Technology Innovation:
Two stage heat pump with greywater energy recovery

The findings will be relevant to the heat pump industry, specifically designers, manufacturers and policymakers

Project lead:

Thermoelectric Conversion Systems Ltd

Partners: None

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What were the objectives of the project?

The project aimed to develop a two-stage "smart" heat pump system integrated with a thermal storage vessel to create a flexible and efficient home energy system. This innovation seeks to address space constraints and installation challenges that limit the adoption of heat pump technology in millions of UK homes. The main technical objective was to realise a domestic/small-scale system that could exploit the high Coefficient of Performance (CoP) that semiconductor Peltier devices can offer. Thermoelectric Heat Pumps (TeHPs) utilise the Peltier effect, which can increase the CoP compared to more traditional designs. The first prototype TeHP constructed by the project achieved a CoP of 12, significantly higher than the CoP of 3 typically achieved in regular heat pump systems. The main objectives of the project were:

1. **Develop an innovative, highly efficient, and compact heat pump system**:
    - Increase system efficiency by designing and integrating a low-temperature grey water source thermoelectric heat pump (WSHP) to recover thermal energy from household wastewater (e.g., bath, shower, kitchen appliances).

- Improve accessibility by designing a thermoelectric air source heat pump (ASHP) to efficiently transfer heat from the air with a small physical unit.
- Optimise the system efficiency and performance through prototype refinement.
- Enable heat pump adoption in homes with space constraints or challenging installation conditions by leveraging compact designs and innovative energy recovery methods.

2. **Integrate Heat Pumps with Thermal Storage**:

    - Combine the heat pumps with an accumulator storage system to maximise the system's efficiency and provide hot water and heating for households.

3. **Enhance System Flexibility**

    - Enhance the heat pump system's operational flexibility by creating a load balancer to support more efficient use and reduce operational costs.
    - Manage and schedule grid energy usage by facilitating seamless integration of heat pumps with Home Energy Management Systems.

4. **Start product commercialisation**
    - Obtain certifications from regulatory authorities to validate the performance of the heat pumps.
    - Ensure a successful product launch by analysing the current market and promoting the prototype.
    - Identify an efficient and cost-effective manufacturing process that is scalable.

What activities were funded?

The following key activities were funded as part of the project:

- Design of the air and water source heat pumps. This included creating functional specifications and CAD drawings of the prototypes. The prototype units were manufactured, and the performance was tested to optimise the designs.
- Design of the load management and control system. Control modules and algorithms were designed and tested to optimise the system's economic operation.
- Quality assurance of the test units to ensure interoperability and smooth integration with home energy management systems.
- Commercialisation of the product by undertaking prototype refinement, market analysis and promotion of the product. Research was conducted to investigate required safety standards and IP clearance for the product and to obtain certification from regulatory authorities.

What did the project achieve?

The project exceeded its original objectives and successfully developed and optimised a two-stage "smart" heat pump system. Grey WSHP and ASHP prototypes were constructed, tested, and refined, delivering efficiency that met or exceeded initial development models.

The system attained a greater output power than initially expected, with one prototype WSHP achieving over 20kW output. The 20kW output makes the system suitable for larger dwellings or buildings with higher heating loads, potentially reducing the need for extensive efficiency upgrades in such cases.

In total, 10 systems were built, modified or redesigned, each evaluated for specific parameters. The output range extended from 0% to 100% of the rated capacity, significantly broader than standard heat pumps, which typically operate between 40% and 100%. The system's CoP has improved significantly, from ~4.5 to ~4.9 on average, and the hardware platform has proven stable and scalable. The improvement has been tracked since the first workable system in December 2022, with ongoing refinements. The operating temperature range has also been wider than anticipated, between -30°C and 80°C, enabling efficient energy delivery to the hot water tank under any likely climatic conditions. Legionella control has also been integrated with the heat pump – something many current commercial systems cannot achieve.

The complete system was assembled and tested, demonstrating effective operation and compatibility with various components. Advanced control algorithms have been developed to optimise heat pump performance and system scalability. , By January 2025 pre-commercial activities, such as SolidWorks modelling, bill of materials preparation, and ISO 9001/MCS Certification efforts, are underway to support manufacturability and market readiness.

Furthermore, the project has laid the groundwork for market acceptance, with the heat pump showcased at industry events like InstallerShow '24. Presence at these events is key to generating interest in the product and engaging potential customers. Early demonstrations have validated the system's potential, and ongoing efforts are focused on finalising component selection, minimising model variations, and transitioning to low-volume manufacturing by 2025. The system is expected to be cost-competitive with conventional heat pumps on a kW-for-kW basis. TCS's target applications include both domestic and light commercial heat pumps, whether air-source (ASHP) or water-source (WSHP).

The final 5kW product from the project will be called "Hummingbird ®", marketed under the "Peltech ™" brand. A larger 12kW product called "Sunbird ™" will follow in late 2025 or early 2026.

Figure 1 "Hummingbird" 5kW Thermoelectric Heat Pump

Project objective 1: Develop an innovative, highly efficient and compact heat pump system

Why is this important?

Developing an innovative, highly efficient, and compact heat pump system is crucial to addressing critical barriers to heat pump adoption, such as space constraints and installation challenges in existing homes. Overcoming these barriers improves heat pump accessibility.

What activities were funded?

The main activities funded to complete this objective were:

- Creating functional specifications for the grey water source heat pumps (WSHP) and air source heat pumps (ASHP) and producing CAD drawings of the prototypes.
- Fabricating the prototype heat pumps and testing to optimise the system's energy efficiency.

What were the project findings, and did the project achieve this objective?

The project successfully constructed, tested and optimised a 6kW grey WSHP and a 4.5kW ASHP (both of these are Thermoelectric Heat Pump (TeHP). Regarding energy efficiency, the system's CoP improved throughout the project, rising from ~4.5 to ~4.9. Regarding compactness, the high-temperature ASHP was optimised to reduce physical size while maintaining performance. A stable hardware platform was established using close-to-final components to ensure robust and reliable performance.

During the development process, the project team developed a new Peltier module that combined the ASHP and WSHP's required attributes. As soon as the testing started with the new module, it became apparent that the ASHP and WSHP designs converged. From then on, the team had only one heat pump to develop further – the TeHP and not the source-dependent units. Consequently, the technical project objectives were accelerated, and the Project Plan was updated to cover these technical aspects sooner. This, in turn, gave the project team more time to address the other essential activities needed to bring a product to market eventually, including MCS certification (well on the way; it was never part of the original plan), a complete model design with part numbers, complete CAD drawing, etc. (needed to produce the manufacturing data), and so on. This, in turn, gave the project team the basis for seeking ISO 9001 accreditation.

In addition to the original project objective, the project team also developed a quiet and compact fan unit for the ASHP and a very high CoP bypass unit for the hot water tank that instantly kills any Legionella bacteria that may be present.

Project objective 2: Integrate heat pumps with thermal storage

Why is this important?

Integrating heat pumps with thermal storage can help to maximise system efficiency and ensure reliable hot water and heating for households. Thermal storage enables the heat pumps to operate flexibly, storing energy during periods of low demand or when renewable energy is abundant and using it when needed. This integration enhances energy efficiency and supports demand-side management, reducing strain on the grid and optimising energy use.

The CoP of a Peltier device decreases exponentially as temperature increases and also varies depending on the electrical current passing through the device. When the temperature difference (ΔT) and current are low, the CoP can easily exceed 60. This means the hot water tank can act as a thermal integrator (as a simple store, not as a smart storage system), storing heat from the device, which can be released gradually when needed. The next stage of development will explore designing a combi boiler replacement capable of delivering continuous high-flow temperatures.

What activities were funded?

The main activities funded to complete this objective were:

- Development and testing of accumulator storage tanks.
- Establishing the optimum drive conditions to maximise overall system efficiency.

What were the project findings, and did the project achieve its objective?

Key achievements included developing and testing accumulator storage tanks with indirect coils for heat transfer from the WSHP and the ASHP. The thermal store was designed to provide hot water and heating, enabling efficient energy storage and delivery. System-level testing confirmed compatibility between components, while performance optimisations, such as improved power delivery (>10 kW) to the thermal store, enhanced overall system scalability and efficiency.

Project objective 3: Enhance system flexibility

Why is this important?

Enhancing system flexibility helps the heat pump system adapt to varying household energy demands, weather conditions, and grid requirements. By incorporating a load balancer and advanced control algorithms, the system can optimise operations in real-time, seamlessly integrating with home energy management systems and enabling demand-side management. This flexibility allows for efficient energy use, minimises operating costs, and supports the integration of renewable energy sources, making the system more sustainable and cost-effective. A flexible system also ensures compatibility with diverse household configurations, increasing its appeal and accessibility for widespread adoption.

What activities were funded?

The main activities funded to complete this objective were:

- Develop a load balancer to optimise the economic operation of the heat pumps.
- Facilitate seamless integration with Home Energy Management Systems to schedule and manage grid energy usage.

What were the project findings, and did the project achieve its objective?

The project successfully enhanced system flexibility through several key advancements. The design and testing of a load balancer optimised the heat pump's economic operation based on factors such as weather conditions and household energy demand. Advanced microprocessor controls and software interfaces were developed to fine-tune the heat pump performance, ensuring dynamic responsiveness to varying operating conditions.

Furthermore, the project team introduced a new concept in analysing thermoelectric heat pump performance: pyroconductance. Pyroconductance has the units of Amps per °C, allowing a control system to adjust the current flowing through the Peltier modules to the optimum efficiency point for a given thermal operating point. Currently, there is no standard analytical or theoretical solution for optimising Peltier device performance, as their behaviour is highly non-linear and rooted in complex semiconductor physics and quantum mechanics. The TCS team's approach has been to develop an empirical solution confined to a specific operating range that works effectively for their system. This allows the control software to apply the concept of pyroconductance in a practical and accessible way.

Project objective 4: Start product commercialisation

Why is this important?

Product commercialisation translates the project's technical achievements into real-world impact. The project can enable the widespread adoption of this innovative technology by bringing the heat pump system to market. Commercialisation enhances the system's availability to consumers, fosters industry growth, and creates economic opportunities. Additionally, refining manufacturability, securing certifications and building a competitive product line will establish a strong foundation for scaling production, improving affordability, and driving market acceptance, ultimately accelerating the transition to low-carbon heating solutions.

What activities were funded?

The main activities funded to complete this objective were

- Testing and refining the prototype heat pump system based on research into regulatory requirements and safety standards.
- Engaging with manufacturing partners and suppliers to identify a cost-effective manufacturing process.
- Ensuring market readiness by pursuing ISO 9001 and MCS certification and promoting the product at industry events to assess demand, gather feedback, and identify potential customers.

What were the project findings, and did the project achieve its objective?

The heat pump system was refined into a stable, high-performance prototype that met commercial viability standards, such as being technically sound, economically feasible, and ready for market adoption. The project secured partnerships with local suppliers for critical components, such as weatherproof metalwork and custom fabrications, enabling cost-effective and efficient manufacturing. The team focused on simplifying product variations, making the manufacturing process more efficient and ready for scaling.

Progress was made in pursuing ISO 9001 and MCS Certification, ensuring the product met the required quality and regulatory standards for commercialisation. These certifications help build consumer trust and market acceptance.

The heat pump was showcased over two days at InstallerShow ’24, receiving positive feedback and generating interest from the market. This helped assess product demand and gain early adopter support.

TCS has sold a small number of TeHP derivatives of the design formulated as part of this project. These include a 20kW / 3Φ / 415V unit used as a WSHP in cooling mode and a 3kW WSHP grey water heat recovery unit connected to a 48V off-grid PV system for an eco-house that is not grid connected.

Summary

What impact will this have?

The project has significantly advanced in creating an efficient, compact, commercially viable heat pump system. Developing a highly efficient and compact heat pump system addressed critical barriers to adoption, particularly for homes with space constraints. Improved performance (CoP ~4.9) and scalable power delivery (>10 kW) were achieved. By integrating the heat pumps with a thermal storage system and optimising operation through advanced controls and load balancing, the prototypes developed under the project can support reliable and flexible energy use. Achieving key milestones in prototype testing, manufacturability, and certification paves the way for product commercialisation. The positive reception at InstallerShow ’24 and support from additional grant funding will aid market entry.

The system is designed to be suitable for over 75% of the market. Its compact size, split-system configuration, and deep modulation capability make it adaptable to a wide range of properties, including multi-storey blocks and flats, which are typically unsuitable for traditional heat pumps. While the system benefits from larger water tanks, it does not rely on them, offering installation flexibility.

The system has gained strong interest from housing associations, which see it as the only viable retrofit and decarbonisation solution for their housing stock. Meanwhile, architects consider it an ideal choice for new builds, citing its ease of integration as a key advantage.

Focusing on manufacturability and cost-effectiveness, the project positions the heat pump system developed under the Heat Pump Ready Programme as an efficient and accessible solution for households, developers, and energy suppliers.

What's next?

TCS Ltd is actively seeking to rapidly expand its ability to manufacture TeHPs in large numbers. If successful it hopes to exceed 100,000 units per annum by 2030, with the potential to yield a £500M per annum business.

Where to find out more

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