EXCESS

FleXible user-CEntric Energy poSitive houseS

Deliverable 2.3: Design principles and test result of multisource heat pumps with high COP DHW

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Abstract
This report explains the design principles and shows test results for a multisource heat pump for a PEB building. The design requirements lie on designing and sizing of heat pumps internal components (evaporator, condenser heat exchangers, source and supply pumps, expansion valve etc.). The design needs to be compatible with deep boreholes and multiple sources. The heat pump also needs to have IoT capabilities for remote support and cloud-based optimisation. Two different heat pump compressor technologies are successfully developed: reciprocating (piston) compressor and enhanced vapor injection (EVI) tandem compressor system.

Keywords
GSHP, Inverter heat pump, reciprocating compressor, EVI compressor, high COP DHW, IoT

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EXECUTIVE SUMMARY

The European Union Energy Performance of Buildings Directive requires all the new buildings to be nearly zero-energy buildings (NZEB) by the end of 2020. Even though all the EU countries had to come up with their own NZEB plans, they are working together to research solutions for the EU building stock to be highly energy efficient. This is an essential element for the Europe's 2050 carbon neutrality target. The flEXible user-CEntric energy poSitive houseS (EXCESS) project aims to research innovative and novel methods to achieve Plus Energy Buildings (PEBs).

This document describes the design principles and test results for the EXCESS project Task 2.3: Multisource Heat Pumps with high COP DHW. The task leader is Gebwell Oy and co-contributors are Tom-Allen Senera (TAS) and Technical Research Centre of Finland (VTT). The developed heat pump will be used in the EXCESS Finnish demo building situated in Helsinki. There are three major factors which needed to be considered when designing the heat pump:

- The use of deep boreholes
- The use of multiple primary sources
- The use of Internet of Things (IoT) for advanced control and monitoring

The development process can be divided into three different parts: heat pump development, IoT development and high COP DHW system development.

Two different heat pump compressor technologies were developed: a reciprocating (piston) inverter compressor and an enhanced vapor injection (EVI) scroll tandem compressor system. In early testing, both systems were working technically well and low frequency resonance noise coming from the heat pump frame and refrigerant pipes were the main issue. Thus, the frame was totally redesigned. The new frame included innovative separate floating enclose for the compressors. After several design iterations an optimal design was found for both developed heat pumps.

Another important aspect for developing the heat pumps was the IoT connectivity. Gebwell uses Siemens Climatix IoT controller and the controller application had to be modified to be compatible with the developed heat pumps. Also, Gebwell's cloud infrastructure had to be further developed. Being able to remotely control and monitor the heat pump is one of the project objectives and for this, a web-based user interface (UI) has been developed. The UI still needs further development to ensure a good user experience.

It is estimated that in the Nordic countries, 50-75% of building's heating need can be for domestic hot water in PEB buildings and as such great energy saving potential lays in improving DHW systems efficiency. TAS and Gebwell have together developed an innovative method to heat the DHW and part of the Task 2.3 is to improve the current system to double the amount of DHW available. The exact design changes have been explained in detail.

Overall, all the aspects of the task have been covered and even though there are some parts which still require further work, the provided solutions are very close to be ready for field testing.

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1 Introduction

1.1 Purpose of the document

This document describes the design principles and shows test results of an IoT capable multisource heat pump which is designed for the EXCESS project Plus Energy Building (PEB) pilot in Finland. This deliverable is being worked on the EXCESS project Work Package (WP) 2 task 2.3. Gebwell Oy (GEB) is the task leader. Co-contributors for the task are VTT and Tom-Allen Senera (TAS). TAS is responsible for the technical design for the high COP DHW system.

1.2 Scope of the document

This document covers the following topics

- Introduction
- Background
- Heat pump, IoT and high COP DHW development.
- Results
- Conclusion

1.3 Structure of the document

In the background section, some relevant information about Gebwell Oy and the problems to be solved for the EXCESS project are introduced. Next, a generic overview of the GSHP technology is discussed and the development efforts for heat pump, IoT and high COP DHW are explained. The last two sections of the document show the results and the document ends with conclusion.

2 Background

This section covers relevant background information about Gebwell Oy, heat pump technology and what are the main problems needed to solve in terms of heat pump development for the Excess project and more specifically for the Finnish pilot PEB.

2.1 Gebwell Oy

Gebwell Oy is a company headquartered in Leppävirta, Finland. The company was founded in 2005 and today employs over 200 personnel in Finland, Sweden, Latvia and Poland. In 2019, Gebwell's turnover was approximately 30M€.

Gebwell specialises in designing and manufacturing of an environmentally friendly heating and cooling solutions. Gebwell product portfolio includes:

- District heating substations
- Ground source heat pumps (GSHP)
- Energy accumulators
- Pivaset Fire Extinguishing product range

All the products are designed and manufactured in Leppävirta production facilities spanning 20.000 square metres. High quality ground source heat pumps, accumulators and district heating substations are all manufactured by skilled personnel in a flexible and high-quality manner [1].

Figure 1: Gebwell headquarters and district heating substation production facility in Leppävirta, Finland.

2.1.1 Gebwell's current heat pump product portfolio

Gebwell's current heat pump product portfolio consist a wide range of products to meet different application requirements. Current heat pump products are summarized in the table 1. Currently, the biggest heat pump, in terms of heating capacity, is the Taurus 90. Even bigger systems can be built by installing several heat pumps in parallel (aka. cascade) operation. In this kind of setup, either building automation system or a master heat pump controls the heat pump system to meet buildings heating demand. Gebwell's current biggest delivered heat pump system is 800 kW.

Table 1: Overview of Gebwell's current heat pump products

Heat pump	Nominal heating capacity	Compressor Type	Application(s)
Aries 6	1,5-7,5kW	Inverter	Single-family houses
Aries 12	2,6-12,8kW	Inverter	Single-family houses
T^2 family	5,3kW to 34,6kW	On/Off	Large single-family houses, multi-family and commercial properties
T3	9,5 – 26,5kW	Inverter	Large single-family house, multi-family housing and commercial properties
Gemini family	45kW to 69,2kW	On/Off	Multi-family housing and commercial properties
Gemini Inverter	9,5 – 57,1kW	Inverter and On/Off	Multi-family housing and commercial properties
Taurus 90	87,7kW	On/Off	Multi-family housing and commercial properties

2.2 Ground Source Heat Pump (GSHP) technology

In this section, we describe the working principle of GSHP technology and give a simplified explanation of the three main components you can typically find in a GSHP systems [2]:

- Primary circuit (or source circuit)
- Heat pump and refrigeration cycle
- Secondary circuit (or supply circuit)

2.2.1 Primary circuit

The GSHP system harnesses geothermal and solar energy which is stored in the ground as heat. The basic operation of the system relies on the temperature difference between the ground and the air; in winter, the outside air is colder than the ground temperature and in summer vice versa. This temperature difference allows transfer of thermal energy all year round to meet buildings thermal demand [2].

The primary circuits can be categorised namely in two different ways: open-loop and closed-loop circuits.

Open loop system operates by pumping water from the water source (well, surface water, flooded underground structure etc.) to the heat pump. After the heat is extracted, the water is typically discharged back in to ground water (discharge well) or in to a surface water bodies [2].

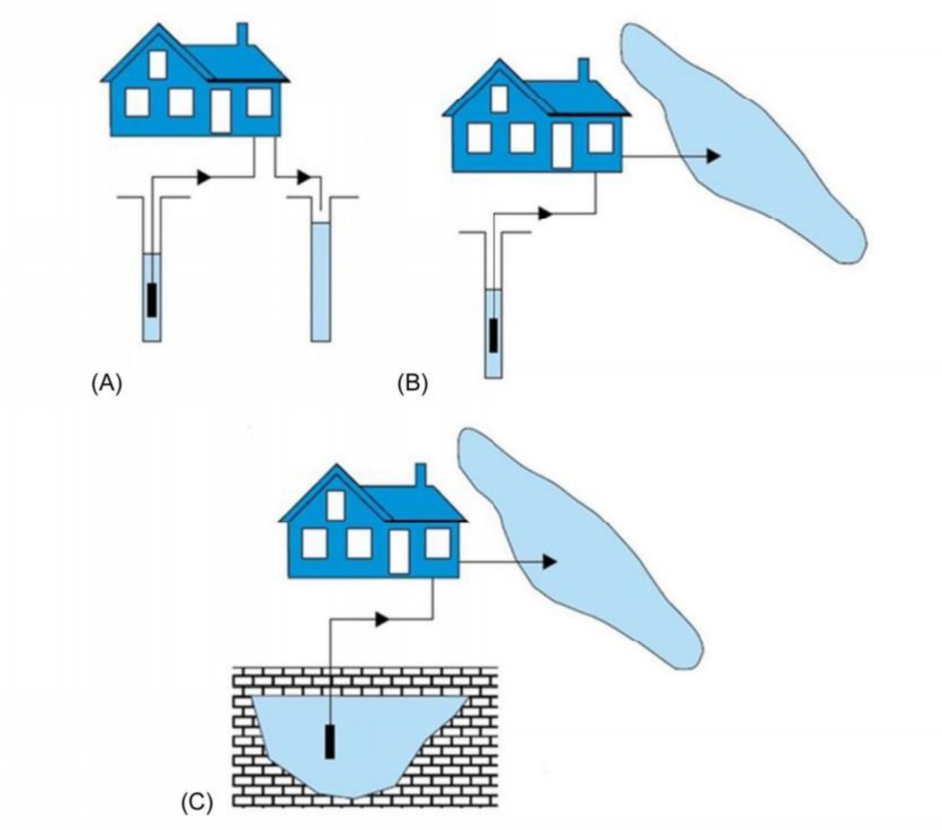

Figure 2: Open-loop ground sources: (A) intake and discharge well configuration, (B) intake well and discharge to a body of water and (C) intake from an underground flooded structure and discharge into a body of water

A closed-loop system uses closed plastic collector pipe network installed and buried underneath the ground surface or inside buildings structural elements. Inside the pipe network, heat transfer fluid (HTF) is circulated, and the heat is transferred from the ground through convection and conduction. HTF is typically either water (in warmer climate conditions) or water-antifreeze mix. Figure 3 shows typical closed-loop configurations [2].

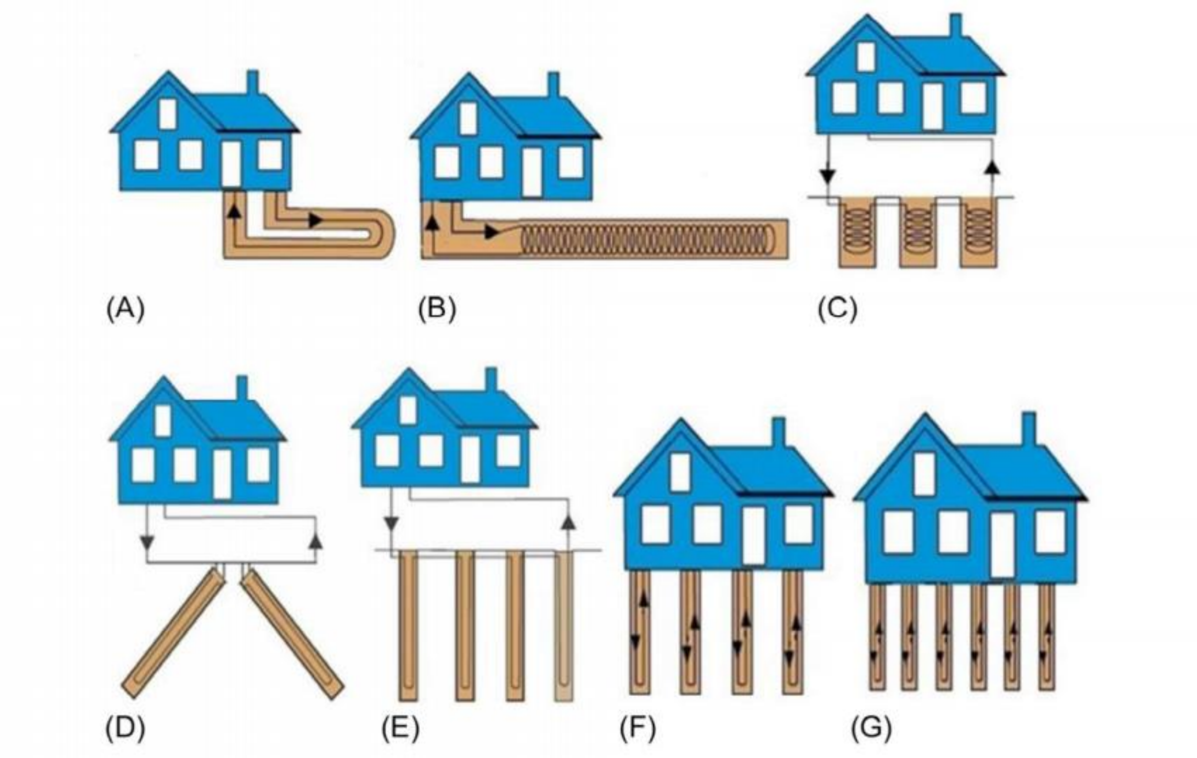

Figure 3: Closed-loop configurations: (A) horizontal shallow straight pipe, (B) horizontal shallow slinky pipe (ground or underwater installation), (C) vertical shallow slinky pipe, (D) slanting vertical borehole(s), (E) straight vertical borehole(s), (F) structural pile foundations elements and (G) structural micropile elements.

In Finland, the most primary circuits are closed-loop systems because of relatively low ground temperatures and thus the HTF needs to have good antifreeze properties.

Most common closed-loop configuration is either straight or slanting vertical borehole, followed by shallow horizontal ground installation and shallow underwater installation into a water system. For a single private dwelling, typically one borehole up to 250m is used. Big residential or commercial GSHP installations can have borehole fields which can have 50 or more boreholes.

Other common primary circuit heat energy sources are building exhaust air, wastewater and heat produces by industrial processes. In the Excess project, the research partners are also investigating using hybrid solar photovoltaic and thermal collector or PVT panels as one of the primary heat sources.

2.2.2 Heat pump and refrigeration cycle

Simplified GSHP refrigeration cycle diagram can be found from figure 4. The most common design includes four components: evaporator, compressor, condenser, and expansion valve (EV).

The evaporator is a low temperature heat exchanger where the refrigerant enters as a low temperature liquid-vapour mix. As the refrigerant absorbs heat from the primary source, the liquid is evaporated, and the refrigerant leaves the evaporator as a low pressure and low temperature vapour. From the evaporator, the refrigerant vapour enters the compressor where the vapour is compressed to higher pressure which also increases the vapour temperature. The high temperature and pressure vapour then flow into condenser. In the condenser, the high temperature vapour rejects the heat to secondary circuits heat carrying fluid and condenses from vapour to liquid which is still high pressure and temperature. Last component in the refrigeration cycle is the EV. When the high temperature and pressure liquid refrigerant passes through the EV, the refrigerant pressure drops which also causes its temperature to drop. The EV transfers the hot liquid refrigerant into a low temperature and pressure liquid-vapour refrigerant mix and from here the refrigeration cycle starts again [2].

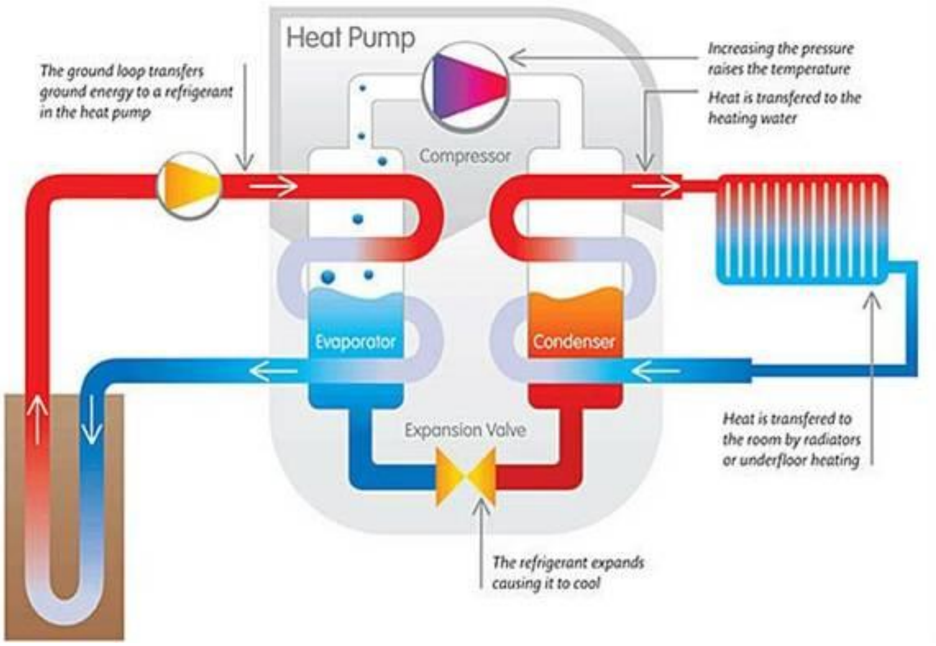

Figure 4: Refrigeration cycle of a GSHP. Source: http://groundenergysupport.com/wp/how-do-geothermal-heat-pump-work/

2.2.3 Secondary circuit

The secondary circuit distributes the heat energy extracted from the ground during winter months or cools down the building during summer months and transfers the heat to ground for heat storage. Typical secondary circuit comprises a closed-loop network of pipes installed in the building structure. The heat is transferred to the heated space through radiators, underfloor heating and/or buildings air ventilation system. Furthermore, GSHP is often used to heat the domestic hot water (DHW) as well.

2.3 Excess project and problems to be solved

The main technical challenges the heat pump design is required to overcome are:

- The heat pump needs to be compatible with multiple primary sources (ground and solar sources) and multiple operating modes (active heating and cooling).
  The heat pump needs to be compatible with deep boreholes.

More specifically, the heat pumps internal components (evaporator, condenser, and the source pump) and the hydraulic design needs to accommodate higher source circuit inlet temperatures delivered by deep boreholes and PVT panels. Conceptual design for a multisource heat pump system can be found from figure 5. Furthermore, Mouvitech has estimated that during peak loads, the HTF flow rate per borehole is 2,24 l/s[1] (+/- 10%) which means 6,72 l/s total flow rate if we have three boreholes connected in parallel. Furthermore, Muovitech estimates that the borehole field pressure drop is around 230kPa. Typical borehole field pressure drop for borehole field which has 200-300 meter deep boreholes is below 100kPa. The higher pressure drop is not a major issue and just need to be considered when source pump(s) is selected.

One part of the project scope is to improve the Seasonal Coefficient of Performance (SCOP) of the heat pump system throughout their expected 20-year life span. For this, smart IoT capabilities for the heat pump will be developed allowing the use of intelligent learning algorithms for heating/cooling optimisation and predictive maintenance. More specially, the idea is to use such algorithms which learn the buildings heat capacity and how it behaves when it is heated or cooled and how outside weather conditions affect the internal temperatures. The use of IoT will also allow remote connection to the heat pump system to ease the installation, setup and during troubleshooting efforts.

Lastly, the energy needed for domestic hot water (DHW) heating is a significant part of a domestic dwelling heat load and significantly reduces the overall coefficient of performance (COP) of a GSHP system. This is due to higher condensing temperatures required (temperatures above 55°C). In addition, higher condensing temperatures will normally reduce the compressor lifespan and lead to increased maintenance costs. The current high COP DHW system jointly patented by TAS and GEB will be further developed to improve the COP for DHW heating.

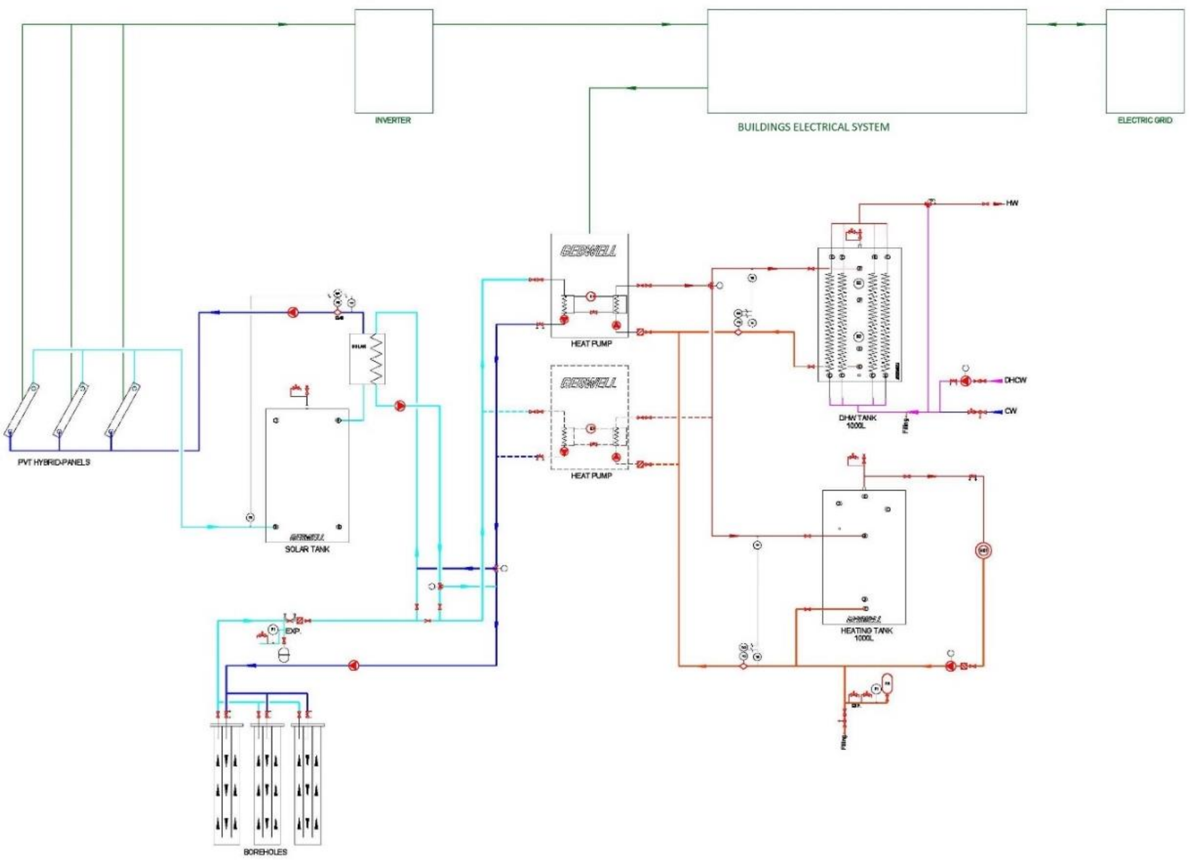

Figure 5: Conceptual design for a GSHP+PVT system.

[1] Estimated temperature difference (dT) 2,5K

3 Development

3.1 Heat pump development

After doing some background research for the current market offering for heat pumps around the 100kW heating capacity size and discussing with our sub-task partners, Gebwell decided to peruse two different technological compressor paths which will be tested in real life conditions: reciprocating (piston) inverter compressor system and tandem scroll compressor using enhanced vapour injection (EVI) system.

Both technological paths have their advantages and disadvantages. The inverter compressor system allows better heating capacity control as the compressor speed can be modified in 1% intervals from 10 to 100% speed. The EVI system uses On/Off compressors which can be turned either On or Off (0% or 100% capacity) so the total tandem system capacity is 0%, 50% or 100%. Furthermore, piston compressors are typically serviceable whereas hermetic scroll compressors are often replaced if the compressor is found to be internally faulty. In addition, with the piston inverter compressor, it is possible to use R513A and R1234ze refrigerants which have lower global warming potential (GWP) value (GWP of 631 and 7 respectively) compared to R410A refrigerant (GWP of 2088) used with the EVI compressor system [3]. Lastly, using the R513A refrigerant, the piston compressor should be able to achieve 85°C secondary side flow temperatures whereas EVI compressor system can achieve around 65°C flow temperatures.

On the other hand, the EVI compressor system should deliver better COP at higher condensing temperatures and thus better overall SCOP when compared to the piston inverter compressor. This is because of the additional performance delivered by the EVI system (the operating principle of the EVI is explained in a later chapter). The total manufacturing costs for the EVI compressor is also expected to be lower due to lower material costs.

3.1.1 Inverter compressor development

The development process was started by researching possible piston compressor models and two were selected for testing: Bitzer 6GE-34Y and Emerson Copeland Stream 6MJ-45X. Bitzer is well known manufacturer of piston compressor systems in the industry and are considered the “Rolls-Royce” option. Emerson was also chosen as one potential manufacturer as they are existing supplier for Gebwell and has had no major issues with Emerson compressors in the past.

Both compressors offer around 85kW heating capacity[2] when using the R513A refrigerant. The inverter chosen to drive the compressors was from Vacon corporation.

Next, Gebwell contacted heat exchanger application experts to get their advice on the selection of the evaporator and the condenser. After careful consideration of the application requirements and completion of simulations, the evaporator and condenser were chosen from Alfa Laval’s product range.

It was also decided to modify the existing Taurus 90 frame to fit the piston compressors and the other equipment needed (heat exchangers, inverter etc.), rather than designing a new frame, to speed up the initial testing phase.

[2]Operating conditions: -5°C evaporating and 55°C condensing temperatures

Figure 6: Bitzer 6GE-34Y compressor on the left and Emerson 6MJ-45X compressor on the right

The results for the comparative testing[3] between the compressors can be found from figure 7. Both compressors worked technically well and as figure 7 shows, the COP is similar between the compressors for the entire speed range. However, the 6MJ-45X offers better overall heating capacity and thus the decision was made to continue the development using only the Emerson 6MJ-45X compressor.

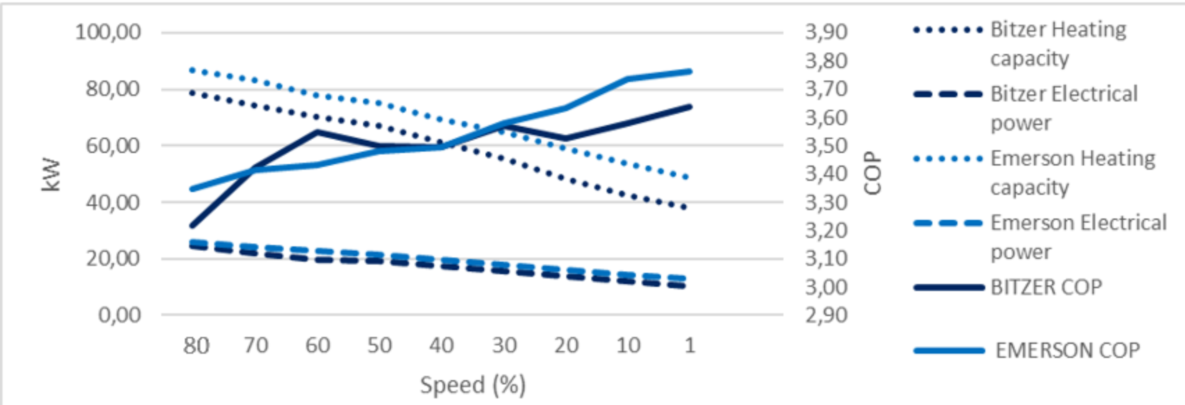

Figure 7: Bitzer 6GE-34Y and Emerson 6MJ-45X compressor comparison

During the initial testing it became apparent that at certain compressor speeds, some parts of the frame started vibrating and making low frequency resonance noise. The problem was believed to be caused by the heavier moving components inside the compressor motor and the old Taurus 90 frame just was not stiff enough. Thus, a new more rigid frame was designed.

Figures 8 and 9 show the new design. The new novel frame design includes a separate insulated floating encloser for the compressor module. The new frame design has gone through several iterations. Critical length for the refrigerant pipes has been especially difficult to find which is typically very challenging aspect when a new heat pump with new refrigerant components is designed. In one design iteration, a muffler was placed in between the compressor and the condenser but this did not help with the vibration problem. After several iterations, Gebwell believes the optimal design has now been found. The sound levels have so far been tested by “ear instinct” of the senior personnel but for the final regulatory approvals, the sound levels will go through official testing.

[3] Testing conditions: 0°C evaporating and 50°C condensing temperatures

Figure 8: New more rigid frame

Figure 9: Compressor enclosure

Figure 10: Muffler trialled in the refrigeration circuit

3.1.2 EVI compressor development

The principle EVI refrigeration cycle and pressure-enthalpy (p-e) diagrams can be found from figure 11. The liquid out of the condenser is separated in two parts; main line and EVI line. In the EVI line, the liquid refrigerant is expanded and directed into the counter-flow economizer heat exchanger (HX) where the main line refrigerant is sub-cooled while evaporating and superheating the refrigerant in the EVI line. The superheated vapour in the EVI line is then injected into the compressors intermediate vapour injection port [4].

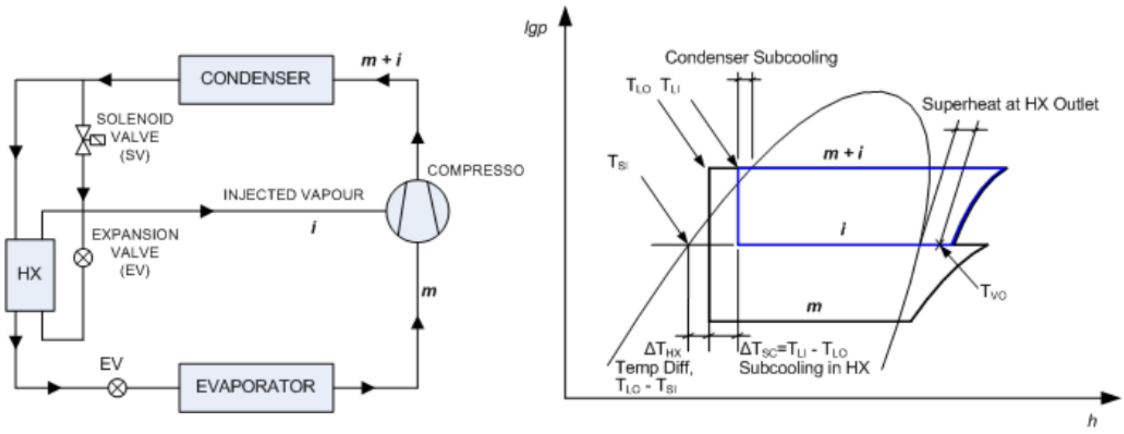

Figure 11: EVI principle refrigeration cycle and p-e diagram

The additional subcooling (T_{LI} to T_{LO}) increases the evaporator capacity by reducing the temperature of the refrigerant and the additional refrigerant mass flow from the EVI line, increases the heating capacity of the condenser (m+i). This is achieved by using the same amount of power as in the conventional compressor thus the better efficiency of EVI compressor system [4].

After researching the current EVI heat pumps on the market and discussing requirements with TAS, it was decided to develop an EVI system which has two compressors in parallel in one refrigerant circuit (aka. tandem system). Superheat heat exchanger was also added for additional DHW heating capacity. The figure 12 shows the refrigeration diagram for the EVI system Gebwell started developing and the first prototype can be found from figure 13.

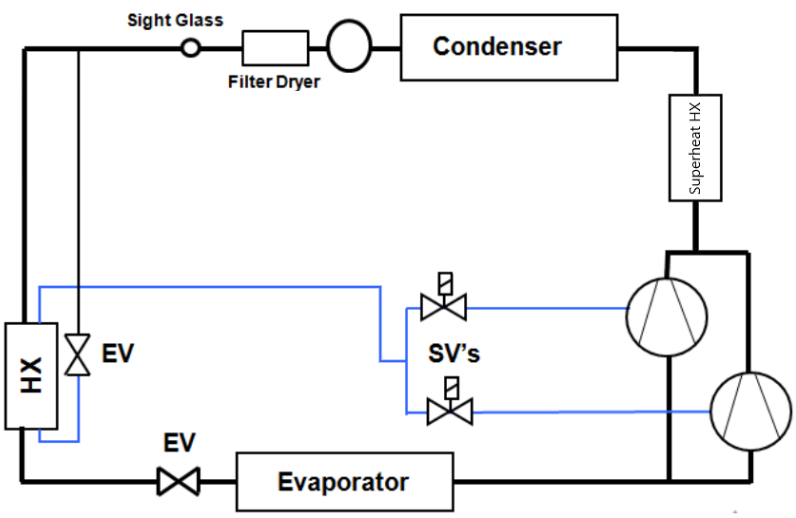

Figure 12: EVI refrigeration diagram for tandem operation including superheat heat exchanger

Figure 13: First EVI heat pump prototype

Initial results can be found in figure 14. As with the inverter development, the first EVI prototype was built into the existing Taurus 90 heat pump frame. There were similar problems with low frequency resonance/vibration sound. As such, it was decided to use a similar frame design as with the inverter compressor.

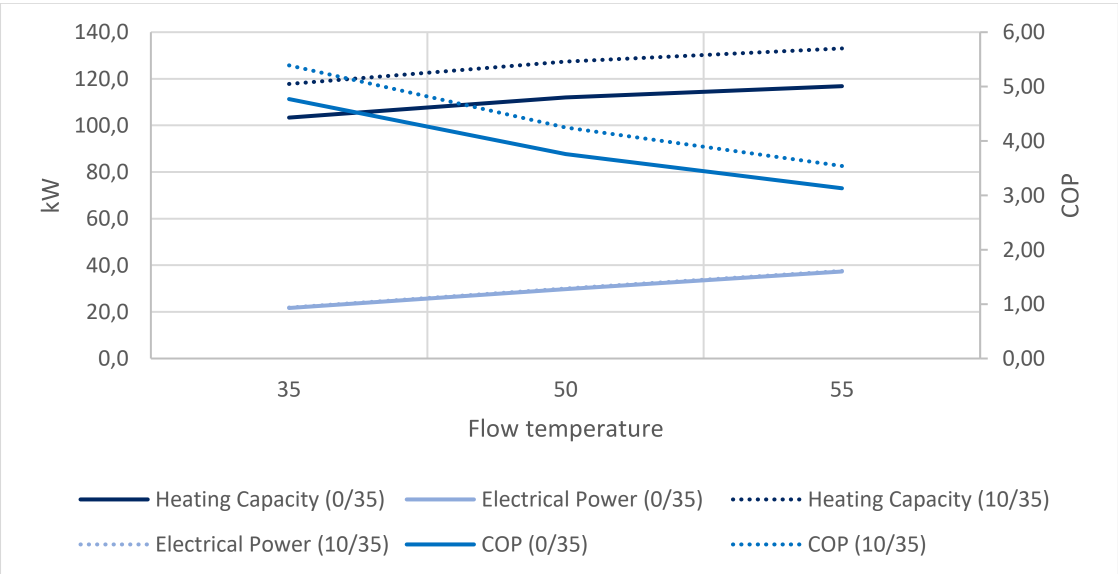

Figure 14: EVI tandem compressor test results

The new frame design went through several iterations and similarly to the inverter development, it has been difficult to find the critical refrigerant circuit pipe lengths. Inclusion of the superheat heat exchanger and EVI circuit has caused additional complexity. Especially the vibration problem with the EVI circuit piping was difficult to solve (see figure 16). The Vibrating pipe inside the heat pump not only causes excessive noise but is also a potential weak point for failures.

Several different EVI heat exchanger positions were trialled. Eventually the optimal design was found and was confirmed using same methods as for the inverter compressor heat pump.

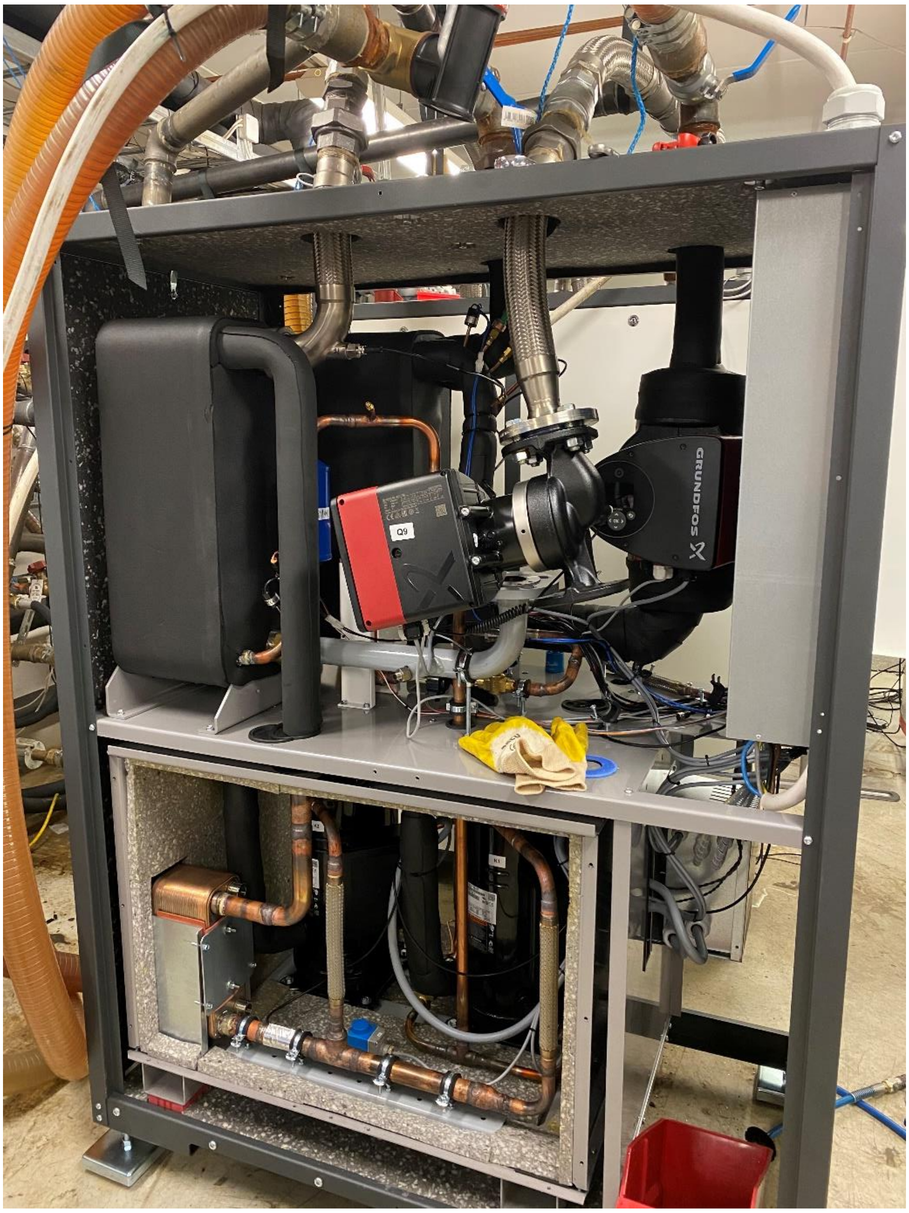

Figure 15: The new frame design including a separate encloser for the compressors

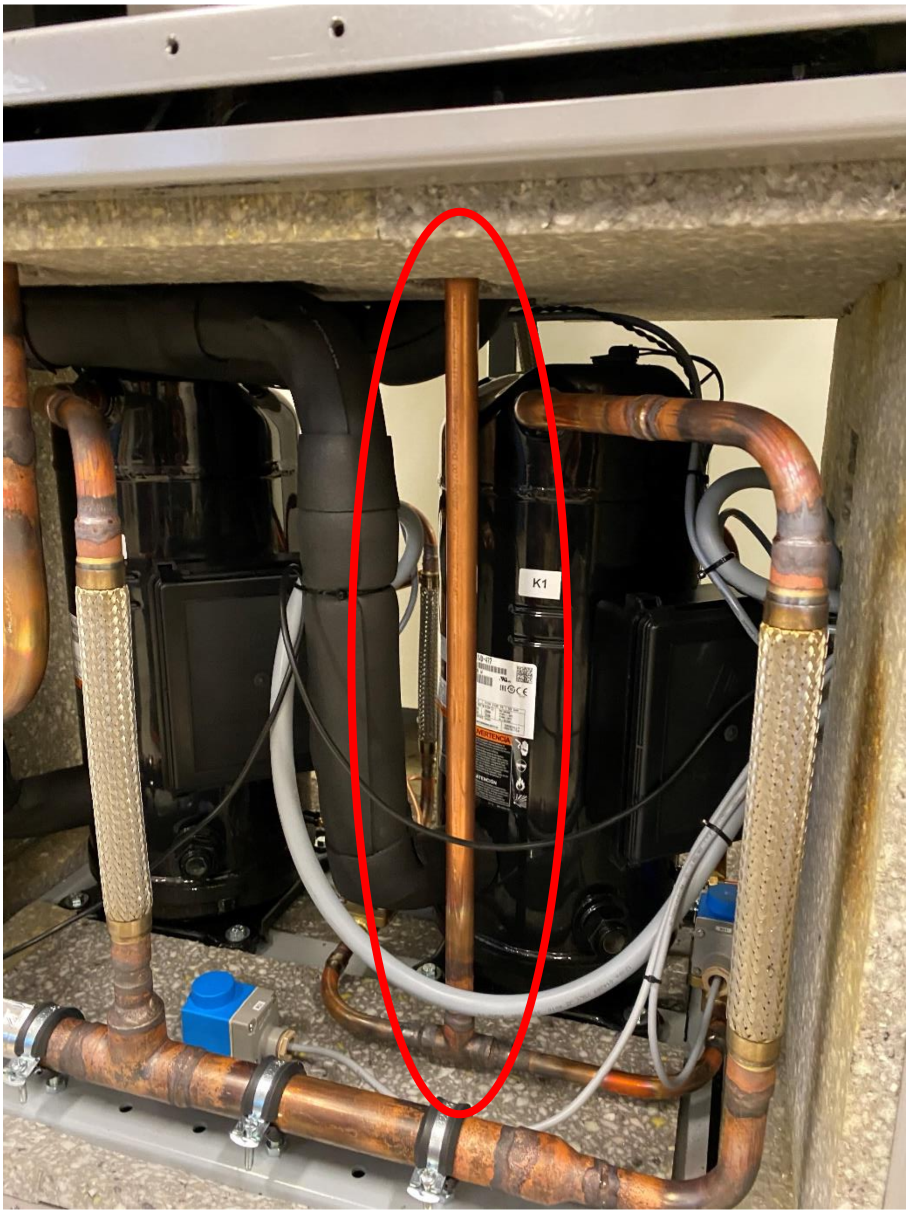

Figure 16: EVI circuit pipe (inside the red oval) has caused vibration problems

3.2 IoT development

Before the Excess project, Gebwell's Aries heat pump was the only IoT capable heat pump in Gebwell's heat pump product portfolio and the IoT environment had been developed specifically for that product. One part of the Excess project was to ensure that the Gebwell's existing IoT infrastructure would support the new heat pump(s). Gebwell is currently using the Siemens Climatix controller with heat pumps and the existing Climatix heat pump application had to be modified to support the new inverter and EVI compressor heat pumps.

The Gebwell cloud backend system had to be modified to enable connection between the developed heat pumps and the cloud. Several important aspects, like capturing relevant data points from the heat pump, had to be developed in the backend systems.

Gebwell has also worked on the cloud-based user interface "Gebwell Control Room". Through the cloud interface, the user can remotely check the status of the heat pump, analyse historical data, acknowledge any alarms on the heat pump and change / fine tune heat pump settings.

The development of smart cloud-based control algorithms has also ensued during the IoT development. More specifically, Gebwell uses learning algorithm to learn buildings heat capacity and using weather forecast information, heating optimisation algorithm can be used to optimise heat delivery from the heat pump. This concept has been successfully trialled in single-family houses and development efforts have been used to apply the same principles for bigger multi-family or commercial buildings. Gebwell has also been trialling smart wireless sensors for monitoring and controlling buildings internal environments (like. temperature, humidity, and air pressure).

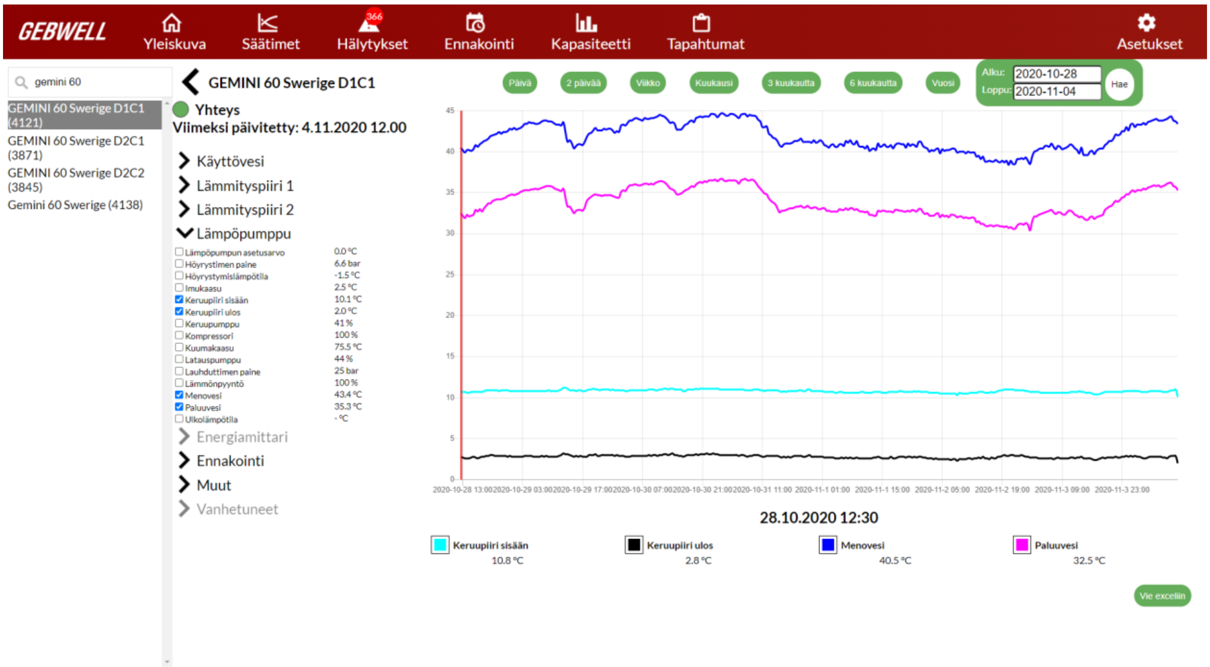

Figure 17: Gebwell Control Room user interface

3.3 High COP DHW development

The Finnish construction code dictates that the Domestic Hot Water (DHW) temperature leaving the heating unit needs to be above 55°C for older buildings and in new buildings above 58°C [7]. The primary reason for this is the elimination of legionella bacteria risk in DHW. To heat the DHW to the temperature of 58°C, more than 60°C heating water from the heat pump is needed. Since the higher temperatures greatly reduce the COP of the heat pump, there is obvious need to reduce the average temperature of the heating water in heating the DHW. In typical new buildings the percentage of DHW heating energy of the overall building heating energy is approximately 50%. In the PEB house concept, due to good overall thermal insulation (including a good U-value for windows) as well as excellent heat recovery in the ventilation, it has been estimated that the percentage of the DHW heating energy may exceed 70% of the total building heating energy. Therefore, to result in a PEB, the greatest potential in energy savings lays in DHW heating. DHW heating consists of two parts, heating of the heat energy losses in DHW circulation as well as heating the spent DHW.

TAS and Gebwell have developed together an innovative method to heat the DHW in an energy efficient and high COP way. This innovative method addresses both the energy efficient heating of the circulation heat losses as well as the spent DHW (poured from the water taps). The method is based on step-based heating of DHW, where the DHW is gradually heated from the inlet temperature of domestic cold water (DCW) to the target temperature of DHW using a specifically designed GSHP system concept [5]. The figure 18 depicts the system configuration, which consists of four stainless steel tanks, heat exchanger, the heat pump as well as the necessary actuators and circulation pumps.

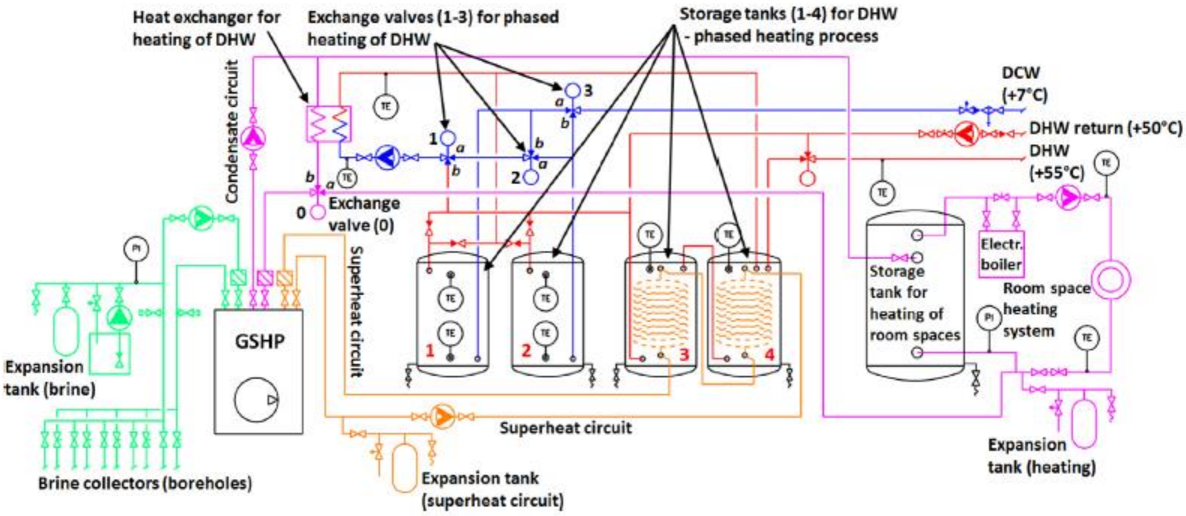

Figure 18: Configuration of the high COP DHW system.

The systems working principle is as follows: Tank 1 is gradually heated from the initial temperature of 7°C to the target temperature of 50–55°C using exchange valve 0 (connection a is closed and b is open) and the heat exchanger. The GSHP system is equipped with variable condensing operation and the DHW is heated using the step-based heating process with 7–8 steps (see Figure for the thermodynamic principle of a five-step heating process), as the temperature increase of DHW is approximately 7°C in each step. When the condensing temperature is high enough, the superheat circuit is started and the superheat energy is discharged to tanks 3 and 4, according to the temperature levels of both the superheat and tanks 3 and 4. The superheat circuit in tanks 3 and 4 is connected in series using heating coils so that tank 4 is heated first and tank 3 is heated second [5].

The thermodynamic principle of the high COP DHW system is illustrated in figure 19.

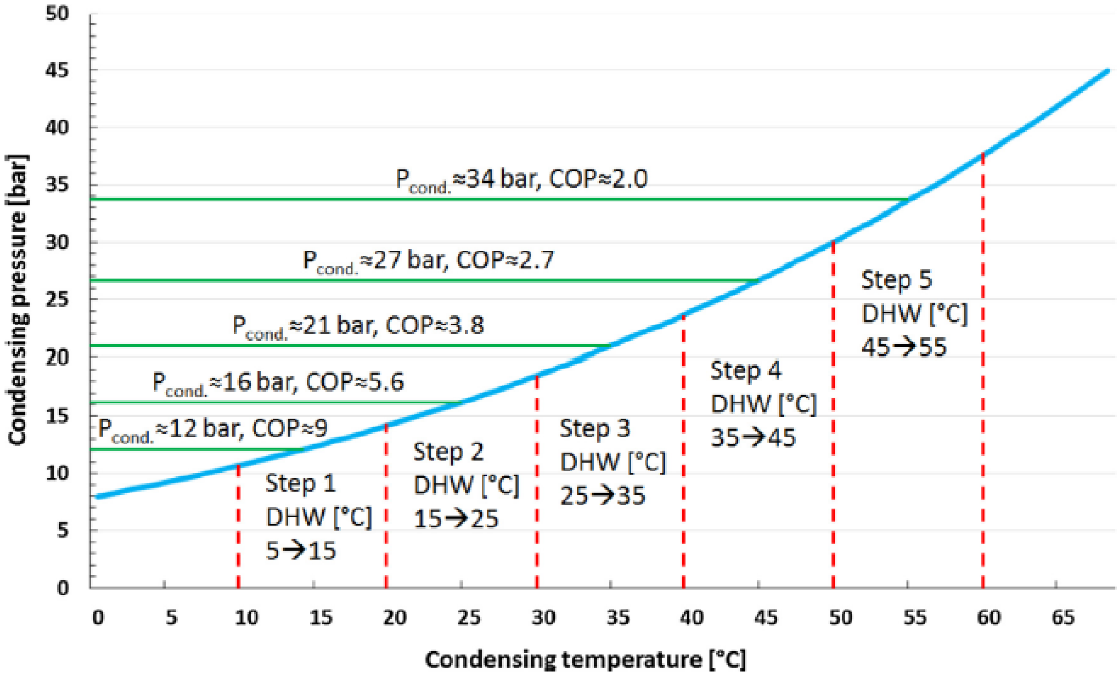

Figure 19: Thermodynamic principle of the high COP DHW system

An example of a currently working system of GSHP and high COP DHW heating system is available through TAS automation system user interface, can be found from figure 20. This system, has been installed into a multi-family residential apartment complex of 110 apartments and the system consists of four 90kW heat pumps, two units of DHW systems, a buffer tank etc. The system shown in figure 20 is about twice the size of the system needed for the Excess pilot building.

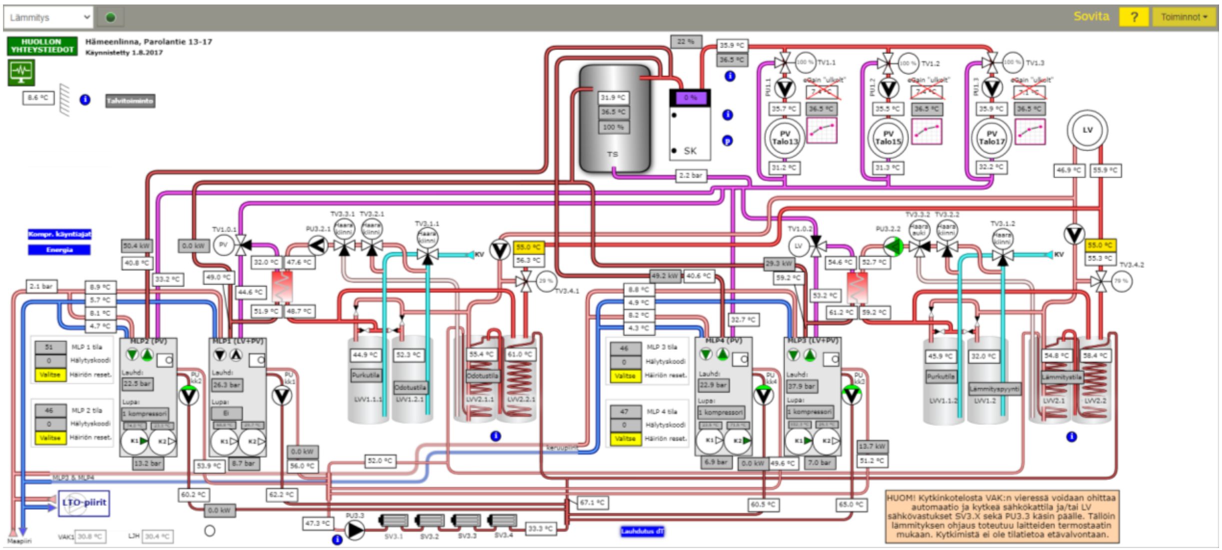

Figure 20: The current high COP DHW system view from TAS automation system

The performance of the novel DHW heating system has been described by Niemelä et. al [5]:

"The developed method was tested and validated using experimental and computational performance analyses and the energy efficiency, operation and potential limitations of the developed application were also studied in existing apartment buildings. To demonstrate the efficiency of the developed application, the performance of the new concept was compared to the performance of a conventionally used GSHP system. The results demonstrated that the developed GSHP concept delivered up to 45–50% improvement in energy efficiency of the DHW heating process over the conventional GSHP application. The measured Seasonal Performance Factors were 2.5–2.6 for the conventional application and as high as 3.7–3.8 for the developed application, when DHW was heated from 7.5°C to 55°C. "

Based on the practical experience of the novel DHW heating system in multiple TAS installed systems, some technical problems have been encountered. The initial novel DHW heating system has been based on the dimensioning so that max. 50kW heating power from the heat pump is transferred to the DHW tanks. This 50kW is derived from the 50% heating power of a GSHP such as Gebwell Taurus. This heat pump has the nominal heating power of appr. 90kW when both compressors are running, and appr. 45-50kW when only one of the compressors is running. The initial concept was to heat the DHW system with only one of two compressors.

This has proven to be a problematic solution in multiple installations since when the heat pump is running at full capacity to heat the radiator system of the building and producing appr. 80-90kW, switching to DHW heating has required switching off the other running compressor, because the heat exchanger, valves, circulation pump and the connecting tubes can only handle appr. 50kW of heating power. Subsequently, heating the DHW pre-heating tanks takes approximately 20 minutes with one compressor only and this 20 minutes gap creates a heat power deficiency in the space heating of the house. This is especially a problem in a radiator heated building and the heating power deficiency has to be compensated in cold days (typically -5°C or colder) using an electric heater. This undermines the high COP performance of the DHW heating system. This problem is accentuated in systems consisting of one GSHP only. In multiple GSHP systems, where there is one GSHP only connected to the DHW system, the issue is not quite as severe as there is always one or more GSHPs available for the radiator network. The short gaps in space heating is most likely not going to be a major problem for a PEB building with the exception if the outdoor temperature is close to the heat pump systems outdoor dimensioning temperature for an extended period as this would create sufficient heating deficiency which needs to be eventually compensated.

As a solution to this technical problem, a concept has been developed to re-dimension and re-design the high COP DHW heating system as follows:

- The heat exchanger is dimensioned for 100kW heat power transfer
- The heat exchanger is dimensioned for appr. 2-3 degrees of temperature difference between the primary (heating water) circuit and the secondary (DHW) circuit.
- The circulation pump at the secondary (DHW) circuit is dimensioned for higher flow, allowing 100kW of heat transfer
- The valves are designed for 2 x the initial flow rate
- The water tubes are dimensioned for a higher flow rate
- The after-heater tank volume was increased from current 2 x 270 litres to 2 x 500 litres.

Another major issue in the novel DHW heating system has been the small water volume of the after-heater tanks. The water volume in the after-heater tanks has been 2 x 270l. This is combined appr. 540 litres of DHW volume. This volume has proven to be too small, resulting in too frequent compressor starts and stops. Frequent compressor starts and stops can greatly reduce the compressor lifetime. The too frequent starts and stops type of problem has been addressed before in installed systems, with means of automation etc. Despite all the efforts in improving the automation, the compressor running times are too short and start and stop frequency too high especially during the summertime, when there is no need for space heating. In winter time the compressors do not start and stop too frequently due to the space heating need, that is, the GSHP running on a single compressor can combine space heating (radiator network) into the DHW heating cycles without the compressor being switched off.

The solution to the too short running cycles as well as too frequent starts and stops has been identified. Quite obviously, the water volume of the after-heater tanks must be approximately doubled. Optimum water volume for each after heater tanks is approximately 500 litres, resulting in 1000 litres DHW volume.

The DHW system automation is updated, optimizing the performance of the system with respect to the new, re-dimensioned components. One specific feature, to reduce the compressor loads, is to incorporate a function into the DHW system, such that when the DHW heating cycle is ended, and the condenser of the heat pump is at its hottest, the cool water flow through the heat exchanger and the condenser of the heat pump is arranged to reduce the pressure at the condenser, to reduce the compressor counterpressure, the mechanical loads and starting currents of the compressor. This feature needs to come into play if compressor is going to be switched off at the end of DHW heating cycle.

With the improvements to the high COP DHW heating system the great improvement in the COP of the heat pump is not sacrificed by other negative effects. This enables a well-rounded, superior efficiency of DHW in residential units aiming for PEB.

4 Results

The final 3D-drawing of the new frame for the inverter compressor can be found from figures 21 and 22. Figure 23 shows the 3D-drawing for the EVI compressor heat pump. Externally the two heat pumps look very similar, main difference being the connectors on top of the heat pump for the superheat heat exchanger.

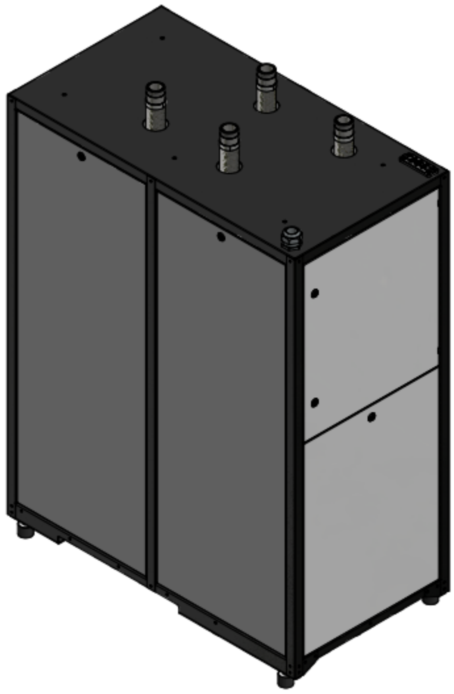

Figure 21: 3D-frame design for the inverter compressor, external

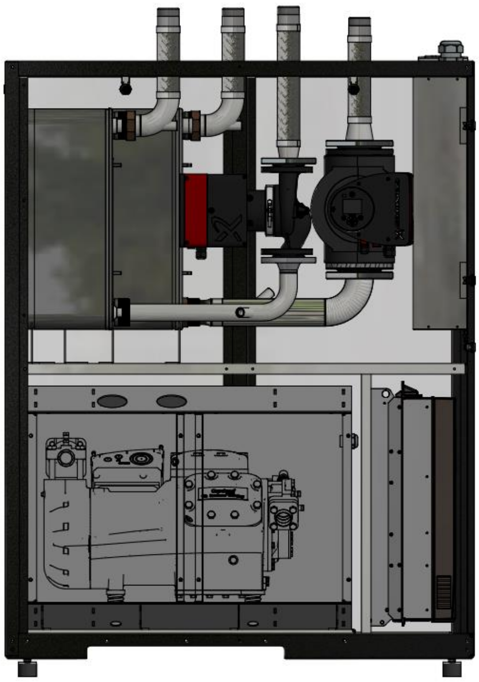

Figure 22: 3D-design drawing showing internal components for the inverter compressor heat pump

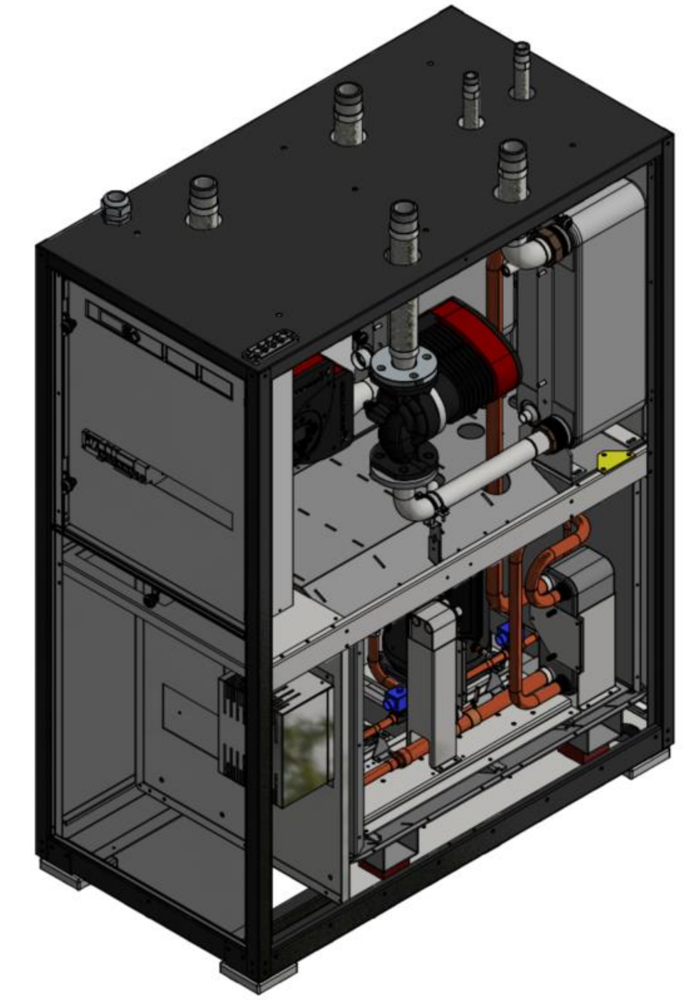

Figure 23: 3D-design drawing for the EVI compressor heat pump

Figure 24: EVI compressor heat pump on the left and inverter heat pump on the right

The inverter and EVI heat pumps performance data can be found from tables 2 and 3 respectively.

Table 2: Inverter heat pump performance table

Compressor speed (%)	Operating Conditions Brine in / Water out (°C)	Imput Power (kW)	Cooling Power (kW)	Heating Power (kW)	COP
20	0/30	8,7	30,8	39,5	**4,5**
	0/35	9,5	30,8	40,3	**4,2**
	0/40	9,8	30,1	39,9	**4,1**
	0/45	10,5	29,0	39,5	**3,8**
	0/50	11,1	27,4	38,5	**3,5**
	0/55	11,8	26,3	38,2	**3,2**
	0/60	12,6	25,1	37,7	**3,0**
	0/65	13,0	23,0	36,0	**2,8**
	0/70	13,7	22,4	36,1	**2,6**
40	0/30	13,2	44,5	57,7	**4,4**
	0/35	14,2	41,7	55,9	**4,0**
	0/40	14,9	42,4	57,3	**3,8**
	0/45	15,6	39,6	55,2	**3,6**
	0/50	16,5	38,5	55	**3,4**
	0/55	17,4	37,2	54,6	**3,1**
	0/60	18,0	34,8	52,8	**2,9**
	0/65	18,6	34,2	52,8	**2,8**
	0/70	19,6	31,9	51,5	**2,6**
64,5	0/30	18,0	60,9	78,8	**4,4**
	0/35	18,7	57,6	76,3	**4,1**
	0/40	19,9	55,7	75,6	**3,8**
	0/45	21,1	52,5	73,6	**3,5**
	0/50	22,2	49,7	71,9	**3,2**
	0/55	22,8	47,2	70	**3,1**
	0/60	24,1	44,9	69	**2,9**
	0/65	24,8	43,2	68	**2,8**
	0/70	25,8	40,7	66,5	**2,5**

80	0/30	19,9	65,5	85,4	**4,3**
	0/35	20,9	62,2	83,1	**4,0**
	0/40	21,9	58,9	80,8	**3,7**
	0/45	23	57,5	80,5	**3,5**
	0/50	24	53,3	77,3	**3,2**
	0/55	25,0	48,8	73,8	**2,9**
	0/60	25,9	47,4	73,3	**2,9**
	0/65	27,1	45,3	72,4	**2,6**
	0/70	28,2	43,8	72,0	**2,6**
100	0/30	-	-	-	**-**
	0/35	-	-	-	**-**
	0/40	26,0	63,5	89,5	**3,4**
	0/45	27,3	60,1	87,4	**3,2**
	0/50	28,0	58,4	86,4	**3,1**
	0/55	29,3	55,7	85,0	**2,9**
	0/60	30,9	52,0	82,9	**2,7**
	0/65	32,3	52,1	84,4	**2,6**
	0/70	32,5	46,4	78,9	**2,5**

Table 3: EVI heat pump performance table

Operating Conditions Brine in / Water out (°C)	Imput Power (kW)	Cooling Power (kW)	Heating Power (kW)	COP
0/25	17,5	76,9	93,4	**5,3**
0/30	19,6	79,6	98,9	**5,0**
0/35	22,0	80,9	102,3	**4,7**
0/40	24,4	81,8	105,4	**4,3**
0/45	27,1	82,1	108,2	**4,0**
0/50	30,3	81,8	111,0	**3,7**
0/55	33,9	81,0	113,4	**3,3**
0/60	38,0	79,5	115,9	**3,1**
0/65	42,9	77,6	118,4	**2,8**
5/25	17,7	87,5	104,9	**5,9**
5/30	19,8	89,4	108,9	**5,5**
5/35	22,0	90,9	112,6	**5,1**
5/40	24,5	92,1	115,9	**4,7**
5/45	27,2	92,7	119,0	**4,4**
5/50	30,4	92,6	121,9	**4,0**
5/55	34,0	92,0	124,6	**3,7**
5/60	38,2	90,7	127,3	**3,3**
5/65	43,0	89,0	130,0	**3,0**

5 Conclusions

Gebwell has successfully developed two different heat pumps using different compressor technologies. Both heat pumps could be used in the Finnish demo building for the EXCESS project. The inverter heat pump offers great capacity control, better serviceability, low GWP refrigerant. With the inverter compressor, you can also achieve high flow temperatures (around 80°C) but these kinds of temperatures are probably not required for the Finnish pilot building. The EVI compressor system offers better COP at higher temperatures and the cost of the system is less compared to the inverter system. The decision which heat pump system will be used in the Finnish demo building will be ultimately made by TAS as they are responsible for the integration of the heat pump with the rest of the heating system and are experts in heating systems design.

Both developed heat pumps are IoT capable and can be connected to Gebwell's cloud infrastructure. The user interface, which allows the user to control and monitor the heat pump, still requires further work but the basic structure is now in place.

The design changes required for the high COP DHW have now been defined. Gebwell still has make the manufacturing plan to streamline manufacturing for the new system.

Overall, all the aspect defined for the task 2.3 have been covered and the new products / technologies are very close being ready for field testing.

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