Government challenges.
Ideas from business.
Innovative solutions.

Department
for Environment
Food & Rural Affairs

SBRI End of Phase Report Form

This report is the company's opportunity to describe the work undertaken during the contract. Describe what work was completed during the project and why this was important. If the work was part of a two phased programme this report will form part of the assessment for Phase 2, it is therefore important that applicants complete the form as completely as possible.

This report must be submitted within 14 days of the completion, or termination, date. The successful contractor should be well motivated to complete this report as completion of this report forms part of the contract.

The report should be submitted to Defra's Climate Ready team at Nobel House, 17 Smith Square, Westminster, SW1P 3JR.

The objectives of reporting:

- to report on the work undertaken, its success in meeting the project's agreed objectives and to provide information on the work so that this can be used in the assessment of further applications (if required and appropriate);
- to explain and prove expenditure; and,
- also provides the company with a comprehensive report to share with stakeholders and those that may help further commercialisation.

The report should be completed by the lead contractor, with input from any sub-contractors or project partners as appropriate. Please answer, wherever possible, on behalf of the business units, divisions, or companies which were involved in the work. If this is not possible (as a result of merger or acquisition, for example), please specify the organisation to which your answers refer.

Please answer the questions in the spaces provided. Try to answer fully, but keep your answers succinct and no longer than necessary to clearly explain them. When describing technical solutions, please regard your audience as being someone familiar with the technology, but not an expert. The report may be done in narrative alone, however diagrams or pictures may be added where these aid clarity within the restriction on the page limit of a total of eight sides of A4.

Because the true impact of an R&D project often takes several years to emerge, Defra or the Technology Strategy Board may approach you for up to six years after project completion to follow up on the questions in this report. Your co-operation with any such follow up work is greatly valued.

1. Details

Registered Company Name: **Greengineering Limited**

Registered Address: **15 Gheluvelt Avenue**

Town/City: **Kidderminster**

Postcode: **DY10 2QP**

County: **Worcestershire**

Country: **UK**

Report Author: **Penelope Brudenell-Pryke**

Telephone Number: **01562 752244**

E-mail Address: **peni@greengineering.co.uk**

Project Reference: **CA0517_3 SBRI project on infrastructure / built environment climate resilient sector designs; Greengineering Ltd re improving the performance of heat pump systems.**

Report Type: **End of Project Report**

Total Contract Cost: (£s) **50,350**

Start Date: **01/01/2014** End Date: **31/03/2014**

2. At the outset of this piece of work what were your aims and objectives?

The UK Government and others are promoting the use of heat pumps as a method of achieving 2020 energy and carbon targets. However, to be successful this requires heat pump technology to be developed further. Some organisations are improving compressor performance with others using more environmentally friendly refrigerant gasses.

Greengineering has been focussing on alternative methods of improving the efficiency of heat pump systems, making a step change in the usage and control of heat pump systems. The technology prototyped in this project has the capacity to lower energy consumption, CO2 emissions and fuel poverty. This project also fulfilled 3 of the requirements specified in section 42 - CCRA Risk of the National Adaption Plan 2013. (Relevant sections: BE1 – Urban Heat Island, BE3 – Overheating of Buildings, EN2 – Energy Demand for Cooling.)

This project used existing technology in novel ways, and hence is a new application of an existing technology. The results of our findings will also lead to heat pumps being more popular, thus extending the application of the existing technology.

The aim of this project was to improve the performance of thermodynamic solar heat pump system. These systems show enormous potential and with some improvement in performance, could dominate the domestic market. The main thrust of the project was to try to reduce operating costs. The concept for this system has attracted interest from social housing organisations and others, who seek to alleviate fuel poverty. There is also a commercial application for the technology to be demonstrated in this project.

The objective of this project was to build a prototype demonstrator to provide test data and develop interest from the industry and potential users of the system, within the agreed project budget and time frame, to the planned quality.

3. Please provide a summary of the outputs of this project and relate these to the original objectives. How do the outputs address the requirements of this competition?

The UK Government and others are promoting the use of heat pumps as a method of achieving 2020 energy and carbon targets. However, to be successful this requires heat pump technology to be developed further. Some organisations are improving compressor performance with others using more environmentally friendly refrigerant gasses.

Greengineering has been focussing on alternative methods of improving the efficiency of heat pump systems, making a step change in the usage and control of heat pump systems. The technology prototyped in this project has the capacity to lower energy consumption, CO2 emissions and fuel poverty. This project also fulfilled 3 of the requirements specified in section 42 - CCRA Risk of the National Adaption Plan 2013. (Relevant sections: BE1 – Urban Heat Island, BE3 – Overheating of Buildings, EN2 – Energy Demand for Cooling.)

This project used existing technology in novel ways, and hence is a new application of an existing technology. The results of our findings will also lead to heat pumps being more popular, thus extending the application of the existing technology.

The aim of this project was to improve the performance of thermodynamic solar heat pump system (TSHPS). These systems show enormous potential and with some improvement in performance, could dominate the domestic market. The main thrust of the project was to try to reduce operating costs. The concept for this system has attracted interest from social housing organisations and others, who seek to alleviate fuel poverty. There is also a commercial application for the technology to be demonstrated in this project. The objective of this project was to build a prototype demonstrator to provide test data and develop interest from the industry and potential users of the system, within the agreed project budget and time frame, to the planned quality.

Prior to the start of this project the deliverables were defined as:

- Interim and end of project reporting
- Working prototype

The interim reporting was submitted as required part way through the project. This report forms part of the end of project reporting.

Delivering the reporting provided reassurance to the project team that the appropriate project controls were in place, and that the project was under control. This also meets the requirement to deliver the project within budget and time frame, to planned quality.

The working prototype system was built using a combination of commercially available off the shelf items and bespoke items. The heat pump management system includes a simple controller with bespoke software and refrigeration valve assemblies. The bespoke components were integrated into a conventional TSHPS for testing and demonstration. The heat pump system was a commercially off the shelf unit, connected to the bespoke parts of the system in a novel way.

The practical testing results have furnished us with data to be used in marketing the system.

In practice the design of the bespoke elements of the system are scalable, to suit both domestic and to commercial applications.

We used a Flir thermal imaging camera in the project to provide information on thermal flows, and to aid in improving performance of the system. Some of these images have been included in the project reporting.

For the prototype the initial controller used was an industrial standard Allen Bradley Micro800 series. This was relatively easy to programme and control, and allowed us to test the programme logic, and function of the system.

This prototype demonstrated that it is feasible and affordable to improve the performance of TSHPS in the UK climate.

This working prototype is capable of providing the following benefits to heat pumps:

- Lower frequency of compressor cycling, thus reducing wear and tear on the compressor.
- Increase capacity for water heating, without increasing fuel usage.

The system could be utilised in commercial buildings to capture waste thermal energy and use this to h water. The use of air sourced heat pump systems (ASHPS) in hotels for example, has sometimes pro to be problematical due to the noise of the external units. Our technology applied alongside a TSH could provide a better solution. This would allow the noisiest component, the compressor, to be locate a sound insulated area indoors, thus preventing noise pollution. Improvements to the performanc these systems will make them more attractive to hotel owners and guests.

All ASHPS work well in summer; however the performance improvement provided by this technology will improve the viability in winter months.

Our technology applied alongside a TSHPS could provide a better solution for city dwellers. The capture of the thermal energy will reduce the effects of the Urban Heat Island. This will reduce the overheating in buildings and consequential energy used for running traditional air conditioning.

Due to the commercially confidential aspects, the system is described more fully in separate document; ***Annex A***.

4. Describe any changes to the original project. What was the reason for these changes? Please include any circumstances that aided or impeded the progress of the project and the actions taken to overcome them.

The project start was delayed due to contractual difficulties. In order to rectify the situation and ensure completion of the project on time various actions had to be taken. These included an increase in planned working hours, rescheduling some tasks, and changing some of the planned components. Thus we have been able to successfully complete the first milestone as planned.

The type of thermodynamic solar heat pump system (TSHPS) purchased has changed from that originally planned. The one actually purchased was almost identical to that planned, but was slightly more expensive. The original plan was to purchase a product for import. However, due to the delay in starting the project the deadline for ordering the product had passed before we were able to place the order. Hence a suitable alternative had to be resourced.

Some of the other key components purchased were changed from those originally planned. These were slightly more expensive but better suited to our requirements.

This project required additional business premises to locate the test rig for the prototype. The original business unit which was used for the cost estimate was not available when required and a slightly more expensive alternative option had to be taken.

The original plan included installation of the external evaporator on a roof or wall. The location of the business workshop unit did not facilitate the correct orientation of solar gain for the heat pump system. The terms of the business unit lease did not allow this. We therefore designed a mobile test bed based on a pallet truck measuring 70cm x 1200cm. This included the external evaporator, heat pump and solenoid valves. The system used flexible water pipes to connect to the hot water cylinder. This allowed the evaporator unit to be located outdoors with the roller shutter protecting the heat pump and valves. This worked well and allowed testing to continue as planned.

The development and installation of the control system software also had to be rescheduled to fit in with the other project changes.

The heat pump worked at the lower end of its performance curve which assisted testing. The increased cycling of the heat pump in these conditions was beneficial to the project. It allowed us to demonstrate the ability of the system to lower or prevent cycling. An unexpected result of the testing was an additional method of increasing the COP of heat pumps.

The cost of the air conditioning engineers was more than we budgeted for. This was partly due to a fault with one of the components and partly due to additional testing. Unfortunately the original thermodynamic panel was faulty, and therefore the engineers had to fit a replacement. We also carried out some additional testing which involved the engineers modifying the configuration of the system.

The heat pump compressor proved to be more reliable than anticipated; therefore we did not have to replace it during testing.

Due to the commercially confidential aspects, this is described more fully in separate document; **Annex A**, and will be the focus of a future research and development project for Greengineering Ltd.

5. Please provide a short factual summary of the most significant outcomes of your work.

Due to the commercially confidential aspects, the system is described more fully in separate document; **Annex A.**

We have developed a system which is capable of improving the coefficient of performance (COP) of thermodynamic solar heat pump systems (TSHPS). This system is scalable which can be adapted to suit both commercial and domestic applications. Our system is also suitable for improving the performance of other types of heat pumps, including traditional air sourced heat pumps.

A method of recovering additional thermal energy was tested during the project. This was effective and reduced the cycling instances of the compressor. The additional thermal energy was recovered with some difficulty as the compressor was a fixed speed unit. This resulted in some overheating issues which could be addressed with an appropriate variable scroll type.

The project was able to demonstrate the adaptability of the TSHPS and the environments where it can be used.

This working prototype is capable of providing the following benefits to TSHPS:

- Lower frequency of compressor cycling, thus reducing wear and tear on the compressor.
- Increase capacity for water heating, without increasing fuel usage.

These same improvements may also be applicable to other types of heat pump systems, including air sourced.

The thermodynamic heat pump used in testing used a fixed speed compressor. This was a basic system which could only operate with the compressor on or off.

- The following graphs contain measurements of the refrigerant temperature at the inlet and outlet of the heat pump. The thermodynamic panel is constantly in shade therefore minimal solar gain is acquired. The first graph records the heat pump system under normal conditions with an ambient temperature of 6^{o}C. The second graph records the heat pump system with the addition of our technology (ambient temperature of 6^{o}C). They demonstrate that our system is capable of lowering the frequency of the compressor cycling, thus reducing wear and tear on the compressor.

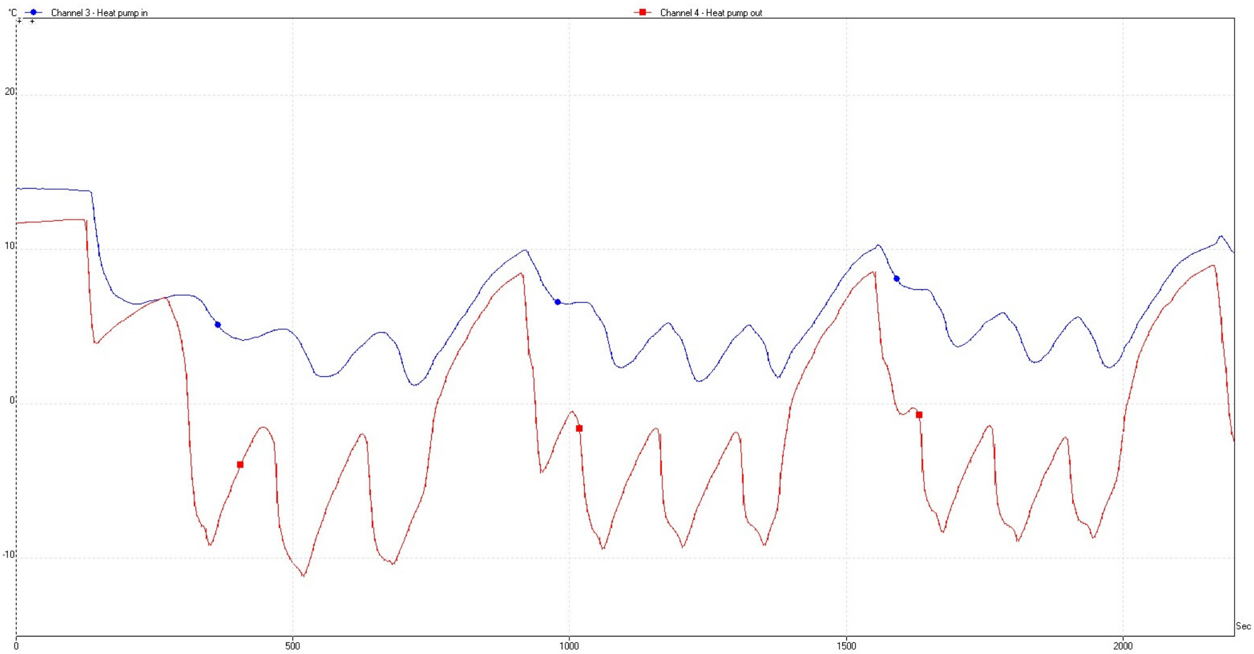

Fig. 1: Heat pump operating in 6^{o}C (note 3 peaks – this is heat pump switching off temporarily)

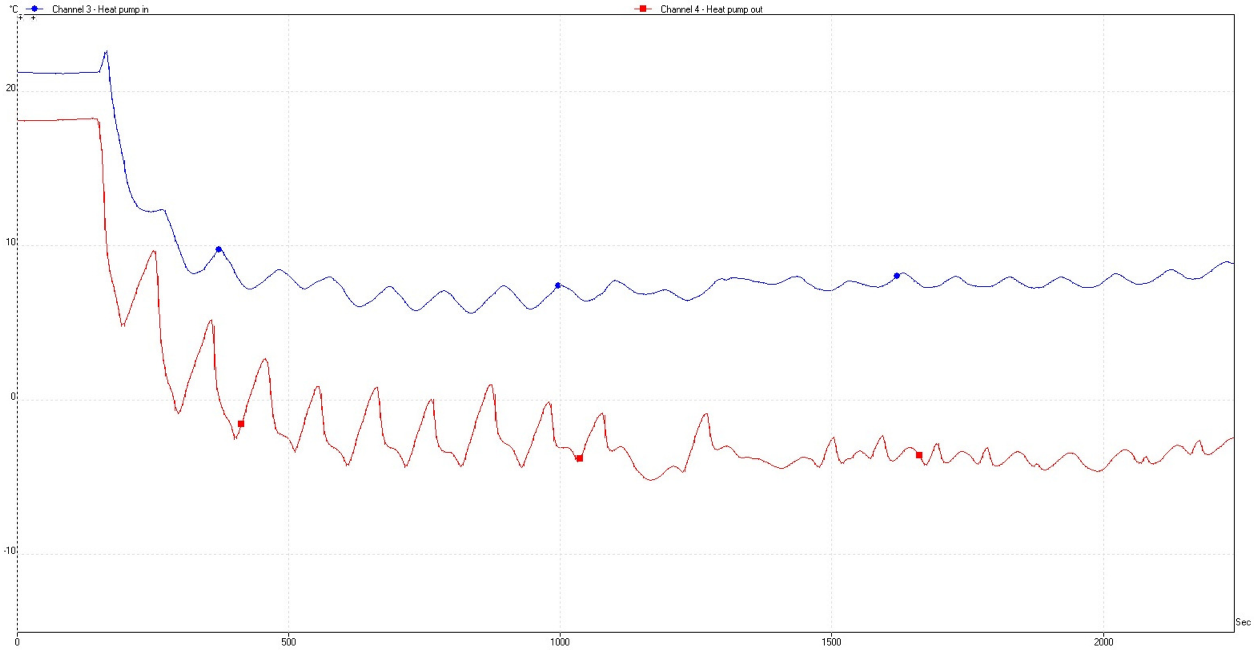

Fig. 2: Heat pump (with our modified system) operating in 6^{o}C (note – no instances of heat pump switching off)

6. Describe the innovative aspects of the work including any new findings or techniques.

We believe that we have developed a scalable system capable of improving the coefficient of performance (COP) of air sourced heat pumps.

The improvements include additional uses for the heat pump equipment.

Innovative uses of the available thermal energy.

Improved methods of standard heat pump functions.

This working prototype is capable of providing the following benefits to heat pumps:

- Lower frequency of compressor cycling, thus reducing wear and tear on the compressor.
- Increase capacity for water heating, without increasing fuel usage.

Due to the commercially confidential aspects, the system is described more fully in **separate document; Annex A.**

7. Please give a description of how funds were spent with reference to the original budget and explain any significant variations.

There have been some minor variations in how funds have been spent on this project, partly due to the changes mentioned in section 4.

Due to the contractual delays resulting in a late project start date, the labour costs increased slightly as evening and weekend working was required to catch up.

The cost of the air conditioning engineers was more than we budgeted for. This was partly due to a fault with one of the components and partly due to additional testing. Unfortunately the original thermodynamic panel was faulty, and therefore the engineers had to fit a replacement. We also carried out some additional testing which involved the engineers modifying the configuration of the system.

This project required additional business premises to locate the test rig for the prototype. The original business unit which was used for the cost estimate was not available when required and a slightly more expensive alternative option had to be taken.

The thermal imaging camera was less expensive than budgeted for, as we were able to take advantage of a special offer.

An alternative cheaper thermodynamic solar heat pump system (TSHPS) was sourced due to lack of stock of the original specified unit. The heat pump compressor proved to be more reliable than anticipated; therefore we did not have to replace it during testing. Some of the other key components and consumable items purchased were changed from those originally planned; some were more expensive but these better suited to our requirements.

Overall we are slightly over budget; however the overall variance is well within the project tolerance set at the start of the project.

Spend includes:	Estimated	Actual	Variance %
Labour:	£38,500	£40,300	
Consumables:	£200	£80	
Tools:	£1,300	£1,062	
Equipment:	£3,450	£2,714	
Travel:	£3,000	£1,740	
Overheads:	£2,900	£3,750	
Subcontractors:	£1,000	£1,325	
Other:	£0	£0	
TOTAL	**£50,350**	**£50,971**	1%

8. Describe any potential long-term collaborations/partnerships entered into. Please list the company and the role they played in the project.

No long term collaborations or partnerships were entered into during this project, however we have agreed in principle to collaborate with a small UK manufacturer of thermodynamic solar heat pump system (TSHPS). We have also discussed collaboration with a large multinational heat pump manufacturer with the potential to use their heat pumps for testing purposes. They have confirmed the innovative nature of our work and are keen to follow our developments.

9. Please describe how your company has gained from this project. What new business opportunities have been created? Do you expect your company to grow as a result of this project?

We have agreed in principle to collaborate with a small UK manufacturer of thermodynamic solar heat pump system (TSHPS).

We have also discussed collaboration with a large multinational heat pump manufacturer with the potential to use their heat pumps for testing purposes. They have confirmed the innovative nature of our work and are keen to follow our developments. An extract of this final report is being shared with them to inform them of our progress. We have signed a mutual Non-Disclosure Agreement with them. The potential to collaborate with other manufacturers remains.

We have gained practical and technical knowledge of heat pumps other associated aspects of this project. This project has provided us with the opportunity to test our theories and provide a demonstration facility for potential customers and business partners. The ability to produce thermal images of our system in operation will allow Greengineering to demonstrate the important elements to a wider audience.

The completion of this project will also allow Greengineering to produce a demonstrator for a planned system. We have been developing a concept whereby individual flats within a block can be fitted with a heat pump system. This would require no moving parts on the outside of the property and could be easily installed.

We expect interest from traditional air sourced heat pump manufacturers and also thermodynamic solar manufacturers. The potential here is considerable and we will seek to establish a license/franchise business with consultancy. We anticipate that the majority of clients will be based outside the UK.

Further information about the potential for exploiting the intellectual property is commercially confidential and is included in separate document; ***Annex A***.

10. Describe the potential for exploiting the work. Please identify any new IP which has been filed or for which filing is anticipated.

We are seeking IP on various aspects. Further information about the potential for exploiting the intellectual property is commercially confidential and is included in separate document; ***Annex A.***

As both air sourced heat pump systems and thermodynamic solar heat pump system are more suited to temperate climates, (e.g. the Mediterranean region,) any improvement to performance will benefit the UK as a whole. We intend to expand our research to include the traditional ASHP's as this is where the greatest environmental and marketing opportunities are.

11. Please insert additional information that may be pertinent. This may be in the form of text, pictures, diagrams, data, graphs that support the work.

Due to the commercially confidential aspects, the system is described more fully in **separate document; *Annex A.***