PROJECT FINAL REPORT

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Project acronym: EFFIHEAT-DEMO

Project title: Demonstration of high EFFiciency Stirling HEAT pump

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Final publishable summary report

Executive summary

The EFFiHEAT-DEMO project aimed to bring an innovative energy efficient technology to the market for the commercial and residential sectors. The heating / cooling technology was targeted, but not limited, to geothermal heat sources enabling up to 75% energy savings and reduced costs for energy consumption. The EFFiHEAT-DEMO project goal was to demonstrate the novel cost-efficient geothermal heat pumps technology at full-scale. Technology was based on a novel design Stirling engine developed within the former EFFiHEAT project.

The project mainly focused on the demonstration of new heat pump technological solution for the commercial and industrial applications. EFFiHEAT demonstrators were installed in the specially selected sites and they were functioning according to their current capabilities. Each field trail was carried out on a single device and the testing site was equipped with measuring equipment to monitor all necessary data allowing performance evaluation according to ISO standards.

The EFFiHEAT-DEMO device operated smoothly in terms of mechanical aspects, but it underperformed considerably in terms of energy output, even though it was able to generate the corresponding Stirling heat pump cycle. Nevertheless, device reliability was quite good allowing the implementation of the field tests without any interruptions or breakdowns. The prototype was easy to operate and the control panel was very effective and user friendly.

The EFFiHEAT-DEMO prototype realised the Stirling cycle and proved its potential application as a heat pump. However, due to the very low energy efficiency yields of the machine with very low thermal and cooling outputs, the machine needs further development and tests.

Several recommendations in this direction have been formulated, namely: simplifying the cylinders driving mechanism by reducing the number of moving parts (eliminating the gear-box, scotch-yoke, motion belts, etc.), changing the swing motion to continuous rotation in one direction, further reducing cylinders friction, using components of very high efficiency, such as Permanent Magnet Brushless DC (BLDC) motor replacing existing EFF2 motor, as well as capturing all generated heat by a larger heat exchange surface at the cylinders.

In general, the Project may be considered as implemented successfully, however, some serious technical obstacles forced the Partners to actively modify and improve the applied strategy for further development of the product and may considerably delay its introduction to the market.

Summary description of the project context and the main objectives

The need of innovative solutions for buildings heating and air-conditioning systems is driven by economic and environmental concerns, which are strongly supported by EU Directives. Buildings account for 40% of total energy consumption in the European Union[2]. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the residential and commercial buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions. The European Council emphasizes the need

[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

to increase energy efficiency in the Union so as to achieve the objective of reducing by 20% the Union's energy consumption by 2020[3] with Member States ensuring that:

- By 2020, all new buildings are nearly zero- energy buildings; and
- After 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.[4]

Meeting the objective would reduce energy bills annually by €78 billion, create one million jobs and save 560Mt of CO_2. Studies[5] show that EU policy measures and related industry efforts would have to triple to achieve this energy savings target, otherwise in 2020 a gap of around 208 Mt will remain. This gap could be closed if the challenges, that the European construction sector and its extended value chain are facing in their ambitious goal of researching new methods and energy efficient technologies to reduce the energy footprint and CO_2 emissions related to new and renovated buildings, would be timely addressed. A significant number of buildings must become energy positive, integrating renewable energy sources.[6] One of the main energy saving measure in built environment is the improvement of energy conversion in buildings by substitution of the less efficient technologies with more efficient ones: here, the most prominent growth of market share occurs for solar heating and heat pumps.[7]

The proposed EFFiHEAT-DEMO project was dedicated to bridge the gap from the having research and laboratory scale results to the real product by proving (demonstrating) the viability of a new solution which is a successful outcome of a Research for SMEs project EFFiHEAT. The developed technological solution offered the potential economic advantage but it could not be directly commercialised as the full scale demonstration of EFFiHEAT product-like prototype was needed for gaining the knowledge on durability, reliability and real seasonal efficiency of developed technology, including the performance verification in large temperature difference, and for overcoming the market entry barriers such as uncertainty of demand caused by low consumer confidence and low market awareness.

The EFFiHEAT-DEMO project was the follow-up of the successful FP7 Research for SMEs project EFFiHEAT "Development of high EFFiciency Stirling HEAT pump" Grant Agreement no. 286814, financed from FP7-SME-2011 call, which has started in October 2011 and ended at the end of September 2013.

The overall objective of the EFFiHEAT project was to develop and validate cost-efficient based on Stirling engine of novel design geothermal heat pump technology with 25% higher COP[8] comparing to technologies in operation. Thus the EFFiHEAT-DEMO project had the overall objective to carry out the targeted full-scale demonstration of the novel cost-efficient geothermal heat pump technology based on novel design Stirling engine and with 4.5/5.5 coefficient of performance in temperature difference of 50/30 °C).

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[3] Proposal for a Directive of the European Parliament and the Council on energy efficiency and repealing Directives 2004/8/EC and 2006/32/EC. COM (2011). European Parliament voted in favour of the Energy Efficiency Directive on 11 September 2012

[4] 'nearly zero-energy building' means a building that has a very high energy performance, as determined in accordance with Annex I of Directive on the energy performance of buildings. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

[5] B. Wesselink (Ecofys), R. Harmsen (Ecofys), W. Eichhammer (Fraunhofer ISI). Energy Savings 2020: How to triple the impact of energy saving policies in Europe. Contributing study to Roadmap 2050: a practical guide to a prosperous, low-carbon Europe. Final Version (2010)

[6] Energy-Efficient Buildings. Multi-annual roadmap and longer term strategy. Prepared by the Ad-hoc Industrial Advisory Group. European Commission, Directorate-General for Research, Industrial Technologies, Unit G2 'New generation of products' EUR 24283 EN (2010)

[7] Green Technologies and Global Markets. BCC Research. ENV012A (2011)

[8] Coefficient of Performance – COP – is defined as the ratio of heat delivered by the heat pump and the electricity supplied to the compressor. COP of 4 means that the heat pump produces four times as much heat as it requires work to generate this heat.

The main *technical objective* of EFFiHEAT-DEMO project was (Milestone 1 and 2):

- To optimise the EFFiHEAT prototype in terms of full reliability, manufacturability and assembly on the basis of results obtained in the previous EFFiHEAT project.

The main *demonstration objectives* of EFFiHEAT-DEMO project were (Milestone 3 and 4):

- To demonstrate and validate the EFFiHEAT geothermal heat pump technology as cost-efficient and with 25% higher coefficient of performance comparing to technologies in operation;
- To prepare business plan for assessment of perspectives for EFFiHEAT heat pump technology and market replication plan for competitive business development.

Non-technical objectives of the project were (Milestone 5):

- To raise awareness of energy efficiency issues to gain more interest in the EFFiHEAT technology;
- To define the exploitation strategy to maximize the value of the project to SMEs.

Description of the main S&T results/foregrounds

In the first phase of the project the EFFiHEAT heat pump prototypes were assembled and the demonstration and validation of EFFiHEAT cost-efficient heat pump solution on-site and in-site tests were performed. To achieve this, an accelerated life testing procedure was defined for the critical components identified in the EFFiHEAT and the tests were performed providing data on theoretical high stress situations performed in EFFiHEAT research project. These data were used to define the testing environment and procedures for further testing, in particular to define the failure mode for critical components and to design the accelerated test corresponding to these situations. After that, critical components were tested in order to guaranty the reliability of the application. As a result the performance of the device has been validated and the set of crucial recommendations for further improvement has been prepared.

The second phase of the project concentrated on evaluation of the EFFiHEAT technology feasibility and preparation of the action plan for market uptake. This was achieved by a profound market analysis resulting in development of an extensive marketing framework and draft business plan, which served as a basis for the final Tactical Plan describing the strategy of device introduction to the market. Also a comprehensive cost-benefit analysis has been prepared which justified the finances such as the sum of investments needed, operating costs, as well as calculated financial and economic performance indicators for the business alternatives developed within the Tactical Plan.

The last phase of the project concentrated on innovation actions targeted to facilitate the take-up of results by SMEs. This was achieved by increasing the knowledge base for using EFFiHEAT cost-efficient geothermal heat pump technology based on novel design Stirling engine. This phase also covered innovation related activities such as dissemination, knowledge management, and of intellectual property protection issues.

In general, the project may be considered as implemented successfully, even though some technical obstacles forced the Partners to actively modify the applied strategy for development of the product and its validation.

The potential impact and the main dissemination activities and exploitation of results

Potential impact

For the SME members in the EFFIHEAT-DEMO consortium, there are clear and demonstrable benefits to be gained from a successful implementation of the developed technology under the EFFIHEAT project.

The advantages to the SME participants are considerable, and can be summarized as: increasing the competitiveness of the individual SME businesses by extending their reputation, increasing their capability to deliver their outputs to a wider market and provide the opportunity to increase their trading performance. At the same time, there will be considerable benefits both to the individual companies and to the wider environment derived from the reduction in their carbon footprint. The use of heat pumps will reduce the amount of fuel used to heat buildings. Due to the efficiency of heat pumps and out of environmental considerations the UK Government has announced the aim to have 1.2 million heat pumps installed by the end of 2020 in order to meet the international green target. The carbon emissions from heat-pumps are directly related to efficiency of the system which is the benefit that the developed EFFIHEAT system has demonstrated to provide (see Figure below).

MET and STRAT will gain a reputation for the heating and cooling solution in one stand-alone system. PSYS will benefit from increased sales, selling a product at a price premium for industrial use with increased consumer demand (as documented by the policy issues such as in the UK outlined above). STRAT will be able to extend the existing product line and start the new business of geothermal heat pumps.

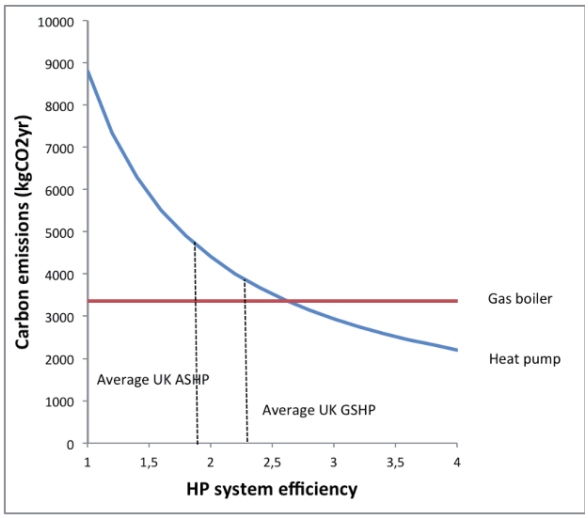

Figure 1: Carbon emissions from gas and heat pump heating systems, UK, 2008 (source: Fawcett, 2011[9])

These benefits will accrue to heating, cooling in residential buildings developers and retailers, and firms within the market for ground-source heat pumps sector. All these benefits will be passed on to consumers who will gain access to 25% more effective systems in the market which allow a market growth at a higher rate. In addition, there will be environmental benefits relating to lower carbon emissions (which will be endorsed by regulators already discussed above). The overall impact of this will place SMEs within the European market for ground-source heat pumps in a highly competitive position in both the European and

[9] Tina Fawcett, "The future role of heat pumps in the domestic sector", ECEEE 2011 summer study, http://www.eci.ox.ac.uk/publications/downloads/fawcett11b.pdf

international level, thereby creating and protecting jobs, increasing revenues to allow further investment and technological developments, while, at the same time, improving wellbeing of citizens.

The impacts will be evidenced widely; *producers* will profit from manufacturing added-value products, *retailers* will benefit from lower operational costs and ease of handling and the *consumer* will benefit from a better product in savings on heat costs up to €200–2500 per site comparing to the existing heat systems. All of these benefits are improvements over conventional products.

Main dissemination activities

The EFFiHEAT-DEMO dissemination strategy was based on experience of partners, recommendations of the European Commission and the best practices from the area of the product management and marketing communication. In order to stimulate interest of EFFiHEAT-DEMO stakeholders, EFFiHEAT-DEMO project has been promoted since the very beginning of the project. As the first demonstration results were achieved only at the end of the first reporting period, the main subject of the dissemination in this period was the project itself. Project was presented to the target audience through national and international events, publishing and other dissemination activities. In particular, EFFiHEAT-DEMO project partners identified the following subjects that have been disseminated during the first reporting period of the project:

- The EFFiHEAT-DEMO project itself and its approach,
- Novel concept of Stirling Heat Machine,
- EFFiHEAT-DEMO interim demonstration results.

In the second reporting period, where the efforts concentrated on testing and validation of the device's performance, the dissemination actions concentrated on presenting the prototypes to potential business partners and building contact networks. To achieve this, the members of the Consortium participated in the number of conferences and heating technology related events, presenting the device by the means of:

- Poster presentations,
- Conference publications,
- Leaflets distribution,
- Test validation summary reports distribution,
- Direct conversations with potential partners,
- Training and demonstrations of the device to potential partners.

Apart from that the construction and performance of the prototype device was also filmed and published on the project website .

Additionally, clear definition of the appropriate target audience was made and a database of stakeholders was prepared. These stakeholders, business, Venture Capitalists and end-users were further invited to demonstrations and trainings run by the consortium.

At last, the progress of the project was constantly monitored by the updates on the project website (www.effiheat.eu). The website also served as a portal for dissemination of project activities to the partnership in the project and present promotional literature to an outside audience.

Exploitation results

The low performance of the device during field trails indicated that further development of the machine is still required, including probably a redesign of the device concept. For this reason, the product cannot be

introduced to the market at its current state of development, nevertheless, the plan of the market intake has been prepared for future, improved versions of the EFFiHEAT heat pump.

The plan envisages that the EFFIHEAT heat-pump will be introduced progressively, starting with the markets where households are larger and generate larger bills. The degree and rate of expansion will depend on the economics of scale in EFFIHEAT heat-pump production, pricing policies and consumer acceptance.

The uptake of the developed EFFIHEAT heat-pump technology will be influenced by:

- The rate of technology validation,
- The uptake by other renewable energy product producers,
- The costs of EFFIHEAT heat-pump, which will be affected by economies of scale.

The initial, introductory price is expected to be of the order of €12000 per unit, but, as demand increases, may follow a standard price/volume curve. The additional cost of EFFIHEAT heat-pump per unit of application will be insignificant, based on a likely price of less than €500 per unit (spent on looper as part of installation), and this will be offset by savings that will accrue throughout the supply chain from:

- Lower transportation costs due to reduced weight and volume (almost 20% reduction in size was achieved during the laboratory prototyping),
- Reductions of 25% in existing costs,
- Shorter manufacturing time and time-to-order.

For an innovative solution to be accepted and profitable for the SME participants a European market is necessary, hence there is a clear need for an international collaborative approach. In order to fully test the EFFIHEAT heat-pump unit, it is necessary to extend the product range; this in turn dictates adaptability in the manufacturing process, supply of large quantities of the end product, and the ability to handle different applications (for residential and industrial purposes). This can only be achieved at a scale far greater than could be demonstrated in the laboratory and / or accelerated testing centre environment.

EFFIHEAT heat-pump will open up new markets for the provider of the developed of innovation solutions for renewable energy (MET), the manufacturer of mechanical constructions (STRAT) and the heat pump installer (PSYS) who will benefit out of commercialization of the validated prototype. The new product line will be added by this novel EFFIHEAT heat-pump in cost-sensitive residential markets because of the proposed system will be 25% more effective.

Contact details

The project website may be accessed at: http://effiheat.eu/

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