Pilot Plants of the EINSTEIN Project

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EINSTEIN

The Effective INtegration of Seasonal Thermal Energy storage systems IN existing buildings

Content

EINSTEIN – Seasonal thermal energy storage IN existing buildings

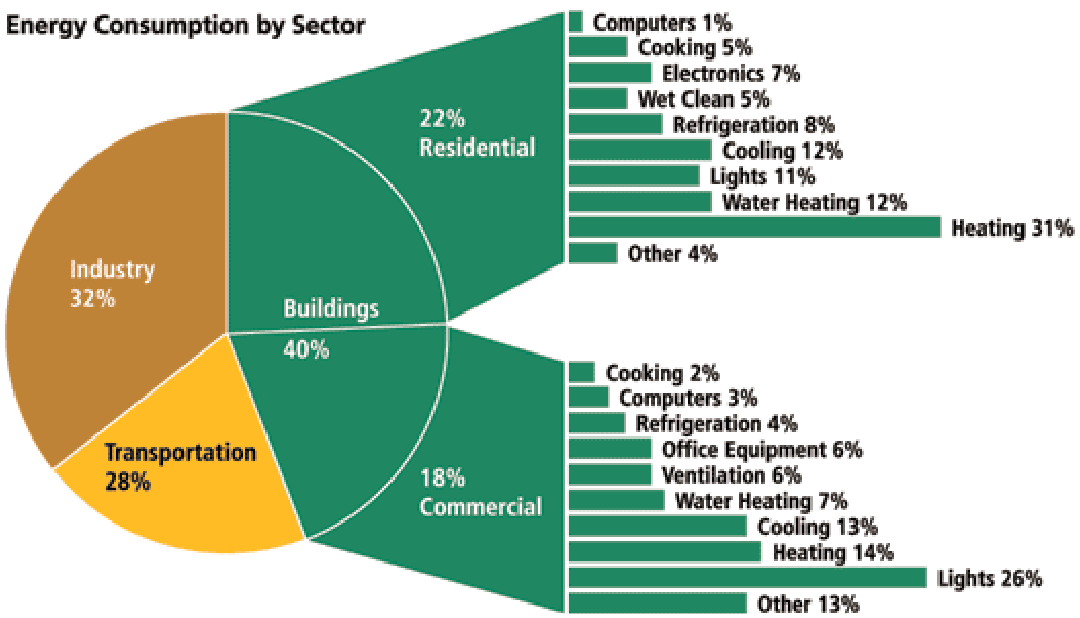
In recent years, European Union policy of sustainable development, concentrated on reducing energy consumption, environmental degradation and increasing share of renewable energy sources. In 2007 The European Council adopted new environmental targets, even more ambitious than those of the Kyoto Protocol. The plan included the so-called "three 20 targets":

- To reduce emissions of greenhouse gases by 20% before 2020, taking 1990 emissions as the reference;
- To increase energy efficiency in order to save 20% of EU energy consumption by 2020;
- To reach 20% of renewable energy in the total energy consumption in the EU by 2020.

This is one of the main challenges for Europe in the nearest future and as residential and commercial buildings are responsible for about 40% of total energy consumption in EU, this is where the biggest opportunities for improvements can be found (Figure 1).

First important step in reducing overall energy consumption by buildings, is to design and construct new buildings in zero-net-energy standard. Next step is retrofitting old buildings in order to reduce their energy demand. Potentially most significant reduction can be achieved by adding or improving envelope insulation, replacing windows with highly efficient ones and replacing old heating systems.

Figure 1.
Energy Consumption by Sector in EU



Implementation of energy storage systems, together with smart ICT controls, make energy peak shaving possible at building level, increasing its energy efficiency. This effect can be amplified in the case of extending the system from one building to, for example, a small district. Coupling such solution with less predictable renewables, makes even more sense, as it reduces also primal energy demand.The EINSTEIN project addresses above issues and provides measurable, sustainable solutions, to reduce primary energy consumption of existing buildings. An integrated system, based on energy provided by renewable energy source and seasonal energy storage has been developed. It is of great importance, to understand such systems purpose in a broader, socio-economical context. In contrast to most research programs, the aim of EINSTEIN, was not only an evaluation of various technical aspects of ready-to-work installation, but also, even more challenging, socio-economic aspects of preceding construction works. Potentially interesting business models were analysed and described.EINSTEIN project approach is the combination of efficient solar collectors system, seasonal water heat storage and existing building(s). Also such components as: intelligent ICT systems for energy management, dedicated heat pump and methodology for trenchless technology of laying pipelines between system elements and buildings were included.

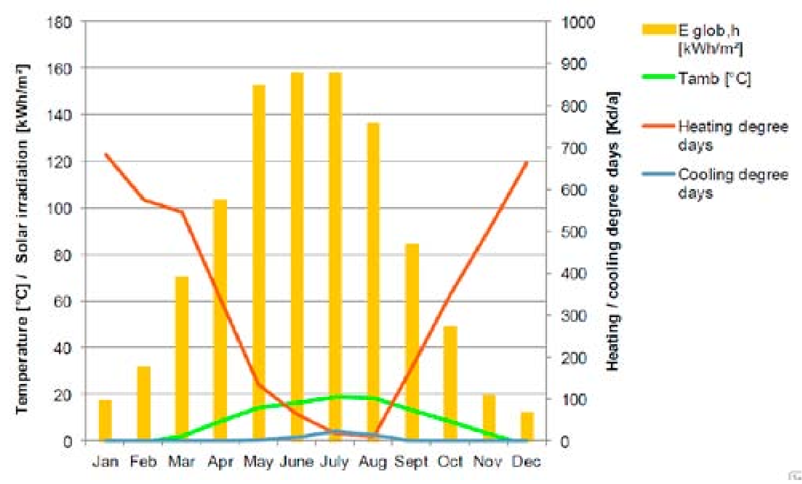


Figure 2.
Monthly values for solar irradiation (E_glob,h), ambient temperature (Tamb), heating and cooling degree days for Warsaw according to Meteonorm.

Heat absorbed by solar collectors during sunny months is accumulated inside the seasonal thermal energy storage tank – the "heart" of the system. During autumn and winter period heat from storage is utilised for space heating purposes. This process can be observed in the Figure 2, where heating, cooling degree days and solar irradiation in the function of months was shown.

Highly efficient, dedicated heat pump operating in higher than usual temperature range (suitable for high temperature radiator space heaters), enables to discharge heat from STES tank, even when temperature inside STES is not high enough for direct heating. Developed energy management system ensures, that the utilisation of non-renewable fuel is reduced to the lowest possible level.

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Seasonal Thermal Energy Storage. Path of development

As a result of the oil crises of the 1970s, many European countries enacted energy saving programmes that aimed for the use of alternative energy sources. At this time it became obvious that in the future, energy supply systems thermal energy storage would be required. One research field of energy saving measure was the long term storage of solar thermal energy during the summer when the supply is highest to the winter when thermal energy is required for heating to cover the demand. Thus, the first seasonal thermal energy stores (STES) were built in Studsvik, Sweden based on national research activities beginning in 1978.

The importance of this research field was recognised by the International Energy Agency (IEA) and Task 7 – Central Solar Heating Plants with Seasonal Storage (CSHPSS) – was founded within the Solar Heating and Cooling Programme (SHC) in 1979. Within this task the baseline for the technology was further developed by an international consortium of experts.

Apart from Sweden, Switzerland, Denmark and Germany have also investigated STES and have built demonstration plants. The first research programmes focused on basic research including: model calculations, laboratory experiments and the construction of small scale pilot plants. The technical and economic feasibility of the storage concepts had to be proven.

For example in 1985, the first gravel water pit STES was built the Institute of Thermodynamics and Thermal Engineering of the University of Stuttgart in Germany to supply heat to the institute building during heating season by collecting solar thermal energy from unglazed collectors during summer time.

Since 1996, eleven large scale CSHPSS demonstration plants have been built in Germany. They are designed for solar fractions of between 35% and 60% of the total annual heat demand for domestic hot water preparation and space heating of the connected residential areas. Several technologies for seasonal heat storage have been further developed and tested within these projects. All common types of STES (see figure below) have been integrated into the demonstration plants.

Since the new millennium, many new CSHPSS have been carried out, especially in Denmark. The STES volumes are often many 10,000 m³ large consisting mainly of the STES pit and are integrated into large solar district heating networks that have solar collector fields often exceeding 10,000 m². Based on local boundary conditions, those systems can compete economically with conventional heating systems.

Thus, it was logical for the IEA to establish a new Task within the SHC-programme to further improve the technology. This was done in 2011 by SHC-Task 45 "Large Scale Solar Heating and Cooling Systems" in which STES has an integral part. Compared to SHC-Task 7 more practical related topics have been analysed, such as performance guarantees of large solar collector fields but also heat pump integration as a measure to improve the STES, and thus, the system's performance.

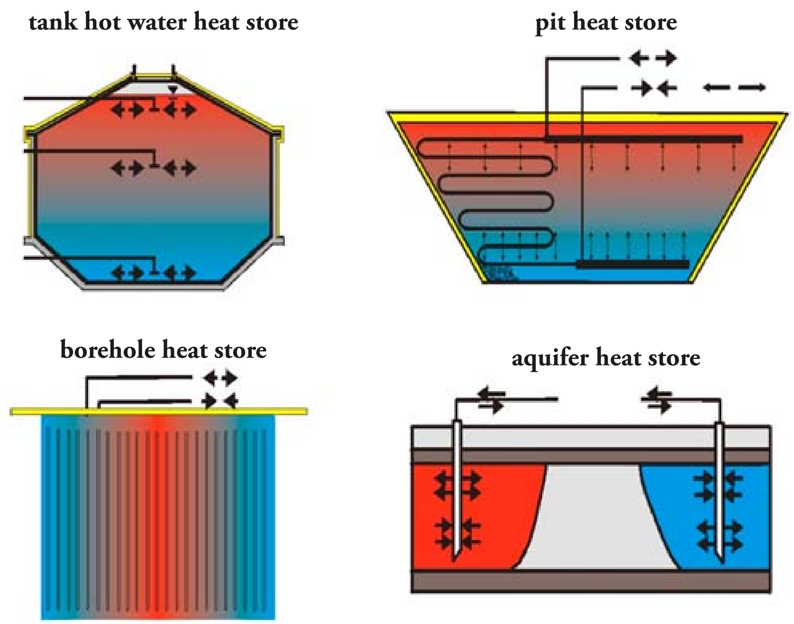

Figure 3.
Most common types of STES

For reasons of economic and technical efficiency STES applications are mainly large scale applications, as they are scope of the EINSTEIN project. However, many projects in single family houses are reported specially in Europe with large solar thermal systems and STES. Stores in small scale applications are mostly house integrated and well insulated steel tanks. Recent research on small scale STES, but not state of the art yet, include highly efficient thermal insulation to install the stores outdoor of the buildings and phase change materials (PCM) as well as thermo-chemical materials for higher storage densities and nearly heat loss free storage of thermal energy.Most of the first CSHPSS were designed for new development areas that were also designed to fit perfectly to the system, newer approaches include retrofitting applications for STES integration. One of the most famous examples is in Copenhagen, Denmark the goal of which is to be CO2 neutral by 2025. Here, STES will also play a significant role in achieving this ambitious goal. The diversity of heat sources for STES has increased from the past to today. Today, not only solar thermal heat is stored in STES but also surplus heat from cogeneration plants, waste heat and even electricity by means of power-to-heat approaches. The relevance of STES will be high in the future energy supply systems, taking into account that not only heat but also cold e. g. for air conditioning in combination with heat pumps can be stored and utilised.

Jose Carlos Esteban Matias, R&D Department, Acciona.

Evaluation tool to assess the cost effectiveness of the different retrofitting strategies

Part of Acciona Infrastructures SA's tasks in the Einstein project has been the development, together with other Partners, of a methodology to assess the most cost-effective global energy retrofitting intervention for the existing buildings, considering active and passive measures and the integration of STES as an alternative. The results have been reflected as a software tool, available from the project's website, where the consortium is continuing its works on it.

The Decision Support Tool DST2.4 analyses the best combinations of retrofitting intervention for every location considered with a holistic point of view, considering many alternatives and different intensities of passive retrofitting, and adapting the dimension of the new active installations required, including the integration of STES to supply the heat required. The results are the selection of the most cost effective solutions, depending on the desired range of primary energy reduction.

Internally, the development of the tool has required the definition of two building models (single and multi-family house). The models have been simulated in four climatic locations that represent the four main climatic regions selected to represent the climatic diversity of Europe (to analyse the integration of STES along Europe in the EINSTEIN project).

The total heat consumption for space heating and domestic hot water in the reference building was obtained though dynamic transient simulation, using the TRNSYS software. This software simulates the energy behaviour of the building on an hourly base, taking the local conditions into consideration: the meteorological conditions, local energy prices, and local retrofitting costs.

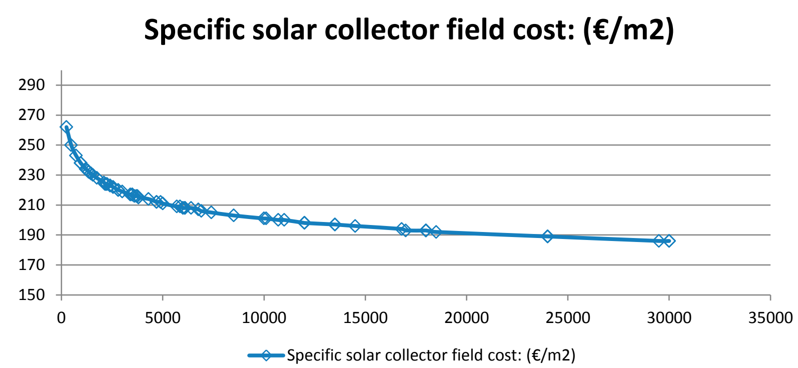

Figure 4. Solar collector filed cost

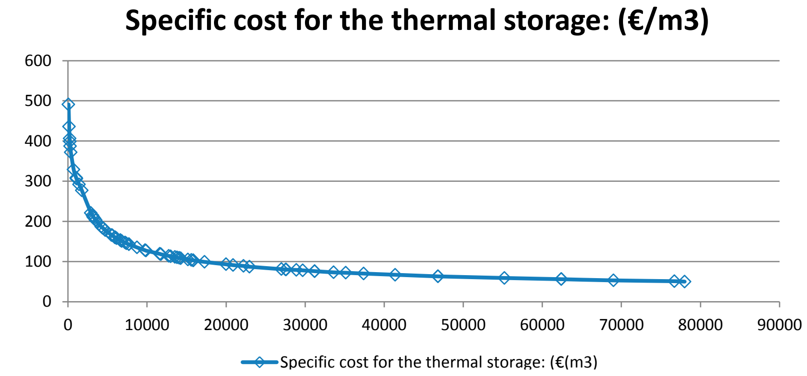

Figure 5. STES cost

The results are analysed in different energy categories, from heat demands, to primary energy consumption and reduction. Finally, in every range of primary energy reduction, the best combination is selected according to the best ratio between primary energy savings and economic savings throughout all the installation life.

As previously mentioned, the three categories of retrofitting considered are: passive, active and STES integration.

The passive strategies consider the reduction of space heating demands, when a reference state of the building is improved with the inclusion of one or more of the following alternatives:

Insulation façades: insulation roof, insulation floor, windows renovation.

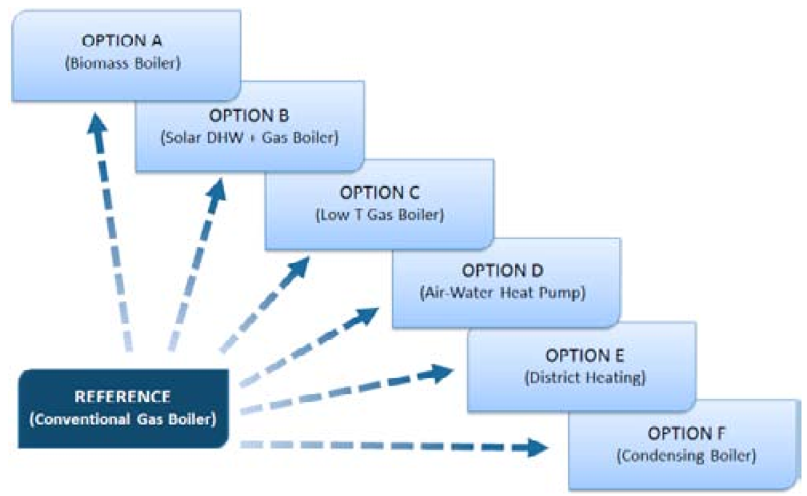

Figure 6. Active conventional retrofitting options considered in Decision Support Tool

Two levels of retrofitting were also considered: medium and deep retrofitting. At that point, the alternatives (per range of space heating reduction) that achieve the best energy reduction with the lowest investment cost were detected.

To meet the necessary heat demand, the options indicated below are considered alternatives for the active systems. The conventional gas boiler has been considered an initial reference heat system. The results of the final energy consumption (fuels and electricity) and investment required are adapted to the degree of passive retrofitting considered in the previous stage.

Finally, the integration of a STES, as a system to meet the heat demands has been considered – a centralized STES (central solar collectors and tank) that provides heat via district heating. Auxiliary heat comes from a conventional boiler. Two proportions of solar coverage to the total heat demand have been considered, 40% and 60% of the solar fraction. The energy and economic results were also assessed.

The large amount of data generated with the simulations has been structured in a database that feed data to the DST. The user should introduce data to define their own study case (climatic region, type of building, total surface to be analysed in that type of building plus the desired % of primary energy reduction) and the DST consult the database to assess all the possible combinations, to assess the best combination for every range of primary energy savings (0–20%; 20–40%, 40–60%, 60–80%, >80 %).

The evaluation is made according to the ratio of total economic savings per kWh of the heat demand attended: per every range of primary energy savings,

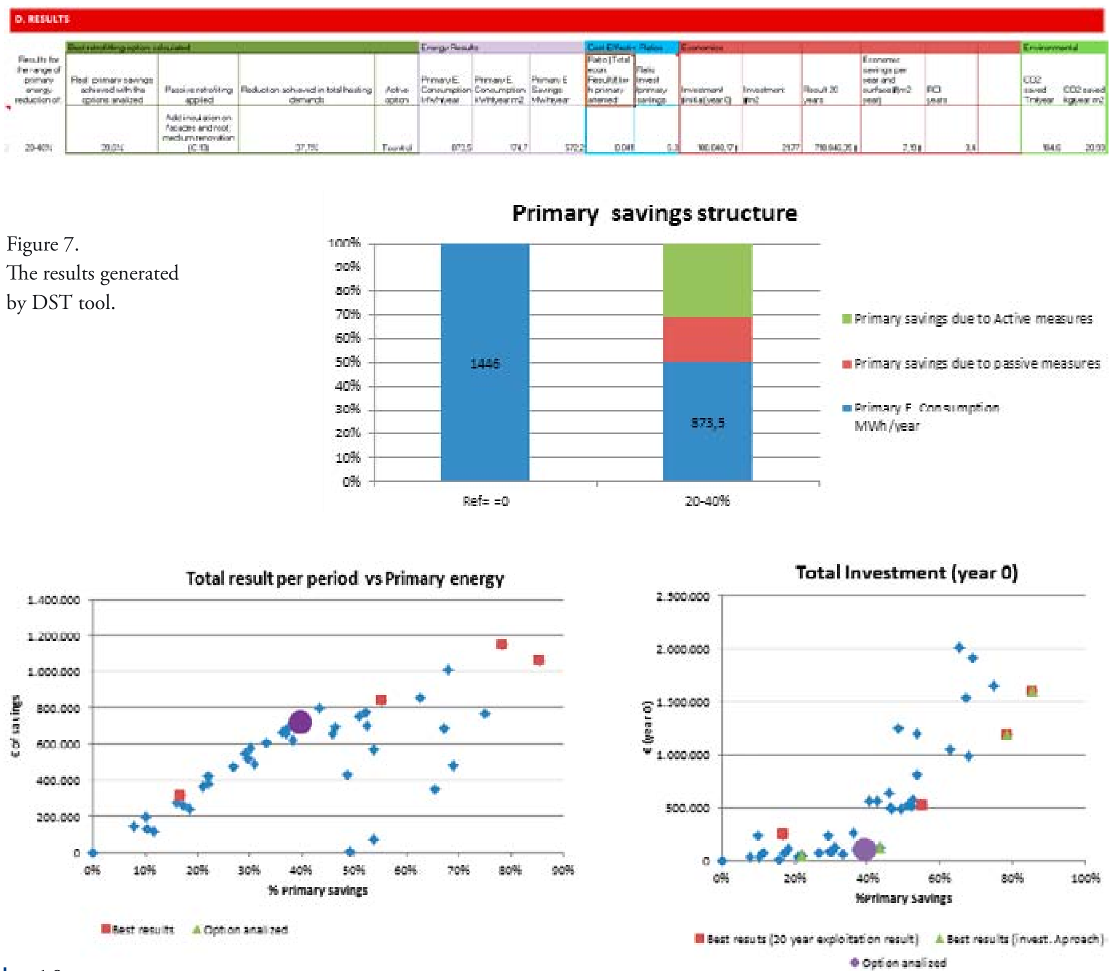

Figure 7.
The results generated by DST tool.

the best options are those that maximize the economic savings, also taking the positive effect of reduction of heat demands into consideration. This means a higher ratio.

It is interesting to mention how the best results are always over a curve of Best results that correspond to a typical Pareto distribution according to the optimization from two variables (economics and energy reduction). There are no options with higher ratios from the data of the points of this curve, but lot of them achieves lower ratios, so any optimal solution is located over them.

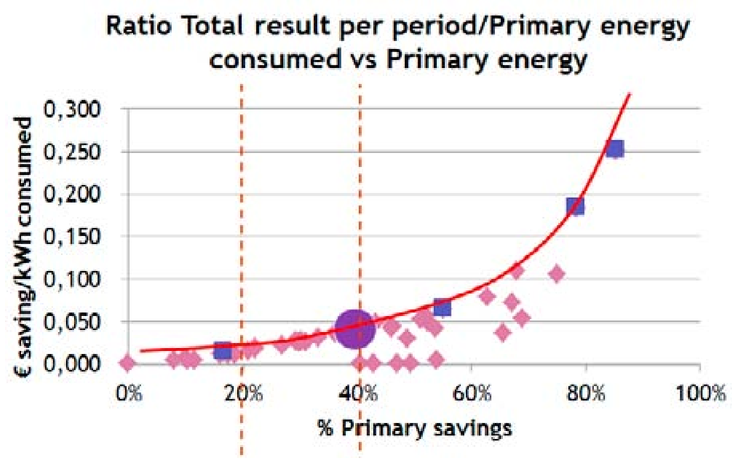

Figure 8.
Ratio Total result per period/Primary energy consumed vs Primary energy

The results that the DST generates for every study case are shown grouped by energy, economics and environmental results; their position is showed also over a graph, were the selected best result for the specific study case can be compared with other combination results

General conclusions can be extracted of all the simulations – it is possible to highlight that results are very promising for the STES in the range of more than 60% of energy savings in all the cities and type of buildings. The passive option included in the selected best options comes to a % of "space heating demand reduction" in the same range that the % of "primary energy reduction" in 84% of the cases; in the rest, the % of "space heating demand reduction" is even higher (mainly when >60% primary energy savings are required). This shows the importance of including passive measures when the primary savings requirement is high.

In the low range of savings, the most cost effective solutions seem to be the "low cost" option – "temperature control". The option of changing to a biomass heater is the best in the medium results. The option of STES is again the best in the range of required savings greater than 60%.

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Head of Group Energy Efficiency & Sustainable Construction, Mostostal Warszawa S.A.

POLAND
The Pilot Plant in Ząbki

In order to validate the results of EINSTEIN project in different climate conditions, two full-scale pilot plants were constructed. One of them was located in the Regional Hospital for Nervous and Mental Diseases in Ząbki, Poland, founded in 1903.

The main office of Administrative Department is located in a two-storey building with a partially underground basement, which gives 793 m^2 of usable area.

The building's space heating installation consist of the gas boiler supplying articulated cast iron radiators. Maximum water temperature for supply and return lines is 80/60°C and is designed for outside temperature up to -20°C. Those are typical temperature values for old space heating systems designed for climate conditions in central Poland. Domestic hot water is supplied by local electric heaters.

The building was retrofitted ten years ago, the renovation included new windows, new 90kW gas fired boiler and weather-compensation control implementation. However, the average annual heat consumption for space heating purposes is still very high due to lack from building envelope insulation – up to 200 kWh/m^2 per year.

At the beginning, conventional gas fired boiler had been the only source for space heating. Within the scope of EINSTEIN project the space heating system was later upgraded by adding flat plate solar collectors, above-ground medium scale Seasonal Thermal Energy Storage tank (STES) and the prototype heat pump (Figure 9). STES and solar collectors in the Pilot Plant are shown in the Photo 1.

Those system components were dimensioned by Solites in the simulation software TRNSYS. The input parameters for program were i.e. heating demand, existing installation parameters, as well as the weather data. As a result, several scenarios were generated to choose between most energy efficient configuration and components dimension. Based on the results of TRNSYS simulation, the solar collectors should be able to provide about 82 MWh/year and the resulting solar fraction will be of about 30–50% of annual heat demand. Due to Administrative Building's high thermal energy demand per square meter, it is possible to refer results to i.e. one much larger insulated building or a complex of several such a buildings.

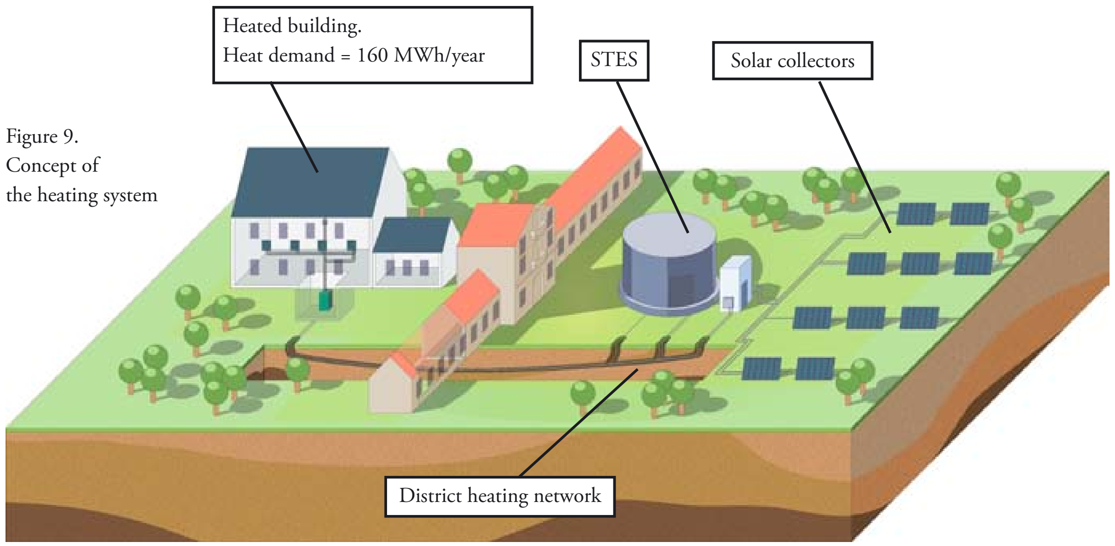


Figure 9.
Concept of the heating system

After choosing optimal system configuration in terms of energy efficiency other feasibility studies were conducted to determine the most suitable construction works solutions. This approach allowed to prepare detailed work schedule resulting in a short duration of construction works. The Horizontal Direct Drilling method was chosen to trace pipes connecting EINSTEIN installation with Administrative Building. Thanks to utilization of a trenchless technology and proper coordination on a construction site, it took only four months to build the complete system.

Photo 1.
View of the Polish Pilot Plant (STES and solar collectors field).

After the design phase, 151 m² (net) of solar collectors provided by Viessman was installed by MAE in the field near the STES. The collectors loop is filled with propylene glycol transferring thermal energy to the heat exchanger's water loop directly into the STES tank. The water supply system is presented in the Figure 11. Cold water is drawn from bottom of the STES and heated water enters thetop resulting in thermal stratification inside the STES in order to increase the overall efficiency of the system.

The polish pilot-plant STES is designed as an above-ground tank and constructed in a similar way to firewater tanks. To keep the heat losses as low as possible, the tank is completely insulated by mineral wool from the sides, by styrofoam and PUR sheets from the top and by foam glass gravel from the bottom. The size and location of the hydraulic connectors to the tank were designed to optimize the efficiency of charging and discharging process. As a result, the installation was connected to the tank at the bottom, in the middle and at the top. The EPDM liner was installed inside the STES to ensure its water-and vapour-tightness. The EPDM is a synthetic rubber, impermeable, resistant to high temperatures, durable and elastic.

The temperature of water inside the STES will vary from 30°C at the end of heating period to about 80°C at the end of the warm period. All of STES constructions works were executed by Mostostal Warszawa S.A. The underground, distribution heating network between STES and the building was performed by ICOP. Based on the characteristic of the terrain and geological data, a decision was taken to carry out

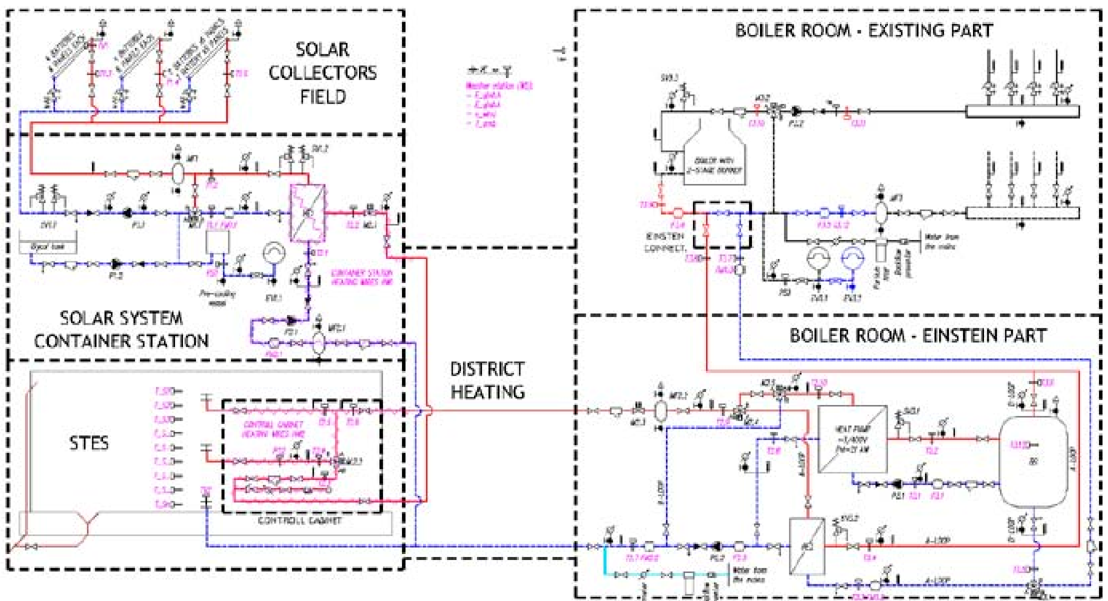
HDPE pre-insulated pipes, using trenchless techniques. The horizontal directional drilling HDD technology was selected as the most optimal. The initial and final part of the pipeline was done by opening trench excavation.

Due to the fact that one of the hospital buildings was located along the route of distribution heating network, the careful monitoring of that building structure was carried out during the trenchless works. In the basement of the Administrative Building the innovative, water-water heat pump was installed. The role of the heat pump is to utilize low-grade heat in order to enhance the overall energy-efficiency system. When water temperature is too low for heating purposes, low-grade heat from STES is converted by the heat pump to ensure adequate temperatures and transferred to a space heating system.

In EINSTEIN project, for the first time in a full-scale STES pilot plant with the heat pump was started-up. The newly developed by Ulster University high efficient heat pump is able to work with wide temperature range of a heat source. It is required as the temperature in the STES circuit will decrease through winter to the end of the heating period. R245fa was selected as the appropriate refrigerant to work safely and stably within the range of the required temperature (between 25°C to 70°C on the evaporator site). The maximum thermal power of the heat pump is 120 kW, thus the unit is able to cover the heat demand of the entire building. To protect the heat pump evaporator against the poor water in the STES, both circuits are hydraulically separated by the heat exchanger.

The final layout of the Polish pilot plant is shown in the Figure 10. The implemented operation strategy involves five main modes. Mode 1 is applied at the beginning of the heating period. The STES is fully charged and covers all of the space heating demand of the building. As the winter progresses, the temperature of the stored water is lowered to the level which is not enough to ensure thermal comfort in the building. In this case, the STES supplies only a part of the building's demand. The rest of the heat is supplied by the gas fired boiler or by the heat pump (modes 2 and 3).When STES is fully discharged the space heating demand of the building is covered by the gas boiler in total (mode 4). The system runs in mode 5 during the warm months. At this period, there is no space heating demand in the building, the STES is charged by the energy absorbed using the solar collectors. A 1 m^3 volume storage buffer is designed to ensure acceptable operation times for the heat pump. The buffer storage is also used to uncouple the energy production of the EINSTEIN part from the energy system from the existing part (gas fired boiler). Dimensions of storage buffer were limited by space availability in the boiler room.

Figure 10.
Final design
of the EINSTEIN
Polish Pilot Plant



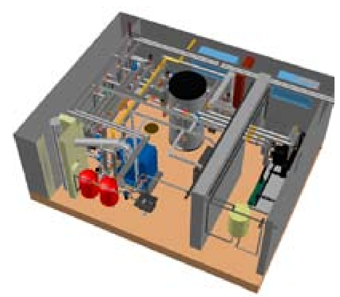


Figure 11.
The 3d layout of the
boiler room after
modernization

Photo 2.
Boiler and its equipment
installedin the Polish
Pilot Plant.

The design process of developing control algorithms was a very complex task integrating six subsystems: solar thermal, storage, heat pump, distribution network, gas fired boiler and inside distribution system. Smooth switching between subsystems is crucial for EINSTEIN system to work in the most energy-efficient manner. The weather conditions, STES level of charge, space heating demand of the building, the key plant temperature, flows and pressures are monitored and taken into account to optimise the system operation. Control algorithm and the monitoring system was developed by CIM-MES.

The STES construction and integration of the boiler room (Figure 11) with the existing space heating system was executed by Mostostal Warszawa SA. The Polish pilot plant started in July 2014 and heat pump was installed and started-up in October 2014. The boiler and its equipment is presented in the Photo 2.

The first year of operation allowed for the testing of heat pump prototype, checking system's reliability and selecting the most appropriate operational strategy. The second year of operation is expected to provide figures on the overall system performance in terms of energy and economic efficiencies.

Patricio Aguirre, Tecnalia. Project coordinator.

SPAIN
The Pilot Plant in Bilbao

The Spanish pilot plant was installed in Bilbao near the centre of the town, and it is dedicated to cultural events. The construction works were executed by Fundacion Tecnalia and Acciona Infrastructures SA. The Seasonal Thermal Energy Storage tank and the entire installation are used only at the building level. The objective of the Spanish pilot plant is to cover approximately 30% of the heat demands of the retrofitted building. The building has been equipped with a low temperature underfloor heating system that covers a surface near 450 m^2. An air handling unit is in charge of supplying ventilation air. The site has a total useful surface of 1,050 m^2 with a capacity for a maximum of 500 people divided in two areas: 800 m^2 for cultural events and 250 m^2 for a cafeteria.

Photo 3.
View of the 800 m^2 surface for cultural events

Photo 4.
View of the 250 m^2 surface for cafeteria and art events

Before the EINSTEIN project demo installation, the facility used a conventional 190 kW natural gas boiler for heating purposes and now both systems are integrated in one unified heating system. In order to define the equipment needed for the seasonal thermal storage system, the heat demand for space heating has been estimated, without domestic hot water, and the total heat demand has been estimated to be about 83 MWh/y. Bilbao is located in the north of Spain. The climate in Bilbao is characterised by two seasons with low intensity thermal variations. Its average annual temperature is 14°C (night) and 19°C, during the day. There is two times more sunlight in the winter than in the north of Europe. The total yearly irradiation is 1272 kWh/m^2, and the total number of solar collectors operation hours is about 4150.

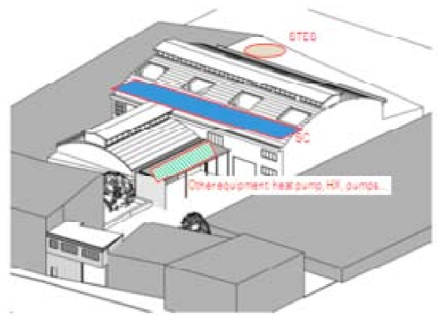
The new installation can supply heat for space heating by means of:

- Solar collectors (62 m^2), directly if the heat demand and enough solar radiation exists, the very high efficiency of solar collectors was achieved by its installation at a tilt of 45°, and with orientation due south.
- STES tank (160 m^3), when there is a heat demand and the water is at a sufficient temperature,
- Conventional heat pump. Once the temperature of the water stored in the STES tank is between 35°C and 10°C, the heat pump uses the heat stored in the STES tank for space heating.
- When water temperature of the STES tank goes down to 10°C (risk of freezing in the HP), the natural gas boiler is used

Photo 5.
View of the STES
in the Spanish Pilot Plant.

According to simulations performed in TRNSYS, the above mentioned data for the solar collectors area and the STES volume has been calculated. Apart from this, another main part of the installation has been dimensioned: a Heat Pump: 69 kW (thermal) and a buffer tank of a 200 m^2 capacity. The heat pump is the water-water unit manufactured by AIRLAN. It can work directly with water between 25–28°C and 10°C.

The STES was erected inside the existing building attached to the demo building. It significantly influenced the tank design – especially the height of the tank and the selected construction techniques. The roof of the building had to be removed and a reinforced concrete slab was built for the load distribution over the pre-existing slab.



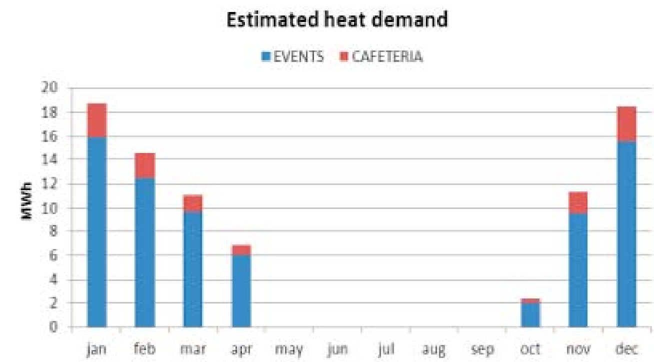


Figure 12.
Main equipment
of the Bilbao Einstein demo

Figure 13.
Estimated heat demand
at Bilbao demo

The STES was designed as a double metallic tank, one inside the other and concentric, and leaving a chamber of to be filled with thermal insulation between them. The inner tank acts as the true watertight container, while the external acts as a container of the insulation (granular). The external tank has the function of containing the insulation of the tank, by filling the cylindrical ring between the two tanks with a granular insulation. Also in the covering, the insulation is made by filling the space between the two covers. For the bottoms, the insulation is made by using a rigid insulation over the insulation slab, and under the waterproofing liner. The tanks are formed of corrugated galvanized sheet bolted steel, and using an epoxy board in each junction. With these characteristics, the design meets some innovative characteristics: a double independent tank, with less thermal bridges due to absence of supports, and the possibility to be filled in with a blowable type insu-

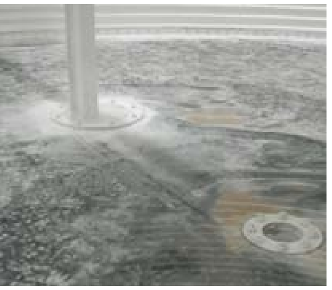


Photo 6
Sealed connections
of accessories

Photo 7.
Bulk insulation of the
tank bottom

Photo 8.
The chamber between two
metallic layers.

Photo 9.
Insulation of the
bottom of the STES

lating material based on recycled Polypropilene; modular construction; insulation over the ground, and regular distribution of charges over the ground (not increased in perimeter).The tank is an open type tank and operates at atmospheric pressure. A venting system located in the upper expansion chamber is designed to avoid a continuous waste of water vapour thanks to a siphon closure. It also acts as an overflow prevention system. The tank is also provided with three stratification devices, with the aim of increasing thermal stratification inside the tank. The insulation needs of the seasonal deposits are higher than those that could have a storage tank daily rate, due to the higher necessities of insulation to prevent the cooling of water over long periods of time. The initial criterion that has been taken to calculate insulation requirements is to establish maximum losses of 10°C (from 85 to 75°C) in a tank during 60 days (considering a static situation of the tank, without adding or extracting heat from the tank). Based on TRNSYS simulations, the final thickness of 0.55 m of insulation was selected. Above that value, the cost of additional insulation is not outweighed by the savings it provides. With the double tank design, the space between both has been filled with a granulated PUR as insulating material. There are no connections between both tanks (they are self-supporting, only the hydraulic piping links them), so that a continuous insulation coverage with no thermal bridges is developed. The material selected for bottom insulation was expanded clay due to it easy availability for use, and good balances between thermal insulation and compression strength. The mortar surface that finishes the insulation expanded clay (under the EPDM layer), is painted with an epoxy coating, that acts as a vapour barrier. A venting system is located in the lower part of the slope, to drain the possible water condensation that could be formed above this coating. The thickness of 0.40 m (minimum) was used for the bottom tank insulation. Due to the thermal stratification inside the tank, the bottom area is the coldest, so thermal losses are lower in this area.The inner tank is painted to protect against corrosion. The painting not only covers the metallic parts, but also covers the outline of the elastic joints between the metal parts, so full protection is achieved. At the bottom, the water closure is achieved by a waterproof layer attached to the base. An EPDM layer is used as the waterproof layer. A vertical thermal stratification method is used to separate warm and cold water inside the STES. Connections can serve as inlet or outlet depending on the operating mode. When charging the tank, the bottom connection acts as an inlet, cold water is extracted from the bottom of the tank that returns hottest thought the upper connections. While discharging (using the stored heat), the flows are the opposite, hot water is taken from the tank thought the upper connections, and comes back to it through the lower connection. To enhance the heat storage, the uptake, and mainly, the discharge of flow into the tank

has been carried out though "stratification devices", elements that increase the area where the flow enters into the tank, so its velocity is low enough to avoid turbulence.

Photo 10.
Solar collectors
(62 m², 27 collectors)

The following pictures show the 62 m² solar collectors installed on the roof of the building and the WRL 200 R410A heat pump that can operate between 28°C and 10°C, it has a total thermal power capacity of 69 kW with a COP of 4.16.

The hydraulic system consists of a primary circuit of isolated copper tubes which uses ethylenglycol as a thermal fluid and solar collectors take part of this circuit. The secondary circuit, with isolated polypropylene piping, is composed by the STES tank, the buffer, heat pump, the natural gas boiler and the space heating system (underfloor heating and air handling unit). The lay-out of the installation is shown in the picture below:

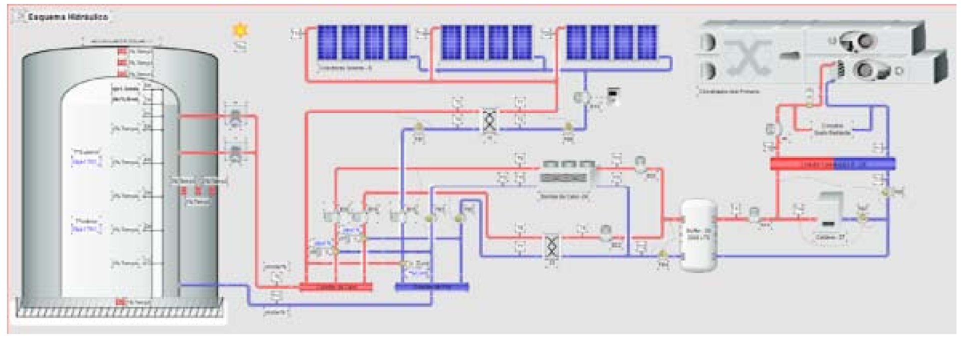


Figure 14.
Layout of the
Bilbao demo.

A control and monitoring system has been installed to measure, display in a screen and record all data related to the hydraulic circuit: five thermocouples inside the STES tank, each one meter in height, seven thermocouples that measure the temperature of the insulating material of the STES tank and also in several points of the primary and secondary circuits. Apart from this, a pressure probe has been installed to measure the water level in the tank, several heat meters are located in the primary and secondary circuits that allow the flow, temperature and heat to be measured. A solar radiation probe has also been installed. Data analysis results will be benchmarked against other plant-operating options to draw comparisons, contrasts and conclusions.

An Exo-Scada design programme has been used to allow data collection, management of failure and alarms, switch on/off the equipment, etc. The system is linked to a web server to connect to the Scada base to check the installation and to operate it by remote control.

Photo 11.
Heat pump

The installation of the equipment of the Spanish demonstration plant started in April 2014 and finished at the end of July. Since 29 July 2014, the installation has been running in charging mode, namely storing water heated by means of the solar collectors in the STES tank, mainly in summer. In winter, several heat discharges to heat the building from the STES tank have been performed.

Neill Hewitt,
Director of the
Centre for Sustainable
Technologies, Ulster
University.

Use of Heat Pumps in combination with STES in low temperatures. The Polish pilot plant case.

The main challenge for Ulster University was to develop a heat pump to upgrade from the STES at temperatures from 20°C to >60°C to meet building requirements at temperatures up to 75°C. While maintaining the belief that off-the-shelf equipment was appropriate for this task, a number of working fluids were examined, the properties of which were such that pressures at temperatures of 75°C and below were in line with traditional pressure ranges of, for example, R134a compressors i.e. –25°C to 15°C or 1 barA to 5 barA. R245fa emerged as a likely candidate with temperatures of 14.8°C and 62.7°C for 1 barA and 5 barA respectively. The challenges are then compressor lubrication (oil viscosity, miscibility etc.) and electric motor temperature when operating at elevated evaporator temperatures. Heat transfer proved to be marginally challenging as major brazed/welded compact plate manufacturers incorporated R245fa properties into their design portfolios. However, expansion valve manufacturers required new algorithms to address superheated properties of R245fa. These solutions, where appropriate, were incorporated into a small scale water to water heat pump facility at Ulster University utilising a scroll compressor, compact plate heat exchangers and an electronic expansion valve to test the theory of R134a equipment suitability.

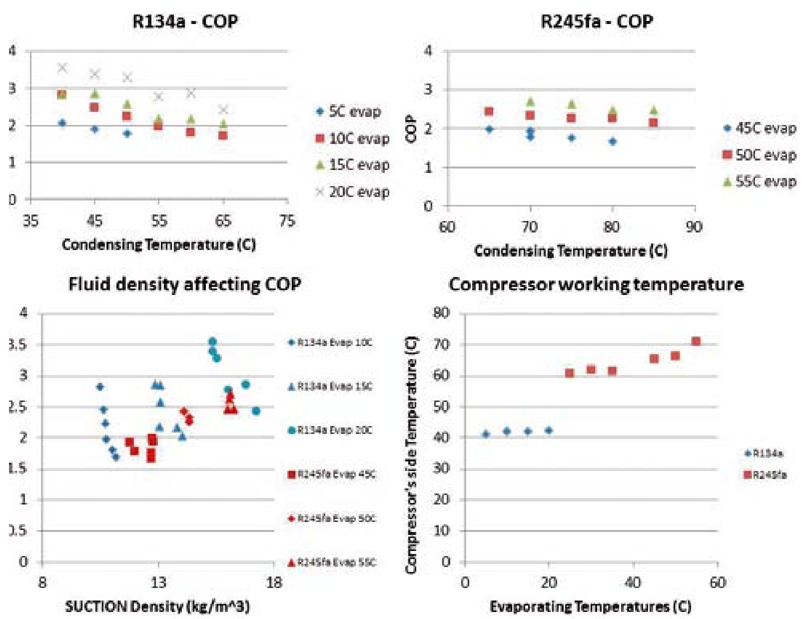


Figure 15.
R134a-R245fa
comparisons

The water to water heat pump was initially tested with R134a at EN14511standards to establish correct operation and a baseline performance. The performance map was the extended to higher temperatures to allow meaningful R245fa tests. Figure 15 illustrates comparative performance between the two fluids.

Thus there was a confidence in moving the tests forwards to a full sized demonstrator capable of heating a hospital building near Warsaw in Poland. The STES provides heat when the temperature in the STES is sufficient and uses for a heat pump as a heat source to make up the temperature when the STES is not hot enough.

The heat pumps used were possibly off-the-shelf components. R134a compressors were utilised in the model after a discussion with the manufacturers. Such discussions confirmed that the existing compressor oil was deemed to be suitable for operation with R245fa, part load operation at low temperature lifts may require additional compressor

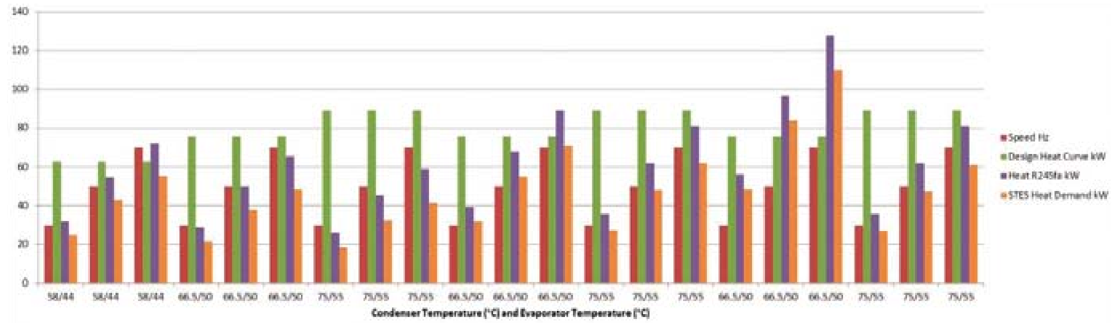


Figure 16.
Performance
comparison for
a range of relevant
R245fa/R134a
conditions.

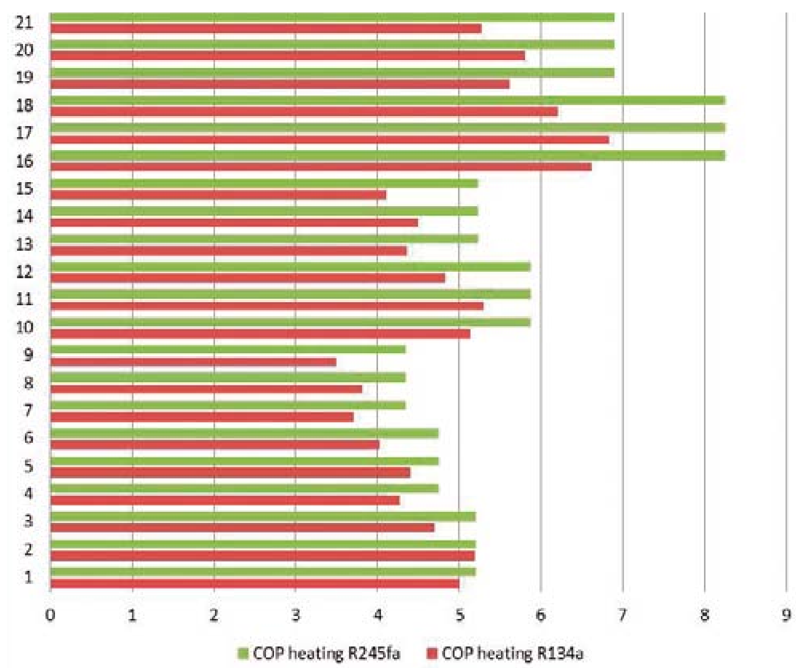


Figure 17.
Modelled R245fa
Heat Pump
Performance.

cooling and the use of the buffer tank ensured that satisfactory run times would be obtained under all conditions. Heat exchangers were selected with R245fa and water in mind but the larger expansion valve proved difficult in obtaining R245fa operating values. It was operated with the compromise setting of R123 which was deemed closest to the R245fa pressure/temperature levels.

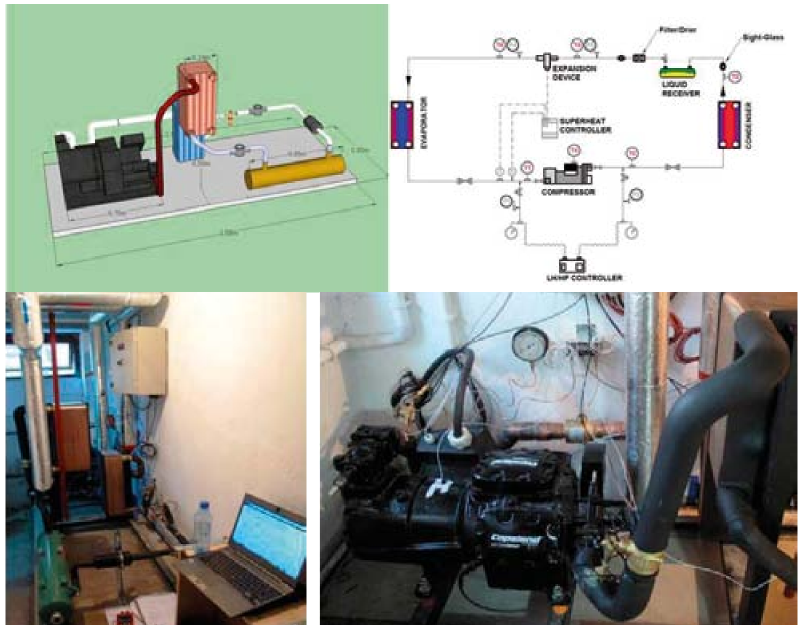


Figure 18. Schematic Sensor Positions and Images of the Heat Pump on site.

The system layout and construction are noted in Figure 20. A simple layout was proposed due to the constraints of space in the building plant room. The main components are as follows: Compressor – Emerson 6MU-40X-AWM/D-D, Heat Exchangers – SWEP B120T x 90 and SWEP V200T x 50, expansion device – Alco ETS6 and its controller EC3-X33, coupled with a Carly 15 Litre receiver to manage capacity changes. Just a charge of 13 kg of R245fa was utilised.After installation and commissioning of the heat pump with cross checks to the extensive control system, 36 hours of operation were carried out at the time of writing. The results are as follows with a typical start and run illustrated in Figure 20.

A pressure drop was noted in the evaporator (Figure 21). This is due to the oversizing of the line from the expansion valve exit to the evaporator entrance. The R245fa leaving the expansion device will potentially expand again. As the evaporator operates under part-load conditions at certain periods of operation, there is already an additional capacity within the heat exchanger as a result of which the pipe size must be reduced. In addition, very low superheat is recorded and represents the challenges of operating such an expansion device with an alternative fluid. This will undoubtedly become rectified R245fa becomes more popular.

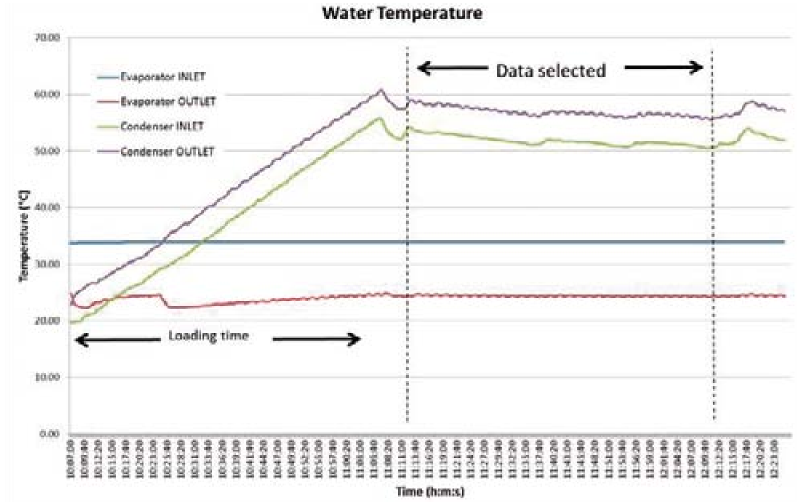


Figure 19. Start and Run Cycle.

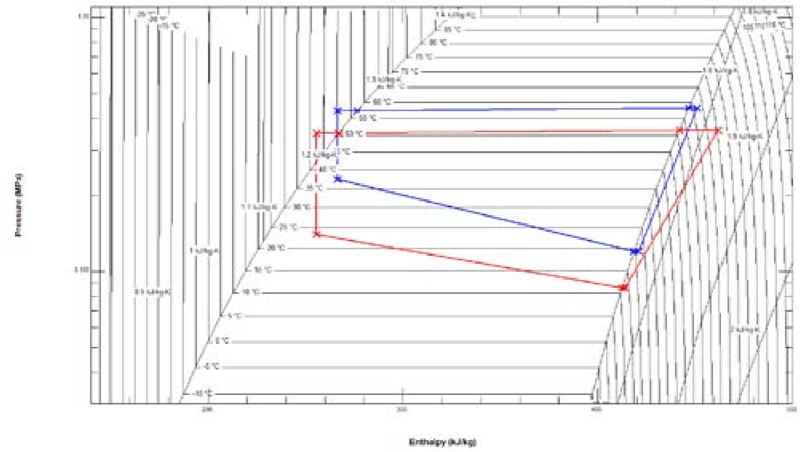


Figure 20. Pressure Enthalpy Diagram of Cycle Operation.

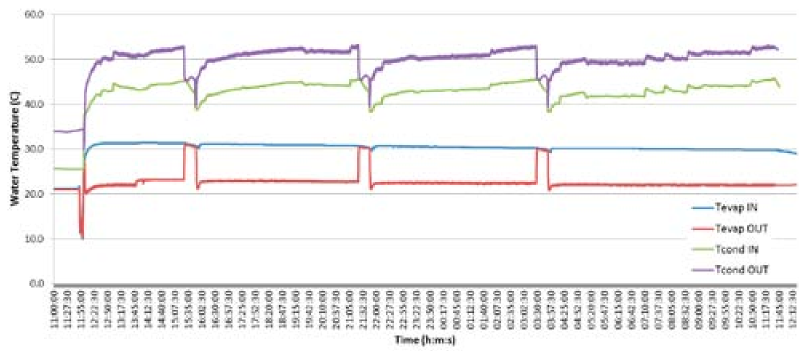


Figure 21. 24 hour test system operation.

Despite these challenges, tests were carried out using the system to heat the hospital administrative building. The most extensive test to date was a 24 hour heating test where the heat pump provided space heating for the building. When the ambient temperature at Ząbki ranged from a minimum of 0.1°C and a maximum of 2.4°C, the building required 38 kW and the heat pump delivered 39.08 kW. During this period, the STES drop in temperature was 1.4°C/24 h. Figure 21 illustrates the system's operation.

Table 1 shows the performance conditions of the heat pump during the 24 hour test and preceding tests while Table 2 illustrates the performance of the heat pump.

Table 1.
Heat Pump Operation Conditions during a number of days.

	EVAPORATOR				CONDENSER			
Date	Inlet	Outlet	Flow	Cooling Capacty	Inlet	Outlet	Flow	Heating Capacity
	C	C	kg/s	kW	C	C	kg/s	kW
01-Dec	33.9	24.4	0.824	32.62	51.8	56.9	1.888	40.36
09-Jan	29.9	19.2	0.507	22.57	45.2	50.7	1.231	28.33
18-Feb	30.9	22.44	0.96	32.45	43.76	50.65	1.22	38.51
19-Feb	29.98	22.04	0.9	30.03	42.98	50.5	1.18	37.14

Table 2.
Heat Pump Performance.

Date	Heating Capacity	Power IN	COP	η isen	Cr
	kW	kW	kW/kW	%	
01-Dec	40.36	7.82	5.16	75.48	3.63
09-Jan	28.33	6.12	4.63	51.64	4.13
18-Feb	38.63	6.97	5.54	70.15	3.31
19-Feb	37.84	6.76	5.59	66.67	3.34

There are a number of aspects of the data that are worth pointing out. The solar energy from the 150 m^2 flat plate collector field was active in winter and this is clearly seen in temperature increases after 9 January 2015. The STES is well insulated – even during operation at near 0°C ambient temperature conditions, the heat loss when the heat pump was operating was only 1.4°C per day. The isentropic efficiency (ηisen) is marginally higher than predicted. This may be a product of the very low superheat operation with perhaps small amounts of liquid entering the compressor. However, there were no noticeable periods of "foaming" i.e. oil and refrigerant mixing in the compressor sump as observed through its sight glass. The exception to this was a short period during the start-up, which was partially addressed by the incorporation of an additional sump oil heater. This aspect will be kept under observation as oil transport issues may become an issue. As the compression ratio (Cr) reduces, there is an increase in refrigerant flow due to the increase in the volumetric efficiency of the compressor, there is an increase in the net refrigeration effect as the enthalpy of the refrigerant entering the evaporator declines and there is a lowering of compressor energy consumption and an overall increase in energy efficiency. In addition, from the limited current data, R245fa appears to have no challenges when operating with R134a equipment with the exception of requiring a dedicated expansion device.

Design and implementation of the EINSTEIN control system

Armen Jaworski

One of main limitation in the development of renewable energy sources (RES) are investment costs. Governmental policies stimulate the development of RES, e.g., by introducing carbon taxes, but higher impact can be achieved by reducing the main limitations of RES coming from unpredictable and frequent changes in power, especially in the case of wind power. The solution for this problem can be distributed energy resources (DER) and distributed energy storages (DES) not only for electric, but also for thermal energy. Connecting the electric and thermal energy generators together with energy accumulation units (e.g. STES) with a district heating grids is very promising, but requires an advanced approach to the control system, as its complexity is strongly increased. Within the EINSTEN project, CIM-mes Projekt sp. z o.o. is developing smart controllers for highly efficient multisource heat generation including district grids and a connection to electrical grid using novel high temperature heat pumps.

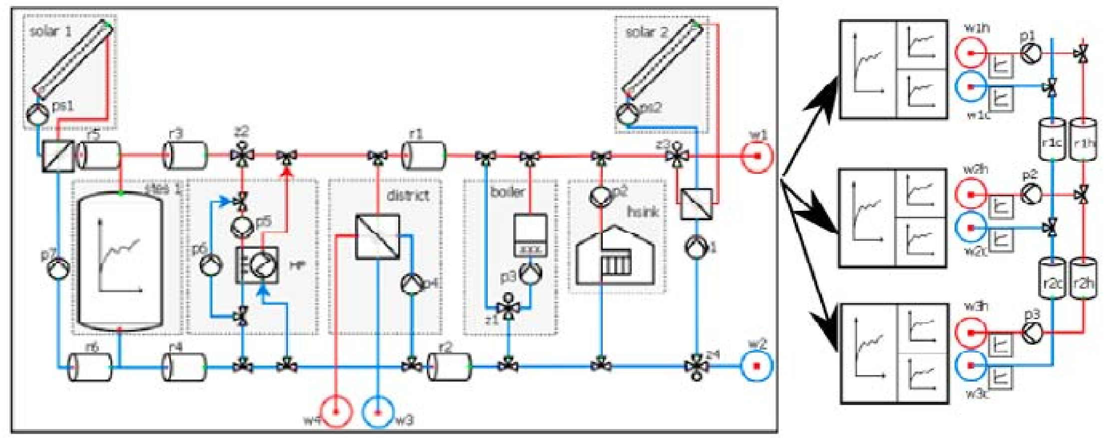


Figure 22.
Simulation of solar collectors and thermal energy storage coupled with district heating.

The control over the considered system is a complex task, due to fluctuating renewable energy sources and contradictory requirements of different system elements, e.g., the solar collectors are more efficient at low temperature and often district heating and existing buildings require high working temperatures. All components must work together regarding variable external conditions (e.g. weather, prices of energy) and several internal and external constraints. It has to combine day-to-day and seasonally varying operation. Working parameters, in particular temperature, flow rate and dynamical constraints must stay within the region of stable and effective operation as the overall performance depends on the efficiency of all system elements. The simulation results and the pilot installations developed within the project show that it is possible to find a trade-off between these requirements, however, advanced numerical tools must be used during the design process, and especially during its operation. Efficient control algorithms optimising the system's performance are crucial.

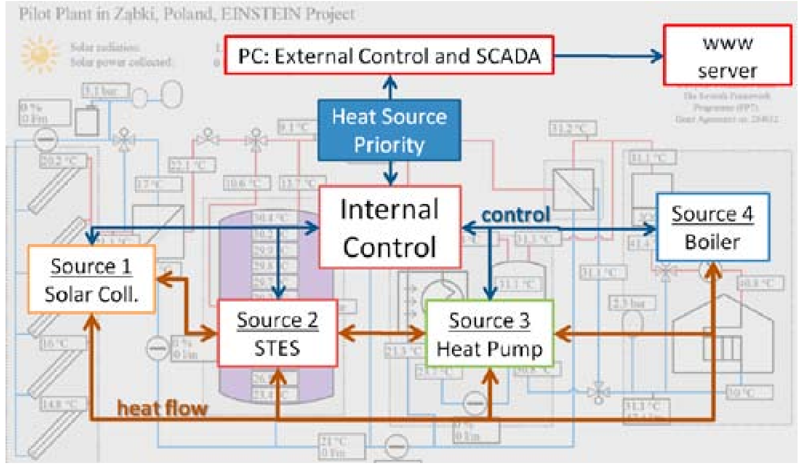
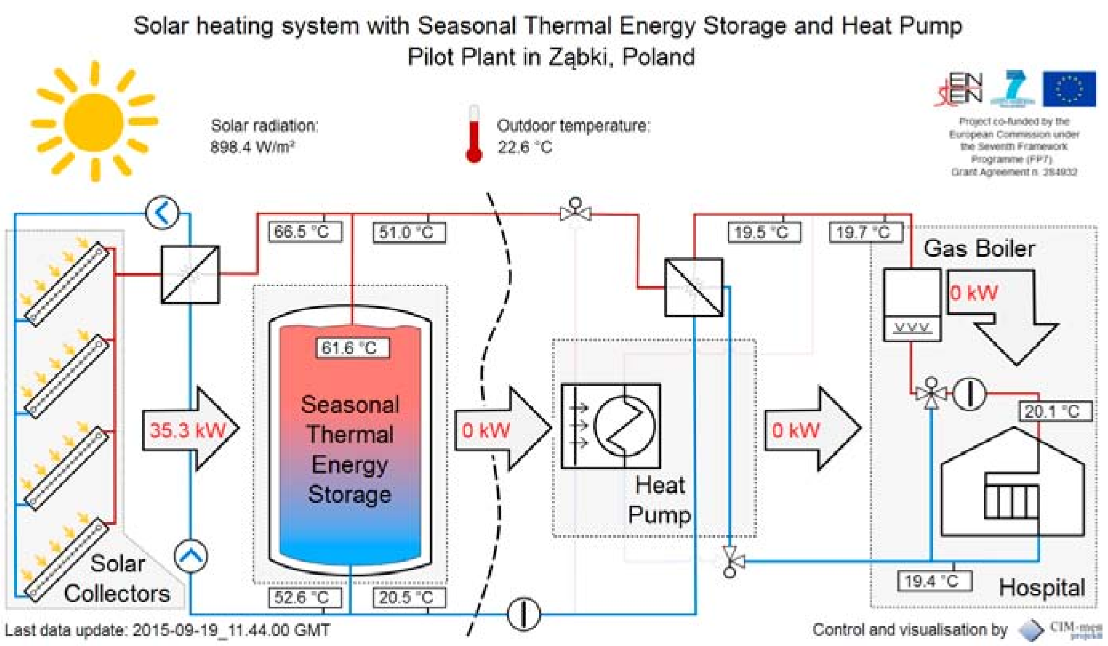


Figure 23.
Control approach at the Polish pilot plant. The multi-source heating system with solar collectors and seasonal energy storage is controlled using a two level approach.

The control algorithm developed for the Polish pilot plant contains a two-level approach. The low level controller is responsible for the implementation of predefined operating modes for heat transfer between different heat sources, heat storages and heat consumers. The high level control is responsible for optimising the overall system performance taking the historical data, current system state and future predictions into account.

Figure 24.
District manager interface.



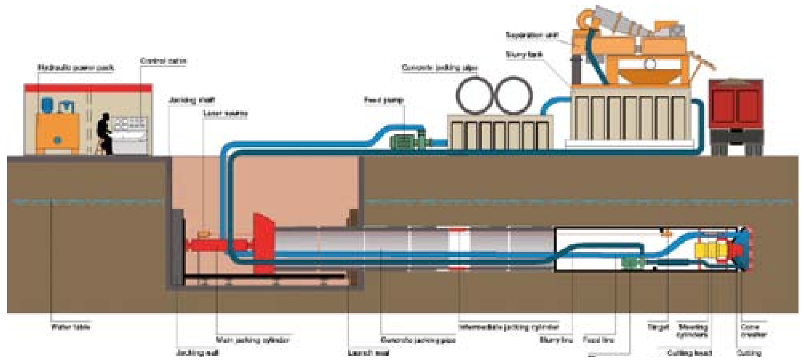
Highly-specialized methods of placing underground utilities in densely built up urban areas

Daniela Reccardo,
Innovation Consulting
Division, D'Appolonia.

Trenchless technologies are particularly attractive techniques for performing minimal invasive construction works and pipe installations in urbanized areas with heavy vehicular and pedestrian traffic and numerous existing underground utilities. In fact, they involve the installation, replacement or renewal of underground utilities with minimum excavation and surface disruption, requiring few trenches or no continuous trenches. In particular, Microtunneling (MT) methods, Horizontal Directional Drilling (HDD) and Direct Pipe (DP) represent the most advanced excavation/perforation techniques currently available on the market that can find a new application for carrying out the piping network associated with the STES implementation. Their application to district heating supply systems allows operating at lower levels underground, thus eliminating the issue that can arise from interferences with other urban networks that have already been installed. The main characteristic of these technologies are briefly described below.

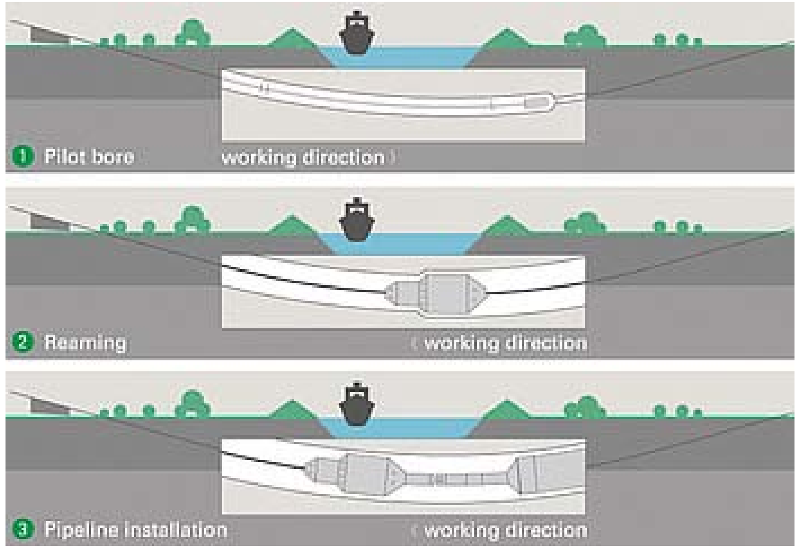
Microtunneling (MT) method

Microtunneling is defined as a remotely-controlled, guided, pipe-jacking operation that provides continuous support to the excavation face by applying mechanical or fluid pressure to balance groundwater and earth pressures. The full-face excavation is carried out by a cutter head (also called microtunneller) that is pushed into the ground together with the pipe to be installed.



Horizontal Directional Drilling (HDD) method

A steerable system for the installation of pipes, conduits, and cables in a shallow using a surfaced launched drilling rig. In HDD, a fluid filled pilot hole is drilled and this is then enlarged by a wash over pipe and back reamer to the size required by the product.



Direct Pipe (DP) method

The Direct Pipe (DP) method is a trenchless pipe-laying method, which consists in the fabrication of a subterraneous cylindrical hole in the ground by simultaneously excavation and installation of a prefabricated pipeline with allowable bending radius for the entire crossing section. Unlike MT and HDD techniques, DP method allows the pipeline to be laid in a single working step without using additional protection pipes or large-volume hydraulic bore hole supporting media.

The employment of these techniques is strongly influenced by the available areas for the construction sites and by economic considerations of convenience related to the size of the work to be carried out.

EINSTEIN Polish Demo site

The site selected for the construction of the Polish pilot plant is placed in Ząbki, Warsaw within the premises of a provincial hospital for nervous and mental diseases. In the scope of the project, an administrative building was equipped with a Seasonal Thermal Energy Storage tank (STES), heat pump and solar collectors. In order to design and implement the hydraulic piping network which connects the installed devices to each other and to the interested building, three different possible scenarios were identified:

- Piping passing below the pavilion building basement and going to the administrative building (option 1)
- Piping passing through the first floor underground of the pavilion building using an already existing window and going to the administrative building (option 2)
- Piping going around the pavilion building (option 3).

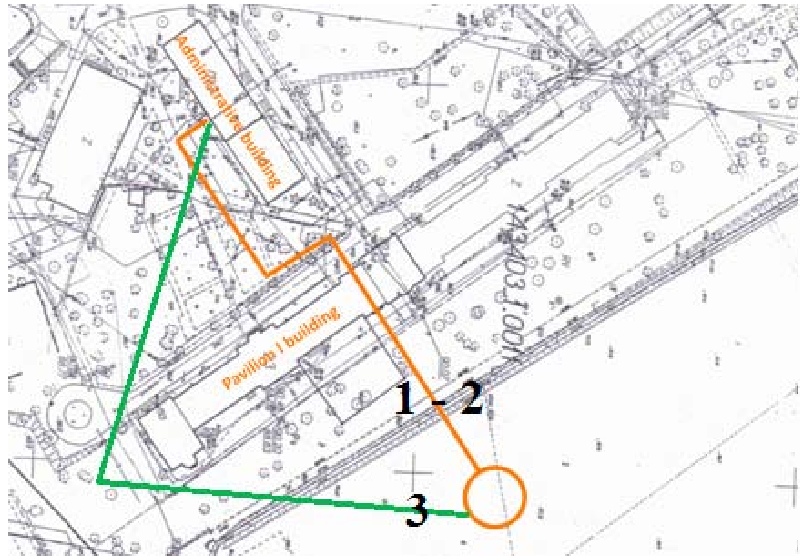


Figure 25.
Ground view on
the Polish pilot plant.

Photo12.
Starting shaft

Photo13.
Arrival shaft

For each scenario, a dedicated analysis of the main parameters that play a key role in the selection of the best excavation/perforation solution (MT, HDD, DP) was performed. In particular, after having viewed the area affected by the installation of the designed structures and having studied the main crossing geometrical characteristics and geological-geotechnical soil data, the HDD technology was selected. The identified technological solution allowed:

- Open trench excavation just at starting and arrival shaft to be implemented
- Damage at existing buildings and trees located near the crossing route to be avoided
- The works to be completed quickly (4 days)
- The inconvenience to the hospital's staff and users to be minimised.

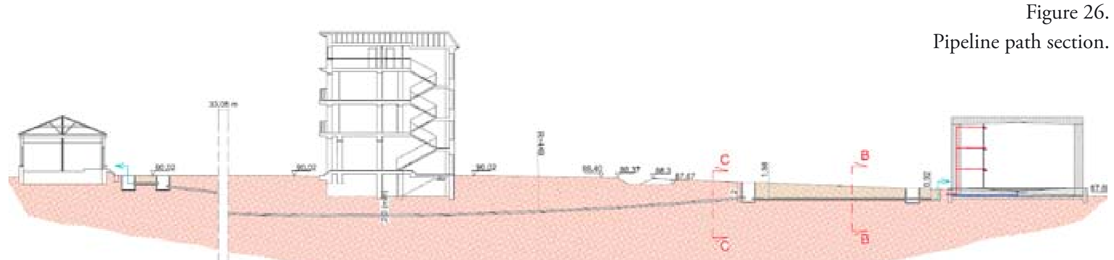


Figure 26.
Pipeline path section.

Administrative information

EINSTEIN project proposal has been prepared for a call opened within Seventh Framework Programme, topic EeB.NMP.2011-2 New efficient solutions for energy generation, storage and use related to space heating and domestic hot water in existing buildings.

Realization of EINSTEIN is co-financed based on grant agreement no. 284932, signed between the project consortium and European Commission

The consortium is composed by 17 partners from 8 countries.

Tecnalia Research and Innovation Foundation: Research institute from Spain. Project Coordinator.

Acciona Infrastructures S.A.:
Construction company from Spain

D' Appolonia SPA:
Engineering Consulting Company from Italy

Mostostal Warszawa S.A.:
Construction company from Poland.

Solites:
Non-profit research institute from Germany.

University of Ulster:
Higher educational school from Northern Ireland.

CIM-MES Projekt:
High tech SME company from Poland.

University of Stuttgart:
Higher educational school from Germany.

TNO:
Independent knowledge company from Netherlands

Scandinavian Homes Fastigheter AB:
Company specialized in passive houses construction from Sweden.

Girotze:
SME company from Spain.

I.C.O.P. S.p.A.:
Company specialized in micro-tunnelling and special foundation works from Italy.

Architectural Spies Ltd.:
Architectural studio from Bulgaria.

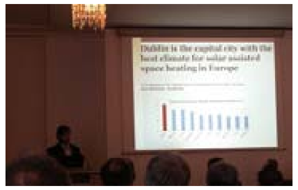
Fomento San Sebastian:
Public entity from Spain.

Mazovia Energy Agency Ltd.:
Public Agency focused on establishing an energy policy in Poland

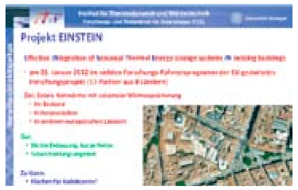
Airlan:
Company specialized in heat pump development from Spain.

Dissemination

The EINSTEIN concept and particular results of the research performed have been widely disseminated, at various scientific and commercial events in Europe and beyond.



May 2012. International Passive House
May 2012. Conference in Hannover,
Solarenergie Germany.

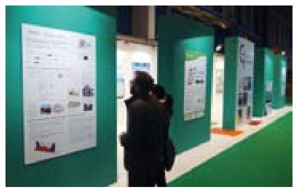


22. Symposium Technische
Association in Bad Staffelstein,
Germany.

February 2013.
Genera Fairs in Madrid, Spain.

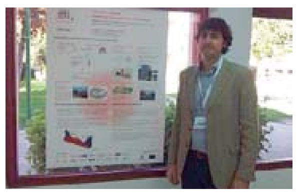
November 2013. ISES Solar
World Congress in Cancun, Mexico.

May 2013. International Passive
House Association Conference
Ellos, Sweden.



February 2015.
Genera Fairs in Madrid, Spain.

Thermomodernization Forum
Congress in Warsaw, Poland.



April 2015.
CIAR Congress in in Madrid, Spain.

Scientific journals and international conferences

Journals

1. Bauer D., Marx R., Druck H. "Solare Nahwärme im Bestand – Technologie und Perspektiven. Proceedings 22. OTTI-Symposium thermische Solarenergie, Kloster Banz, Bad Staffelstein, Germany, 09.–11.05.2012. Mangold D., Schmidt T., ''Experience from national first movers in solar assisted district systems with seasonal heat storage". Colclough S., McGrath T., Griffiths P., Hewitt N., ''Net Energy Analysis of a Solar Combi Systems with Seasonal Thermal Energy Store". Proceedings ISES Solar World Congress 2013. Bauer D., Marx R., Druck H. "Solar District Heating for the Built Environment – Technology and Future Trends within the European Project EINSTEIN". Proceedings ISES Solar World Congress. Cancun, 3rd–7th November 2013.

2. Jaworski A., ''Sterowanie siecią ciepłowniczą z całosezonowym akumulatorem ciepła". Proceedings PBEC, December 2013.

3. Colclough S., Cambronero M.V., Griffiths P., ''The Einstein Project and Integrating Seasonal Thermal Energy Storage into the Heating Systems of Existing Buildings". Proceedings Eurotherm Seminar #99. Lleida, 28th–30th May 2014.

4. Alberto G. Alonso, ''Energia de future para uno vieja nave de zorrotzaurre", Deia Newspaper. 10th June, 2014.

5. Hewitt N., Huang M., Ramirez M., ''R245fa Heat Pumps for Seasonal Solar Thermal Storage Applications". Proceedings International Congress of Refrigeration. Yokohama, 16th–22nd August 2014.

6. Bauer D., Marx R., Druck H., ''Medium Scale Seasonal Thermal Energy Stores for Solar Thermal Applications within the European Project EINSTEIN". Proceedings IEA Grennstock Congress, Beijing, 19th–21st May 2015.

7. Marx, R.; Bauer, D.; Drück, H.: Solar District Heating and Seasonal Thermal Energy Storage within the EU Project EINSTEIN. EuroHeat&Power, English Edition Vol. 11 I/2014, 26-29, ISSN 1613-0200-22698, Februar 2014.

Conferences

1. Ulster. Presentation on viability of STES. International Passive House Association conference, 4th–5th May 2012.

2. USTUTT. Bauer D., Marx R., Druck H. "Solare Nahwarme im Bestand – Technologie und Perspektiven". 22 Symposium Thermische Solarenergie, 9th–11th May 2012.

3. Fomento de San Sebastian. Presentation of the Renewable Energy and Energy

Efficiency Cluster of San Sebastian. Forum Batiment Durable, 9th February 2013.

4. Acciona. Conference about EINSTEIN project objectives. Genera 2013. "Energy and Environment International Trade Fair. Madrid, 27th–28th February 2013.

5. D'Appolonia. Presentation on EINSTEIN project objectives. "Energy-efficient buildings PPP impact workshop". Brussels, 12th–13th March 2013.

6. Ulster. Presentation on viability of STES. Passive House Association of Ireland conference. Ulster, 21st March 2013.

7. Fomento de San Sebastian. Presentation of the Renewable Energy and Energy Efficiency Cluster of San Sebastian. Energias Renovables – Bionergia. Casos practices. 9th May 2013.

8. D'Appolonia. Presentation about EINSTEIN project objectives. Smart village in tour. "Nearly zero energy building design and construction". Genoa, 22th May 2013.

9. Scandinavian Homes Ltd. Presentation on STES. International Passive House Association Conference. Ellos, May 2013. Ulster. Presentation on financial analysis of STES. Sustainable Energy Storage in Buildings Conference. Dublin, 19th–21st June 2013.

10. Ulster. Presentation on National Carbon Dioxide Strategy Buildings incorporating Seasonal Thermal Energy Storage. Cancun, 3rd–7th November 2013.

11. USTUTT. Bauer D., Marx R., Druck H. "Solar District Heating for the Built Environment – Technology and Future Trends within the European Project EINSTEIN". ISES Solar World Congress. Cancun, 3rd–7th November 2013.

12. CIMMES. Jaworski A. "Sterowanie siecią ciepłowniczą z całosezonowym akumulatorem ciepła". Research and Development in Power Engineering conference, Warsaw, 12th December 2013.

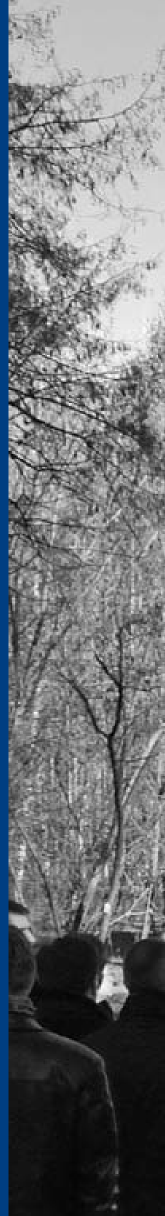
13. Acciona. Conference devoted to discuss key enabling technologies, competitiveness and smart growth in Europe. Intech 2014. Industrial Technologies 2014. Athens, 9–11th April 2014.

14. Ulster. Hewitt N.,Huang M., Ramirez M.,, R245fa heat pumps for seasonal solar thermal storage applications". Internal Congress of Refrigeration. Yokohama, 16th–22nd August 2014.

15. Acciona. "Einstein: Integracion efectiva de sistemas de Almacenamiento termico estacional (STES) en edificios existents". Genera 2015. "Energy and Environment International Trade Fair". Madrid, 25th–27th February 2015.

16. Acciona. Esteban J.C., Cambronero M.V., Bote J.L. ''Proyecto Einstein. Sistemas de Acumulacion Termica Estacional". CIAR – Congreso Ibero-Americano de Climatización y Refrigeración. Madrid, 28th–30th April 2015.

17. USTUTT. Bauer D., Marx R., Druck H., ''Medium Scale Seasonal Thermal Energy Stores for Solar Thermal Applications within the European Project EINSTEIN". IEA Grennstock Congress, Beijing, 19th–21st May 2015.



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