SUREFIT

SUstainable solutions for affordable REtroFIT of domestic buildings

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Other authors	**Instituto de Soldadura e Qualidade (ISQ)**

WP4 - Deliverable D 4.4

Heat Pumps

Dissemination Level

PU	Public	**X**
CO	**Confidential, only for members of the consortium (including the Commission Services)**	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

Document History

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Abbreviations

SAHP	Solar assisted heat pump
GSHP	Ground source heat pump
TP	Thermal pipe
DX	Direct expansion
PV	Photovoltaic
HWT	Hot water tank
DHW	Domestic hot water
COP	Coefficient of performance
GHE	Ground Source Heat Exchanger

Publishable summary

A comprehensive assessment of solar-assisted heat pump integrated with thermal storage and PV panels (SAHP-TS-PV) for heating electrification retrofit is made. The concept of solar assisted heat pump (SAHP) is the same as a traditional heat pump. The main difference is the use of a thermodynamic solar panel as evaporator, which permits extraction of heat from environment and the absorbed solar radiation in the solar panel.

Introduction

Leading Beneficiary: University of Nottingham (UNOTT)

Participants: Instituto de Soldadura e Qualidade (ISQ)

Task description:

The work package involves fabricating and testing the key components and assembling the components into complete prototypes of technologies. The technologies will be tested in the lab to assess their performance under the nominal set conditions. The testing results will be used to modify and improve the design of the final prototypes, if necessary, which will be used in WP6 (field tests). The availability of this prototype system for field trials will be milestone 3. UNOTT is the work package leader.

Task 4.2: Produce solutions for energy efficient facilities (UNOTT, M7-M17)

• UNNOT will construct innovative multi-purpose heat pumps (both DX-SAHP and TP-GSHP). Research will be carried out to maximise the efficiency of heat pumps by integrating thermal storage, making use of waste heat from exhaust air or waste water and applying to low heating sink systems such as floor heating or high cooling sink systems such as chilled ceiling.

This deliverable concerns the reporting for the demonstrator planned for Deliverable 4.4- Heat Pumps.

1 Summary

1.1 Direct Expansion Solar Assisted Heat Pump (DX SAHP)

Heat pumps have been developed and used in buildings mainly for heating so far. A solar-assisted heat pump combines a solar air collector with heat pump technology. Such a heat pump including direct expansion type (Fig. 1) has been developed by the project partner (UNOTT) and will be used for retrofitting in domestic buildings to provide heating and/or cooling and hot water for buildings. The compact heat pump can utilise ambient air as the heat source (or other heat sources such as heat from exhaust air and IT) or could be combined with photovoltaic (PV) panels in order to extract solar energy from the back of panels. The cooling of the PV panel will enhance its efficiency.

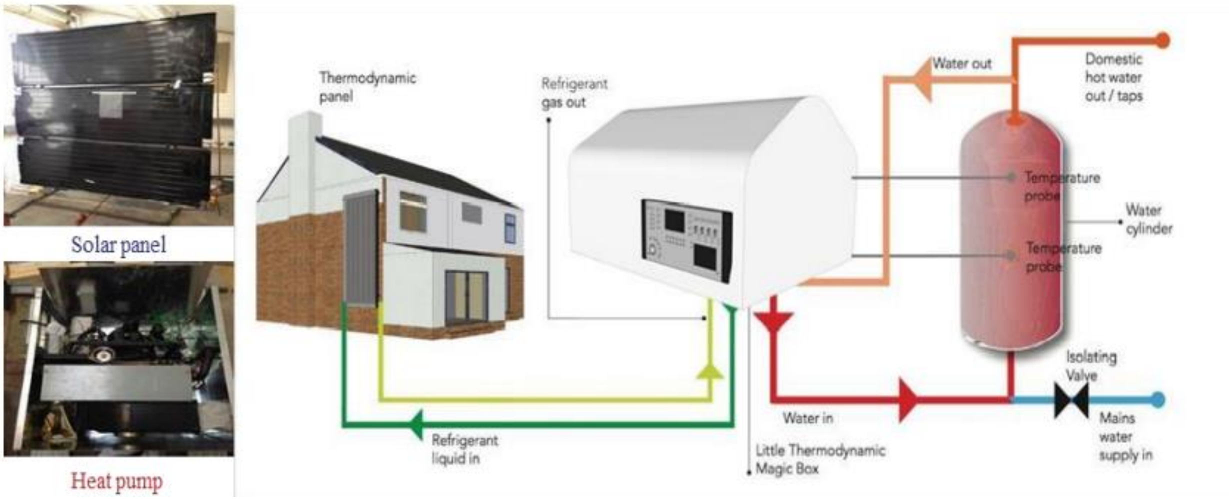

Fig. 1. Schematic diagram of the DX-SAHP system

The key innovations are summarised as follows:

i. Combination of the heat pump and solar collector is a mutual beneficial way of enhancing the coefficient of performance of the heat pump and solar collector efficiency (see Fig. 1).

ii. The heat pump COP can be elevated to the great extent on the temperature of the evaporator. The solar collector loop enables to boost the heat source temperature of the heat pump, thereby improving the annual and seasonal performance of the heat pump.

iii. The evaporator/solar collector panel for the DX heat pump has been designed to achieve a high efficiency as a result of using multi-channels so that the refrigerant liquid can travel through, resulting in greater traveling time. This allows the liquid to gain more heat from solar energy and ambient air. Therefore, DX-SAHPs combine two processes (absorbing solar energy and vaporize refrigerant) in only one unit.

1.2 Innovative ground source heat pump using thermal pipes (TP GSHP)

An innovative "thermal pipe" (TP) has been developed by UNOTT. It can be driven into the ground using a handheld piler and act as a heat source/sink for a heat pump.

In comparison to conventional ground coil heat exchangers, the TP provides significant advantages, notably low cost, and easy installation (Fig. 2) especially in locations inaccessible to drilling machines. The TP can either be a solid rod or a "hybrid" tube containing a liquid such as propylene glycol/water. Heat transfer from the TP to the heat pump is achieved via a glycol circuit that includes a heat exchanger on the top of the TP.

Key features are as follows:

(1) Innovative thermal pipes driven vertically into the ground to a depth of 5-10 m (see Fig 2): The pipes proposed for this project are low-cost sealed pipes made of materials such as copper or steel filled with a working fluid such as water, glycol/water or an organic fluids ethanol and Hydro-Fluoro-Olefin (HFO). The 5-10m depth is very shallow compared to a conventional borehole with a depth of 100-300m. In this technology, there will be a field of several thermal pipes to make up for the low depth.

(2) Installation using an economic portable piling machine (See Fig. 2): The thermal pipes can be easily and economically installed using a portable petrol-hydraulic hand piling tool in less than 10 minutes, already proven feasible by UNOTT. By avoiding expensive, large drilling rigs required for conventional borehole, the use of portable piling machines allows pipes to be installed on otherwise inaccessible sites. Hence, the technology is well suited for retrofit applications of homes.

Fig. 2 Thermal. pipe heat pump system (left), low cost piling unit (right)

(3) Thermally conductive micro particulate materials to enhance soil thermal conductivity around the pipes (See Fig. 3): The micro conductive materials used will include, but will not be limited to, carbon/graphite which are natural particles that are environmentally benign. There is

increasing use of graphite particles in industry and research for thermal management of composite materials. Other than graphite particles, the use of biochar to enhance soil heat transfer will also be explored.

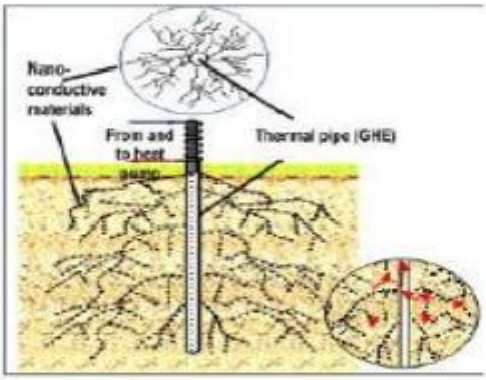

Fig. 3. Heat conduction network of particles

Key Innovations:

The project is clearly innovative and timely. A literature review/patent search (Google patent search, Web of Science, Espacenet, Uspto.gov) produced no relevant prior art. A patent application (GB1521627.8) for the innovative thermal pipe heat exchanger integrated with GSHP has been filed by UNOTT. The key innovation of the proposed project are as follows:

• Easy to install. The fundamental barrier to wider adoption of existing GSHPs for retrofit is the area required for ground coils and the high cost of their installation. The area required can be reduced by deep well systems, but these are also expensive. Heavy machinery is required to install ground coils which may not be practical on sites with restricted access, especially existing residential housing. The proposed thermal pipe design is novel and immediately solves the conventional GSHP high cost problem. It avoids expensive, large drilling rigs required for conventional GSHP system.

• Increased soil thermal conductivity. Existing studies have shown that ground heat exchanger (GHE) have serious limitations imposed upon them when installed in soils having low thermal conductivity and diffusivity. Researchers have attempted to address the issues with thermally enhanced grouting, in providing improved thermal contact between the pipe loop and the ground. However, such design is restricted to application immediately within the borehole area. As the soil still imposes a significant resistance to heat transfer outside the grouted area, the overall effect of grouting on improving heat transfer is limited. In this project, the injection of high thermal conductivity particles into the ground around the pipes will increase the thermal conductivity of soils. Heat from the surrounding soil to the GHE will be absorbed and transported through either thermally conductive networks in the air volume or nanofluid in the water volume that will be formed by injecting or diffusing benign micro conductive materials into the soil in the vicinity of GHE.

• It creates a new commercial opportunity for EU industry addressing fuel poverty by making space heating/cooling cheaper.

2 Concept of DX SAHP

2.1 Background

It is well understood that the combinations of solar energy and other energy sources have been used in various applications [1]. These include cooling/heating systems, agriculture industries and water treatment. Energy storage materials have been used as an efficient method for providing additional thermal heat for improving the thermal storage capacity of the domestic hot water tank in cold climate [2].

Solar energy and heat pump systems are promising means of decreasing the consumption of fossil fuels and carbon emissions. Several ideas have been proposed to improve the performance of conventional heat pumps. Several researchers have investigated 'SAHP' which is based on the integration of heat pumps with solar collectors [3, 4]. The main principle of the SAHP is to enhance the performance of the heat pump using solar energy as well as a low-grade ambient heat. The SAHP system can be used for delivering hot water and/or space heating.

A great deal of research concentrating on numerical and experimental studies of SAHP systems were implemented as early as in the 1970s [5]. Furthermore, theoretical and experimental studies on SAHP were performed later in the 1990s [6]. Comakli and co-workers [7] have designed a solar heat pump for residential heating using thermal energy storage system. Another study using indirect expansion SAHP type system was found to be suitable for regions with abundant solar insolation. SAHP with a coefficient of performance (COP) of 4.0 was found to be economically viable [8]. A direct-expansion solar-assisted heat pump directly integrated with a Reverse-Rankine refrigeration device was firstly considered by Sporn and Ambrose [9]. Huang and Chyng [10] proposed the design of the first integral-type solar-assisted heat pump SAHP that combines a heat pump and solar collector. They have come up with a unitary system that can be easily installed in buildings. Kuang et al. [11] have performed experimental and analytical studies on a direct expansion solar-assisted heat pump which was applied in Shanghai. In this study, the effects of various parameters under variable speed compressor have been investigated. A SAHP system which was able to supply low costs in domestic heating as well as space cooling during the summer was investigated by Moreno-Rodríguez et al. [12]. Since the solar collector serves as an evaporator while the refrigerant absorbs the solar energy, the energy discarded by the condenser is used for water heating, provided that solar collectors can provide energy at steady state condition for overall performance analysis [13]. The overall COP's of the system is affected considerably by the load demands and changes in climatic conditions especially for low-temperature water heating applications [14]. Li et al. [15] applied experimentally a methodology for design optimization of two direct expansion solar-assisted water heater systems. Mohamed [16] developed a new concept of ternary collectors used to enhance the DX-SAHP for air-space heating. The performance results showed that the system has a significant improvement compared to the conventional heat pump. The coefficient of performance of the (DX-SAHP) system would increase over that of the air-source heat pump system alone [17]. Even in the absence of solar insolation, air source heat pump can be utilised for space and water heating applications [18]. Recently a study for water and air space heating was conducted to evaluate the heating performance of a multi-functional DX-SAHP [19]. The experiment indicated that the system could provide a good alternative to existing DX-SAHP. The study also indicated that the formation of frost in an air source heat pump for the fan-driven condenser is inevitable. Thermal refractory performance investigation is performed on collectors using thermal camera. In spite of the aforementioned advantages of using heat pump for space heating and water heating, DX-SAHP option has not been popular. The applications of DX-SAHP were not widely used due to their performance limitations in cold regions [20]. Most of the previous studies focused on the developments under typical working conditions, in particular water heater system, while other systems that under low temperature heating conditions were given little attention [21].

This project aims to develop a new heat pump based on the utilisation of solar radiation and ambient air. This could be used to drastically cut the primary energy usage in domestic buildings. Low-grade energy from solar radiation is readily available, besides ambient air and indoor exhausted heat that can be upgraded appropriately. These sources could be used with the heat pump to improve its performance. The technology would be particularly useful to fulfil the gap of moderate cold regions requirements. The work so far demonstrates theoretically and experimentally that the new multi-source heat pump, using the solar energy as its initial energy source, ambient air and indoor wasted heat as its supplementary energy resources could work well with a very high performance.

2.2 SAHP System Introduction

Solar-thermal and air-source heat pumps have the potential of achieving efficiencies above 100% based on their primary energy consumption. Both technologies are well developed, and work well, but have limitations particularly in very cold regions. The low ambient temperatures make the heat pump units less efficient and therefore less attractive than conventional cheaper water heating systems. To alleviate some of these deficiencies, researchers have proposed a variety of hybrid systems that incorporate various technologies to improve overall efficiency and seasonal performance. Of these, solar boosted heat pumps have generated significant interest. The potential and mutual benefits of combining solar and heat pump systems were identified over six decades ago and various system configurations have been tried since that time. To date, only a few systems have been commercialised due to their apparent complexity and high cost relative to conventional energy technologies. There is, however, renewed interest in developing solar-boosted heat pumps for domestic hot water; primarily driven by the need to reduce conventional energy consumption, greenhouse gas emissions and to control electric utility peak demands. Solar assisted heat pump is applied to supply space heating and generation of domestic hot water, which is combined by a compact core box and solar thermal dynamic panels. The compact core box contains compressor, condenser, and thermal expansion valves, connecting with the solar thermal dynamic panels, which serve as the evaporator. The refrigerant of the SAHP system is R134a, which will flow through the solar thermal dynamic panels, and evaporates in any weather, including sunny, cloudy, rainy and even at night. As tested in the laboratory, solar irradiation, wind condition, and outdoor temperature will have impact on the COP of the system. The experiments are carried out at the University of Nottingham, with the dynamic panels installed vertically. The SAHP system is connected to a hot water storage tank to provide both hot water and space heating for the occupants. Two installation samples of the solar thermodynamic panels are shown in Figure 4, one on the roof top of the building, and another on the façade surface.

(a) Installation on the building facade (b) Installation on the building roof top

Fig. 4. Two installation types of thermal dynamic panels

2.3 Holistic SAHP Concept

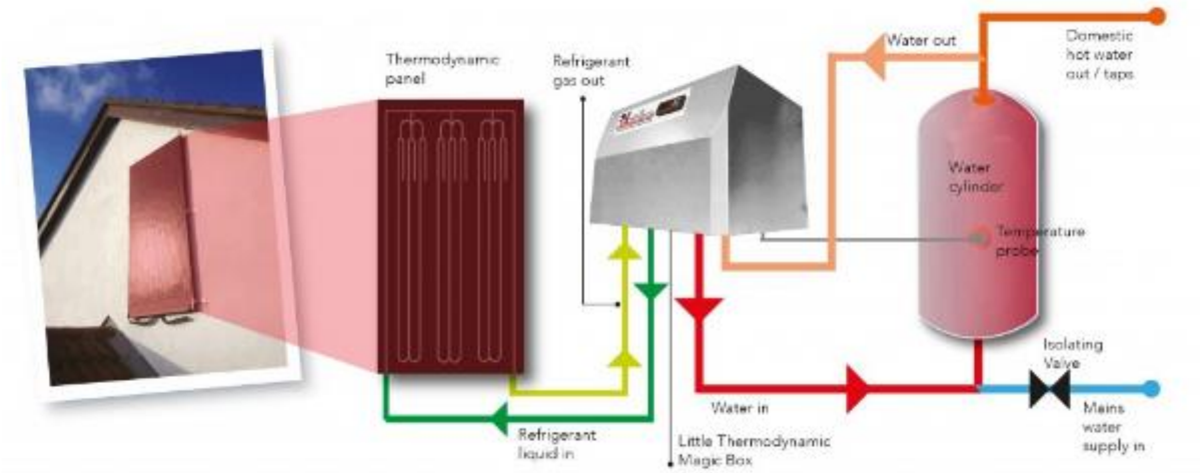

Fig. 5. Schematic diagram of SAHP system

The solar assisted heat pumps integrate two commercial technologies, the heat pump and solar thermal collector. The heat pump is quite economical technology, with the heat produced from the renewable element, which varies solely in keeping with oscillations by the ambient temperature. The solar thermal collectors are another commercial technology to supply domestic hot water, which is limited to work efficiently only in hot and sunny days. Therefore, to eliminate the impact of the ambient temperature oscillations in the heat pump working process, the traditional evaporator heat exchanger is replaced by the solar thermal panels with refrigerants filled in. In the new concept of the solar assisted heat pump, the extracted heat in the evaporator side changes from air source to the integrations of solar source and the external air source, which achieves stable heat transfer process. Besides, the new configuration of the solar thermal panels, as well as the refrigerants charging replacement, can significantly enhance the heat transfer capacity and reduce the working temperature. Thus, a consistent thermal physical diagram is formed by integrating the solar thermal system with forced circulation and sharing with elements of heat pump, managed to surpass the restrictions of the referred two separate technologies. Through the cooling refrigerants (R134a) that covers a loop, the liquid goes into the solar thermal panel and suffers the action of sun, rain, wind, atmosphere temperature and different climate factors. The solar assisted heat pump can supply the domestic hot water (DHW) and the space heating with integration of the underfloor radiant heating. Additionally, the refrigerant R134a has a boiling temperature of roughly -35℃, which will still work 24 hours each day, even at low external temperatures, cloudy/rainy days and night-time. It is considered that the SAHP fit well with the goal of SUREFIT project. More details on the concept of the SAHP system are presented in the next section.

2.4 System Configuration

A multi-mode functional SAHP system for domestic applications is shown in Figure 6. It mainly consists of a ternary unique coated aluminium flat-plates, a variable speed hermetic compressor, centrifugal fan-coil units (air-cooled condenser), a water-to-refrigerant heat exchanger, a water circulating pump and piping, a domestic hot water tank (DHWT) with an immersed condensing coil loop (water-cooled condense), thermostatic expansion valve electronic control and electrical valves. Supplementary components are added to facilitate cycle running such as centrifugal fan, expansion vessel, water circulating pump, and solenoid valve.

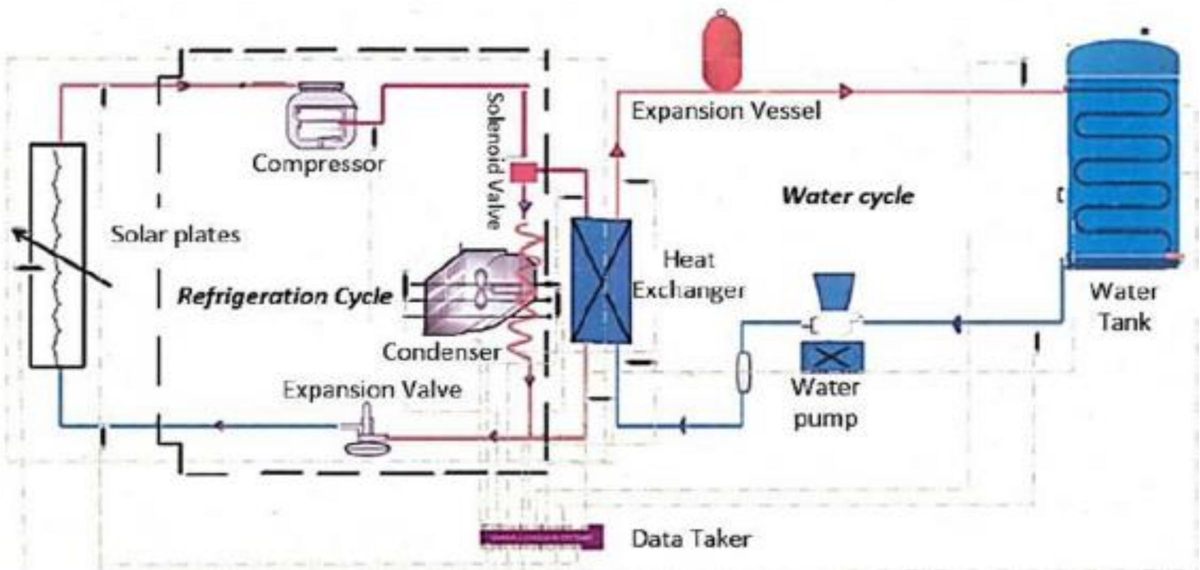

Fig. 6. Details of Schematic developed DX-SAHP diagram

The jacket containing the pure water is used to store and release the heat produced from the condenser of the SAHP system. The jacket is based on the single tank (HWT) configuration, which is shown in Figure 7. Figure 8 illustrates how the existing SAHP retains its immersion heater for energy input connected to the hot water supply which is based on a heat pump coupled to ternary evaporator panels located in the loft space and exterior roof, in addition to auxiliary components such as air heater, blower fan and humidifier. It is worth mentioning that in real application moisture laden air can be extracted and recycled from the interior of the house such as showering or cooking areas. The new system incorporates into a household using the existing hot water tank and hot water central heating pipe system, providing additional heat directly through the radiators valves to control the temperature to suit preferred comfort levels. This offers a distinct advantage for retrofitting with minimal disruption during installation.

Fig. 7. Hot water storage tank

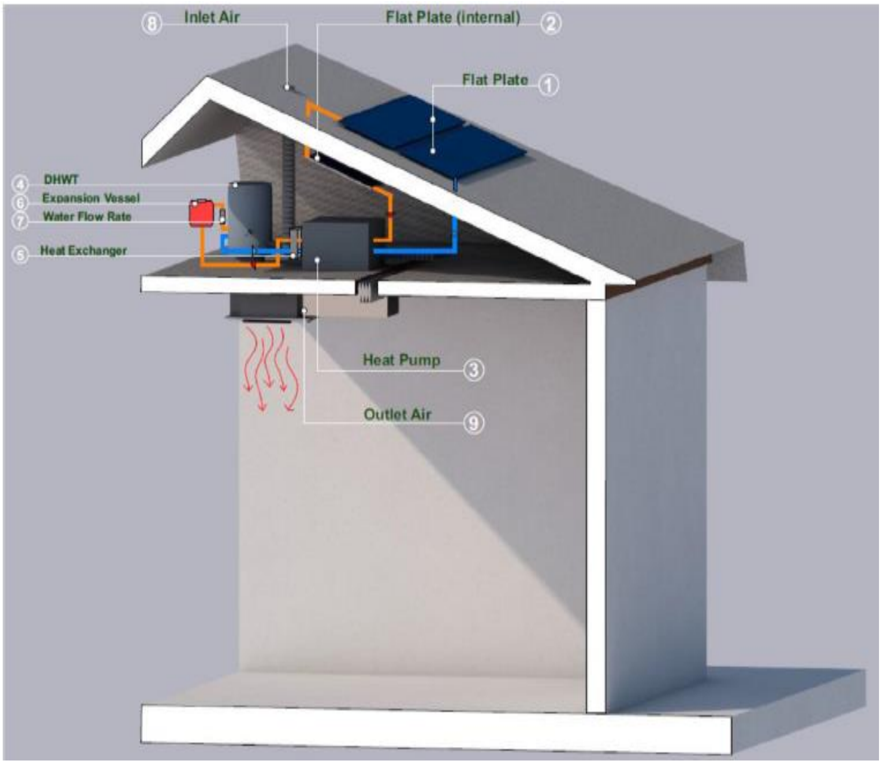

Fig. 8. The system configurations on building's roof

The variation of the compressor's speed was obtained via variable frequency drive, to avert the compatibility between its variable loads and in order to reach the steady capacity of the compressor (Figures 9, 1). A refrigerant receiver (Figures 9, 2), and the accumulator are imbedded in the system to facilitate in controlling the refrigerant distribution, while the external pressure equalizer with thermal expansion valve to control the degree of superheat at the compressor inlet by controlling the pressure. It also liquidises the refrigerant's flow to evaporators (Figures 9, 3). The heat pump has two heat rejection modes, one of which is through a heat exchanger made of copper tube and aluminium fins (Figures 9, 4), whereby centrifugal fan can deplete energy to contribute to space heating load. The other is through a copper tube as coil closed loop immersed in a cylinder of 200 L, a fully insulated (DHWT) (Figures 9, 7), and water-to-refrigerant plate heat exchanger (Figures 9, 5). The water-to-refrigerant plate heat exchanger is linked to the DHWT through circulating piping pump, expansion vessel (Figures 9, 6-8) and water flow rate controller (Figures 9, 9) in order to maintain the hot water demand. The heat rejected by the condenser (copper tube and aluminium fins plate) is used for the purpose of exchanging the heat between the refrigerant and inlet air to contribute to space heating.

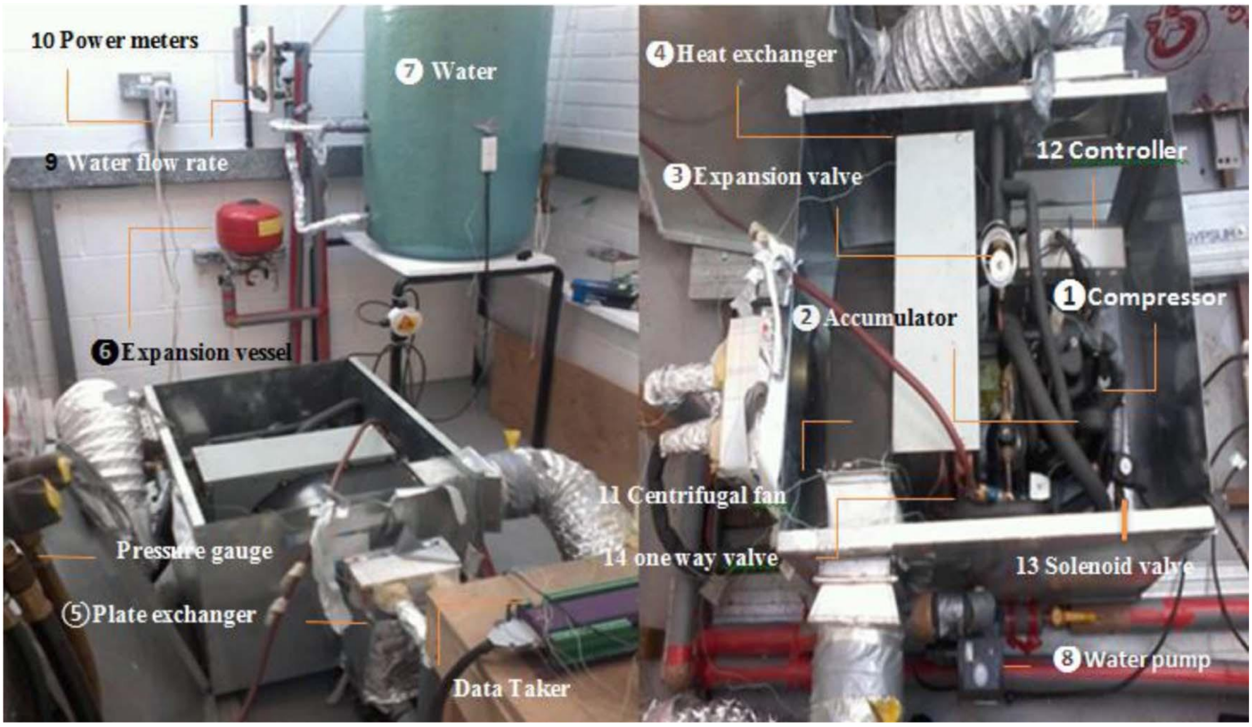

Fig. 9. SAHP system components

In general, the multi-mode-functional SAHP system can offer three fundamental operating modes; Space heating-only-mode, water heating-only-mode and combined hot water and space heating mode. In present experiment, the switching between those modes is by means of valve position and on–off controls. There is a two-way solenoid valve (Figures 9, 13), one-way non-reversing valve on the refrigerant pipes at the locations shown in Figures 9, 14. A controller box is employed to determine and govern the operations and running modes of the system, which is supplied with digital cabinet output to organise the compressor's frequency (Figures 9, 12).

To simulate solar insolation under laboratory conditions, an artificial portable light source combining metal-halide and thirty tungsten halogen floodlights source is assembled in Figure 10. The main purpose of the solar simulator is to deliver a controllable indoor sun light for the heat pump system. This solar simulator with a regulator switch is able to adjust solar spectrum wavelengths ranging between 360 and 2500 nm and solar irradiance in the range 0 to 800 W/m2 covering an area of 3.2m2 as shown in Figure 11. The switch acts as a regulator in order to maintain solar irradiance variations evenly. The collector is placed indoors up-right in the lab, 200 cm distance in the front of the solar simulator to achieve the required operational conditions. In this case unevenness values at most points obtained is found less than 9%, which is in a good agreement with the British Standards values for indoor solar simulator. The working sample of thermodynamic panels is shown in Figure 12.

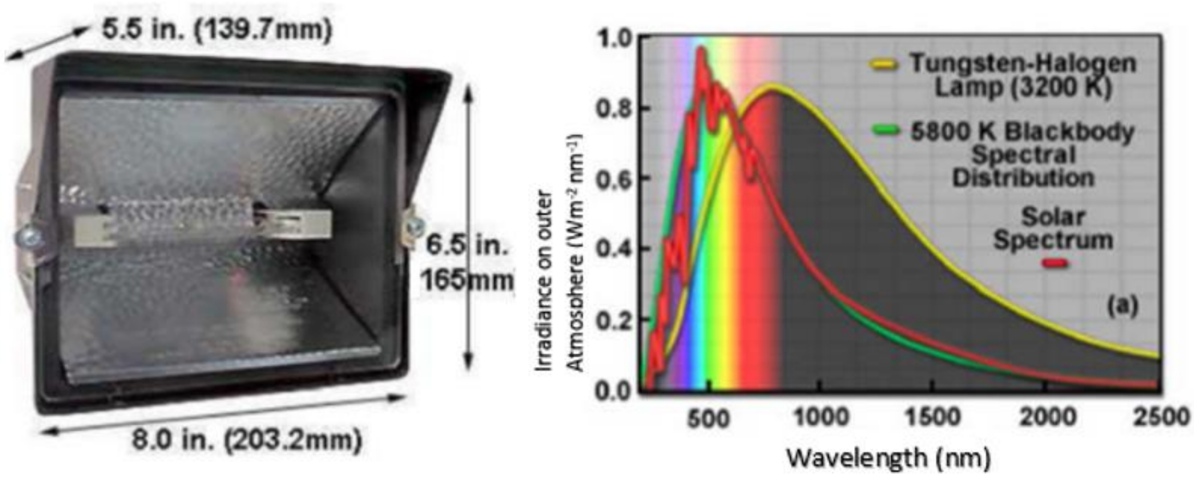

Fig. 10. Solar insolation simulator and light regulator

Fig. 11. Solar insolation simulator and light regulator

Fig. 12. Working sample of the thermodynamic panels

3 Design and development of DX SAHP system

3.1 Configurations

Thermodynamic water heater transfers heat from the ambient to water, providing high-temperature hot water up to 60°C. With innovative and advanced technology, the direct-heating heat pump can operate very well at -7°C ambient temperature with high output temperatures up to 60°C. Compared with traditional oil/LPG boilers, a high-temperature heat pump produces up to 50% less CO_2 whilst saving 80% in running costs. General features of this technology includes:

1. Low running costs and high efficiency

   ·A high coefficient of performance (COP) of up to 5 results in lower running costs compared with traditional STWH technology.

   ·Immersion heater supplement is required in the hot water cylinder.

2. Reduced Capital Costs ： Simple installation

3. High Comfort Levels

   ·High storage temperature results in increased hot water availability.

4. No potential danger of any inflammable, gas poisoning, explosion, fire, electrical shock which are associated with other heating systems.

5. A digital controller is incorporated to maintain the desired water temperature with friendly user interface and blue LED back light.

6. Long-life and corrosion resistant composite cabinet stands up to severe climates.

7. High-efficient compressor ensures outstanding performance, ultra energy efficiency, durability and quiet operation.

8. Self-diagnostic control panel monitors and troubleshoots heat pump operations to ensure safe and reliable operation.

9. Separate isolated electrical compartment prevents internal corrosion and extends heat pump life.

Table 1 Design and specifications

Model		AR60-C	AR80-C	AR120-C
Heating capacity	W	1800	2800	5000
Heating capacity min/max	W	900/2250	1400/3500	2500/6250
Suggested water tank capacity	L	60-150	150-260	200-320
Heated Water output (20～50℃)	L/h	52	80	143
Rated outlet water temp.	℃	55		
Max outlet water temp	℃	60		
Rated power input	W	450	700	1250
Rated current input	A	2.15	3.35	5.98
Power supply	V/Hz/Ph	220-240V/50Hz/1Ph		
Compressor type	/	Rotary		
Heat exchanger type	/	High efficiency tube in shell heat exchanger		
Throttling device	/	Emerson thermal expansion valve		
Number of Panel	/	1	2	3
Liquid Line	POL	Φ9.52	Φ9.52	Φ9.52
Suction Line	POL	Φ12.7	Φ12.7	Φ12.7
Refrigerant	/	R134a		
Noise	dB(A)	43	43	43
Water pipe connection size	inch	Rc3/4	Rc3/4	Rc3/4
Cabinet	/	stainless steel/Galvanized powder coated steel		
Product Net weight	Kg	27	35	40
Product dimensions	mm	310*365*565	310*365*565	310*365*565

Note:

The above design and specifications are subject to change without prior notice for product improvement. Detailed specifications of the units please refer to name plate on the units.

Correct installation is required to ensure safe operation. The installation requirements for heat pumps include the following:

1. Dimensions for critical connections.

2. Field assembly (if required).

3. Appropriate site location and clearances.

4. Proper electrical wiring.

3.2 Installation

The following general information describes how to install the DX SAHP system.

Materials needed for Installation

The following items are needed and are to be supplied by the installer for all SAHP thermodynamic water heater installations:

1. Plumbing fittings.

2. Level surface for proper drainage.

3. Ensure that a suitable electrical supply line is provided. See the rating plate on the heat pump for electrical specifications. Please take a note of the specified current rating. No junction box is needed at the heat pump; Connections are made inside of the heat pump electrical compartment. Conduit may be attached directly to the heat pump jacket.

4. It is advised to use PVC conduit for the electrical supply line.

5. Use a booster pump for pumping water in case of low water pressure.

6. A filter on the water inlet is needed.

7. The plumbing should be insulated to reduce its heat loss.

Note: We recommend installing shut-off valves on the inlet and outlet water connections for ease of serviceability.

Installation details

All criteria given in the following sections reflect minimum clearances. However, each installation must also be evaluated, taking into account the prevailing local conditions such as proximity and height of walls, and proximity to public access areas. The heat pump must be placed to provide clearances on all sides for maintenance and inspection.

1. The installation area must have good drainage and be built on a solid foundation.

2. Do not install the unit in areas accumulated with pollutions like aggressive gas (chlorine or

acidic), dust, sand and leaves etc.

3. For easier and better maintenance and troubleshooting, no obstacles around the unit should be closer than 500mm.

4. The heat pump must be installed with shockproof bushes to prevent vibration and/or imbalance.

5. Even though the controller is waterproof, care should be taken to avoid direct sunlight and high temperature.

6. The plumbing pipes must be installed with proper support to prevent possible damage due to vibration.

7. The acceptable operating voltage range should be within ±10% of the rated voltage.

8. The heat pump unit must be grounded /earthed for safety purposes.

Power supply

1. If the supply voltage is too low or too high, it can cause damage and/or result in unstable operation of the heat pump unit, due to high in rush currents on start up.

2. The minimum starting voltage should be above 90% of rated voltage. The acceptable operating voltage range should be within ±10% of the rated voltage.

3. Ensure the cable specifications meet the correct requirements for the specific installation. The distance between the installation site and mains power supply will affect the cable thickness. Follow the local electrical standards to select the cables, circuit breakers and isolator breakers.

Grounding and Over Current Protection

In order to prevent electrical shock in case of leakage from unit, install the heat pump according to local electrical standard (Figure 13).

1. Do not interrupt the voltage supply to the heat pump frequently as this may result a shorter life expectance of the heat pump.

2. When installing over current protection, ensure that the correct current rating is met for this specific installation.

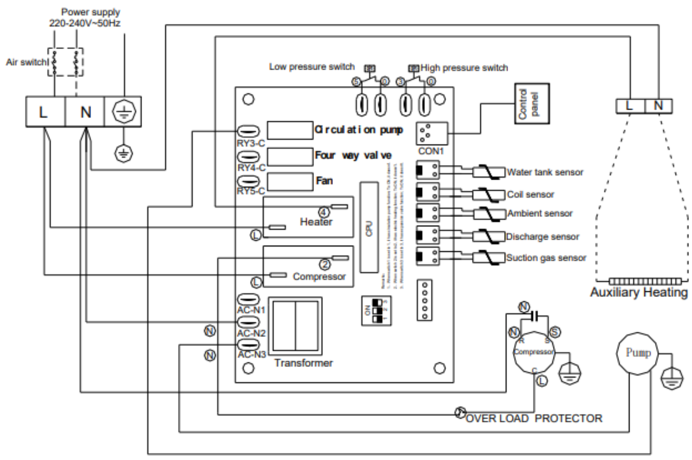

Fig. 13. Electrical Wiring Diagram AR60-C, AR80-C, AR120-C

4 Concept of TP GSHP

4.1 Background

This section is intended to investigate the influence of the Soil Thermal Conductivity Enhancement Using Different Types of Soil and Varied Moisture Content. The results of this will help demonstrate the impact of the Efficient Geotech system when installed in different regions of the UK. A CFD and numerical analysis will be carried out to simulate the short- and long-term performance of GSHP respectively over one years and 20 years. Future weather data will be adopted in order to simulate the future heating and cooling demands of the selected building under two different buildings' insulation standards (UK Building regulation, and Passive house (German: Passivhaus)).

The specifics objectives:

To model the Thermal Pipe Ground heat exchanger (GHEX) (Figure 14) using three conductive materials: copper, steel or aluminum with working fluids water/glycol, CO_2 or environmental friendly HFOs without the additional nano/micro-conductive materials and electro-osmotic flow (EOF) in the soil.

To model selected nano/micro-conductive materials around the GHEX.

To model several candidates of nano/micro-conductive materials diffusion into the soil.

To model electro-osmotic flow (EOF) in the soil with and without the additional nano/micro-conductive materials.

To determine the number of thermal pipes for the two different buildings' insulation standards (UK Building regulation, and Passive house (German: Passivhaus)) under climatic conditions of Nottingham (Ranskill Garden's Site).

To develop a modelling and optimization method for the Efficient GeoTech system.

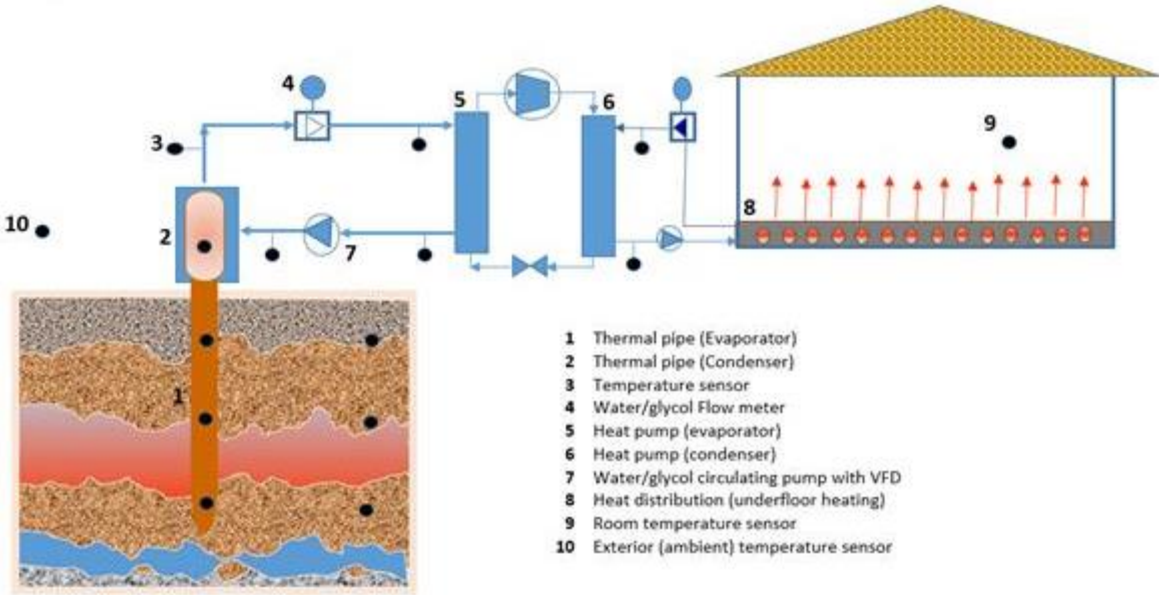

Fig. 14. Thermal Pipe (Ground Source Heat Exchanger (GHE)) with heat pump system, and underfloor heat distribution system

4.2 Components of the novel GSHP System

Assumptions taken into consideration for the derivation of the theoretical model:

1. A one-dimensional flow model.
2. The "thermal pipe" is considered as a gravity-assisted thermosiphon in the vertical orientation, i.e. zero tilt angles.
3. Isoflux heating, uniform radial heat flux of heat and cooling processes in the evaporator and condenser.
4. The mass of vapour is very small; therefore the working fluid is taken at the saturated liquid conditions.
5. Constant wall material (copper, steel) properties, such as density, specific heat and thermal conductivity.
6. The kinetic and potential energy components are neglected in the energy balance equations when compared with heat transfer rate.
7. The density, thermal conductivity, enthalpy and other properties of saturated liquid are temperature dependent.
8. There is no heat lost axially from the two ends of the thermal pipe "thermosiphon" to the environment.

9. The local evaporation heat transfer coefficient of the evaporator and the average heat transfer coefficient of the condenser are calculated at mean value for both.

10. The fluid thermal capacity may be approximated to the liquid heat capacity.

11. The thermosiphon starts up from initial condition when heat pump is suddenly on.

12. The thermosiphon shuts down from steady-state condition when heat pump is suddenly off.

13. Since there is a fixed volume liquid water (constant volume), it takes less heat to produce a given temperature change at constant volume for reaching the saturation temperature, any heat added causes the saturated fluid.

5 Design and development of TP GSHP

5.1 Configurations

Case 1: Thermal Pipe Ground heat exchanger (GHEX) standard soil

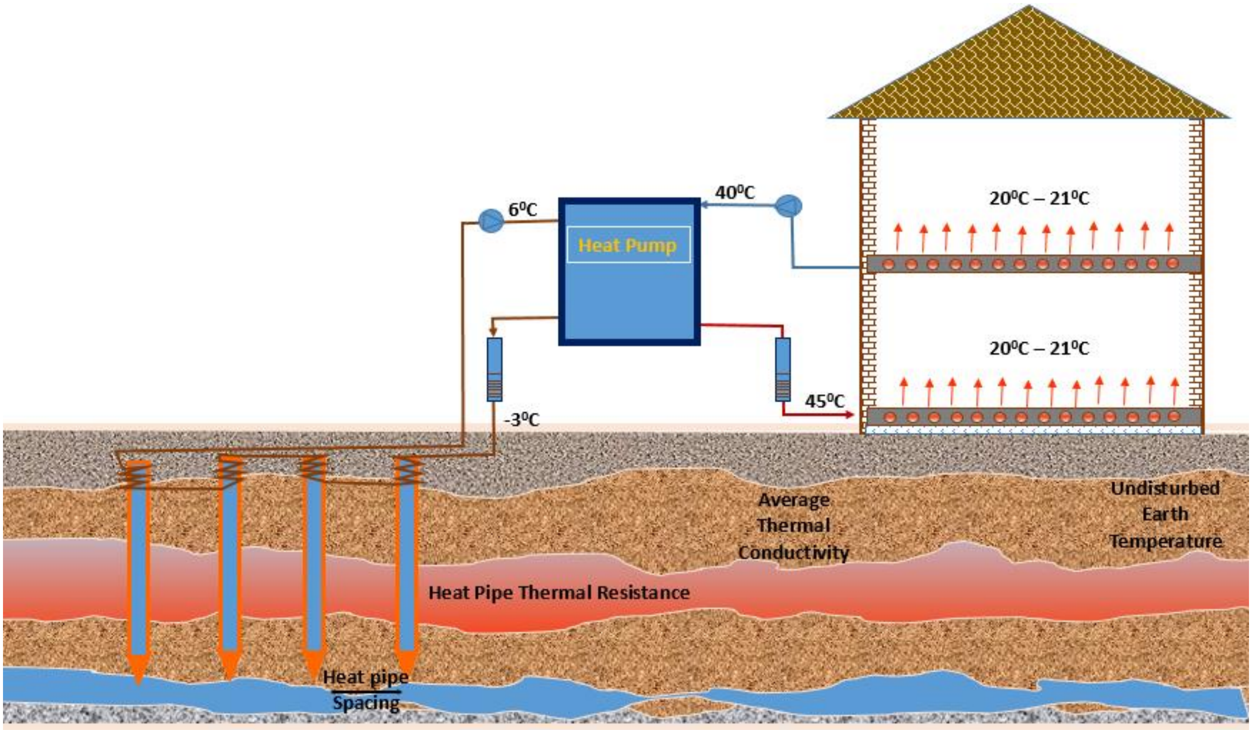

Fig. 15. Thermal Pipe Ground heat exchanger (GHEX) standard soil

Table 2 Soil type, moisture factor and description of case 1

Case 1	Soil Type	Moisture Factor (MF)	Description
a	Clay	1	Dry clay soil, completely dry with no enhancement component
	Mid - Moist Clay	1.1	Wet clay soil, with 4.3g water content with no enhancement component
	High – Moist Clay	1.3	Wet clay soil, with 166.7g water content with no enhancement component
b	Loam	1	Dry Loam Soil, completely dry with no enhancement component

	Mid - Moist Loam	1.1	Wet Loam soil, with 59.3g water content with no enhancement component
	High – Moist Loam	1.25	Wet Loam soil, with 133.6g water content with no enhancement component
c	Sandy	1	Dry Sandy Soil, completely dry with no enhancement component
	Mid - Moist Sandy	1.1	Wet Sandy soil, with 38.6g water content with no enhancement component
	High – Moist Sandy	1.3	Wet Sandy soil, with 115.7g water content with no enhancement component

Case 2: Thermal Pipe Ground heat exchanger (GHEX) with nano/micro in the soil.

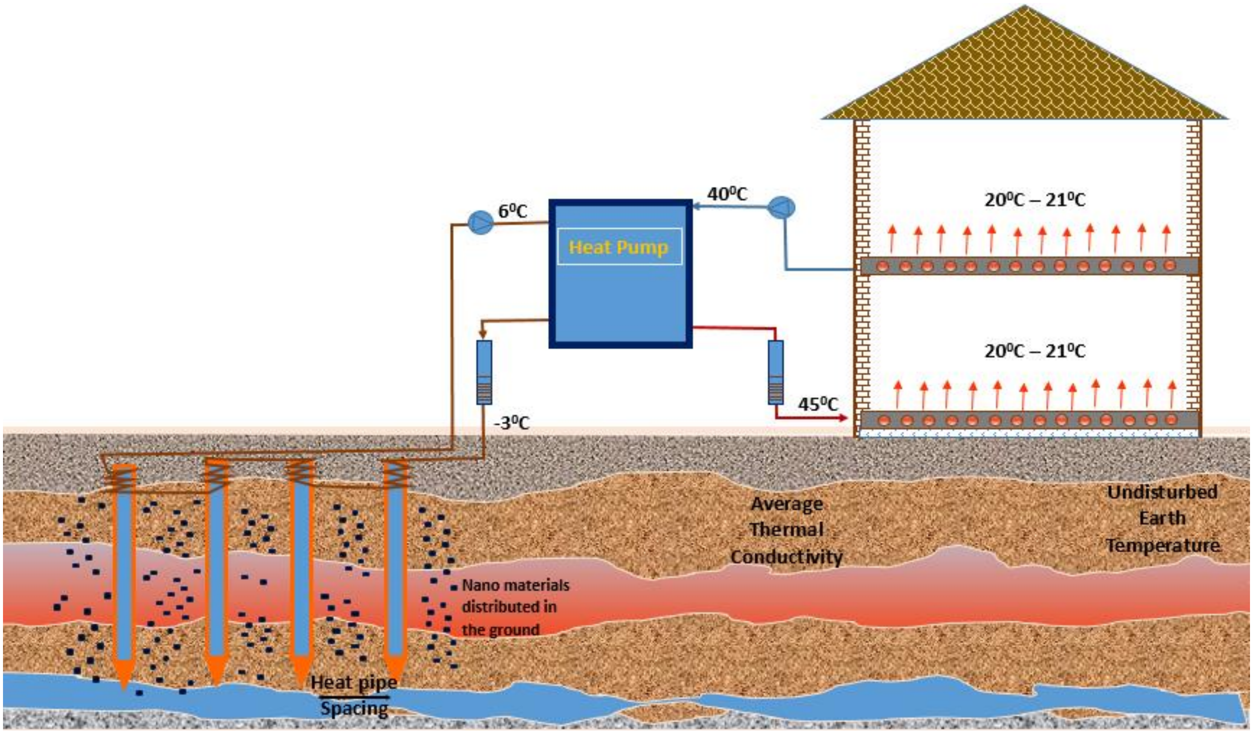

Fig. 16. Thermal Pipe Ground heat exchanger (GHEX) with nano/micro in the soil

Table 3 Soil type, moisture factor and description of case 2

Case 2	Soil Type	Moisture Factor (MF)	Description
a	Mix Clay and graphite	1.2	Wet clay soil, with 97.3g water with 14.6g of graphite

b	Mix Loam and graphite	1.2	Wet Loam soil, with 133.6g water + 20.4g of graphite
c	Mix Sandy and graphite	1.2	Wet Sandy soil, with 86.6g water + 13.4g of graphite

Case 3: Thermal Pipe Ground heat exchanger (GHEX) with nano/micro in the soil and electro-osmotic flow (EOF).

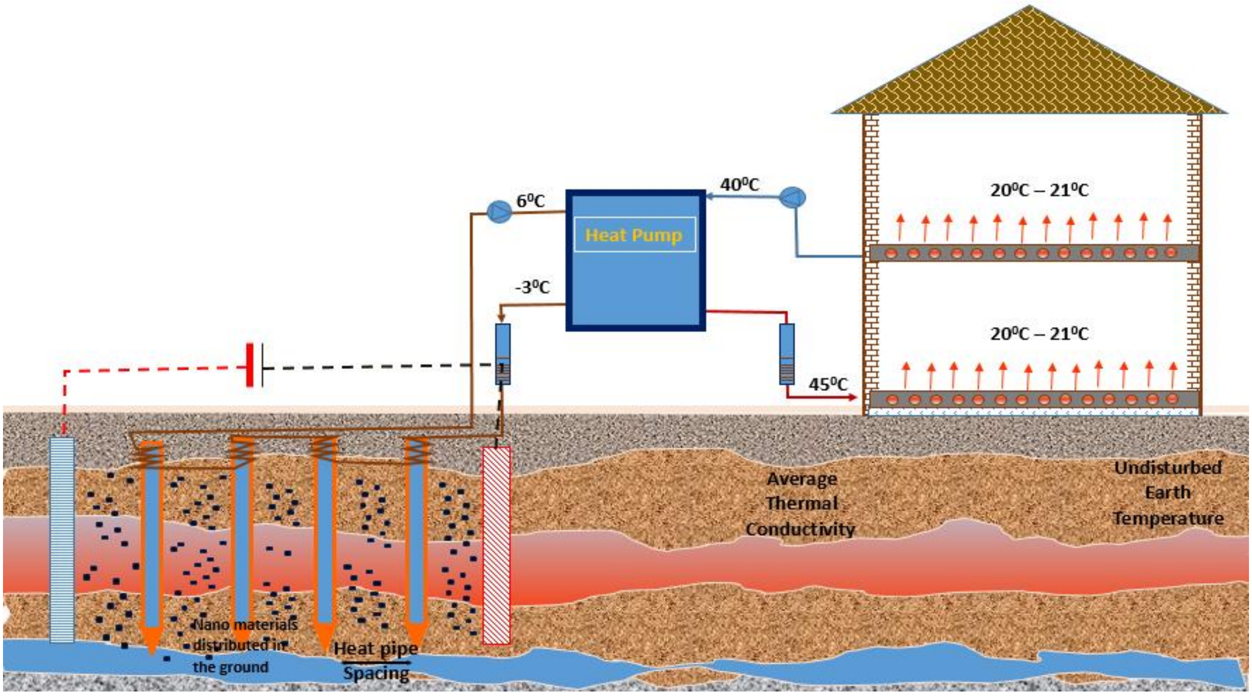

Fig. 17. Thermal Pipe Ground heat exchanger (GHEX) with nano/micro in the soil and electro-osmotic flow (EOF).

Table 4 Soil type, moisture factor and description of case 3

Case 3	Soil Type	Moisture Factor (MF)	Description
a	Mix Clay and graphite	1.2	Wet clay soil, with 97.3g water with 14.6g of graphite
b	Mix Loam and graphite	1.2	Wet Loam soil, with 133.6g water + 20.4g of graphite
c	Mix Sandy and graphite	1.2	Wet Sandy soil, with 86.6g water + 13.4g of graphite

5.1.1 Methodology

The purpose of these experiments is to determine the impact of introducing graphite particles into different types of soils. The thermal conductivity is an intensive property, meaning that it is independent of system size.

A KD2 Pro Thermal Properties Analyzer was used to measure the thermal conductivity of samples. Samples of the three main types of soil were obtained including: Loam, Sandy & Clay. These samples were dried in an oven for over 12 hours at 115°C to ensure that all traces of water were removed. These samples were then weighed and prepared.

The wet weight of the soil was determined by the following equation:

$$Wet\ weight\ (g) = Dry\ weight\ (g) \times \left(\frac{1}{(1 - Moisture\ Factor)}\right)$$

The added water for a given test was evenly mixed into the soil to obtain the test sample. This was then transferred into a container and compressed with a 500g weight to ensure that soil compression does not influence results. The probe was then inserted into the sample. Three measurements of thermal conductivity were taken, with the TR-1 sensor which was designed for use with soil.
For the tests with the graphite enhancement, 3wt% of graphite was introduced to the moistened soil before taking measurements.
Osmosis damp proofing uses a series of anodes placed at the base of the wall and a cathode rod buried at a lower level in the ground (Figure 18). This electric damp proof course imparts a small electrical charge into the masonry and this positive charge repels free moisture molecules from the anodes where they are attracted to the negative cathodic earth rod.

Fig. 18. Electro-Osmosis Damp Proof Monitor

Fig. 19. graphite particular

Graphite (Figure 19) has the same chemical composition as Diamond, which is also pure carbon, but the molecular structure of Graphite and Diamond is entirely different. The test equipment is shown in Figure 20.

Fig. 20. DT85 data logger , K-thermocouples , Flow meter , Hand help thermometer, and Air flowmeter.

Table 5 and Figure 21 shows the lithological description of the site, and was taken from the Geological report.

Table 5 Local geology of the ground at the trial side

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WS4

Project No. 37034

Sheet 1 of 1

Samples and Tests				Description of Strata	Legend	Depth & (Thickness) (m)	Casing (m)	Ground-water	Installation
Depth (m)	Type	Sample Ref	SPT "N" Value						
0.20	D	D1		Grass over brown silty sandy topsoil with occasional flint (MADE GROUND)		(0.35) 0.35			
0.45	D	D2		Loose to medium dense dark brown sandy gravel with inclusions of slag and concrete (MADE GROUND)		0.60			
0.80	D	D3		Medium dense becoming dense orange-brown slightly silty gravelly SAND. Gravel is fine to coarse sub-angular to sub-rounded quartzite (NOTTINGHAM CASTLE SANDSTONE FORMATION)					
1.00 - 1.45	C		12			(0.80) 1.40			
1.90	B	B1		Dense yellow-brown silty SAND (NOTTINGHAM CASTLE SANDSTONE FORMATION)		(0.60) 2.00			
2.00 - 2.45	C		50/30mm	End of Borehole at 2.00m					

Description of Strata	Legend	Depth & (Thickness) (m)	Casing (m)	Ground-water	Installation
Grass over brown slightly silty slightly gravelly sandy topsoil with inclusions of flint and brick (MADE GROUND)		(0.40) 0.40			
Loose to medium dense pale yellow-brown slightly clayey gravelly sand with inclusions of flint, brick and coal (MADE GROUND)		(0.60) 1.00			
Dark brown silty slightly gravelly sandy TOPSOIL with occasional fragments of brick and black carbonaceous inclusions (BURIED TOPSOIL)		(1.00) 2.00			
Medium dense becoming dense orange-brown slightly silty slightly gravelly SAND (NOTTINGHAM CASTLE SANDSTONE FORMATION)		(1.00) 3.00			
End of Borehole at 3.00m					

Fig. 21. Lithological characterization of the site

For a given soil type the thermal conductivity (Table 6) is relatively constant above a specific moisture content index, referred to as the *Critical Moisture Content* (CMC). Below the CMC the thermal conductivity drops significantly. During summer, when recharging the soil, in this process the heat is injected in the ground through thermal piles to the surrounding ground. And this will drive away the moisture from the soil near the piles. In a situation when the soil is at or near its CMC, the reduction in the moisture could significantly reduce the soil's thermal conductivity. A soil of such characteristic is thermally unstable and can significantly degrade the ground heat exchanger performance.

In most region of Europe including of the UK, the seasonal ground temperatures remain relatively constant beyond a depth of 10m. Values between 6ºC and 12ºC predominate to a depth of about 15m, and then 12ºC-15ºC predominates to a depth of about 50m. Such temperatures represent ideal conditions to permit economical space and water heating by using energy piles structures and heat pumps. Substantial temperature fluctuations in summer and winter during the year would reduce the efficiency of heat pump systems. The soil battery know as thermal energy storage using energy piles in the residential sectors is an existing technology but not yet proven in the UK, one of the drawback could be because of the extremely variable characteristics of the UK ground that is use to balance winter cold and summer heat gain by storing heat. One of the purposes of the further work from this project could be to investigate the capability of UK soil to store heat.

Table 5 Geology and results for thermal response tests carried out

Geology	Thermal conductivity, λ_{eff} (W/m K)	Resistance, Rb (K/(W/m))
Silt and clay (Quarternary/Tertiary)	1.6	–
Mesozoic sediments	2.7–2.8	0.10–0.18
Marl ("Emschermergel", Cretaceous)	1.5–2.0	0.11–0.12
Sand/silt, marl (Cretaceous)	2.3	0.08[a]
Sand and clay (Quarternary/Tertiary)	2.8	0.11
Sand and clay (Quarternary/Tertiary)	2.2–2.3	0.07–0.08[a]
Marl, clayey	2.5	0.12
Marl, sandstone, limestone (Mesozoic)	4.0	0.08[a]
Silt, sandy (Quarternary/Tertiary)	3.4	0.06[a]

[a] Filled with thermally enhanced grout ("Stüwatherm").

Figure 22 Different soil types and moisture factors

5.1.2 Heating Distribution Systems the house - the outputs

For maximum performance of ground source heat pump, underfloor heating is ideal. The different heating temperature of heat distribution unit is shown in Table 7. The underfloor heating system performs better than radiators because the heat is transferred equally across the whole surface, whereas radiators need to spread the heat from one corner to the entire room.

Table 6 Heating temperature of different heat distribution unit

Indoor heat distribution system	Heat carrier temperature ^{0}C
Underfloor heating/radiant floor heating system	30-45
Low temperature radiator	45-55
Conventional radiators	60-90
Air system	30-45

However, due to the higher cost of underfloor heating, radiators are also a good choice that results in high performance. The heat transfer area of a floor-heating system is larger than in the case of radiators, so a lower temperature can meet the heating demand. The SCOP is higher for underfloor heating compared to radiators because heat distribution is well designed with underfloor heating and therefore the floor system will likely have a lower output temperature than a radiator, meaning a higher coefficient of performance.

5.1.3 Mathematical Models

The vertical temperature distribution of the ground can be modelled based on the method developed by Kasuda who found that the temperature of the ground is a function of the time of year and the depth below the surface that can be described by the following correlation:

$$T_{soil(D,tyear)} = T_{mean} - T_{amp} * \exp\left(-D\sqrt{\frac{\pi}{365*\alpha}}\right) * \cos\left(\frac{2\pi}{365}\left(t_{year} - t_{shift} - \frac{D}{2}\sqrt{\frac{365}{\pi*\alpha}}\right)\right) \ldots(1)$$

where:

$T_{soil(D,tyear)}$	= Soil Temperature at depth D and Time of year
T_{mean}	= Mean surface temperature (average air temperature). The temperature of the ground at an infinite depth will be this temperature
T_{amp}	= Amplitude of surface temperature [(maximum air temperature - minimum air temperature)/2]
D	= Depth below the surface (surface=0)
α	= Thermal diffusivity of the ground (soil)
t_{year}	= current time (day)
t_{shift}	= day of the year of the minimum surface temperature

Figure 21 shows the averaged results for each moisture factor. There is a clear and obvious trend that increased moisture factors lead to increased thermal conductivity. This would suggest that if electroosmotic flow can be implemented in the Efficient Geotech solution, there are significant heat transfer benefits which could be obtained. The cross marks show the thermal conductivity of the enhanced soils. It suggests that clay soils have the most to gain from being enhanced, with a thermal conductivity improvement of +0.88 W/mK (+93%). There were improvements in all types of soils tested.

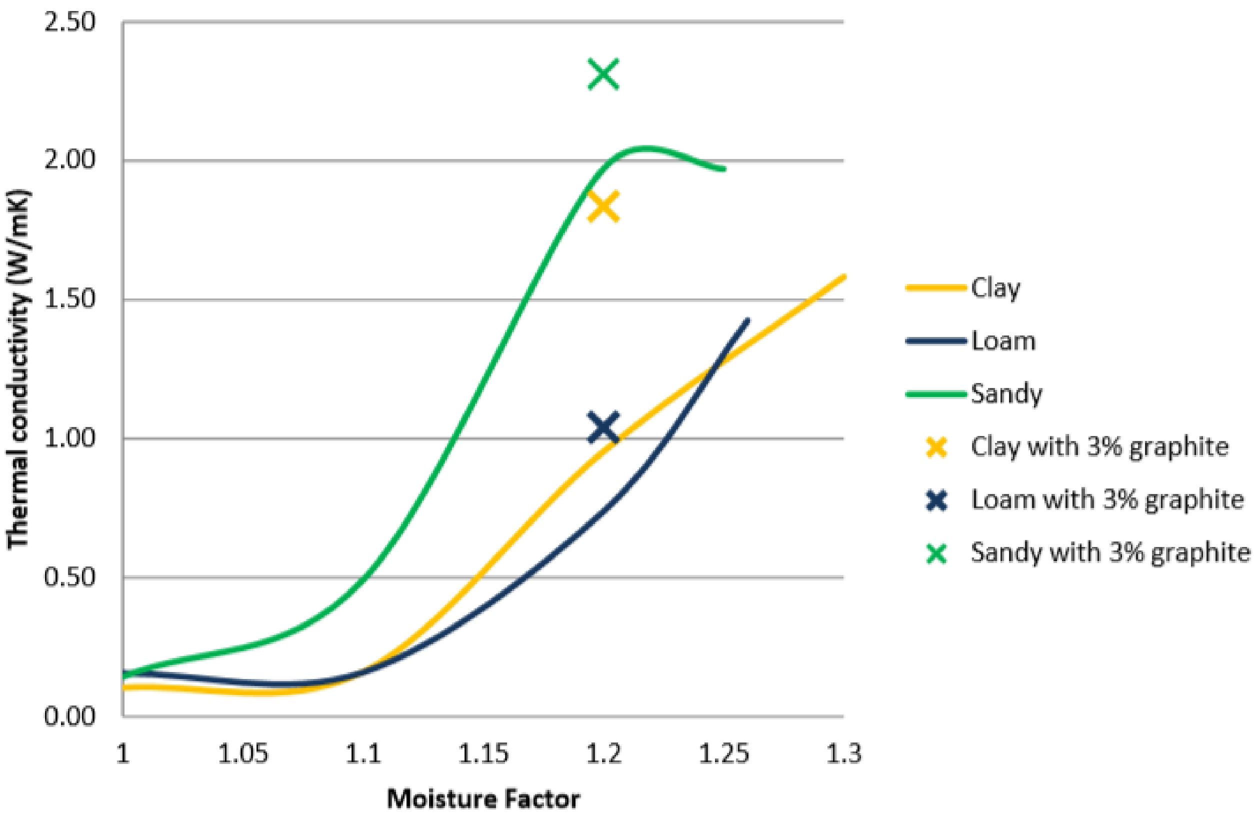

Fig. 23. Averaged results for each moisture factor

5.2 Experimental Specifications

Table 8 Specifications of nominal thermal heat capacity of SAHP

Nominal thermal kW rating	3.0	6.0
Performance data - rated heating output at B0/W35 BS EN14511		
Power consumption	0.8kW	1.6kW
Co-efficient of Performance*	4.05	3.84

Brine (primary) based on 0°C in / -4°C out		
Design flow rate kg/min	9.2	18.4
Pressure drop kPa at design flow rate	5	16
Max inlet temperature °C	25	
Min temperature °C (outlet)	-5 (at standard settings)	
Heating water (secondary) based on 30°C in / 35°C out		
Design flow rate l/min	8.62	16.88
Pressure drop kPa at design flow rate	1.0	0.64
Max flow temperature °C	65 (RHI applications 64C)	65 (RHI applications 60C)
Electrical values at B0/W35		
Rated voltage	220-240 v / 50-60 Hz	
Power supply rating amps	13	25
Rated current (max) amps	7	14
Typical running current at B0/W35 amps	4	8
Starting current amps	30	34

Refrigerant circuit		
Process medium	R134a	
Fill volume kg	0.7	1.6
Compressor type	Reciprocal	
Dimensions		
H X W X L (mm)	515 (H) X 480 (W) X 360 (D)	585 (H) X 610 (W) X 595 (D)
Dry weight kg	60	100
Operating pressure		
Brine circuit min (primary) bar g	0.3	
Heating water circuit min (secondary) bar g	0.6	
Low pressure reset bar g	1.8	
Connection sizes		
Primary IN and OUT	Valves and anti-vibration leading to 22mm	
Heating flow and return	Valves and anti-vibration leading to 22mm	
Performance (based on Average Climate) at 35°C		

ErP rating	A+	A+
SCOP**	3.68	3.45
Seasonal space heating energy efficiency	139%	130%
Performance (based on Average Climate) at 55°C		
ErP rating	A+	A+
SCOP**	2.99	2.97
Seasonal space heating energy efficiency	112%	111%
Sound Power Level		
Sound Power Level (dB)	47dBA	52dBA

* The COP figure quoted is calculated as per EN14511.

**The SCOP figure quoted is calculated as per EN14825.

Nominal thermal kW rating	7	9	13	17
Performance data - rated heating output at B0/W35 BS EN14511				
Power consumption	1.8	2.3	3.4	4.6
Co-efficient of Performance*	4.48	4.36	4.14	3.81
Brine (primary) based on 0°C in / -4°C out				

Design flow rate kg/min	29.1	28.4	39.2	50.6
Pressure drop kPa at design flow rate	12	11	17	29.2
Max inlet temperature °C	15			
Min temperature °C (outlet)	-5 (at standard settings)			
Heating water (secondary) based on 30°C in / 35°C out				
Design flow rate l/min	22.4	28.5	38.9	51.2
Pressure drop kPa at design flow rate	4	5.7	10.1	28.3
Max flow temperature °C	64	63	63	50
Electrical values at B0/W35				
Rated voltage	220 - 240V / 50 - 60 Hz			
Power supply rating amps	25	25	40	50
Rated current (max) amps	18.5	20.6	31.1	35
Typical running current at B0/W35 amps	8.4	11.4	16	23
Starting current amps	18.2	28.7	41.3	45
Refrigerant circuit				
Process medium	R407C			
Fill volume kg	1.9	1.9	2	2.1

Compressor type	Scroll			
Dimensions				
H X W X L (mm)	1145 x 600 x 575			
Dry weight kg	153	154	167	167
Operating pressure				
Brine circuit min (primary) bar g	Settable at commissioning			
Heating water circuit min (secondary) bar g	Settable at commissioning			
Low pressure reset bar g	Settable at commissioning			
Connection sizes				
Primary IN and OUT (speedfit) mm	28			
Heating flow and return (speedfit) mm	28			
Performance (based on Average Climate) at 35°C				
ErP rating	A+++	A+++	A++	A++
SCOP**	4.72	4.64	4.40	4.06
Seasonal space heating energy efficiency	180%	178%	168%	155%
Performance (based on Average Climate) at 55°C				
ErP rating	A++	A++	A++	A+

SCOP**	3.7	3.62	3.48	3.16
Seasonal space heating energy efficiency	140%	137%	131%	118%
Sound Power Level				
Sound Power Level (dB)	49.4	56.1	49.7	56.2

* The COP figure quoted is calculated as per EN14511.
**The SCOP figure quoted is calculated as per EN14825.

Conclusions

In this work package, the development and construction of DX SAHP and TP GSHP systems have been completed. Its accuracy has been validated and its no-load operation has been checked. Optimisation and functional tests with materials are necessary as part of work package 4 previously to the demo site works phase. In this deliverable, the design of these DX SAHP and TP GSHP systems have been detailed. The different components of the system have been explained, both hardware (electric, control, mechanical, safety and external systems, room controller and central controller) and software (control program and path adaptation). In addition, the way of installing the equipment, recommendations and solutions to potential problems have been explained. Finally, the construction of the prototype for the SUREFIT Project has been documented. It is important to note that although these developments are considered of great interest in different types of environments, the normative regarding these kind of systems is not ready yet, so it is not clear whether it will finally be possible their installation in any of the demo sites planned in the project. Anyway, this technology will be validated at laboratory scale and the possibility of use in a demo site is being studied.

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