERIAL

In the framework of T8.3 of the Heat4Cool project, we are presenting you the training material dedicated to each of the four demo sites involved in the project, and the different technologies tested and installed in these facilities.

This training material aims to present to external stakeholders the functioning of the Heat4Cool technologies installed in each demo, and present the systems developed within the project; thus, to allow a better comprehension, increase the interest of the audience and promote the use of the project solutions in the market.

The training material is divided into **four dossiers,** each one dedicated to one demo site.

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Demo site in Valencia (Spain)

Demo manager: Symelec

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1 HEAT4COOL PROJECT INTRODUCTION AND OBJECTIVES

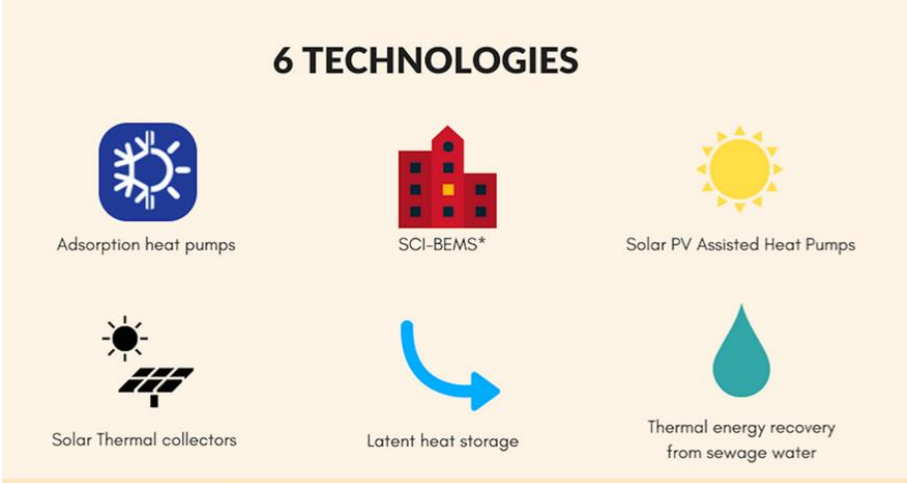
1.1. Introduction

The Heat4Cool project is an EU funded project, started in October 2016 and will run for four years.

The project proposes innovative, efficient and cost-effective heating and cooling solutions to optimize the integration of six technologies:

- Adsorption heat pump,
- PCM storage batteries,
- SCI-BEMS, Solar PV,
- Solar thermal,
- Heat recovery from sewage water

at building and district level, to meet net-zero energy standards.



The project will showcase four different retrofitting solutions, three of them will be focusing on residential buildings where the new innovative systems will be monitored and controlled through the SCI-BEMS (self-correcting intelligent building energy management system).

1.2 Testing technologies

The technologies based on solar energy and heat pumps developed within the Heat4Cool project are being implemented in Tecnalia's Kubik® facility, located in Bilbao (Spain).

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In the facility, Tecnalia tested the thermal storage system coupled with a reversible heat pump and the solar driven adsorption cooling system.

The main aim of these tests is to carry out a proof of concept for two complete systems in order to assess the thermal performance of Heat4Cool solutions under realistic boundary conditions. These two systems are already connected to the centralized HVAC system to test the effective integration of the heating and cooling technologies.

The thermal storage system coupled by a reversible heat pump is the concept solution developed by Sunamp. A total of 7 PCM (Phase change material) heat storages connected to an air to water electric heat pump have been installed. This is the first version of the system that will later evolve to a DC driven heat pump connected to a PV panel field, a solution that will be implemented in the pilot buildings of Sofia and Chorzow. The system to be tested in Kubik will allow improving the interaction between the heat pump and the heat storages while the contribution of the solar field will be post-processed.

The solar-driven adsorption cooling system has Fahrenheit's Zeolite prototype chiller as the main innovative component. Combined together with a solar thermal field composed of flat plate collectors, the heat pump will produce cold water that will be stored into an 800L tank connected to the cooling circuit. As a result of the adsorption process, waste heat will be produced at medium temperature (35-40 °C), which will be used for preheating of domestic hot water or dissipated to the atmosphere by means of a dry cooler unit.

Preliminary tests have been performed for both sets and performance data of the components are being collected to evaluate the contribution and benefits of implementing both concepts.

1.3 Project Outcomes

The integrated solutions developed and tested in Heat4Cool project will provide:

- **Space heating, cooling and domestic hot water** in one case by integrating the Adsorption heat pump to the natural gas boilers, and in the other case by coupling the DC heat pump powered by photovoltaic panels and PCM storage.
- **Renewable energy solutions**
- **Smart control system** which the "brain" of the heating and cooling energy system and will constantly monitor the environment conditions and the performances in order to identify the optimal option in terms of comfort and energy efficiency.

Heat4cool project aims to achieve:

- a **reduction of 30% in energy consumption** in a technically, socially, and financially feasible manner,
- demonstrate a **return on investment** lower than ten years,
- and provide **best practices examples** for the construction sector.

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1.4 Demo sites introduction

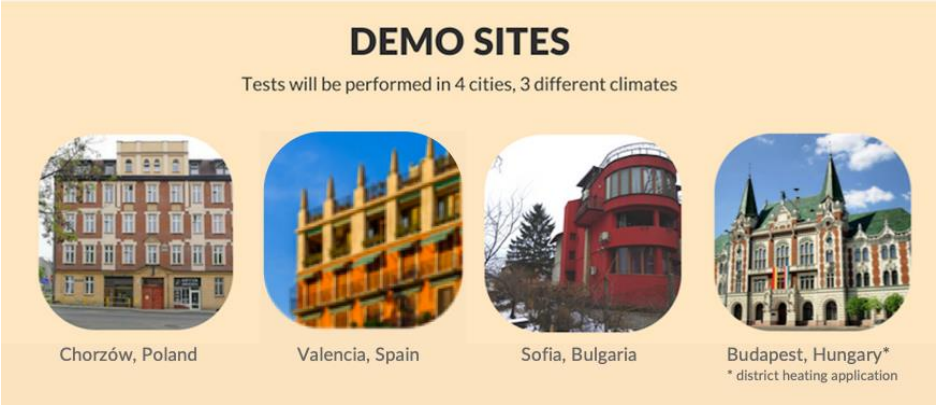
The Heat4Cool technologies has been installed and tested in four demo sites located in three different climate areas in Europe.

1. **Chorzow, Poland**
    - The building is a multi-story house with three commercial activities on the ground floor, 12 apartments on the other floors and a total floor area of 998 m^2.

2. **Valencia, Spain**
    - Apartment housing composed by composed by 12 flats, 610m^2 of total floor area.

3. **Sofia, Bulgaria**
    - Residential building, 3 apartments, total floor area of 564m^2.

4. **Budapest, Hungary**
    - District H&C system supply three different buildings: two public buildings (a recently retrofitted over 100-year-old and a ~2-decade-old building) and one newly constructed mixed-purpose building (commercial and cultural institution).



1.5 Consortium

The Heat4Cool project is composed by 13 partners from 7 associated European countries, more into details:

- 3 research organisations
- 9 SMEs
- 1 non- profit organisation

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Project coordinator, Politecnico di Milano – Dr. Marcello Aprile (marcello.aprile@polimi.it)

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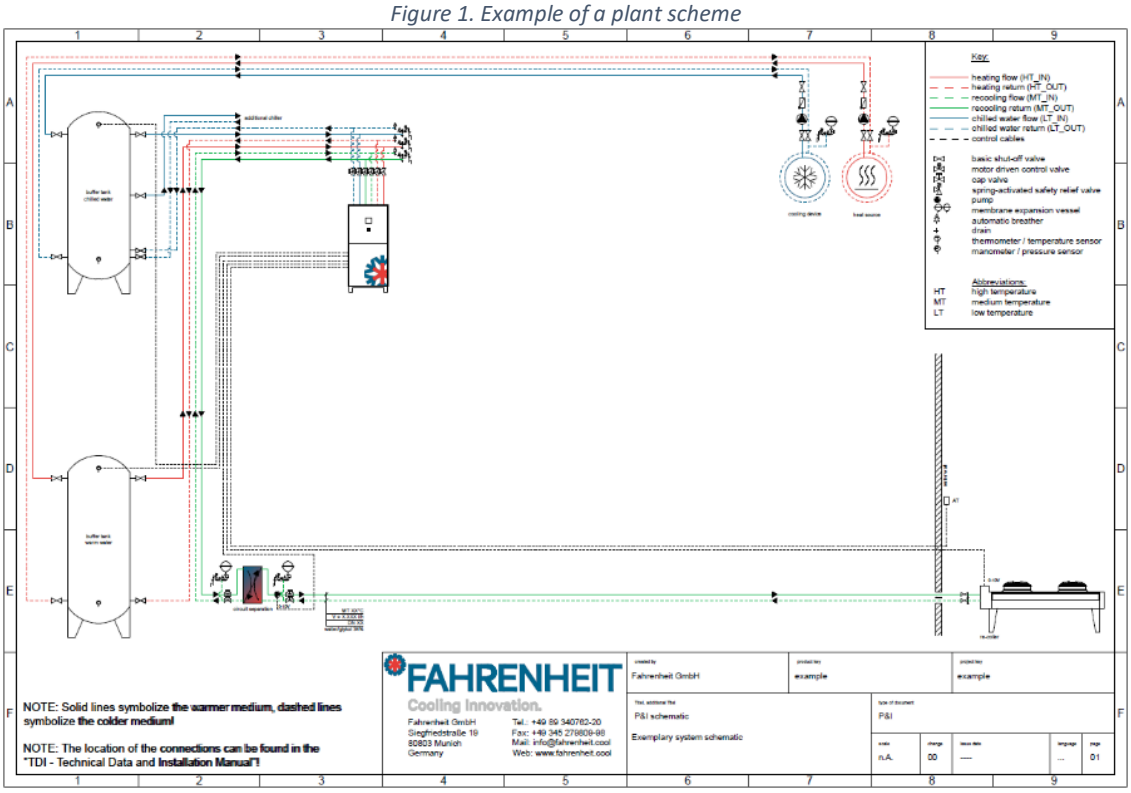
2 TECHNOLOGIES INTRODUCTION

In this section all the technologies installed in the demo site in **Valencia (Spain)** have been presented.

2.1 ADSORPTION HEAT PUMP (FAHRENHEIT)

2.1.1 Blueprint

Figure 1. Example of a plant scheme



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In accordance with the Machinery Directive 2006/42/EC, the adsorption heat pumps of Fahrenheit GmbH are treated as incomplete machines. To properly operate, they must be integrated into a system consisting of:

- High temperature source suppling the drive heat e.g. solar collectors, CHP, process heat;
- Low temperature source – distributing the generated cooling energy e.g. fan coils;
- Medium temperature source – dissipating the absorbed energy e.g. dry cooler, cooling tower;
- Source of electrical power to supply the circulation pumps and controller.

An example of a plant containing an adsorption heat pump is presented in **Error! Reference source not found.**. The main components of this plant are:

- Hot water storage tank (bottom left),
- Cold water storage tank (top left),
- Dry cooler (bottom right),
- Heat exchanger to separate the indoor water circuit from the outdoor water-glycol circuit (right to the hot water tank),
- Circulation pump in the water-glycol circuit (between the heat exchanger and dry cooler).

The adsorption heat pumps are suitable for indoor use only. In the presented plant, the only device placed outdoors is the dry cooler. Temperature sensors installed in both storage tanks are connected to the adsorption heat pump to allow better control of its operation. Two 0-10 V signals sent by the adsorption heat pump control the rotating speed of the pump and dry cooler's fans – this is one of the partial load control features.

2.1.2 Component Description

The adsorption heat pump of Fahrenheit GmbH installed in the Valencia demo site utilizes silica gel as adsorption material and consists of the following components:

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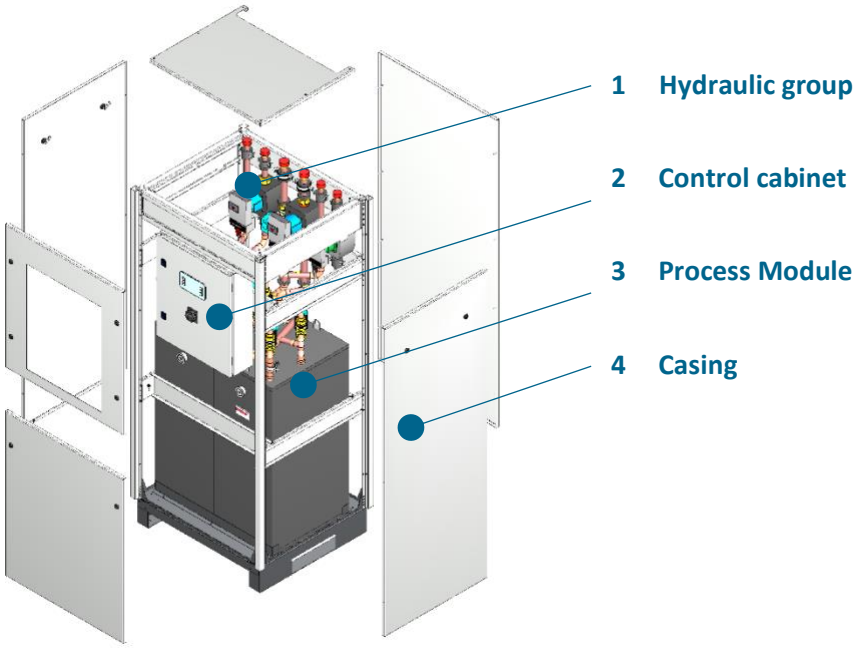

Figure 2. Structure of the adsorption heat pump.

Hydraulic group

The hydraulic group consist of three circuits, the drive circuit (HT), the re-cooling circuit (MT) and the cold water circuit (LT). For each circuit, the connections of the supply and return lines are located at the back or at the top of the unit. The hydraulic group includes also high efficiency pumps – one in each circuit of each module pair. The lower part of the hydraulic group contains three-way valves and contact temperature sensors for controlling and monitoring the operation of the adsorption heat pump.

Control cabinet

The control cabinet consists essentially of a controller with an operating panel (HMI) and a main switch. All control and connection cables, as well as the interface to the operating panel, converge in the control cabinet. The controller monitors and controls the operating processes and enables the operation of the adsorption heat pump. Information about operating state, as well as the fault messages are displayed on the operating panel (HMI). The power supply is disconnected with the use of the main switch.

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Process modules
The adsorption heat pump in Valencia demo site consists of two identical, vacuum-tight, welded, and diffusion-tight insulated process modules. Two process modules each (one left and one right) form a module pair. In each pair, individual modules alternate between adsorption and desorption processes.
Casing
The casing protects the process modules and the hydraulic group from damage. For commissioning or maintenance tasks, the side panels can be removed. During the operation, the panels should not be removed!

2.1.3 How it works:

The adsorption heat pumps use waste heat, for example solar plants, combined heat and power plants (CHP), district or process heat, in order to generate cold in an environmentally friendly and cost-effective way. This is also possible in small capacity range. There are no moving parts in the process modules, since neither steam flaps nor the circulation of process water is required due to the patented dual-chamber principle. Moreover, operation at low drive temperatures is possible

The Fahrenheit adsorption heat pumps are characterized by the patented dual-chamber process modules without moving parts. A process module is a vacuum-tight, welded chamber made of stainless steel. Inside the process module there are two heat exchangers which are called evaporator and adsorber or condenser and desorber depending on the operating phase. Furthermore, a precisely defined quantity of process water is contained in a process module, which carries out the heat transfer between the two heat exchangers by evaporating and condensing repeatedly. Each process module is thermally insulated.

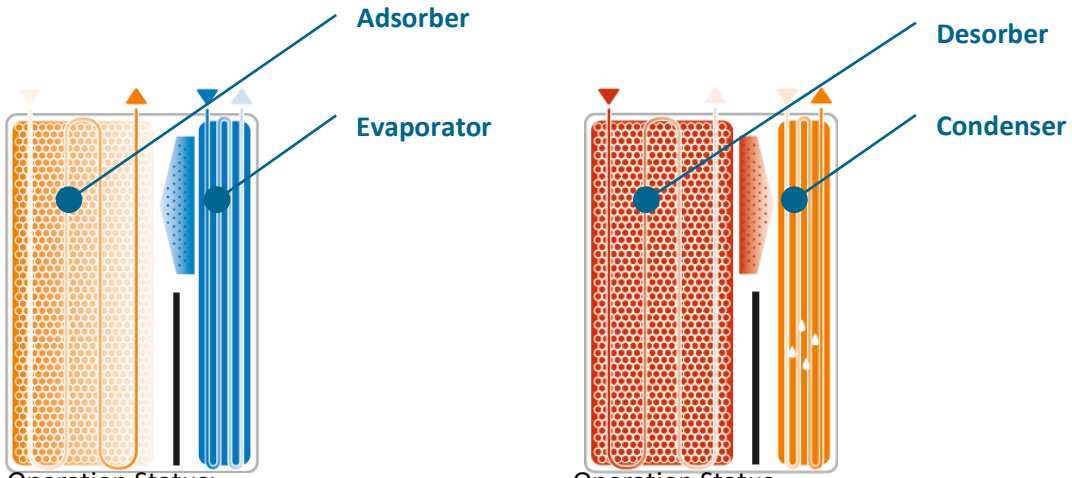

Figure 3. Representation of process modules.

Heat is extracted from the space or process to be cooled by means of a heat exchanger through which chilled water flows. This cools the space or process and simultaneously heats the chilled water. Via the hydraulic group of the adsorption unit, the heated chilled water reaches the evaporator of the

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adsorbing process module, where it is cooled down again and can thus be fed back into the cooling circuit.
The process module contains an adsorber and an evaporator with water (R718) as the refrigerant on its surface. Due to the low pressure in the process module, the refrigerant evaporates at temperatures as low as 6°C. Evaporation heat is supplied from outside during evaporation. This heat transfers part of the refrigerant into the vapour phase. The heat extracted from the warm chilled water and the liquid refrigerant during evaporation is now contained in the refrigerant vapour. Due to the physical characteristics of adsorption, the refrigerant vapour flows in the direction of the adsorber.
The surface of the adsorber is coated with an adsorbent (strong hygroscopic substance, e.g. silica gel or zeolite). The refrigerant vapour accumulates on this adsorbent (**Error! Reference source not found.**), whereby the heat is released exothermically. In order to dissipate this heat, a re-cooling water circuit flows through the adsorber. The re-cooling water heats up and dissipates the heat from the adsorption unit to the environment via a re-cooler.
If the adsorbent is saturated with refrigerant vapour, the water molecules must be dissolved or expelled from the adsorbent so that adsorption can start again. The controller switches over the circuits of the integrated hydraulic group so that the hot water of the drive circuit flows through the adsorber and thus becomes the desorber. At the same time, the evaporator becomes a condenser, as water from the recooling circuit now flows through it.
The hot water is cooled by the heat input via the drive circuit into the desorber. The dissipated heat is added to the drive circuit outside the adsorption unit by a heat source. The bound water molecules on the adsorbent are dissolved via the desorber (**Error! Reference source not found.**). The superheated refrigerant vapour flows to the condenser. The cooler surface of the condenser withdraws heat from the refrigerant vapour, causing it to condense and precipitate on the surface. The heat released during condensation is transferred to the re-cooling water and dissipated to the environment via an external re-cooler. The condensed and cooled refrigerant is available for the next adsorption process.
a)

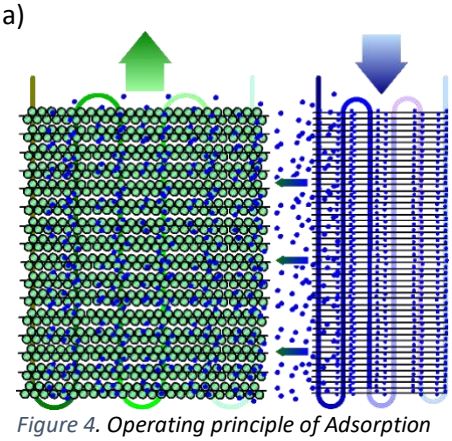

Figure 4. Operating principle of Adsorption

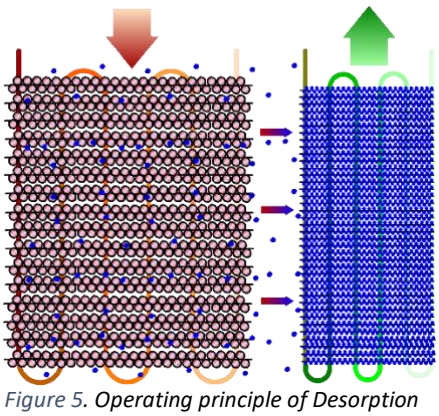

Figure 5. Operating principle of Desorption

In order to continuously extract heat from the chilled water circuit and maintain continuous cooling, two process modules are operated cyclically. While an adsorber absorbs refrigerant vapour from the evaporator (adsorption), the desorber releases refrigerant vapour to the condenser (desorption). This cyclic process causes the periodic temperature fluctuations typical for adsorption chillers, which can be smoothed out by buffer storage. The valve switching of the hydraulic group is controlled by adjustable parameters. In addition, the controller can influence the volume flows of the three circuits. The two process modules with the heat exchangers and the adsorption, desorption, evaporation and condensation processes are referred to as thermal compressors.

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The temperatures, flow rates and working mediums of the three circuits have a direct effect on the cooling capacity and the thermal COP. The desorption process is influenced by the drive circuit, the adsorption and condensation process by the re-cooling circuit and the evaporation process by the chilled water circuit.
For the proper use of adsorption heat pumps the following operating limits apply:

Table 1. Operating limits

Description	Limits
Maximal operating pressure	4 bar
Drive temperature (HT)	55 … 95°C
Re-cooling temperature (MT)	< 45°C
Chilled water temperature (LT)	> 8°C
Surrounding temperature	> 5°C

2.1.4 Energy and material flow:

As mentioned before, the adsorption heat pumps are integrated into its environment via three hydraulic circuits, as presented in **Error! Reference source not found.**.

- Hot water (HT),
- Cold water (LT, and
- Re-cooling (MT) circuit.

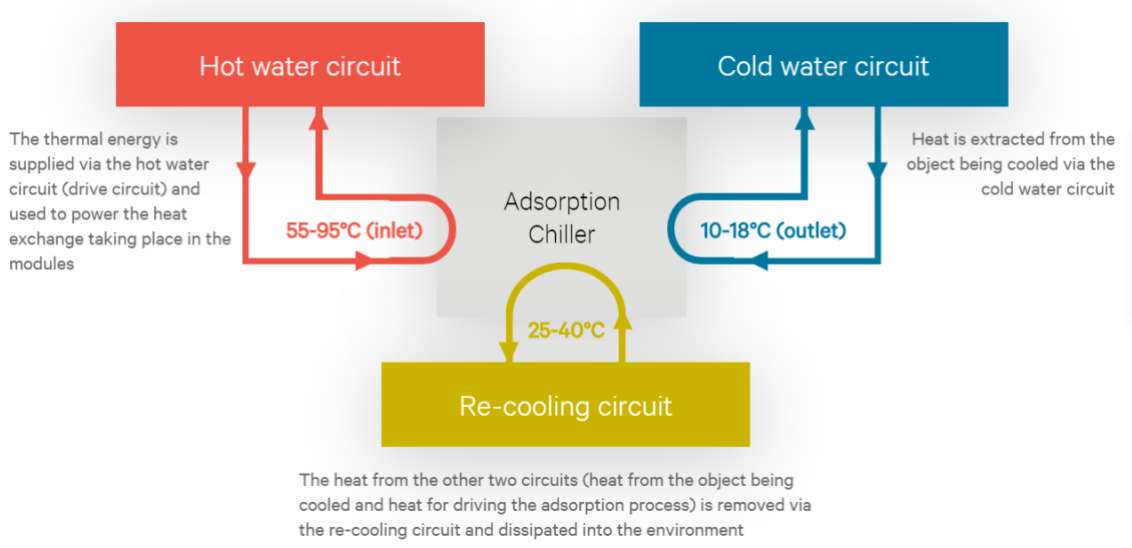

Figure 6. Energy flow during the operation of the adsorption heat pump.

As can be seen in Figure 7, the energy from hot water and cold water circuits is supplied to (flows towards) the adsorption heat pump at the high and low temperature level, respectively. This absorbed energy is dissipated to the environment at medium temperature level in the re-cooling circuit.

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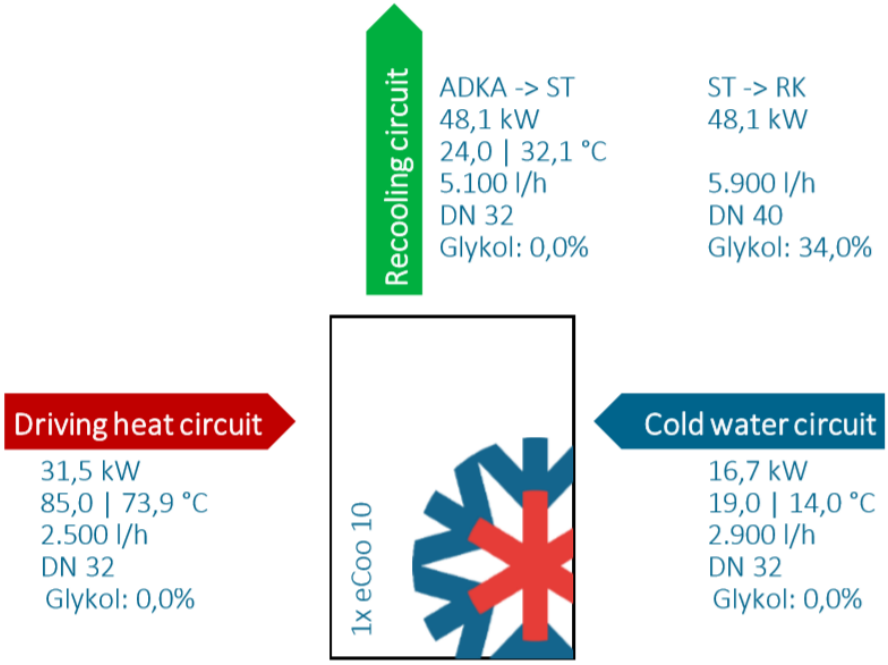

Figure 7. Energy flow of the eCoo 10[1] in nominal conditions.

2.1.5 Performances:

The performance of the adsorption heat pumps depends strongly on the operating temperatures in the three circuits. Generally, in terms of cooling capacity, it is better to drive the adsorption heat pump with highest possible temperature levels in hot water and cold-water circuits and with lowest possible temperature levels in re-cooling circuit (of course in all cases within the operating limits).
The most beneficial operating conditions for a silica gel heat pump are:

- HT inlet 65-90°C,
- MT inlet 22-27°C,
- LT outlet 15-21°C.

Since the adsorption heat pump has no mechanical compressor like the electrical heat pumps, there are two parameters, which can be used to evaluate its performance. One of them is the thermal COP, which indicates how many kW of cooling energy can be generated from 1 kW of driving heat. The silica gel adsorption heat pumps of Fahrenheit can achieve a thermal COP of up to 0.65. The thermal COP is calculated as follows:

$$COP_{th} = \frac{Q_{LT}}{Q_{HT}}$$

[1] eCoo 10 is a commercially available adsorption heat pump of Fahrenheit GmbH.

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The second parameter that helps to evaluate the performance of an adsorption heat pump, is the EER, which is the ratio of the cooling capacity and the consumed electrical power. The main consumer of the electrical power in the adsorption heat pump are the circulation pumps. Further calculations of performance could also take into account the total system, with all the auxiliary elements included, especially the dry cooler that dissipates the re-cooling heat.

$$EER_{AHP} = \frac{Q_{LT}}{W_{AHP}}$$

$$EER_{aux} = \frac{Q_{LT}}{W_{AHP} + W_{DC}}$$

Where W_{AHP} is the electrical consumption of the circulation pumps and controller of the adsorption heat pump and W_{DC} is the electrical consumption of the dry cooler's fans.

2.2 SOLAR THERMAL (AES SOLAR)

2.2.1 Blueprint

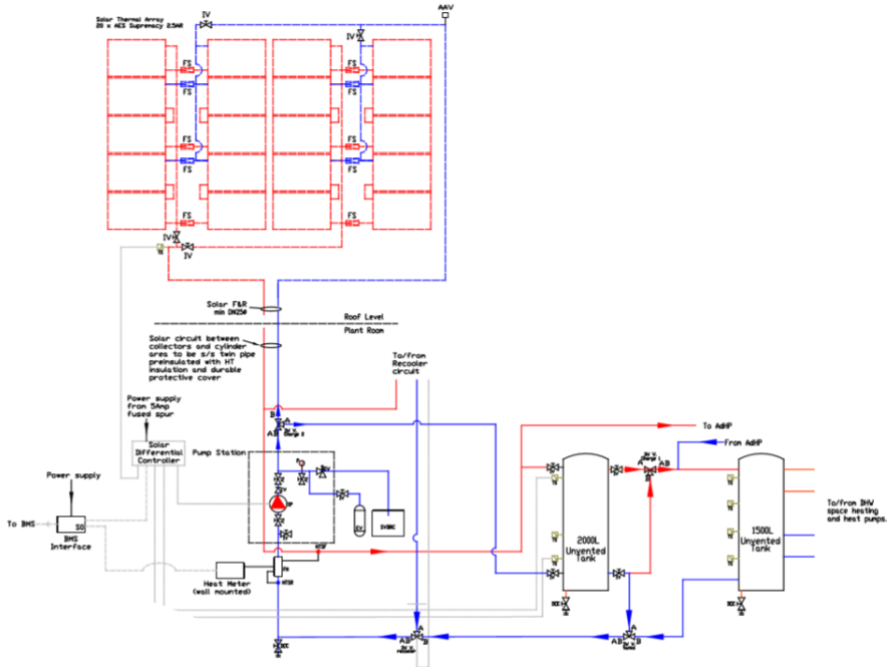

Figure 8 Schematic for Heat4Cool solution at Valencia

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2.2.2 Component Description:

Solar Thermal collectors generate heat from solar energy. They can be connected in an array sized according to the amount of heat required. The collector type and configuration can vary according to the temperatures needed and the amount and timing of solar irradiance available at the location. Flat collectors offer a cost-effective solution that can provide a good amount of heat at high enough temperatures where the local climate and available space allow. Evacuated tube collectors are a more efficient alternative that can deliver higher temperatures in most situations but at approximately 50% greater cost. There are also much more fragile and can be more troublesome and expensive to maintain due to greater degradation over their lifetime because of the higher stagnation temperatures and higher average temperatures during their lifetime.

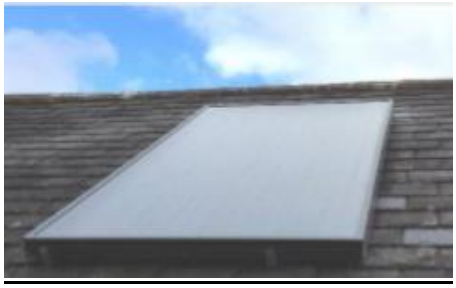

Figure 10 Flat Plate Solar Thermal Collector

Figure 9 Evacuated Tube Collector

A number of factors will affect the sizing and configuration of the system including availability of space for collectors, internal space to locate stores and practicalities around running pipe circuitry. When retrofitting older buildings in particular the construction methods and lack of roof space at good orientations and inclinations can be restrictive on how much solar can be installed cost effectively.

Usually, a heat store will be required to act as a buffer between the variable heat supply and the variable heat load. For individual buildings this is often in the form of large thermal stores, but other mediums can be used such as phase change material stores or for very large district systems it is possible to use large underground reservoirs or geological formations.

The system will include pumps to circulate a heat transfer fluid to transfer the heat from the collectors to the store and various valves and gauges for monitoring and safety.

There are various system topologies possible. The most common is a closed, pressurized system which offers easily install ability and optimal control of heat transfer. It should contain glycol in areas where temperatures could fall near to or below freezing.

Drainback systems require less safety components and be more easily decommissioned and refilled but do add extra considerations and limitations to possible installation set-ups. For example, the collectors must be higher than the drainback tank and all pipework must have a fall to ensure fluid drains out when the system is not circulating. Further – it introduces a delay to beginning heat transfer due to the time taken to fill the system each time the pump starts which is less optimum for control of heat transfer. It increases power consumption of the pump because it has to overcome the geodetic

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height between the drainback tank and the collector on each pump start. This is not the case with pressurized systems.

Thermosyphons systems can be used in very hot climates to eliminate the need for pumps all together but they require the store to be highest point of the system and offer the least responsive control of heat transfer.

2.2.3 How It Works:

The HEAT4COOL solution utilizes a large flat plate solar thermal array connected to two thermal stores.

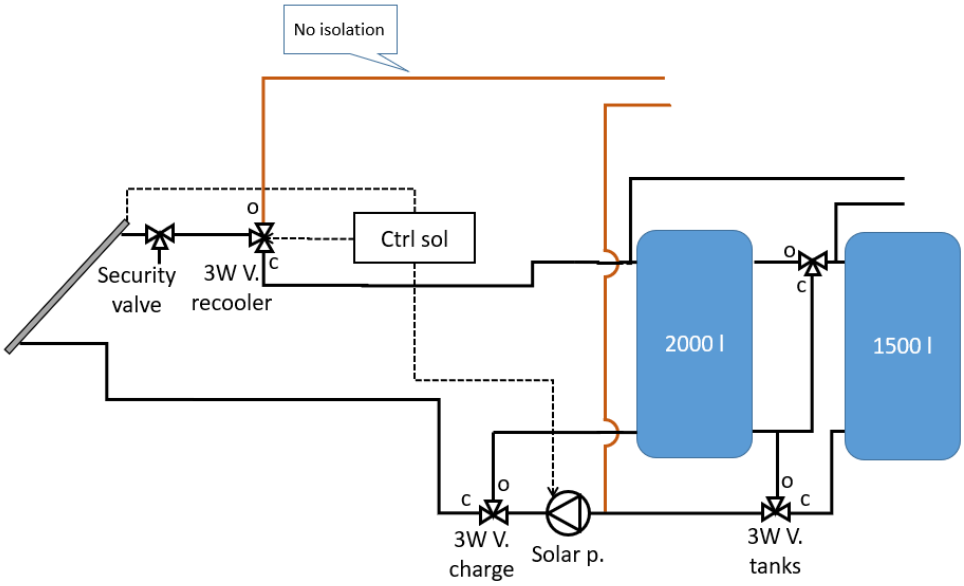

Figure 11 Simple Schematic of HEAT4COOL System

The solar heat transfer is controlled by an algorithm in the SCI-BEMS. Whenever the positive temperature difference between the solar array and the store input is above a set point the solar pump is activated to transfer heat to the stores. When the temperature difference falls below the set level the pump stops.

The stores can be isolated independently so that when there is less solar generation available only one store is used to maximize the temperature achieved. When the first tank is hot the second tank can be utilized to increase the total amount of solar energy that can be stored. This system helps to maximize the amount of time that solar can provide an outlet temperature suitable to drive the adsorption heat pump whilst also providing a high storage capacity when it is useful.

The stores provide heat to drive the adsorption heat pumps, which produce cooling. The heat can also be used for domestic hot water purposes and space heating.

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A cooling circuit is also included in case it is required to remove any excess heat from the system that cannot be used.
Adsorption heat pump cooling technology is used to introduce a cooling load to the solar heat demand. This results in the overall solar heat demand of a building over the year being levelled out. This solves the mismatch between solar availability and space heat demand where the peak solar availability is in summer, but space heating mostly occurs in winter. Having this higher and or consistent year-round heat demand allows the solar contribution to the building energy load to be increased – the DHW and space heating fraction is increased and a contribution to cooling is introduced. Overall solar contribution and solar fraction is increased and cost per kWh of solar heat is reduced.

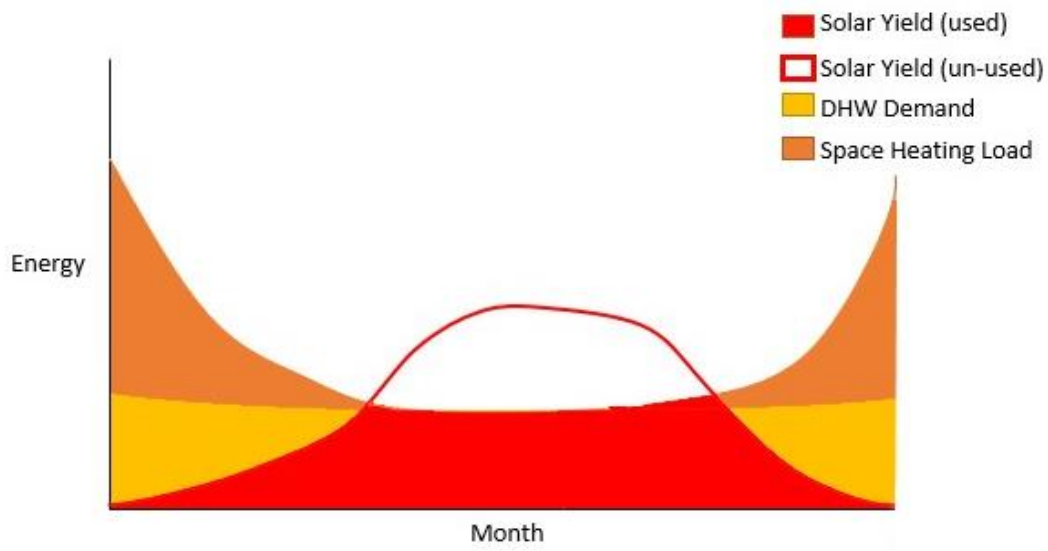

Figure 12 Illustrative Sketch – Typical Solar Yield vs Building Heat Demand over 1 year

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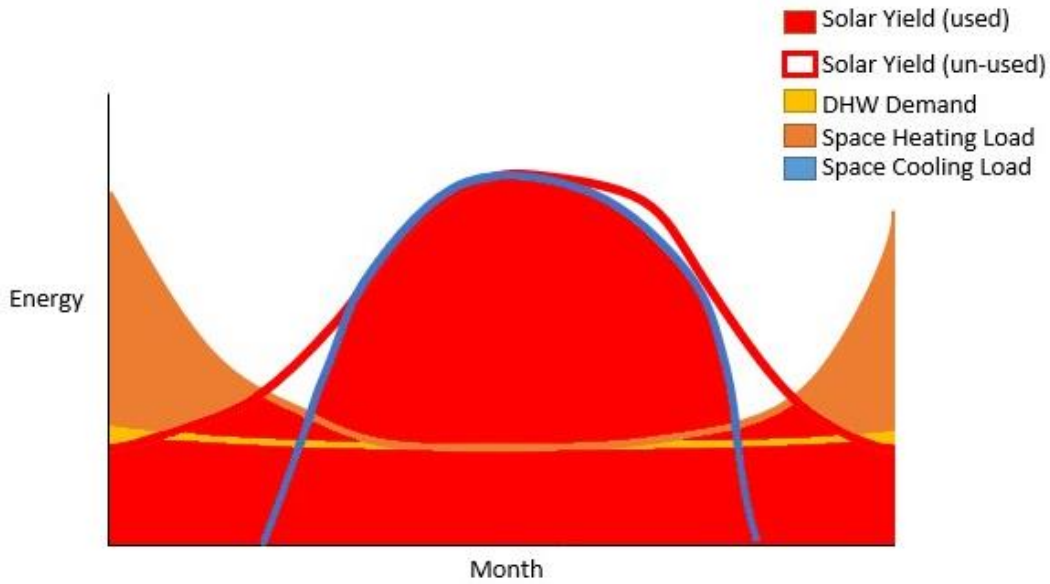

Figure 13 Illustrative Sketch – Potential Solar Yield and Building Heat Demand including Heat for Cooling over 1 year

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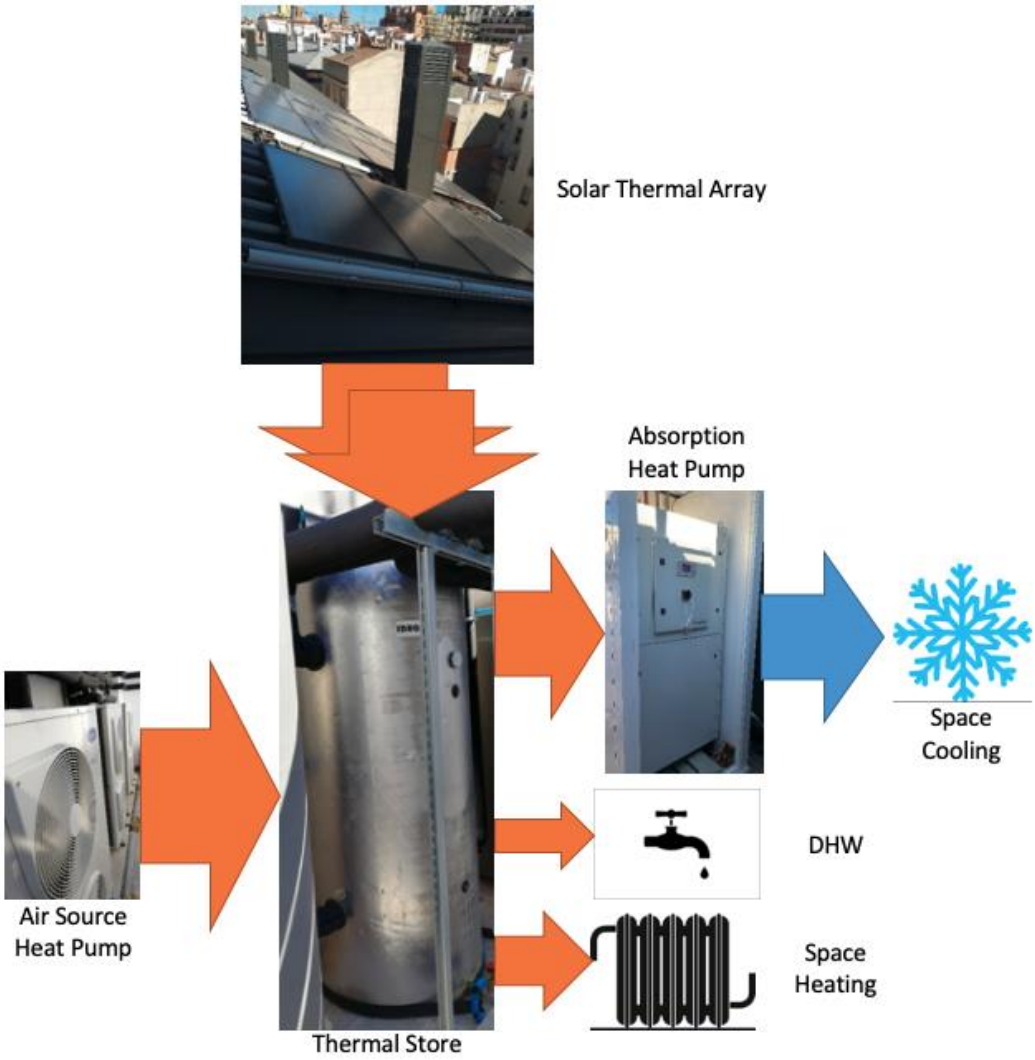
2.2.4 Energy and Material Flow:



2.3 SCI-BEMS (HYPERTECH and WATT & VOLT)

2.3.1 Blueprint:

The SCI-BEMS system concentrates on the monitoring and control, from one side of the centralized heating/cooling energy generation system, and on the other side on the comfort-based energy efficient automation of the end-user demand.
The monitoring and principles of optimal use for the central system were defined and setup through rigorous testing and simulations by the technical partners, taking into account the different conditions and setups of the various pilot sites.

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On the demand side, the system consists of a smart home installation that allows real-time recording and control of the emission system. The basic workflow for the optimization is shown in the figure below.

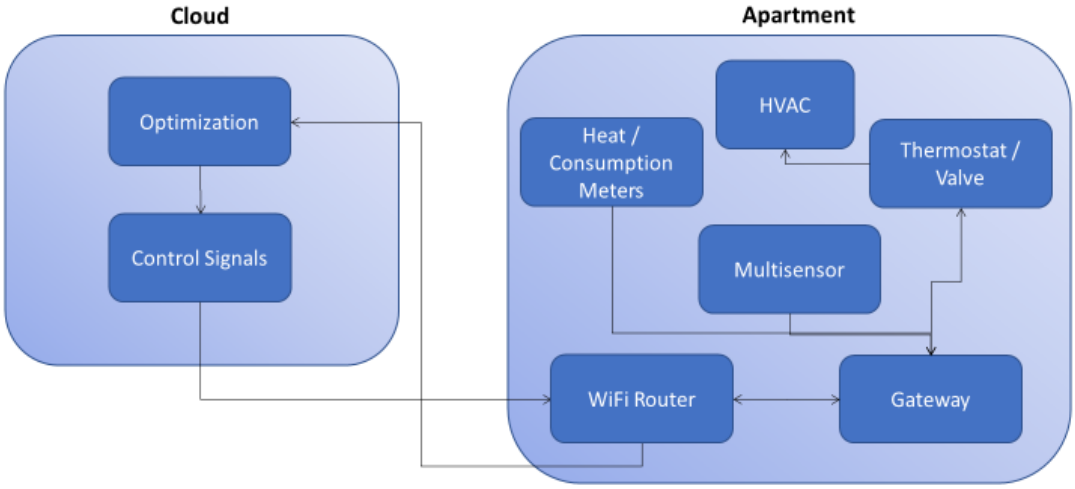

Figure 14 Graphical representation of the demand side SCI-BEMS system.

2.3.2 Component Description:

The main objective when designing the system is to enable the detailed monitoring of the heating/cooling system in its entirety, as well as its constituent components, as well as the ability to apply certain control strategies in a remote and automated manner. To that extent, a plethora of metering and monitoring devices, along with communication servers are deployed in the pilot sites. Due to the specificities of each one, the solution was tailored according to each pilot site's needs. More details on this are reported in the installation section below.

When it comes to the in-apartment infrastructure, a common approach was adopted, based on a solution comprising a gateway device and various z-wave enables sensors and thermostats. The figure below depicts the main components of such an installation. What is now shown in the figure is the non-hardware part of the installation, which comprises of cloud-based services for the recording and processing of the data.

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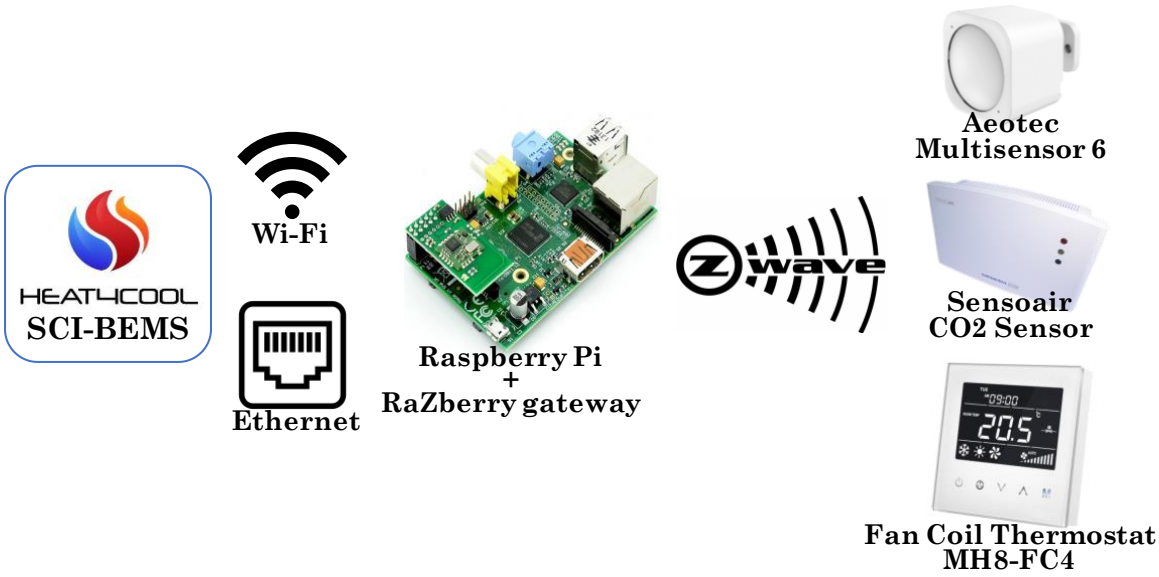

Figure 15 SCI-BEMS components.

2.3.3 How It Works:

The critical part of the SCI-BEMS automation algorithm focuses on the efficient management of the apartments' demand for heating and cooling. The approach consists of a number of steps, which can be seen in the following figure.

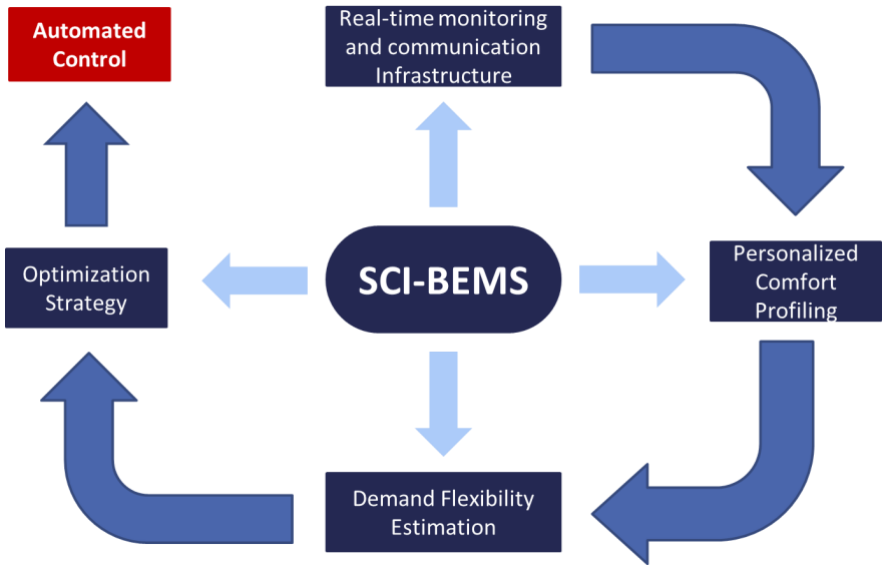

Figure 16 SCI-BEMS automation workflow.

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Through the real-time monitoring of environmental conditions and HVAC data, we are able to extract in an automated and consistent manner the comfort preferences of the occupants. These are used as constraints in a model predictive optimization of the system's emission setpoints. The optimal control signals are then applied to the fan coil or radiator units remotely.

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3 TECHNOLOGIES SOLUTION ON SITE

3.1 Valencia demo site Presentation:

The Heat4Cool Pilot 2 is a residential building located in the city centre of Valencia (Spain).
Valencia has a Subtropical Mediterranean climate with very mild winters and long, warm to hot summers. The annual average temperature is 17.8 °C.

The building was constructed in 2001. Its main façade is oriented to west and is composed of a ground floor, which is assigned to commercial use, and 4 other floors, which are dedicated to residential use and comprise of 12 flats with a total floor area of 610 m^2.

Figure 17 Main façade of the demo site in Valencia

After retrofitting windows and envelope, the annual final energy consumption is currently 61 kWh/m^2, of which 54 kWh/m^2 from natural gas and 7 kWh/m^2 from electricity. The annual thermal needs are 23 kWh/m^2 for space heating, 25 kWh/m^2 for DHW and 22 kWh/m^2 for space cooling.

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Previous central thermal system consisted of three air-water heat pumps that supplied two different heat and cold-water tanks. At the same time those tanks supplied DHW system, as well as climatization fan coils units located in the different apartments of the building.

3.2 Installation

Updated thermal energy generation system consists of a solar thermal field, an adsorption heat pump and three air-water electric heat pumps. These units are responsible for generating the heat and cooling energy necessary to meet the demands of DHW and air conditioning. The heat and cooling energy produced are stored in the hot and cold water tanks and supplied to the DHW and heating/cooling distribution circuits.

The core of the new system is the adsorption heat pump. The adsorption heat pumps utilize heat, in this case from solar collectors installed on the building's roof, in order to generate cold without the use of mechanical compression. The thermodynamic cycles of the adsorption heat pumps are sometimes called "thermal compression" and are based on the periodic heating and re-cooling of an adsorbent (highly hygroscopic substance e.g. silica gel or zeolite) within an adsorption bed. An important auxiliary component of the adsorption heat pump is a re-cooler, which dissipates the energy absorbed by the adsorption unit during its operation. The rest of the installation consists of pipes, heat exchangers, fan coils etc.

Figure 18: Adsorption unit inside protection climatized case.

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The innovative adsorption heat pump installed in Valencia´s pilot site is based on a well-developed technology. However, the use of adsorption in solar cooling applications is still not widely spread due to different barriers.

The main purpose of the further work in this pilot site is to provide necessary on-site training gathering all the know-how learnt during the design and dimensioning processes for the adsorption system proposed at the Heat4Cool project.

The adsorption heat pump is driven by thermal energy supplied via the hot water circuit (drive circuit). The units with silica gel coating, as the one installed in Valencia, are capable to make use of low-grade heat at a temperature above 55°C. The cooling effect is distributed via the cold water circuit at a temperature range 8°C-20°C. The heat from the other two circuits (heat from the object being cooled and heat for driving the adsorption process) is removed via the re-cooling circuit and dissipated into the environment in a dedicated dry cooler. The adsorption heat pumps are an energy-efficient alternative to compression chillers. Circulation pumps, valves and controller are the only components of the adsorption unit, which are driven by electrical energy and their power consumption is just a small fraction of a traditional compressor's power input. The power consumption of the adsorption heat pump installed in Valencia reaches a maximum of 0.8 kW for a cooling power of 16.7 kW.

Figure 19: Adsorption pump Energy dissipation system

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The adsorption unit operation is assisted by a solar thermal installation carried out on a building existing roof (in its South-East skirt). A solar-thermal installation of 48.5 m2 consisting of 20 flat solar collectors of 2.31 m2 each one was erected. This system was developed and projected under architectural integration criteria.

Figure 20: Solar field.

The solar system will contribute to cover a large part of DHW and heating demands during winter season. Solar energy production could be excessive mainly during summer due to the low heat demand (just ACS) with an excess of production that should be dissipated. However, this heat will be used for the production of cold water by the adsorption unit.

To reduce the energy consumption of the building, a SCI-BEMS system has been designed and integrated with suitable equipment. SCI-BEMS System detects necessary environmental conditions within the area, captures set-points of the thermostats, controls total energy consumption and user's occupation patterns extracted by reading sensors and provides ad-hoc remote control over specific loads (HVAC, DHW…).

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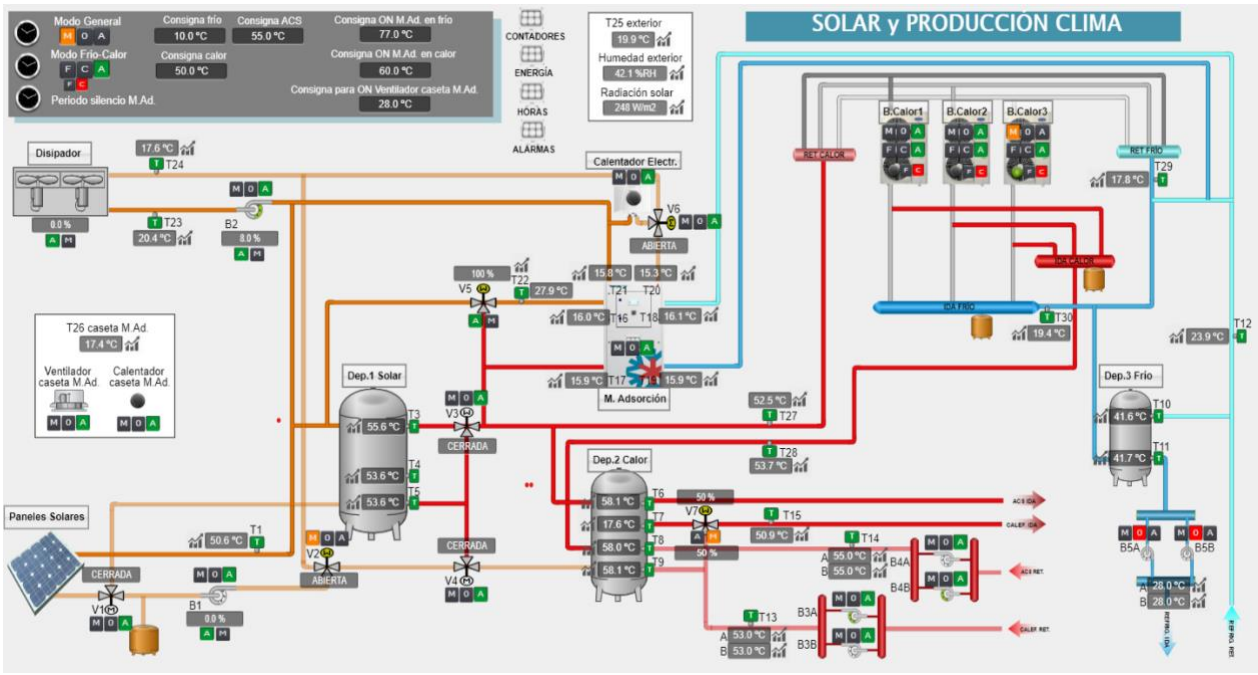

Figure 21: Monitoring and Control system main screen.

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3.3 Demonstration of the benefits in the real case and how the different technologies are integrated

The main goal of Valencia´s demo sites is to demonstrate the energetic and economic feasibility of these systems and show examples of right exploitation in order to provide visibility to the technologies with a well-working example which can achieve the expected energy efficiency parameters and consequently achieving energetic and economic savings as well as an environmental impact reduction.

Final objective of this installation is to generate energy savings in heating, cooling and domestic hot water of 30% through renewable generation sources such as thermal solar energy with a less that ten years payback period.

According performed simulations data results compared with baseline status, solar thermal system resulted able to cover till the 52% of the heating (SH+DHW) energy needs, while the use of solar assisted adsorption chiller showed its potentialities in the reduction of the energy consumptions for the cooling needs, contributing to the total cooling energy production that reaches the 27%.

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