Final report: project j.nr: 64014-0511

ENTIFFIC EV

Self-powered cabin heater

Project details

Project title	Energy efficient EV Cabin heating for extended driving range
Project identification (program abbrev. and file)	ENTIFFIC EV – Journalnr: 64014-0511
Name of the programme which has funded the project	EUDP 14-II
Project managing company/institution (name and address)	**Alpcon A/S** Østre allé 6 9530 Støvring
Project partners	**Aalborg Universitet** CVR. Nr. 29102384 V/Institut for Energiteknik DK-9220 Aalborg **Insero E-Mobility** CVR. Nr. 32654533 Vitus Bering Innovation Park Chr. M. Østergaards Vej 4a DK-8700 Horsens
CVR (central business register)	32787185
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1.1 Short description of project objective and results

English version

The project objective was to develop a cost-competitive supplement to the existing air conditioning in electrical vehicles, especially for cabin heating in cold climates, without compromising the range of the vehicle. Both objectives have been reached and verified, with the design and test of a battery independent efficient heater at a system retail cost at €600 capable of maintaining cabin comfort even under extreme weather conditions.

Cost acceptance has been verified through potential user interviews, and the results have already resulted in Innobooster funding to develop the market for electrical busses. An analysis of the rules and framework conditions for cabin heaters and market analysis of existing cabin heaters has been carried out, together with a preliminary study of user needs and interest.

Danish version.

Projektets formål var at udvikle et supplement til det eksisterende klimaanlæg i elbiler, specielt til kabineopvarmning i kolde områder - en effektiv kabinevarmer, der vil øge el-køretøjets rækkevidde og ydermere forbedre passager komforten ved at kunne holde køretøjet opvarmet uden afladning af køretøjets batteri.

I projektet er der udviklet en selv-dreven kabinevarmer prototype som kan opvarme elektriske køretøjer uden brug af elbilens batteri hvilket resulterer i længere kørselsrækkevidde, selv i et koldt klima. Den selv-drevne kabinevarmer er blevet testet i en elbil hvor kabinevarmerens funktionalitet og ydeevne er blevet valideret.

Der er lavet en analyse af regler og rammevilkår for kabinevarmere samt markedsanalyse af eksisterende kabinevarmere og forstudie af brugerbehov og interesser

1.2 Executive summary

A greater uptake of electric vehicles (EVs) is a prerequisite for decarbonizing the transport sector. EVs currently emit less than half the CO2 of conventional cars (expected to be 95% less by 2020).

While EVs today offer the same operational reliability and comfort as conventional cars, they have disadvantages in terms of limited range and availability of recharging, which causes ‘range anxiety’ for both current and potential users: will the battery last to my destination?

Range anxiety presents one of the biggest barriers to EV uptake. The challenge is particularly urgent in colder regions, where battery powered cabin heating causes reduction in the driving range of up to 50%. Contrary to conventional cars, the electric engine is so efficient that it produces a minimal amount of surplus heat and so heating must be actively supplied by the battery. This means that EV drivers are faced with a trade-off between comfort and range.

The objective of this project has been to extend the EV driving range and comfort in the wintertime and by this facilitate an increased uptake of EVs in colder regions.

This has been reached by the development and validation of a self-powered cabin heater – “ENTIFFIC EV” - which is affordable at a retail cost of approx. €600, highly energy efficient and entirely independent of the car’s battery.

The cabin heater is based on the patented HEXTEG technology, which uses temperature differences within the heater to generate electricity to power the integrated ventilation fan, meaning no battery dependence, increased heating efficiency and no loss of driving range. In an extended integration of the ENTIFFIC EV, excess electricity can be used for battery charging. Heating related CO2 emissions are also reduced. This profile makes ENTIFFIC EV unique on the EV market.

1.3 Project objectives

The project objectives were the following

- Increased range of >1.000 km per year compared with battery driven heating, in average, confirmed through user tests documenting e.g. reduced range anxiety.
- Improved or maintained comfort level without range loss, confirmed through user tests documenting comfort level.
- User price of €600, confirmed through cost evaluations.

Overall, the project evolved as planned, although some changes in individual work packages did occur. Notably, in WP2 Demonstration changes were necessary, in order to incorporate the use of the Serenergy Fiat 500 MeOH FC electric hybrid into the project. These were due to coordination issues with the mechanical modifications and technical approvals of the vehicle. For this reason, the first implementation was in a Fiat 500 EV with no fuel cell. The ENTIFFIC EV prototype was subsequently moved from this vehicle to a second similar Fiat 500 EV, and it is in this vehicle that tests have been carried out, so that the final demonstration and climate verification was able to be carried out as planned.

1.4 Project results and dissemination of results

The project has consisted of a number of stages:

- Establishment of requirements – spatial, technical, regulatory, operational
- Design, construction and initial test of prototype
- Integration in EV and demonstration of fulfilment of objectives
- Economic, market and user assessment of ENTIFFIC EV cabin heater

These are described in more detail in the following.

1.4.1 Design criteria

In order to fit both the ENTIFFIC EV and a methanol fuel cell into the Fiat 500 EV, significant modifications have had to made to the vehicle and it was chosen not to integrate the actual heater to a great extent into the vehicle, but rather to mount it as shown in Figure 1.

Figure 1 Installation of ENTIFFIC EV in Fiat 500 EV.

The only modifications necessary to the vehicle are the mounting of a flange for the double-tube combined exhaust-fresh air intake to the heater. This ensures that exhaust fumes from the heater do not entire the vehicle cabin. Furthermore, the ENTIFFIC EV has an internal, re-chargeable battery for start-up, which is charged during steady operations. This makes electrical connection for basic operation unnecessary.

As part of the initial design criteria, a risk evaluation was carried out. This showed no coincidence of serious risks, high frequency and lack of noticeability, and no issues resulting in dangerous conditions or malfunctions which would jeopardize either vehicle operation or passenger safety. The risk analysis is included in appendix.

1.4.2 Design, construction and initial test of prototype

The final design of the ENTIFFIC EV is shown in Figure 2. It is a closed cabinet, removing hot and moving parts from reach and contact with surfaces.

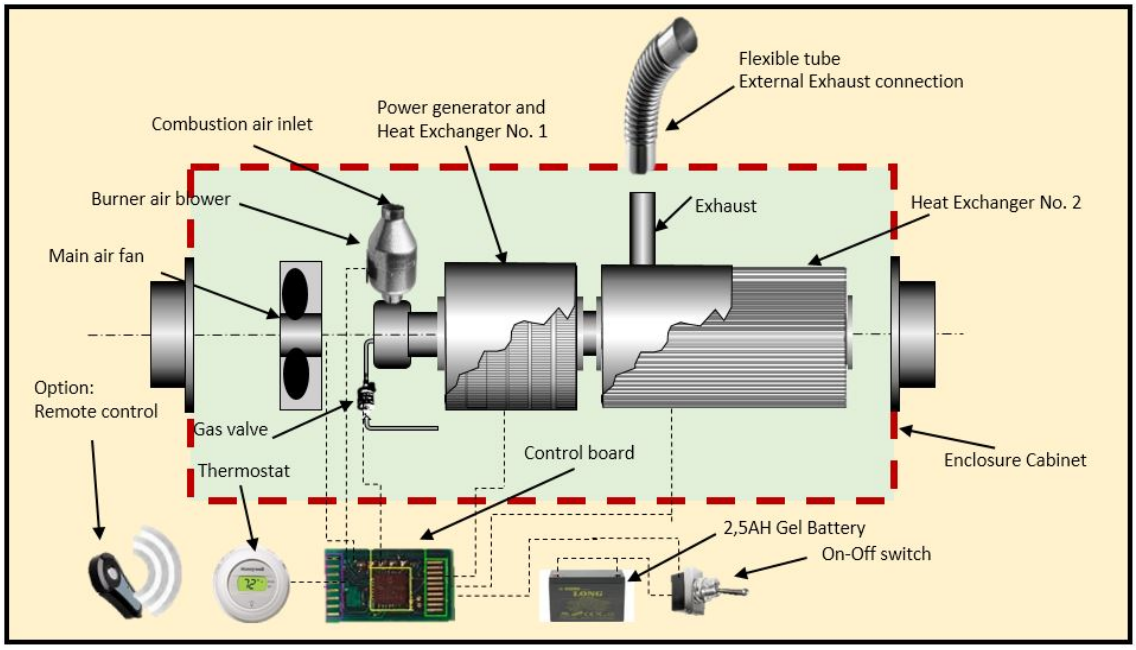

Figure 2 ENTIFFIC EV cabin heater structure

The interfaces with the vehicle/operator is through a cabin sensor (adjustable) to provide the temperature set-point within the range of 15-35˚C. A thermostat in the exhaust ensures that if temperature increases beyond 150˚C, the combustor and fuel supply shuts down while the fan still operates, maintaining the supply of warm air to the cabin. Once below 120˚C at the exhaust, the system resumes normal operation.

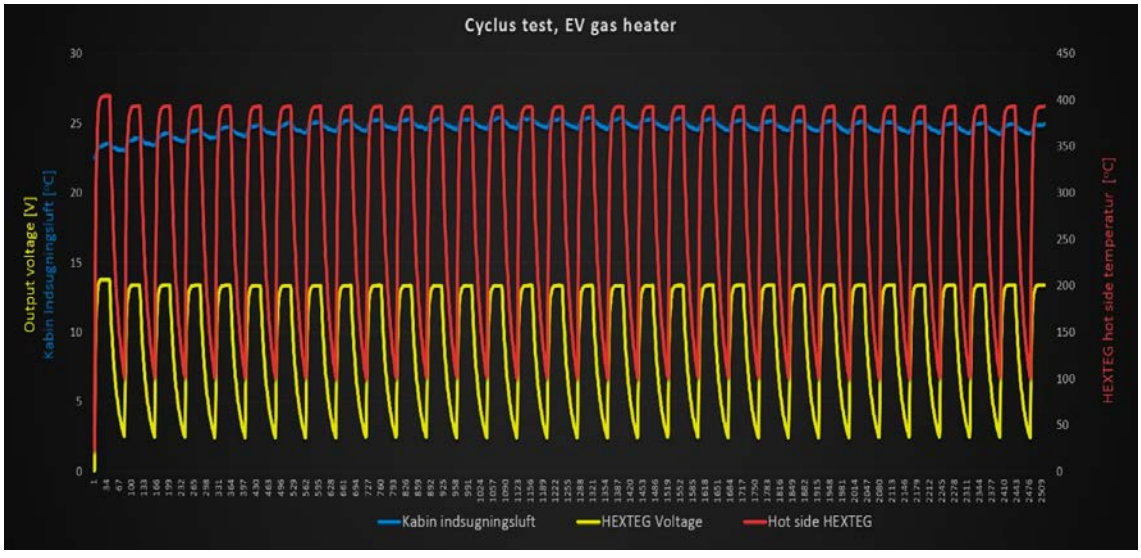

Figure 3 Thermal cycling of the ENTIFFIC EV at a cabin temperature of 24˚C

In order to optimize operation, several tests have been performed to adjust heater outputs and on-off sequence. An example of such test is shown in Figure 3, which gives the cabin air temperature, hot heat exchanger side temperature and output voltage as a function of time for a set point temperature of 24˚C. If the heater has several start-stop actions over a short period, the charging of the battery will lag behind and prevent the system from starting at some point. In the current design, the fully charged internal battery has a capacity corresponding to 5-6 starts, which will cover most operational patterns. In order to eliminate even the smallest potential of

discharging the internal battery, an option is to connect the ENTIFFIC EV to the battery of the vehicle as a fail-safe.

1.4.3 Integration in EV and demonstration of fulfilment of objectives

As mentioned, the ENTIFFIC EV was installed in two separate Fiat 500 EVs. In the first vehicle, the heater was operated during normal driving to test driver comfort and satisfaction. In the second vehicle, the heater was tested at extreme conditions in the AAU climate chamber facility. As shown in Figure 4 and Figure 5, the entire vehicle is enclosed in the container-scale climate chamber, with full control of ambient temperature.

Figure 4 Climate chamber tests at AAU

For these tests, the ENTIFFIC EV heater was tested at ambient conditions down to -11°C, with data logging taking place at -10°C. During these tests, the heater output was approx. 1.0 kW, i.e. half of the rated power of the burner, in order to maintain a cabin temperature of 24°C at approximately shoulder height. This implies that the current power rating is sufficient for a significantly larger vehicle than a Fiat 500 EV, or that even lower temperatures can be endured. In Figure 6, relevant temperatures and battery voltage are shown during the test sequence lasting for 3:45h. Starting at a cabin temperature of about 10°C, the heater ramps up to full power to heat up to the set point, and charges the internal battery during this period. Once this is reached, the heater shuts down and restarts when cabin temperature drops 2°C below the set point. This is repeated a few times, before a slow shutdown sequence is initiated.

These tests confirm the capacity of the ENTIFFIC EV, and fulfill the project objectives of designing, constructing and testing a prototype EV heater which is independent of the EV battery, and thus does compromise EV range when used.

Figure 5 Climate chamber tests at AAU

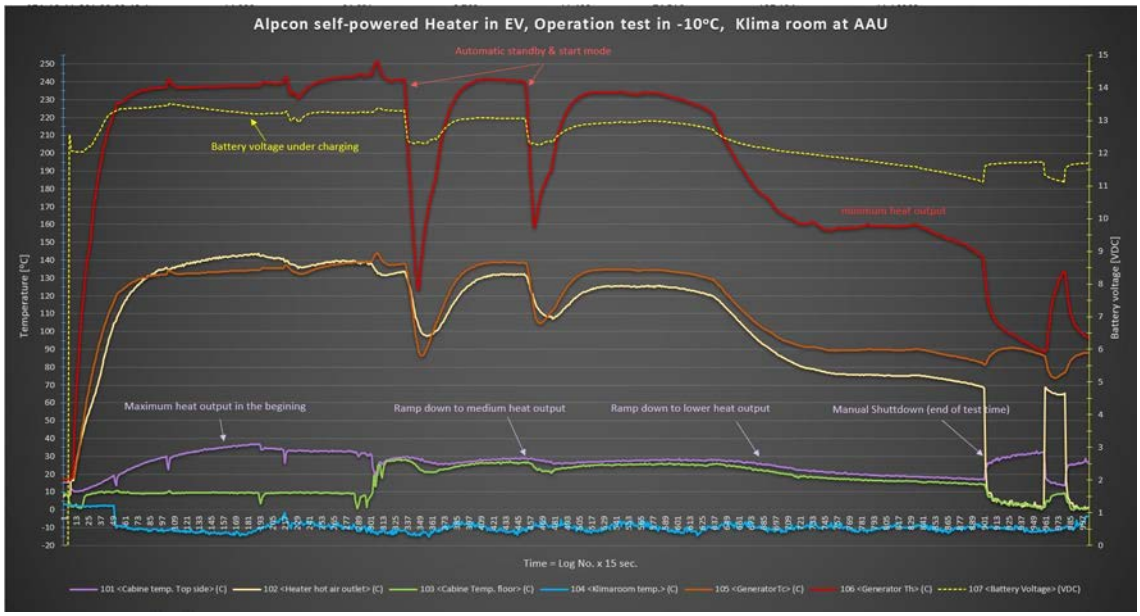

Figure 6 Results of climate chamber testing

1.4.4 Economic, market and user assessment of ENTIFFIC EV cabin heater

In order to bring the ENTIFFIC EV to the market, a number of regulatory aspects must be adhered to, both in terms of general manufacturing liability and, more specifically, regulations for vehicle cabin heaters. In Denmark, these are tied to “Vejledning om syn af køretøjer” and refer exclusively to standard IC vehicles. As such, there may be requirements which cannot be met in an EV implementation. For commercialization of the ENTIFFIC EV, EU directives take precedence, and for this particular product it is EU Directives 661/2009/EU (vehicle heaters),

85/374/EU (manufacturer liability). Furthermore, Danish legislation LBK nr 261, 20. March 2007, covers this product.

The existing market for cabin heaters is dominated by the following types and manufacturers:

- Fully integrated diesel or gasoline heaters (engine/cabin) from Webasto or Eberspächer
- Fully integrated systems from DEFA, electrical cabin heaters by external power connection
- Non-fixed systems with timer, powered by external power connection

Dominating the market are products from Webasto and Eberspächer, according to retailers. The main reason for not choosing DEFAs solution is the requirement of an external power supply; on the other hand, the two former products require professional installation and are thus more costly to install.

For consumer inputs, a small Danish Facebook-based survey has been carried out in connection with an EV oriented online debate, supplemented by an interview with a single motivated respondent. Although this is far from a solid foundation, some general trends have been extracted to indicate aspects which are found important from this segment.

- Use of renewable fuel to power the ENTIFFIC EV is important (green profile)
- To offer both OEM and retrofit solutions, it is necessary that the internal HEXTEG functions as either air-air or air-water heat exchanger
- Remote control, either separate or integrated into EV remote control, is important

The cost target for the cabin heater was set to €600, comparable to traditional off-the-self-heaters and estimated for high volume production. This target is archived with potential for further reduction cost reductions on vital system components. The ENTIFFIC EV heater also have additional benefits that will reduce the lifetime cost from the improved system fuel to heat efficiency.

The market interest for self-powered heating and extended driving range for EV's is significant for light-duty, heavy-duty and many niche EV's. It is expected that the transition from the traditional vehicle heaters to the ENTIFFIC heaters will be fast especially in the retrofit/after sales market and OEM in longer term.

1.4.5 Dissemination

The ENTIFFIC EV proof-of concept has been introduced and demonstrated to potential EV end-users, EV OEM's and cabin heater manufactures. There is much interest from the market and the project already resulted in collaboration with potential customers who will support the final stage product maturing and field demonstration. Further dissemination activities are ongoing through partner and customer networks. The project results is planned to be published in relevant scientific journals and conferences. The ENTIFFIC EV is also accessible for students at Aalborg University with the objective to strengthen the Energy Harvesting research area by training students in EH system modelling and system integration.
The ENTIFFIC EV heater is also be suitable for heating of conventional vehicles, which gives a much greater market/sales potential. The heater is already being introduced to various potential customers and end-users providing a lot valuable and positive feedback.

1.5 Utilization of project results

Alpcon is a partner in an ongoing Innobooster project with the objective to develop a proof-of concept/test unit of a self-powered 30kW engine-heater running on diesel fuel for conventional busses. This project is led by the Danish company Stroco, a manufacturer and supplier of bus heaters for OEM bus manufactures. The Danish Technological Institute is the test partner in the project and will validate the heater performance at high temperature and heating ranges with analysis of the heater exhaust and scalability.

The results from both the EUDP and Innobooster projects will be the base for a phase II EUDP project application. The objective of a new development & demonstration project is to mature the heaters concepts to a prototype specified for electrical busses in collaboration with involvement of researchers, bus operators and bus manufactures. A full scale demonstration is intended to validate the extended driving range and passenger comfort in electrical heavy vehicles.
A study of the battery performance with self-powered heat management installed will also be a part of the phase II project.

1.6 Project conclusion and perspective

The ENTIFFIC EV is both price competitive and meets market demands. It can provide cabin comfort with no reduction of range, something which no other cabin heater for electrical vehicles offers. This is a very strong business proposition, not only for personal vehicles but also for heavy-duty vehicles, niche vehicles and space heating.

Furthermore, this is a basic functionality heater providing only heat as required. Based on the core of this heater, it is possible to design heaters which – while still delivering this – also incorporate features such as off-grid charging, intelligence by incorporating sensors and communications devices which can operate even when the vehicle is completely discharged and other features such as remote control taking advantage of the generator capabilities of the ENTIFFIC EV.

The EV battery capacity is expected to be improved being able to manage the battery temperature by implementing the EV heater in the EV climate management system.

Annex

- FMEA analysis
- Installation manual, ENTIFFIC EV
- Note, regulatory aspects and international markets