Project Case Study: Modular Heat Pumps for Cell-Based Microfactory Assembly

Project theme:

Innovation in heat pump manufacturing

Project lead:

Ventive

Partners:

QM Systems (no longer partners – went into administration. Their project participation ended in July 2024)

Clear Blue Energy

Contact:

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Funding:

£1,498,858

Project duration:

2022-2025

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What were the objectives of the project?

To address critical issues in the heat pump market, such as high costs, unsightly designs, and complex installations, the project developed an innovative modular heat pump design and a semi-automated cell-based assembly process. These issues impact various stakeholders: consumers face affordability challenges due to high costs, installers and property developers encounter difficulties with complex installations, and unsightly designs can deter homeowners and end-users.

Unlike traditional heat pumps, the semi-automated modular design allows for more flexible manufacturing, reducing production costs. While the installation process remains largely the same, the modular components simplify the setup, allowing installers to work with pre-assembled units that are easier to handle and integrate into homes.

The heat pump unit used in this project is an exhaust air heat pump (EAHP), which extracts heat from the building’s ventilation system. EAHPs are typically compact and can be installed indoors, making them ideal for buildings with limited outdoor space. However, standard EAHPs can struggle to meet peak thermal demand in most homes. To address this, Ventive EAHPs incorporate a high-capacity phase change material (PCM) thermal storage system. This enables the unit to modulate its thermal output in response to fluctuating demand, delivering up to 6 kW during peak periods by supplementing the compressor with stored heat energy. The system replenishes off-peak, enhancing efficiency and cost-effectiveness compared to conventional EAHPs. This innovative design can help improve consumer energy efficiency through lower bills while supporting grid operators with better load management.

The system is scalable for both new builds and retrofits, making it easier for developers, housing associations, and homeowners to meet sustainability targets. Overall, the modular approach drives down manufacturing costs and supports the wider adoption of heat pumps, benefiting manufacturers, installers, and policy-makers working toward environmental goals. Ultimately, the project aimed to **provide a scalable heat pump solution suitable for new builds and retrofits**, helping **reduce manufacturing costs**, **improve efficiencies and promote wider heat pump adoption**.

Specific project objectives were:

1. **Develop modular heat pump design**: advance the design of a modular, platform-based heat pump system that is scalable and interchangeable, enabling flexible use across various applications.
2. **Design and implement a cell-based assembly process**: streamline production for efficiency and scalability.
3. **Conduct testing and certifications** to enable the widespread adoption of the technology innovations developed under the project.

What activities were funded?

Several key activities were funded as part of the project to help develop and optimise modular heat pump technology. These included design and specification optimisation for the heat pump and its assembly process and setting up a prototype micro-factory. This micro-factory featured a cell-based assembly station, substation prototypes, and an End of Line (EOL) test station prototype for heat pumps. Additionally, production and EOL testing controls and software were developed, certifications and testing were carried out, and a comprehensive supply chain and Value Optimisation (VO) report was created. The project also included on-site trials and demonstrations to validate the technology.

What did the project achieve?

The project achieved significant milestones in developing a modular heat pump system design, although production at scale has not yet been realised. The conceptual design of the modular heat pump unit and the factory setup are shown below. Figure 1 shows the parallel production of modules. It also demonstrates that the semi-automated assembly process retains human involvement.

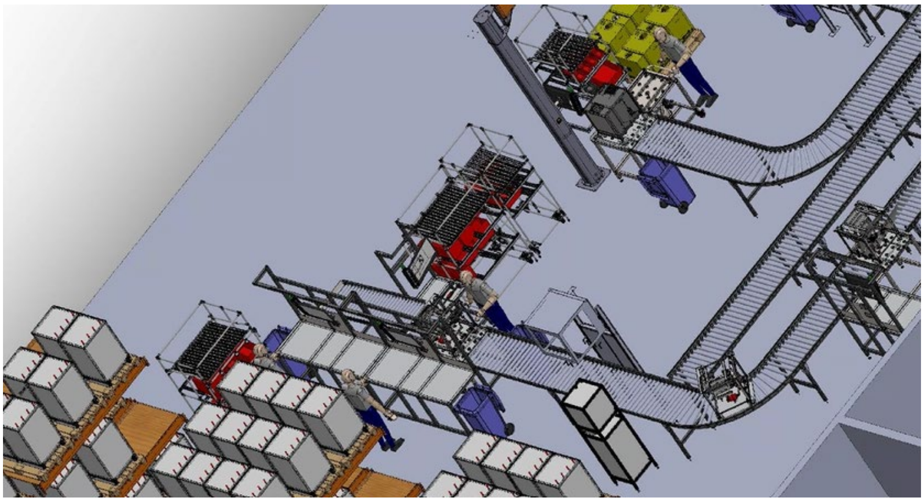

Figure 1: Illustration of the parallel production of modules

A factory was set up but had to be relocated after one of the project partners, QM Systems, went into administration during the second half of the project. Despite this challenge, the team overcame several technical hurdles, particularly integrating phase change materials (PCM). Initial difficulties with low-temperature PCM modules, which failed to melt as expected, were resolved by redesigning the refrigeration cycle. This included using a new compressor and refrigerant (R32) to accommodate higher discharge temperatures. While this adjustment resulted in lower overall system efficiency, achieving a Coefficient of Performance (COP) of 3, the team anticipates that alternative refrigerants such as propane (R290) could boost the COP to nearly 4. A heat pump with a COP of 4 is considered very efficient. This means that for every unit of electrical energy used, the heat pump provides four units of heating energy.

A fundamental concept of the system includes its ability to store energy through PCMs. A PCM can store and release large amounts of energy, which helps maintain a stable indoor temperature, reducing the need for additional heating. Using PCM can also enable demand-side flexibility by responding to carbon and price signals, which was successfully validated within this project through testing at Brunel University. The integration of PCM makes the system more adaptable to future growth in demand-side response markets, where flexible energy consumption is critical. Additionally, PCM integration future-proofs the heat pump system by enabling greater compatibility with excess and renewable energy sources. While integrating PCM storage can significantly increase overall efficiencies, it is still challenging to integrate it with the heat pump system due to complex design requirements and thermal efficiency concerns. The project aimed to overcome these challenges by developing advanced control strategies, optimising system architecture, using cost-effective materials, ensuring compatibility with current technologies, and adhering to regulatory standards through rigorous testing and certification processes.

Project objective 1: Develop modular heat pump design

Why is this important?

Developing a modular heat pump design is important because it could improve production efficiency and reduce costs. Heat pump units of various types and sizes can be constructed using standardised and interchangeable modules. Modular units are scalable, allowing manufacturers to produce heat pumps that can be easily configured to meet specific customer requirements, e.g., bespoke heat exchangers and air handling units. The modular design simplifies the assembly process, as the main components of the heat pump are bolted together, offering flexibility when assembling different modules. This flexibility means the same core components can be used across various configurations, depending on customer needs. As a result, **modular designs streamline manufacturing, reduce costs, and enhance the adaptability of heat pump systems in diverse applications**.

What activities were funded?

The main activities funded in the project focused on the conceptual design and testing of a scalable modular heat pump that integrates phase change materials (PCM) for energy storage. This included developing the modular system and building and testing the heat pump units to ensure they were functional and scalable.

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

The heat pump was tested at the Clear Blue Energy Lab in Scotland. Key findings centred around integrating different components and achieving acceptable operating efficiencies.

The system's operational efficiency was tested and validated, described in more detail in Objective 3, including PCM information. However, the anticipated benefits of the modular approach—such as improved production efficiency and scalability—could not be fully demonstrated within the project timeline. This is because large-scale production, which is essential for validating the advantages of modular design over traditional approaches, was not achieved during the project. Therefore, while significant progress was made, the project’s full objectives relating to production validation remain to be explored in future stages.

Project objective 2: Design and implement a cell-based assembly process

Why is this important?

Designing and implementing a cell-based assembly process is important for modern manufacturing. It enables the creation of smaller assembly lines that eliminate the need for large, costly setups. By adopting a modular cell-based approach, the assembly process can be significantly accelerated, allowing for quicker production times. Each module within this system can undergo individual testing and verification before integration into the final unit, enhancing overall quality and consistency. Furthermore, this method minimises human error and ensures that each module meets the necessary standards through automation, leading to a more reliable and efficient manufacturing process. Fully automated production lines often require a high initial investment in specialised machinery and infrastructure. A modular system focuses on smaller, adaptable units, which generally require lower initial capital expenditure and can be more cost-effective to maintain.

What activities were undertaken?

The activities undertaken included the design of the factory setup and its components, specifically focusing on mobile trolleys and robotic cells. This involved creating layouts that optimised workflow and efficiency within the manufacturing environment. Following the design stage, QM Systems implemented a semi-automated assembly approach, leveraging robotic cells and trolleys to streamline production processes. This integration of robotics aimed to enhance the speed and accuracy of assembly tasks and to allow for greater flexibility in adapting to varying production needs. Following the factory set-up, the first cell-based assembly prototype was developed. Several DV (Design Validation) Prototypes of the Modular Heat Pump have been completed and tested. One of these prototypes is shown in Figure 2.

Figure 2: Modular Heat Pump prototype

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

The project successfully designed and set up a factory, implementing a flexible and efficient layout where mobile trolleys replaced traditional conveyor belts. This shift improved mobility and adaptability within the assembly process. The production set-up assembly is shown in Figure 3.

Figure 3: Production set-up assembly

Although the factory line was built, it has not yet been tested for production, and no units have been assembled using the new setup. As a result, the assembly line has yet to be validated, and this will take place outside the timescale of the Heat Pump Ready project.

Project objective 3: Conduct testing and certifications

Why is this important?

Testing and certifying the proposed modular heat pumps is crucial to ensure safety and performance. Certifications such as CE marking are important as they confirm compliance with European safety, health, and environmental protection requirements. Furthermore, certifications build confidence among consumers and regulators and support broader adoption.

What activities did the project fund?

- The project involved rigorous testing. Kiwa (a global leader in testing, inspection, and certification (TIC) services) and Centre for Built Environment (CBE) conducted these tests to ensure the system met all performance and safety standards. This included evaluating the system's efficiency, durability, and overall functionality.
- Brunel University focused specifically on testing PCM components. This testing did not involve the full assembly of the heat pump system but instead concentrated on the performance and characteristics of the PCM storage.
- The project aimed to secure CE Marking for the production prototype of the modular, integrated heat pump. This certification is essential for selling the heat pumps in the UK and involves passing various tests, including EMC, CE Marking, and UKCA tests to ensure compliance with relevant health, safety, and environmental standards.

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

Challenges such as low charging/discharging rates were encountered during initial PCM testing. This issue has been resolved by adapting the system to use an alternative PCM module with higher discharge temperatures. Modifications also included using a new compressor and refrigerant (R32 – propane) to accommodate higher discharge temperatures. While this adjustment resulted in lower overall system efficiency, achieving a Coefficient of Performance (COP) of 3, the team anticipates that alternative refrigerants such as propane (R290) could boost the COP to nearly 4.

A significant challenge emerged at this stage due to the lack of established test procedures for components like PCMs. As a result, the team could not secure CE markings. Final testing is scheduled for May 2025, at which point the team will work to address these challenges and achieve full certification.

Summary

What impact will this have?

The new modular heat pump technology will support the wider adoption of heat pumps by offering consumers a broader choice of options. One notable advancement is the enhancement of exhaust air heat pumps, which traditionally have limited thermal output, constraining their application primarily to commercial buildings. Integrating PCMs into these systems boosts their thermal output and enables them to be applied to larger or less efficient homes.

The modular design further enhances this technology by allowing for customisable configurations, making it easier to tailor the system to specific needs and building types.

The project also successfully established a cell-based factory with a flexible layout, replacing traditional conveyor belts with mobile trolleys. This change enhanced mobility and made the assembly process more adaptable.

Overall, this innovation expands the range of properties that can benefit from heat pump technology and introduces possibilities for greater flexibility in system deployment, which could lead to reduced operational costs. Ultimately, these advancements could facilitate a more extensive acceptance and integration of heat pumps in various sectors, including residential homes and commercial buildings, promoting sustainable heating solutions across diverse residential and commercial applications.

What’s next?

The project's next steps involve several key initiatives to further enhance the modular heat pump technology. One important focus will be exploring using R290 refrigerant to increase efficiency. Further testing is scheduled for May 2025, when the team will validate the current heat pump configuration and assembly process.

Plans are underway to develop an additional air source module to use outside air as a heating source. This new module would complement the existing exhaust air module, providing flexibility in operation, mainly when exhaust heat is unavailable. These strategic next steps aim to refine the technology, expand its applicability, and ensure it meets the demands of various environments and consumers.

Where to find out more

https://ventive.co.uk/

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