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Replicable Water Source Heat pumps for A Zero Carbon Future

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Abstract

The United Kingdom (UK) is beginning to invest heavily in the construction of district heating networks as it recognises their potential for decarbonisation. Unfortunately, the vast majority of these are designed around burning fuel in one form or another, but with the undeniable effects of climate change being constantly reported and the surge in public awareness, alternative technologies are being sought after, primarily, heat pumps.

Although there is huge success in European countries regarding heat pump projects, the UK is still hesitant in deploying the technology even though the majority of large towns and cities are built on the backs of rivers.

By analysing the key sections required to deliver a successful water source heat pump (WSHP) for large urban district heating networks, a simplified methodology for repeating similar projects has been developed. Based on the learnings gathered from designing Scotland’s largest, hottest WHSP being installed in Clydebank, utilising the river Clyde as a source, real examples of design and technology will be detailed.

Keywords: Water source heat pump, Design, District Heating

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1. Introduction

Time is running out for every country to fulfill the agreements and pledges signed on 22nd April 2016: The Paris Agreement [1]. Some countries have went further declaring climate emergences [2], however little to no real progress has been made. With so many technologies confusing the pathway to decarbonising the UK it is not surprising that most towns and cities end up either doing nothing or “quick wins” which see a small impact made on the overall challenge. It is time to start taking large chucks out of our carbon footprint and this paper will describe how, by utilising a natural resource that almost every town and city has, we can achieve this.

2. Heat Pump Sections

An unavoidable fact about water source heat pump (WSHP) projects is that every location is different therefore we must look to simplify, where possible, the methodology to approaching each project and equipment selections. A WSHP heat pump project can be split into its basic constituent sections that can be further refined.

Table 1.

Section 1	**Section 2**	**Section 3**	**Section 4**
Water Source	Heat Pump	Heat Network	Secondary Network

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2.1. Section 1: The Water Source

Every river that flows through a town or city is unique but there are some basic questions that help begin selections:

1. Is the river fresh water or salt water?
   This determines pipework and heat exchanger materials and selections on the source water side.
2. Is the river tidal or controlled through weirs?
   Determines filtration equipment location and pipe routes, helps determine abstraction pump style.
3. River depth at abstraction location?
   Determines abstraction location and pump style.
4. Is there information relating to the flora and fauna of the water abstraction area?
   This has knock on effects to the filtration requirements. Eels and Mussels can impact on pre filtration quite significantly and so can migrating Salmon if this happens to be at the same time you intend to disrupt the water course.
5. Yearly water temperature profile?
   Allows more accurate heat pump performance data to be calculated.
6. Annual river flowrate profile?
   Determines the amount of available water for abstraction.

Engagement with the environmental agency is crucial at as early a stage as possible for any project as they will have their own requirements to follow such as; Allowable water volume than can be abstracted (based on Q95 or Q50 value etc.), temperature change allowed on the water, velocity at discharge location.

A decision will have to made about the handling of the source water side. There are different techniques being put forward for this such as:

1. Glycol pipework loop in the river.
2. A hydraulic break loop: River water is abstracted and fed to a heat exchanger where it transfers its heat to a glycol loop. The glycol loop is then sent to the heat pump evaporator.
3. Open loop: The river water is sent directly to the heat pump evaporator.

As the focus is on multi MW district heating, the glycol loop can be discarded as the size and amount of pipework would not be viable. A hydraulic break loop is considered to be a sound option however the inclusion of one has multiple negative effects such as extra installation costs, additional running cost (glycol pump circuit) and a negative effect on the heat pumps performance (heat transfer required across the break loop heat exchanger which results in a lower evaporating temperature at the heat pump). Pumping river water direct into the evaporator is viewed as risky but with the right technology installed this risk can be contained.

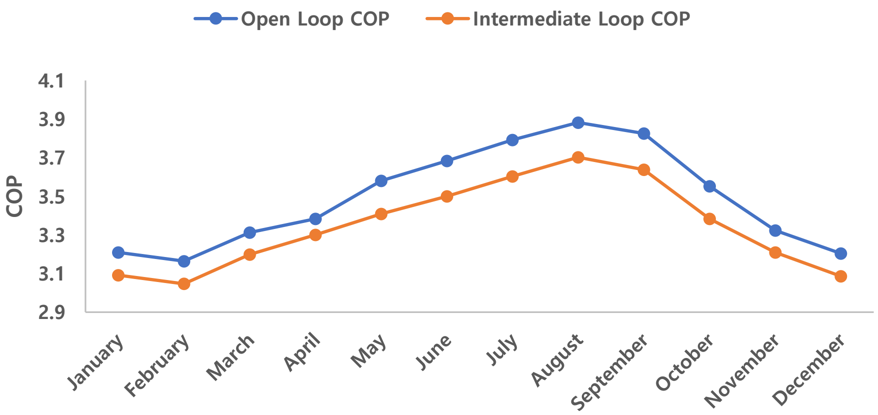

Fig. 1. COP performance graph of open loop style abstraction Vs including a hydraulic break loop

When looking at an open loop style system, there are multiple methodologies for achieving water abstraction:

1. Cutting away a section of the riverbank and inserting an abstraction chamber.
2. Floating a pipe out with concrete sections and sinking it to a desired depth.
3. Laying a pipe along the bottom and upturning the end.
4. Design a building to sit on a pontoon or floating barge where the abstraction pumps sit directly above the water. If made big enough you could house the entire abstraction system inside.

For the Clydebank heat pump project, the abstraction chamber will sit at the edge of the basin where pipework will vertically enter the water. The following basic layout describes the source side of the heat pump system

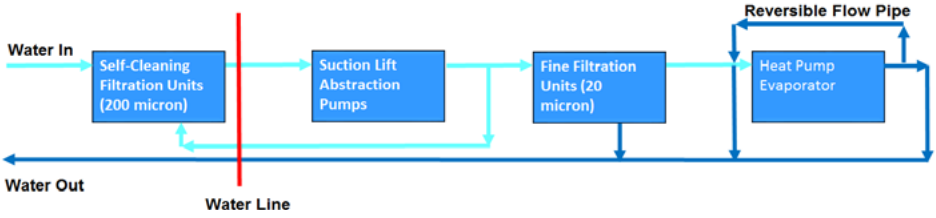

Fig. 2. Abstraction Layout

Due to the location of the project three major challenges had to be overcome: Salt water, extreme tidal fluctuations and mussels being present.

Challenge 1 – Salt Water:
The heat pump is an open loop style, so the river water from the Clyde enters directly into the heat pump evaporator. To overcome the issues of salinity in the heat exchanger a Spray Chiller Evaporator style was selected with Titanium tubes, titanium coated tube plates and super duplex end boxes. The evaporator itself is self-cleaning as explained in challenge 3.

Challenge 2 – High Tidal Fluctuations:
At the abstraction location the river can vary in height from over 4m to under 1m during the course of the tides. To ensure abstraction can continue the filters are placed under the minimum height expected from the lowest tide. A second problem was foreseen due to the abstraction point being in a manmade basin where silt could build up if the filters were placed on the river bed. To avoid this the filters are held 300mm off the river bed.

Challenge 3 – Silt and Mussels:
The river Clyde has mussels which means there are mussel seeds. These seeds are around 20 microns in size so very fine filtration is required. There are three types of filtration on the source water side to help combat this. First there are self-cleaning backwash style filters in the river. These are made self-cleaning as a small portion of the water being delivered to the heat pump, is sent back to the filters where a rotating bar with nozzles ejects the water back through the mesh. The second piece of filtration is a bank of spinning disk style units which are sized to stop the mussel seeds from progressing in the system.

The final piece of filtration is on the spray chiller evaporators. Each evaporator contains 770 tubes which are externally and internally enhanced as per figure 3. Each tube is fitted with a brush (figure 4) and a cage on both sides to catch the brush as it travels through the tube (figure 5).

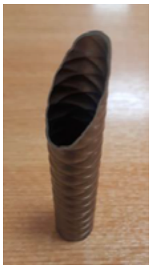

Fig. 3. Spray Chiller Enhanced Tube

Fig. 4. Spray Chiller Brushes [3]

Fig. 5. Spray Chiller Cages

As water flows through each tube, the brushes settle at one side of the evaporator. Silt and other fouling can accumulate in the tubes, leading to a negative effect on heat transfer. To use the brushes a series of valves and pipework reverse the flow allowing the brushes to be pushed to the other end of the evaporator, dislodging any fouling that has accumulate. The water is then discharged back to the river.

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Fig. 6. Flow Reversal Pipework On the Side of the Spray Chiller Evaporator

2.2. Section 2: The Heat Pump

The heat pump while complicated in its own right, is by far the simplest piece of equipment to put together in this type of project. Its working conditions are preset on one side by nature and the other by desiring a calculated outcome.

To narrow in on a design, there are always three initial questions for the selection of any water source heat pump:

1. Source water: flow and return temperature (°C)?
2. Heating network: flow and return temperature (°C)?
3. Capacity required (MW)?

Advanced selection criteria that can influence the design of the heat pump are:

4. Refrigerant Type?
5. Electric Voltage?
6. Variable Speed Required?
7. Source Water and style of abstraction?
8. Source Side and Hot Side fluids?
9. Does COP meet project requirements?

Using Clydebank as an example

1. Source water: Varies from 4°C in winter to 18°C in Summer. Based around conversations with SEPA we are allowed a 3K ΔT.
2. Heating network: 80°C/60°C then dropping to 75°C to 45°C
3. Capacity required: 5.2MW
4. R717 as refrigerant (GWP<1, ODP 0)
5. 690V electric motor
6. Salt water, open loop abstraction and treated water for the district heating loop.
7. Average COP of >3

Fig. 7. 2-off 2.6MW Water Source Heat Pumps for Clydebank

Each heat pump at Clydebank consists of a positive displacement, oil injection, twin screw compressor with the rotation provide from an air cooled electric motor. Once the ammonia is compressed, the oil and ammonia mix is sent to an oil separator where the ammonia carried on to a desuperheater, condenser, subcooler, expansion valve and evaporator before being drawn back into the compressor. The oil is sent from the oil separator to an oil cooler, filters, oil pump and finally re-injected back into the compressor.

The district heating water is fed into the heat pump where it is split so that some water goes to the oil cooler and the rest passes through the subcooler, condenser and the desuperheater. The water from the oil cooler and desuperheater are then joined back together and returns to the district heating network.

The source water is as per fig. 2.

Currently the United Kingdom (UK) offers the Renewable Heat Incentive (RHI) to compliant heat pump systems. This is a tariff paid over 20 years for every kWh of heat generated renewably and the heat pump must conform to certain requirements such as an average COP of 2.5. This has been put in place to not only help stimulate the marked but offset against the cost of cheap gas and expensive electricity (known in the UK as the spark gap). The cut off point for projects is that they must be installed and commissioned by March 2021.

2.3. Section 3: The District Heating Network

District heating networks come in all different shapes, sizes and most importantly for the heat pump, temperature ranges. The temperature ranges are often referred to as Generations [4], with the flow temperature of the 3rd generation being (<100°C) and 4th (≤70°C). There are other styles being examined such as ambient loops however as detailed in section 2.4. this does not provide the least intrusive method for the consumer in a retrofit procedure.

Project networks can be devised into several categories:

1. Existing networks: These are already in place, delivering heat to existing building stock where the heat is generated, typically, by the burning of fossil fuel. This a very challenging case for heat pumps to fit into due to the networks predominantly being on a high flow and return temperature, typically with a poor ΔT. The high temperature is normally a function of reducing end consumer impact (changing building internals)
2. New networks for existing buildings. This is the most challenging case to make heat pumps fit in as typically in the UK, each building has its own gas boiler connected to the gas network. Finding ways to encourage people to move away from cheap gas to what is seen as a new methodology for delivering heat (district heating) can be very complicated.
3. New network for new buildings: Network temperature is designed specifically for the heat pump from the beginning and so are the consumers building internals (radiators, heat interface units etc).
4. New network serving new builds and existing stock: The heat pump will be deployed to serve existing building stock while new builds come online. Existing buildings will transition to a lower network temperature and wider ΔT. Careful consideration needs to be given to heat pump heat exchanger design as flowrates can half so extra passes may have to be designed in.

The Clydebank project falls under point 4. Currently existing stock to be included in the district heating project is the West College Scotland Clydebank campus and the Clydebank leisure center (The pink section of Figure 2. The red section is for all the new builds: 1063 dwellings, 80 bed care home, NHS medical center, a hotel, food store and various other retail and commercial facilities.

Fig. 8. Clydebank Project Sections.

Due to the Clydebank project looking to secure RHI, the heat pumps are going to be installed before the majority of the site has been completed which leads to some complications.

5. Stage one of the project is to send heat to the college and leisure center while waiting for the new development to bring buildings online. The college and leisure center will be retrofitted to work on the lower district heating network temperature however the heat pumps will begin operating on 80°C flow and 60°C return before this work is carried out.
6. When the network comes online the college and leisure center will be retrofitted and the whole system will operate on 75°C flow and 45°C return. This has two positive impacts on the heat pump as the output temperature has been lowered and the ΔT has been increased, allowing for more subcooling on the units. See section 3 for more details.

In reality if water source heat pumps are going to tackle dense urban city centers then projects fall under point 1 or 2. If we look at point 2 and take Glasgow city center as an example, how can you roll out district heating when each building is currently served off the gas grid, operates individually and has no incentive to switch. The main schools of thought are around providing concession areas for district heating companies and setting air quality limits (which are within Scotland's devolved powers).

2.4. Section 4: The Secondary Network (The Consumer)

There are several examples of what to expect when faced with a consumers internal building network

1. Currently existing with no plans to retrofit.
2. Currently existing with plans to retrofit.
3. New build where a desired temperature can be installed form the start.

Ultimately, the temperature required on the consumer's network is what sets the district heating network flow and return temperature and to decarbonise a city center, the major challenge will be changing customers with the mindset of point 1 to point 2 especially if the intent is to run the network from heat pumps.

Customers who fall under point 1 have the biggest detrimental effect to the heat pumps performance. They will typically be served by a gas boiler and have an internal network of 82°C flow and 71°C return. Most buildings do not even achieve this ΔT and it can be as little as 1 or 2K.

A key starting point to minimise disruption would be to survey the buildings internals and calculate if the equipment installed can operate on lower temperatures (was it over sized when it was installed?).

If the network serves multiple different consumers and for example one of them is an industrial heat consumer and requires very high temperature heat., instead of designing the network based on that one consumer's requirements, design for the majority at a lower temperature and look at installing a booster heat pump at the client's location to deliver site specific requirements. This could allow the industrial consumer heat up to 150°C if required.

Ambient loop networks are being discussed as a solution instead of district heating. Similar in concept to a district heating network except the water sent to each building is around 15°C, this water is then used as the source to an individual heat pump placed in each building. Each building takes a bit of heat out of the loop and the loop is cooled. A large heat pump would be required to balance out the ambient loop. Ideally buildings would equally be heating and cooling to self-balance the loop, however in Winter there is little cooling demand. A drawback for this style of system in a city center is where you want to minimise end consumer building internal changes as everything is a function of cost. The individual heat pumps placed at each building will be small capacity and so limited in outlet temperature (around 65°C) so a full retrofit will probably be required and unlikely given the scale of existing building stock.

3. Heat Pump Performance

Although heat pumps can achieve reliably 85°C/90°C for district heating, they generate the best performance at lower temperatures on the hot side and higher temperatures on the cold side. In this instance the cold side is the river and although this is variable throughout the year, it is a fixed point that cannot be altered. This leaves manipulating the hot side where possible to increase performance. There are two areas to strive for improvement:

1. Reduction of the network temperature
2. Increasing the network ΔT

Figure 9 below shows a yearly trend for COP based on a typical river profile for 3 different heating scenarios.

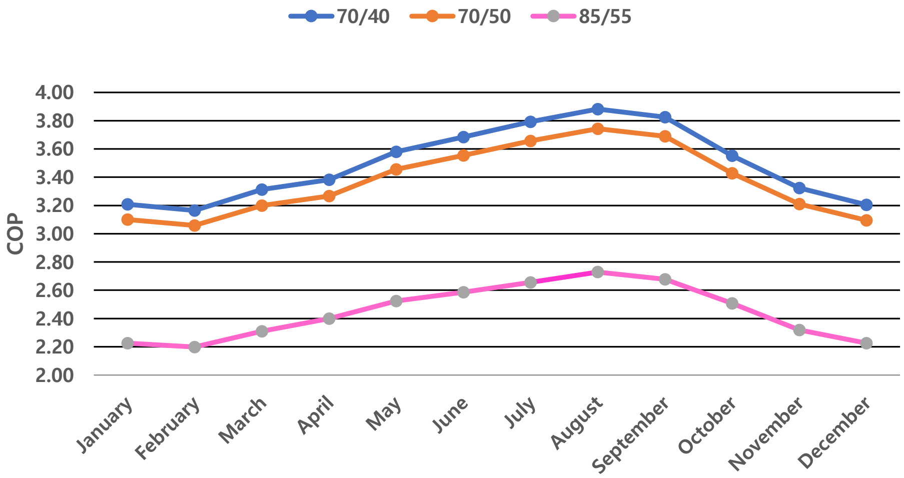

Fig. 9. COP variations for changing Network temperature and the network ΔT

4. Advanced Thinking

Like many types of projects there are ways to further optimise a system. With a heat pump led district heating network the following areas can greatly enhance the viability and efficiency of a system:

1. Thermal storage.
2. Flexible electricity tariff (half hourly).
3. Off-peak/ surplus electricity consumption.
4. Incorporate the cooling generated by the heat pump.
5. Lower the network temperature.
6. Reduce network heat losses.

Points 1, 2 and 3 work together as heat consumption from a district heating network is not constant. Low periods of heat consumption generally coincide with lower electricity prices, so if you are on a flexible tariff, instead of operating the heat pumps at 50%, run them at 100% (achieving the best COP), consuming the cheap electricity to fill a thermal store. You have then developed a buffer that if sized correctly could allow the heat pumps to be switched off at peak network consumption, avoiding expensive electricity charges. The same point applies to the electricity grid if it is being supplied with more electricity than it requires. Heat pumps could be switched on to fill thermal stores, avoiding the constraint payments wind farms are paid to switch off during over production.

Point 4 highlights the fact that to generate heating on one side of the heat pump you have created a cold source that can either be returned to the river or sent to a process that requires cooling. If the heat pumps are strategically placed this cooling can be sent to a data center or a hospital for example, offsetting their own electrical consumption and increasing the heat pumps overall COP. This can form another revenue stream for the district energy company making project more viable.

5. Environmental

The pathway to decarbonising the UK, can at best be described as complex. With so many technologies on the market providing quick wins in reducing carbon (but not fully decarbonising) or providing the illusion of decarbonising while having a negative impact as the grid decarbonises (Gas CHP) it has never been more confusing to pick a solution that is right. Mix in the vested interests from major oil and gas companies that would push the introduction of hydrogen into the gas grid or a full relaying of the pipework to have 100% hydrogen sent to homes it is not surprising that very few projects begin.

Heat pumps operate by consuming electricity so their carbon footprint is inherently tied to that of the electricity grid feeding them. If a heat pump has a COP of 3 then you take the electrical grids carbon content per kWh and divide by 3 to obtain each unit of heats carbon footprint. If your grid is 0gCO_2/kWh, then so is your heat. This make heat pumps one of the only scalable zero carbon methods for generating heat.

Even though the UK has made great strides to decarbonise its electrical grid, unfortunately documentation in the building sector is lacking in supporting the deployment of heat pumps. New projects have to use documentation published in 2012 which states the electrical grid has a footprint 519gCO_2/kWh [5] even though planned updates in 2016 (showed grid at 398gCO_2/kWh) [6], 2018 (Showed grid at 233gCO_2/kWh) [7] and now 2019 (Shows grid at 136gCO_2/kWh) [8]; all of which, have yet to be implemented.

6. Conclusion

With cities such as Glasgow and Edinburgh setting a target of net zero carbon by 2030 [9],[10], Scotland by 2045 and the rest of the UK by 2050 drastic changes have to be taken now if there is any hope at succeeding.

The main barriers that often block project conception range from a lack of understanding though to the complexity of aligning all the appropriate project partners. There any many companies that can assist local authorities in how to get projects moving and can even take on the whole project scope leaving the local authority in charge on the network at the end.

Although challenging, water source heat pumps provide a real way to decarbonise a cities carbon footprint now and every day that projects like these are delayed in conception, another day is lost in preventing further climate change.

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