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Waste water transformed into heat energy

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Abstract

This study investigates the feasibility of utilising ground water ingress into the Glasgow Subway system. At present this unused excess water is being discharged into the city's drainage system as waste. This valuable resource could be channelled through a Water Source Heat Pump (WSHP) to produce heat energy for domestic or public use (heating and domestic hot water).

A study has been carried out in order to calculate the heat contained in the water. Water flow and water temperature have been recorded over a ten month period (since May 2014) at fifteen different points within the network of underground tunnels. Water sampling has also been undertaken at all of these points, with chemical analysis results for six of them already obtained. The measurements will continue for at least seven more months to have readings for an 18 months period. A feasibility study to review the number of support factors (i.e. Renewable Heat Incentive) that could profit the subway system has been undertaken as well.

Options have been discussed and a selection of a site inside the tunnels for a pilot system has been decided and is due to be installed in June 2015.

The findings of this study are expected to develop an appropriate renewable solution through a cost effective heat pump system design. This waste water will be collected and used as renewable energy. During this process energy will be produced from a waste product using a sustainable and environmental friendly method. A similar approach ought to be transferable to many other subway systems around the world, some of which experience ground water ingress.

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1. Introduction

The need for replacing conventional fuel finding alternative sources becomes day by day bigger. A basic factor that led the UK government into more environmental friendly ways of heating are the obligation of reducing the CO₂ emissions in 1990's levels by 2020 (*Scottish Government, 2012*) and to fully decarbonise heating until 2050 (*DECC 2013*). Ground source heat pump (GSHP) systems have shown potential to reduce energy consumption and as result a CO₂ reduction of more than 50% compared with conventional heating systems (electricity, oil).

A study has been carried out since June 2014 in the Glasgow Subway system to investigate the possibility of using the water ingress inside Glasgow's Subway tunnels for space heating and Domestic Hot Water (DHW) through a ground source heat pump (GSPH).

The Glasgow Subway forms a circle in the centre-west of the city. The entire passenger railway is underground, contained in twin tunnels, allowing clockwise circulation on the 'outer' circle and anticlockwise on the 'inner'. Fifteen stations are distributed along the route length of just over ten kilometers. The river Clyde dissects the circular route, with eight stations in the North and seven in the South as shown in figure 1.

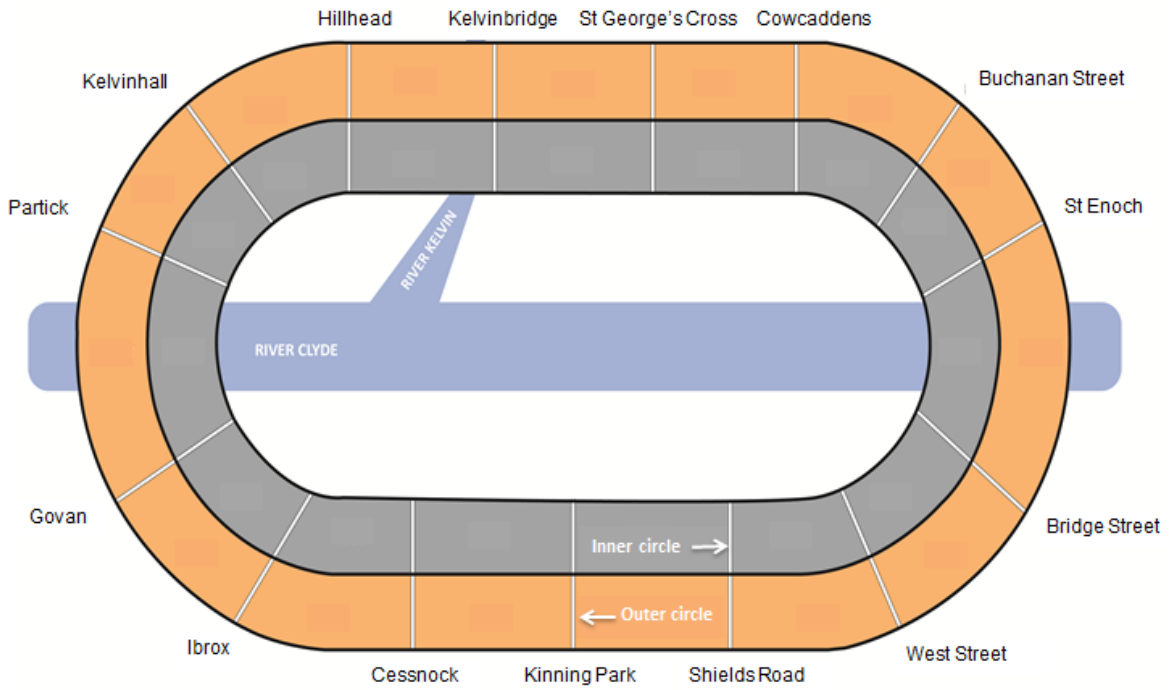


Figure 1: A typical Glasgow Subway map

Heat pumps have always been the key technology in the use of excess heat in lower temperatures. They use compression (the same principal as a refrigerator) to extract tepid low grade heat to produce heat for space and / or water heating in general. They can also be reversed to produce cooling. Heat pumps, as shown in Figure 2, are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one. A heat pump uses some amount of external power to accomplish the work of transferring energy from the heat source to the destination (space heating / hot water).

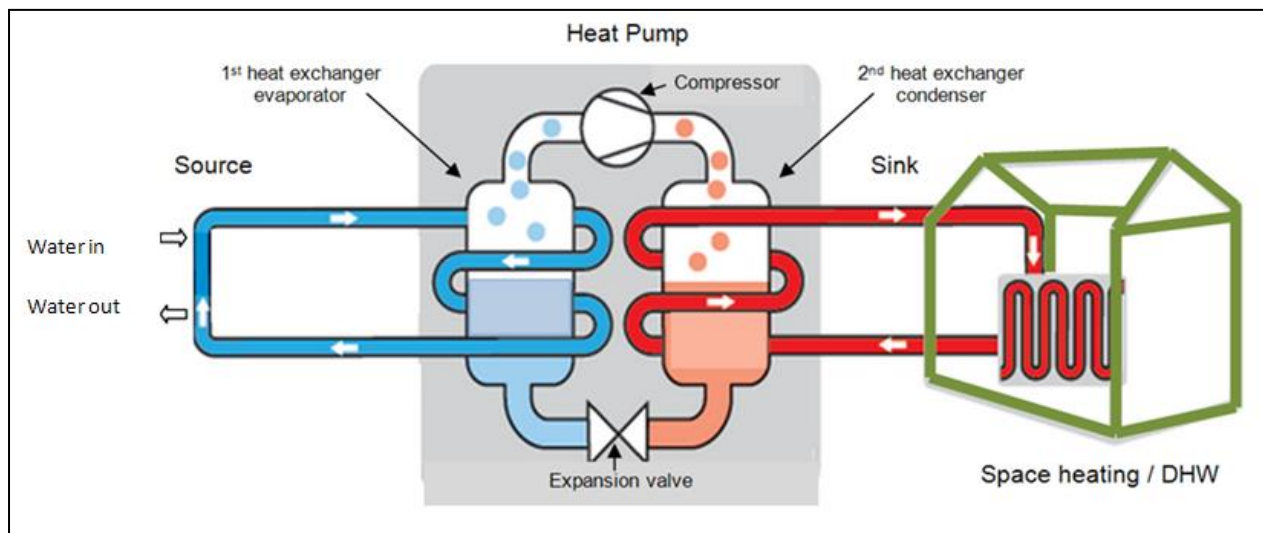


Figure 2: A typical ground (water) source heat pump (GSHP).

2. Methodology

A series of measurements have been ongoing since the 1st of May 2014 and these consisted of the following: measurements of temperature and flow of the ingress water, consideration of geological and geotechnical parameters to identify sites suitable for heat pump locations. This procedure will continue until the end of this project (end of 2015) in order to work out the seasonal variations of the water ingress. Water sampling has been carried out at all sumps for the chemical analysis of the water regime. The 21 sumps located inside the tunnel system that have been monitoring are displayed in Figure 3.

In addition to the above, atmospheric data is also compiled in order to monitor the Glasgow weather changes i.e. do temperature, humidity, atmospheric pressure and rainfall. This is done by using Glasgow Caledonian University's meteorological station to collect the readings for each day of the site visits. A monthly meteorological table has been produced to parallelise the tunnel conditions with the Glasgow climate conditions.

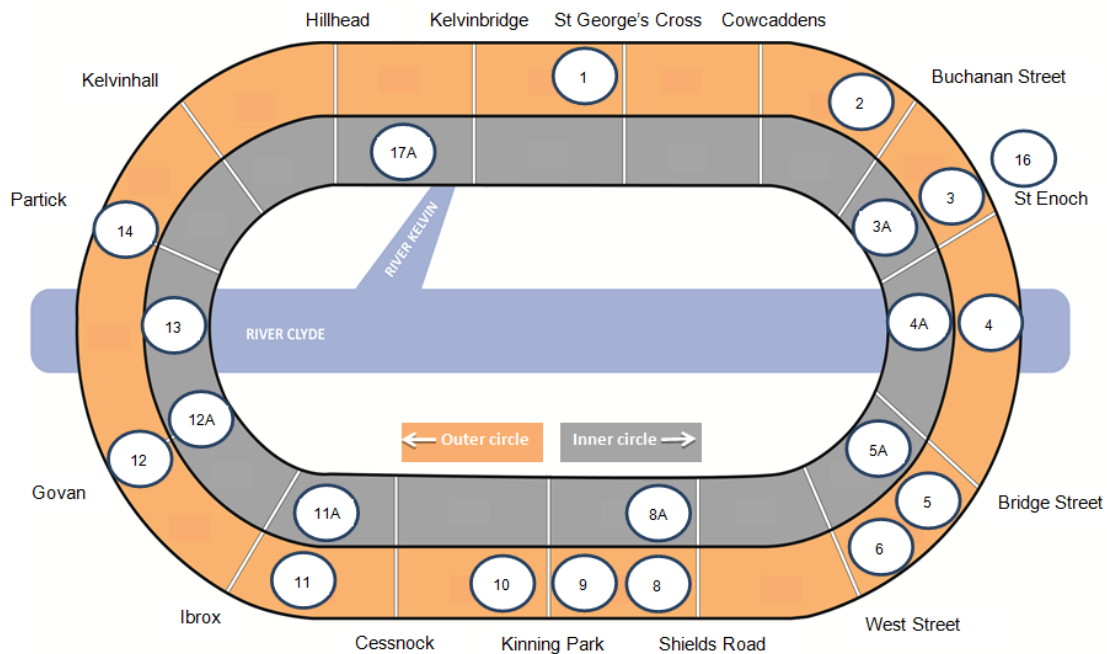


Figure 3: Sump locations in the Glasgow Subway system

The sumps (Figure 4) are generally flat bottomed rectangular chambers formed either within the tunnel invert or station platforms and range from 0.50 m to 2.50 m in depth from access level. The pumping stations inside each sump are generally equipped with two submersible pumps. The excess water from the tunnels is being pumped out and discharged into the network adjacent to the vicinity of the nearest Subway station.



Figure 4: A typical sump located between the rail tracks in the Glasgow Subway system.



Figure 5: Measuring the sump water level

The two most critical measurements are the water flow and the water temperature in each sump. Some additional data has been collected at the same time in order to help us evaluate the water flow through out a year. (Average Glasgow temperature, humidity, and precipitation)

2.1 Water flow measuring methods

2.1.1 First method of water flow measurement (Drop test)

In each sump there is a probe that when the water reaches a certain level the pump starts pumping the water out of the sump. This period is called “active time”. When the pump will stop functioning; it takes some time before the water flux will raise (inside the sump) the water level up to a point that the pump will start working again. This period is called “inactive time” and this is the actual water flow. Given that the dimensions of each sump are known; the water flux can be calculated by measuring the water level inside the sump (Figure 6) between the “active time” and the “inactive time”.

Sump 1

Dimensions: 2.00 X 0.90 X 2.15 overall depth

Area (surface of the sump) A		1.80 m ²
1st measurement	Pump started	
	Start level - (higher point) B	1.11 m
	Stop level - (lower point) C	0.31 m
	Depth dropped (B - C) D	0.80 m
	Volume (A x D) E	1.44 m ³
	Time F	138 sec 2'.18" min.sec
	Flow (E/F) G1	0.010435 m ³ /s 10.43 l/s
Total vol. discharged (G1 x F) G2		1440.00 liters
2nd measurement	Pump started	
	Start level - (higher point) B	1.13 m
	Stop level - (lower point) C	0.37 m
	Depth dropped (B - C) D	0.76 m
	Volume (A x D) E	1.37 m ³
	Time F	133 sec 2'.13" min.sec
	Flow (E/F) G1	0.010286 m ³ /s 10.29 l/s
Total vol. discharged (G1 x F) G2		1368.00 liters
1st measurement	Pump stopped	
	Start level - (lower point) C	0.31 m
	Stop level - (higher point) B	1.13 m
	Depth raised (B - C) D	0.82 m
	Volume (A x D) E	1.48 m ³
	Time F	790 sec 13'.10" min.sec
	Flow (E/F) G2	0.001868 m ³ /s 1.87 l/s
2nd measurement	Pump stopped	
	Start level - (lower point) C	0.37 m
	Stop level - (higher point) B	1.15 m
	Depth raised (B - C) D	0.78 m
	Volume (A x D) E	1.40 m ³
	Time F	743 sec 12'.23" min.sec
	Flow (E/F) G2	0.00189 m ³ /s 1.89 l/s

Figure 6: Two consecutive water flow measurements in sump No.1

The higher water level (when pump starts working) and the lower level (when pump stops working) are thus measured (Figure 5). This height difference multiplied by the area (surface) of the sump, gives us the water volume that is being pumped out. Dividing this volume by the time (seconds) that the pump is active gives the discharged volume during the active time of the pump. From the lower point when the pump has stopped the time that the water takes to reach again the highest point in the sump is being measured (until the pump will start working again). This depth raised multiplied by the sump surface gives us the water volume that inflows the sump in a specific period of time (F). This is the average water flux in each sump. At least two readings are taken during each visit in each sump are taken to have more data and therefore more accurate averages of the water flux.

Readings are taken with a rigid measuring stick as well as with “water sensitive depth meter sensor”. A water sensitive sensor is attached at the end of the measuring cord which beeps when it touches the water level. This calibrated cord indicates the distance from the both water levels to the surface.

2.1.2 Second method of water flow measurement (ultrasonic flow meter)

In order to crosscheck the water flux in each sump a second method is being used as well. A digital ultrasonic “clamp on” flow meter (Figure 7) has been used providing more accurate water flow measurements. The device is being calibrated prior to each measurement inputting in the software the pipe material (uPVC or steel), the diameter of the pipe (Ø120 or Ø160) and the liquid (water).

The portable transducers (Figure 8) are being clamped onto the pipe applying also liquid silicon to the transducers to assist “reading” the flux.



Figure 7: The ultrasonic flow meter showing the water flux (l/s)



Figure 8: The transducers clamped onto the discharge pipe

2.2 Temperature measurements

Water temperature is being measured inside each sump and also from all the water inlets into the sump and the average is calculated. A digital probe thermometer (Tinytag 2 TGP-4020) is used to record the temperature every 2 sec. The thermometer is kept in place for 2 minutes (as a minimum) so the minimum 12 temperature measurements are received from each measuring point. The data is downloaded onto a computer which then provides the average temperature (Figures 9 & 10).



Figure 9: The digital thermometer

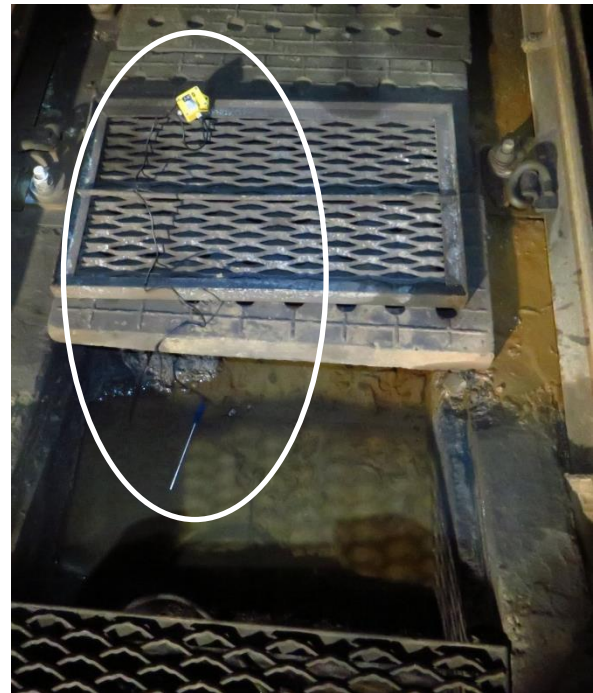


Figure 10: The same digital thermometer inside the sump taking readings

Atmospheric data is also compiled in order to see if the changes in the weather i.e. do atmospheric temperature, pressure and rainfall, have any effect on the subsurface tunnel water. This is done by using the University's meteorological station to collect the average temperature, rainfall, atmospheric pressure and humidity for each day of the site visits. A monthly and an annual meteorological table will be produced with the same data to parallelise the tunnel conditions with the Glasgow climate conditions.

3 Results

3.1 Water flow & water temperature readings in all sumps

Sump No: 1					
WF1: Water flow WT1: Water Temp. GMT: Glasgow Mean Temp. GMH: Glasgow Mean Humid.					
Month	Year	WF1 (l/s)	WT1 (°C)	GMT (°C)	GMH (%)
May	2014	6.7	14.17	11.40	80
June	2014	6.3	13.45	16.70	83
July	2014	5.3	14.95	15.80	77
August	2014	3.9	16.03	16.00	88
September	2014	1.9	15.40	15.00	67
October	2014	1.8	16.13	12.00	67
November	2014	1.8	14.90	10.00	75
December	2014	2.0	13.20	04.10	96
January	2015	2.2	14.10	05.80	77
February	2015	2.2	12.10	05.70	80

Table 1: Readings from sump 1

3.2 Subway station's heat demand & heat energy output from the water

A constant water flow has been monitored in three out of twenty one sumps. Those are: 1, 2 & 17A. The following five stations are the closest ones to the three sumps with the highest and constant water flux: Buchanan Street, Cowcaddens, St. Georges Cross, Kelvinbridge and Hillhead.

To assess where heat output can be delivered and used, a heat load calculation (in kW) for all the Station has been completed (Table 2). The calculations have been done according the BS EN: 12831-2003.

Station name	Total design heat load (W)	Total design heat load (kW)
Kelvinbridge	4755	4.8
St. George's Cross	5185	5.2
Cowcaddens	3369	3.4
Buchanan Street	3778	3.8
Kelvinhall	2599	2.6
Hillhead	6641	6.6

Table 2: Heat Loads for the fifteen Subway stations (Accord. BS EN: 12831)

St. Georges Cross subway station has been chosen for the pilot installation of a Water Sourced Heat Pump (WSHP). This station is in the closest proximity from the source point (water sump no.1) to the sink point (station's ticket office)

The heat energy H (in kW) can be calculated from the following formula (Banks D, 2009):

$$H = Q \times \rho \times Svc \times \Delta t$$

Where Q	Water flow of the system (m ³ /s)	0.0043 (m ³ /s)
ρ	Density of the water (kg/ m ³)	1000 (kg/ m ³)
Svc	Heat capacity of water (kJ/kg X K)	4.18 (kJ/kg X K)
Δt	Temperature difference (C)	(° C)

Example: If we take the average water flow from May 2014 to February 2015 for sump 1 (Table 1), which is 3.4 lit/sec=0.0034 m³/sec, we can estimate the output. $H = 0.0034 \times 1000 \times 4.18 \times 4 = 56.85 \text{ kW}$

St. Georges Cross station's heat load is 5.2kW (Table 2), so a selection of a system to provide heating and Domestic Hot Water (DHW) is feasible according to the heat energy output from sump 1.

The following table (3) is an example of the calculation of St. Georges Cross station thermal needs according BS EN 12831:2003.

St. George's Cross room name	Transmission heat load	Ventilation heat load	Higher temperature factor	Heating- up capacity	Total design heat load
	T _i	V _i	f	RH _i	HL _i
	W	W	p.u.	W	W
Ticket-Office	845.62	215.37	1	239.20	1300.19
Hallway (Ground)	448.60	74.72	1	82.81	606.13
Hallway (Upper)	337.90	36.62	1	40.56	415.08
Canteen	987.77	232.25	1	257.40	1477.43
Female Toilet	276.31	78.83	1.6	58.24	448.32
Male Toilet	276.31	78.83	1.6	58.24	448.32
Store	377.76	31.36	1	80.21	489.33
Total	3550.28	747.98	-	816.66	5185

Table 3: Thermal needs of St. Georges Cross Subway station offices

A basic design for this pilot installation has been undertaken and a water source heat pump (WSHP) of 8kW output is required to meet the Subway stations heating and domestic hot water demand (DHW). This case study will feed five new low temperature fan coil radiators which will be sufficient to heating the station replacing the existing four electric radiators (3kW each) (Figure 11). This system is expected also to provide cooling as a by-product during summer months.

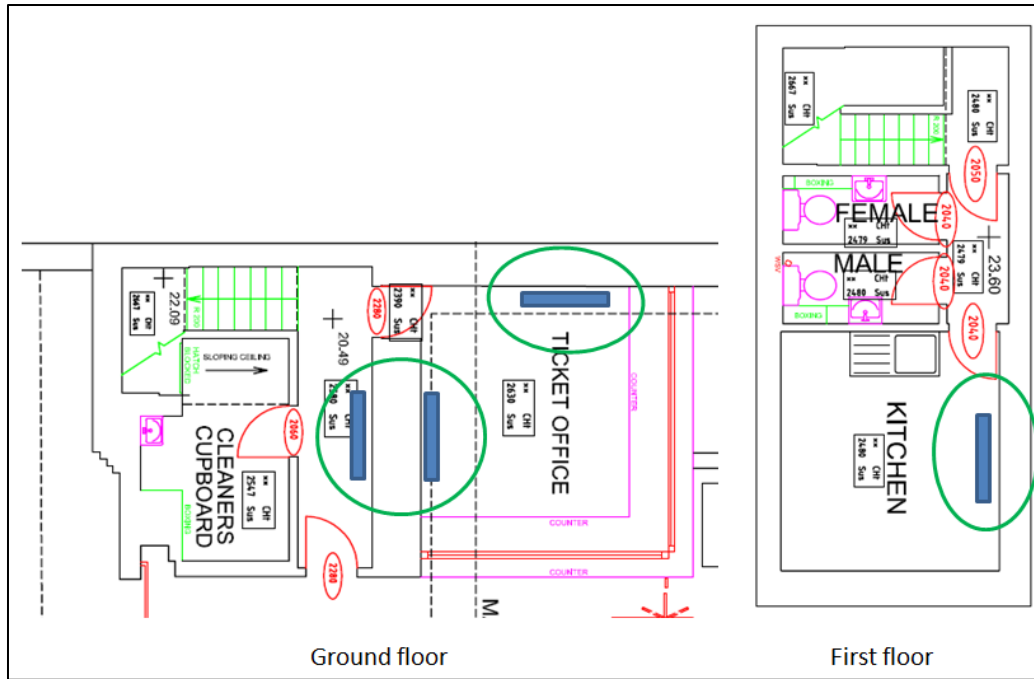


Figure 11: St. Georges Cross station drawing

4. Discussion - Conclusions

Out of the 21 sumps inside the Glasgow subway system; only in three there is a constant water flux.

Because of the position of Glasgow, north of the UK, it is common that heating starts even from September.

Currently the Subway stations are heated with electric radiators where the energy cost and the CO₂ emissions from the use of electricity are high.

A WSHP generally can perform with seasonal performance factor of 2.80 (*OFGEM - Energy Saving Trust*).

The coefficient of performance (*COP*) can be up to 4. The higher *COP* equates to lower operating costs.

It is feasible to install a GSHP in four Subway stations to cover its thermal needs.

St. Georges Cross Subway station has been chosen to install the first WSHP in the ticket office which will provide the space heating and the domestic hot water for the station.

This will be the first installation which is expected to prove the efficiency of the suggested system before it will be scaled up in the other stations in the Subway system.

A basic design for this system has been completed and the installation is expected to take place during May 2015.

A WSHP of 8kW will replace the station's heating system to cover the heating demand and DHW (Domestic Hot Water). Station's heat load: 5.2kW (Table 2)

The four electric radiators that currently provide only heating for this station will be replaced by four new low temperature fan coil radiators (with a return temperature of 45°C).

This system is expected to cover the space heating, the DHW and provide as a by-product cooling during summer months.

A COP for a return temperature of 45°C and inlet air temperature) of 5 °C is approximately 2.5 to 3. This means that for every kW of energy spent through the compressor the heat energy output is 2.5 to 3 kW. It is expected with the same return temperature of 45 °C and inlet air temperature of 13.5 °C even during December to have a COP of more than 4, which means that the energy consumption will be reduced approximately 75% compared to the existing system.

The CO₂ emissions are expected to be reduced more than 60%.

The amount of water which will be pumped from the sump to the WSHP will be discharged afterwards to the local sewers. This will reduce the operation of the existing pumps and the volume of the water that is being discharged through the pipes to manholes.

A waste product will be used as renewable energy in order to provide space heating, space cooling and domestic hot water with an environmental friendly method reducing significantly the energy cost and the carbon footprint.

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