Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Thermal Management System for a thermally controlled food delivery electric vehicle integrating heat pump, cold storage unit, solar panels and PCT resistors

Marco Biasiotto[a], Pietro Perlo[a] , Gregorio Iuzzolino[a], Gioele Sabato[a], Marco Grosso[a], Sergio Pozzato[a],Davide Penserini[a], Christopher Roemmelmayer[b], Reiner Jhon[b], Daniela Mayer[b] , Jiabin Wang[c], Helder de Campos Garcia[d], Mathieu Leborgne[d]

[a]*Interactive Fully Electrical Vehicles, Pietro.Perlo@ifevs.com*, I-FEVS *strada carignano 50/1 10040 La Loggia, Italy,*
[b] *Infineon, Address, City and Postcode, Germany*
[c]*University of Sheffield, UK*
[d]*Hutchinson, France*

Abstract

The paper describes the development of a novel thermal system for all kind of low consumption electric vehicles. For the first time in our knowledge, a compact thermal system integrates a heat pump, a thermal storage unit, a photovoltaic panel and distributed high efficiency annular fans including PCT resistors in their centers. The vehicle is divided in three independent compartments: food storage, battery pack and cabin which are thermally managed with defined priorities in relation to whether the vehicle is plugged-in, in motion or parked unplugged. The implemented control strategies adapt themselves in relation to the outdoor temperature to minimize energy consumption. Phase Change Materials PCM are used to keep the battery pack temperature conditioned even when the vehicle is parked unplugged in the open air at extreme cold temperatures, in that case during the day the PMC material integrated in the battery pack accumulate the energy produced during the day by the solar panels and release heat during the night. Following simulations of various condition of operation rather advanced algorithms have been implemented into an electronic board so that the conditioning of the three compartments is made by autonomous decisions in practically all conditions of operations. The cold storage unit has been dimensioned in such a way that per the typical two-hour mission of a hot summer, the three compartments of the temperature controlled food delivery vehicle could be temperature and humidity conditioned using only the thermal energy storage. The system could also be monitored and activated by a smart phone. The temperature controlled food delivering vehicle integrating all developed technologies will be demonstrated in operation at the exhibition of TRA 2018.

Keywords: Vehicle thermal management system, user centric design, thermal energy storage, thermally controlled batteries, insulation technologies, comfort control systems, energy.

1. Introduction

This paper describes the approach implemented to maximise the operation range of a fully electric vehicle designed to be used as a temperature controlled food delivery van. For the purpose the OSEM-EV partners have simulated and developed all systems integrated in the vehicle and the demo vehicle itself. A compact single source heat pump, a cold storage unit, a photovoltaic panel and distributed high efficiency fans-PCT systems are used to monitor and stabilize the temperature of three separated compartments: food van, battery pack and driver's cabin. The three compartments being designed and developed implementing advanced thermal insulation concepts. For the design of each sub-system we refer to other papers presented by the OSEM-EV partners in this proceeding. In this paper we focus on the design criteria adopted for the full system and on integration of the sub-systems in the vehicle.

2. Review of thermal conditioning and energy management aspects of fully electric vehicles

Between 15% to 25% of the average annual energy demand of the latest generation of EVs is needed for auxiliaries, conditioning of the battery pack and passenger acclimatisation. During cold (< -10 °C) and hot (>35°C) periods the energy demand to keep thermally conditioned the battery pack and for passenger acclimatisation can be as much as twice the annual average. Tests performed in 2014 on commercial EVs have demonstrated that the range was for all models greatly reduced in winter times diminishing to 40% of the nominal value for a vehicle at the top in the raking of sales. For large-size EVs with a relatively large battery capacity, energy demand for thermal conditioning requires an annual average of ~ 15 % of the battery capacity, while it can require ~ 30 % for a micro car. In general the smaller the vehicle the higher is the ratio between the external surfaces to the useful volume and the higher is the challenge of thermal conditioning. Several thermal and energy management aspects contribute to distinguish and eventually mitigate the differences in range and performance per a defined vehicle type or a defined vehicle mission due to temperature excursions. In the following sub-paragraphs we briefly review the critical aspects considered and implemented in the specifically developed OSEM-EV I-FEVS demo temperature controlled food delivery vehicle.

2.1. Battery self-discharge and energy consume in the unplug state at rest

The typical evaporation rates of gasoline and diesel fuels in conventional motorizations are respectively less than 1.5%/month and 0.5%/month. For lithium-based battery packs, self-discharge is around 2 to 3 per cent per month, though it varies with specific cell chemistry, geometry and temperature. Everything from battery monitoring and telematics systems implies a power consumption when an EV is at rest unplugged. The warranty of all EVs is based on the condition that **the battery is kept charged,** consequently when an EV is parked unplugged for a long period, battery self-discharge should be compensated through energy harvesting while energy consumption should be minimized switching off all electronic loads while limiting the monitoring of the battery state of charge and temperature.

2.2. Battery thermal control

The temperature dependant performance of batteries is well known. **Thermal isolation** of the battery compartment reduces the energy needed to keep battery cells at a defined (optimal) nominal temperature when the vehicle is either at rest or running. **Temperature monitoring and conditioning** are necessary not to allow the battery to reach bottom and top temperatures at which it would be permanently damaged, while at the extreme values of the allowed temperature range the battery has to be limited in current to avoid permanent stress. Conditioning implies: - the **circulation of de-humidified air** to avoid the stagnation of highly inflammable gases - **heating and cooling** either by **forced air** or a **temperature controlled liquid circuit** (most EVs). Cells with a low internal resistance of few mΩ (typically pouched or prismatic cells) are easier to cool than cells with a high internal resistance up to several tens of mΩ (small cylindrical). For the former forced air cooling can be sufficient for the latter liquid cooling is usually applied. Although a temperature controlled liquid circuit is more complex it allows lower thermal gradients across cells and a better temperature control (specifically during fast charging), besides it can also be less energy consuming than a forced air circuit.

2.3. Vehicle to Home V2H and Vehicle to Grid V2G

Batteries must be kept charged and conditioned when the vehicle is parked to avoid permanent damage. Pre-heating or pre-cooling the different vehicle compartments while the vehicle is still plugged-in (V2H, V2I, V2G) is important for several reasons related to robustness, comfort and range:

- Avoids large temperature gradients in batteries,
- Avoids the supply of large currents when the battery pack is at non-ideal temperatures,
- Maximises the range per a given battery capacity in that it avoids the use of a large portion of the stored battery capacity to thermalize the compartments. The vehicle is ready to be used with ideal temperatures in all compartments; only minimal capacity of the battery pack is used to keep properly conditioned the compartments while travelling,
- Allows time saving in that the vehicle is ready to be used any moment; for example avoiding the defrosting of the windshield,
- Offer immediate comfort to the driver or passengers entering the vehicle.

Pre-heating or pre-cooling the different compartments while the vehicle is still plugged-in is far amongst the most important aspects of thermal conditioning-management of EVs. V2H and V2G are then a major opportunity to maximize the efficiency of EVs in motion and more in general in terms of global energy efficiency, in that direction the development of smart phone like **remote control systems becomes particularly relevant.**

2.4. Energy losses during charging

Energy losses during charging are still very high and sometimes very difficult to manage. High energy losses varying very much in relation to the power are typical of AC fast chargers in that it is difficult to match the charger and the on-board AC-DC converter stage to assure high efficiency across all power levels. The infrastructure is rapidly moving to low cost DC fast chargers but the dispute on the charging technology to be adopted and the level of complexity to install on-board chargers is likely to continue for years. The burden related to the use of conducting cables and charging poles in cities demand for efficient, compact and low cost wireless solutions. Inductive charging is spreading in all application contexts as V2G, V2I and V2H as well. The typical efficiency of Inductive charging is of the order of 90%. Although energy losses during charging do not influence the range of the vehicle in motion, they have an impact on safety and on the overall lifetime (robustness) of the components.

2.5. Energy recovery during deceleration and braking

In EVs most of the recovered energy is obtained during deceleration. Lots of research is on-going aiming at the optimal blending between electric and mechanical braking and for the purpose computer controlled sensor pedal systems are usually integrated into or electro-mechanic braking system. For the time being the regulations prohibits pure electrical braking. The high currents produced during fast braking are a problem usually managed at the inverter level, which has to be thermally designed to dissipate-diverge the currents above a defined threshold that would otherwise stress or permanently damage the battery pack.

2.6. Power train: power electronic, single and multi-motors approaches

The higher efficiency of the electric powertrain over the conventional ICE one is well known. Electronic drives with efficiency >95% and motors with efficiencies > 90% are common. Modern mid-size EVs have been measured with an average consume of the order of 130Wh/km on most driving cycles, thus consuming just some per cent above the theoretical calculated values for a 1200kg ideal EV[1]. Powertrains with one single motor in a 2WD configuration can satisfy all needs, but powertrains adopting two motorized axles in 4WD configurations can reduce energy consumption several per cent, however rather than for energy saving they are usually addressed to boost the acceleration, for higher fail-safe properties and higher vehicle stability on curved, wet and iced roads. Improved thermal management and energy saving in the powertrain of next generation EVs demand for **higher efficiency semiconductor technology (thinner Si chips, GaN, SiC..)** and **new algorithms-strategies to manage the power-energy flows**. Motors and their associated electronic drives can be air cooled only at nominal powers below 15kW while they are usually liquid cooled at higher powers. Within OSEM-EV simulations have demonstrated that harvesting the heat generated in motors and electronic drives to thermalize the different compartments of the vehicles (cabin or battery packs) is justified only at extreme cold temperatures and for long range missions. As a matter of fact, this option would be counterproductive if a vehicle is expected to be mainly used in non-extreme cold temperatures. Implementing a single liquid based thermal conditioning circuit system remains a challenge.

2.7. Peculiarities of the thermal sources: battery pack, motor-differential-inverter

Motor(s), inverter(s), differential(s) and battery pack are the main sources of heat in an EV. Their temperature operating ranges and the temperature gradients they are exposed during operation differ considerably. When liquid cooling circuits are used they have to be designed keeping into consideration the different temperature ranges as well as the electric (conductivity) properties of the sources they are in contact with. The drivetrain subsystems have specific thermal requirements that have necessitated a separate thermal loop for each subsystem. The battery must be cooled during hot ambient conditions to prevent degradation of battery cell life and must be heated during cold ambient conditions to enable adequate discharge power. The typical range of temperature control for the battery cells is 15°C to 35°C. The drivetrain subsystems must be cooled so that they remain below their maximum operating temperature limits to prevent thermal damage or failure. The typical thermal limits for the Power Electronic and E-Motor components are around 150°C. Separate cooling loops typically entail additional heat exchangers at the front end of the vehicle, water/ethylene glycol (WEG) coolant, piping, and WEG pumps. The disadvantage of multiple cooling loops is that they increase vehicle weight, aerodynamic drag, and fan/pump power, thus reducing the EV range.

2.8. Thermal isolation of the full vehicle body

Thermal isolation of the full vehicle body is most often coupled to the soundproofing performance of the vehicle both properties demanding for **fire extinguishing, low cost, non-conductive and easy to apply materials.** For pure electric vehicles **the very first criterion** to follow is the selection of the colour. White colours vehicles in warn-hot southern countries and dark colours in northern countries are suggested. The thermal load difference due to the colour may be higher than 20%. The mission of the vehicle is also of concern, for instance to deliver temperature controlled products at temperatures of the order of 1ºC-4ºC a white high reflectance body is very much preferred.

2.9. Hybrid and bi-layered glazing

The higher thermal insulation of polycarbonate and bi-layered glass-polymer glazing over pure glass system is also well known, besides, de-icing and de-fogging requires much less energy. Bi-layered and coated polycarbonate glazing is already applied in most cars for the Japanese market on side windows and backlights while limitations remain for windshields due to the higher abrasion-resistance properties required. Because glazing cover in between 30 % to 35% of a vehicle surface the introduction of high insulation coated polycarbonate glazing has a growing interest in the design of EVs. The regulation E/ECE/324/ Rev.3/Amend4 published on 9 November 2015 provides the “Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles” including: rigid plastic windscreens, laminated rigid plastic panes and laminated rigid plastic windscreens.

2.10. Energy and power routing

The consumer world has taught that the autonomy of battery devices like PCs and Smart Phones has been increased up to three times by the introduction of a dedicated smart energy power processing unit (source: Intel). The functionalities are ranked per their energy consumes then energy and power are routed by applying **smart de-powering and automatic switching-off of non-safety critical functions**. The introduction of advanced processing units for energy and power routing **is at its infancy in electric vehicles** demanding for a partition amongst auxiliaries and powertrain. The tenths of energy consume sources available in an EV can be managed by applying smart de-powering and automatic switch-off of the non-safety critical functions.

2.11. Thermal storage (iso-thermal)

Once a thermal storage unit based on phase change materials PCM is brought at the selected temperature a thermally isolated volume requires only minimal energy to be kept conditioned at the desired temperature. The energy storage unit can be "reconditioned" by an on-board heat source such as a solar panel or by a plugged in external sources. PCM foils can also be used to thermalize the battery pack[2].

2.12. System integration and partitioning

System partitioning is more and more crucial to assure higher robustness, simplicity, higher fail-safe redundancy, cost reduction, simplified maintenance independency from suppliers. Rather than stressing systems integration, EVs demand smart partitioning of the macro functionalities.

2.13. Solar and other forms of energy harvesting

Smart photovoltaic impacts battery management, heating and cooling, besides in the EU-MOBY cluster projects it has been demonstrated that it can assure up to 20km of daily average range in small EVs. Low cost solar harvesting by bendable foils is forecasted **by most roadmaps to 30-35% efficiency within a decade.** With that, the use of smart solar harvesting surfaces will be an important aspect to consider for the design of next generation EVs. The current state of the art offers **24% efficiency** smart photovoltaic. White high reflectance (>95%) paints are preferred to solar panels when the purpose is to minimize the thermal load, in fact with a solar panel the non-electrically converted energy would transmit a higher thermal load than the one transmitted by the paint. Aiming at quasi energy autonomous electric vehicles the integration of high efficiency miniature wind generators are also contributing to charge the vehicle when parked.

2.14. Heating and cooling "H-C" by heat pump systems

In general, very few data are available to compare the many different solutions of cooling and heating the compartments of electric vehicles. No data are currently available to compare vehicles pre-conditioned while plugged-in and vehicles which are not pre-conditioned. Although the PTC heater could provide sufficient heat energy to warm up the cabin-battery compartments, its energy is derived from the battery and because of that the actual driving range can be significantly reduced. Radical simplification and improved efficiency can also be obtained by distributed PTC sources. When using PCTs only for heating purposes the literature reports an average 20-25% reduction of the driving range for fully EVs[3] up to 50% range reduction <-10°C ambient conditions[4]. In modern EVs the AC system consists of an electric compressor, a blower (conventional forced ventilation system), an integrated PTC heater, an inverter, pipes and heat exchangers. The mission of vehicle is conceived for is also of concern to select the most cost-performance heat and cooling system. **A heat-pump cabin heater** improves power consumption when the heater is being used since it heats the cabin using the temperature difference between a refrigerant and the outside air, obtaining a heating effect other than consuming electricity, and making it possible to heat the passenger compartment with less power than conventionally possible with a resistor. The heat transferred can be three or four times larger than the electrical power consumed, giving the system a **COP of 3 or 4**, as opposed to a COP of 1 of a conventional electrical resistance heater [5]. A heat-pump is unique in that **one refrigerant circuit can be used for both cooling and heating**. In fact it is an easily reversible vapour-compression-refrigeration device optimized for high efficiency in both directions of thermal energy transfer, the heat from the outside (cabin) air being transferable to the cabin (outside) just by the power consumption of the pump. For all heat pumps, the coefficient of performance (amount of thermal energy moved per unit of input work required) decreases with increasing temperature difference, that is, to operate with a high COP in different temperature conditions, the heat pump should be equipped with different typologies of refrigerants. To avoid the use of different types of refrigerants new EVs tend to integrate a heat pump with PTC resistive heaters (enter in operation at temperature below the freezing point) and allow preheating or cooling while the vehicle is still plugged-in. A heat pump is the most efficient concept that can address both heating and cooling while minimizing the influence of the H-C system on driving ranges but it comes with its own drawbacks on complexity, volume, cost and range of efficient operation. In most modern EVs peak power demands are still quite high of the order of 3kW so that H&C conditioning remains a major challenge when developing energy efficient EVs. Various studies have been performed to enhance the heat pump H-C system efficiency, especially the heating performance when faced with low outdoor temperatures. Besides single air source heat pump H-C systems, multiple source heat pump H-C systems could be developed for EVs. However, as explained in the sub-paragraph 2.7, the use of all possible heat sources in EVs enhances the efficiency of the conditioning system only under very low outdoor temperatures.

3. The OSEM-EV temperature controlled food delivery demo

The OSEM-EV vehicle demonstrator is built on a tubular chassis made a with mix of Advanced High Strength Steels so that it could meet full frontal and lateral EuroNcap crash tests. The 4WD powertrain has two identical axle systems integrating state of-the-art high efficiency motor and Si-MOSFET inverters assuring a quite flat efficiency curve peaked around 94%. This architecture has also been selected because particularly suited for AV applications in the urban environment. The final vehicle and the schematic representation of its three main compartments is shown in figure 1.

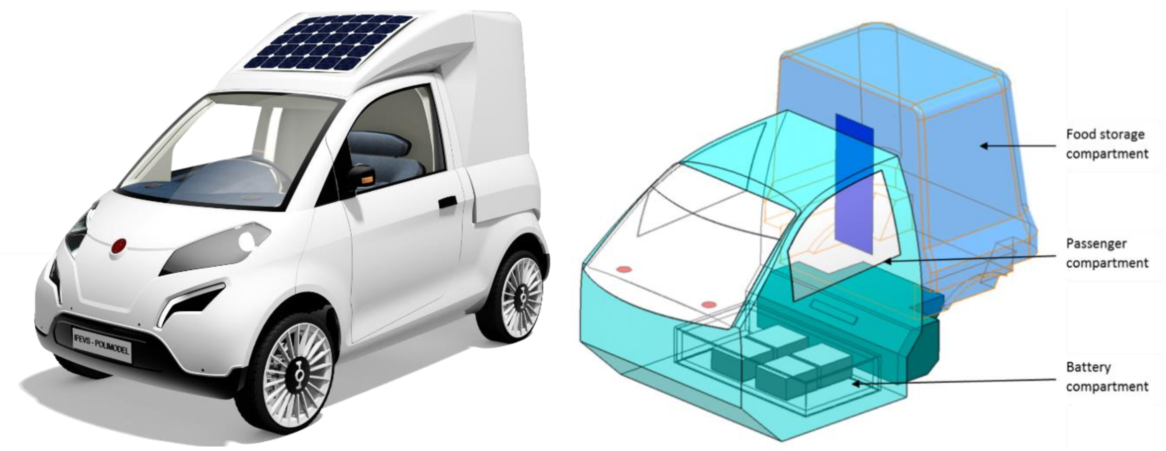

Fig.1: OSEM-EV temperature controlled food delivery van that will be demonstrated at TRA 2018.

4. Preliminary thermal system dimensioning and overall system simulation

Food storage compartment: Parameters of the cold storage compartment are shown in the table 1. The overall heat transfer coefficient of the food storage compartment is calculated and plotted as shown in figure 2. The thermal conductivity of the insulation dictates the overall heat transfer conductivity and therefore the overall heat transfer coefficient shows negligible dependence on vehicle speed.

Table 1. Food storage compartment temperatures.

Parameters	Units	Value
Volume	m^3	1.25
Surface Area	m^2	7.02
Interior mass	kg	50
Specific heat capacity	J/kg/k	1200
Insulation thickness	mm	40
Insulation thermal conductivity	W/m/k	0.02
Overall heat transfer coefficient	$W/m^2/k$	0.5

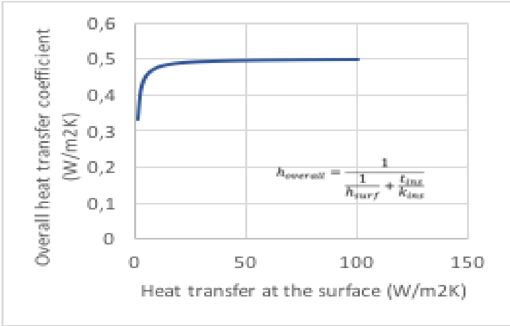

Fig.2: Heat transfer coefficient as a function the heat transfer coefficient at the vehicle body surface

Battery compartment: Battery modules are cooled using cooling plates and the housing is insulated using a PCM material. The housing of the battery compartment is modelled with a heat transfer coefficient which is dependent on vehicle speed but the PCM material is not yet included in the results to follow. Surface area of the battery compartment is 0.604 m^2.

Passenger compartment: Parameters of the passenger cabin are summarised in the table below with realistic assumptions made where necessary.

Table 1. Passenger cabin parameters

Parameter	**Units**	**Value**
Volume	m^3	1.93
Surface Area	m^2	11.08
Window surface area	m^2	1.18
Window slope angle	°	42
Interior mass	kg	100
Specific heat capacity	J/kg/K	1200
Thermal conductivity	W/m/k	0.03

The overall conditioning system is schematically shown in figure 3. It consists of three main components: The Heat Pump - The Coolant circuit- The Cold Storage.

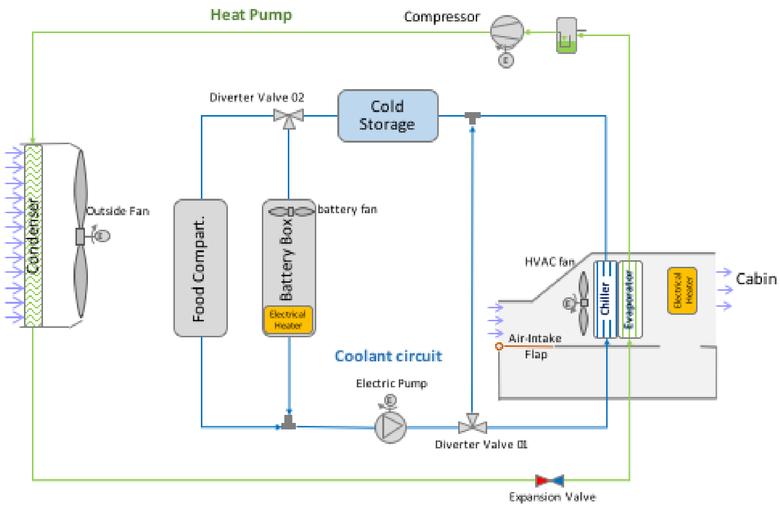

Fig.3: Scheme of the overall conditioning system simulated and developed.

Key components are: Chiller dimensions: 340 x 80 x 120 (40 plates) - Radiator dimensions: 230 x 150 x 35 mm (1 row, 12 tubes)- Evaporator dimensions: 250 x 250 x 60mm (Multi-pass arrangement -2 row, 2 pass) .
The food storage compartment is cooled using a radiator component with recirculated air blow across it. The air mass flow rate through the heat exchanger was set to 0.03 kg/s. Physically the evaporator of the heat-pump faces the heat exchanger of the coolant circuit (chiller). The coolant, powered by the electric pump, flows throughout the cold-storage, the battery-box and the food-compartment. In the Battery-Box the heat exchange between the coolant and the surrounding air is tuned by the fan: if the fan is turned off no noticeable heat exchange is observed. Different paths of the circuit are selected by means of two Diverter-Valves (DV), the followings are the most typical cases:

- DV 01 off / DV 02 off → coolant flows in the Cold-Storage and in the Food-Compartment. It represents the nominal working condition with running vehicle.
- DV 01 off / DV 02 on → coolant flows in the Cold-Storage and in the Battery-Box. It cools-down the batteries in heavy driving conditions.
- DV 01 on / DV 02 off → coolant flows in the Chiller, the Cold-Storage and the Food-Compartment. It represents the nominal working condition with vehicle plugged-in.

The simulation results for hot conditions (+40°C) and thermal load of the heat pump heat exchangers are shown in figure 4.

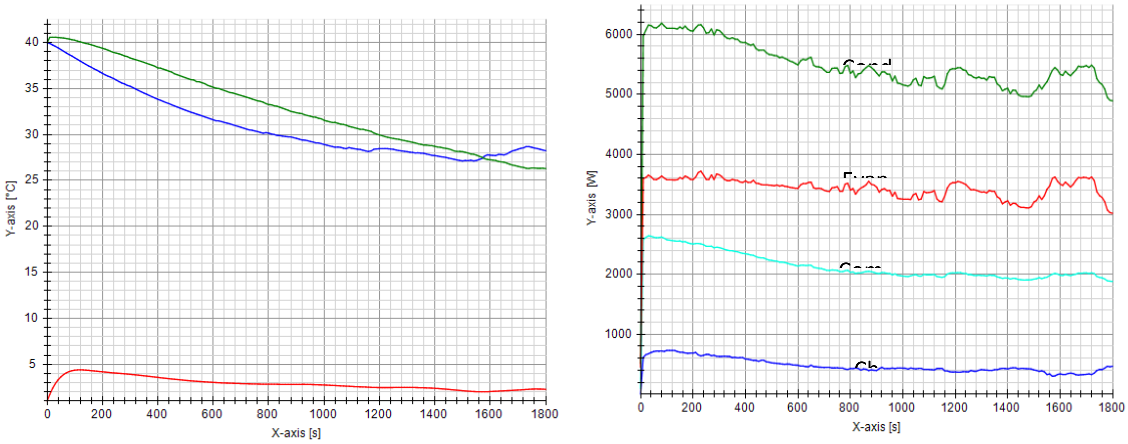

Fig.4: Left Compartment temperature over a WLTC driving cycle. The food storage and the coolant circuit were assumed to be pre-conditioned to 1°C while charging. Right: Thermal load of the refrigerant system heat exchangers The average COP of the refrigerant system is 2.

The refrigerant mass flow rate through the condenser and the parallel branch of the evaporator and chiller are shown in figure 5 a. Over the course of the WLTC driving cycle, the thermal energy required to maintain the food storage compartment temperature below 4°C in shown in figure 5 b.

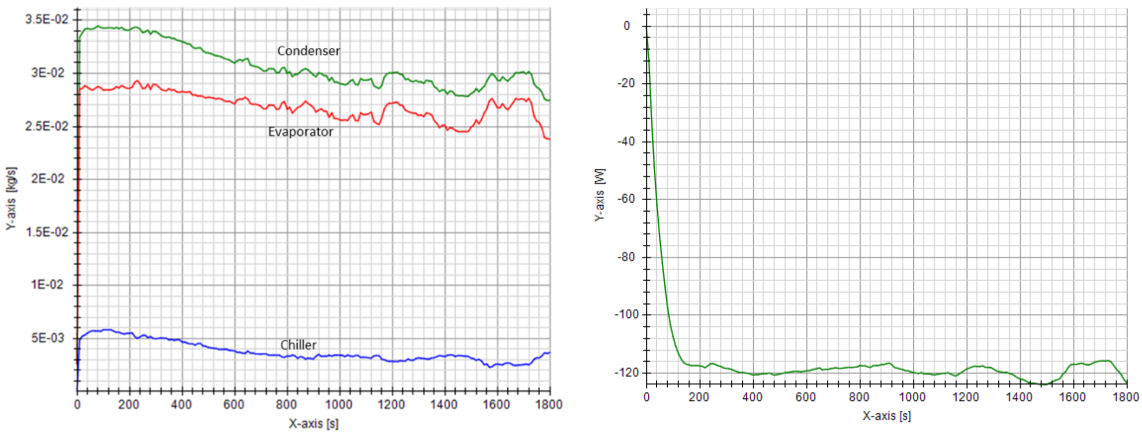

Fig.5: A: Refrigerant mass flow rate of the heat exchangers. B: Thermal power transferred to the food storage compartment.

5. Thermal insulation of the battery pack

The battery pack is composed by 8 Li-ion modules conditioned by liquid cooled heat exchangers and by a diffusion unit. When the vehicle is parked unplugged for a long period of time the PCM panels and accumulators inside the battery enclosure are used to accumulate and release heat so that the batteries could be kept conditioned within an ideal temperature range between 15^{O}C to 25^{O}C. The solar panel on the spoiler supplies the needed energy to a resistor during the day, this heats up the PMC panels which keep conditioned the battery enclosure during the night. Hutchinson super-insulating foils cover the battery enclosure and make its interior highly isolated from environmental temperature excursions.

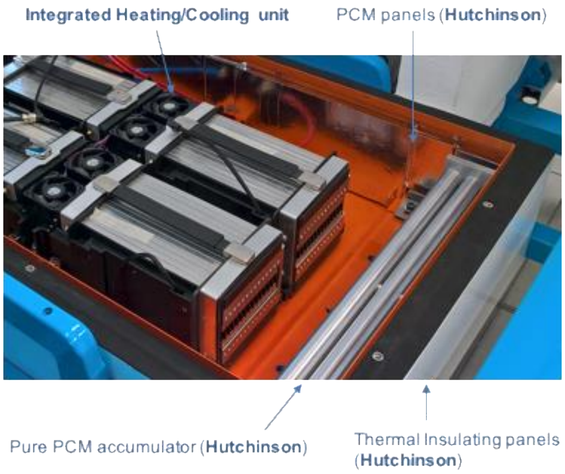

Fig.6: View of the battery pack enclosure.

6. Thermal insulation of the vehicle cabin and food compartment

The insulation of the battery cabin is a key aspect of the vehicle design and manufacturing in that the insulating panels are made by a light weight and low cost composite that close the chassis while performing as noise control and structural elements. The insulation of the food compartment is made by a 4cm thick roto-moulded elements filled with high density polyurethane.

7. Sub-systems integration in the vehicle

The developed heat pump and the cold storage unit are studied to condition the food compartment and the battery pack by liquid cooled cooling plates. The cabin is conditioned by a temperature controlled air flow. The overall system is shown in figure 7.

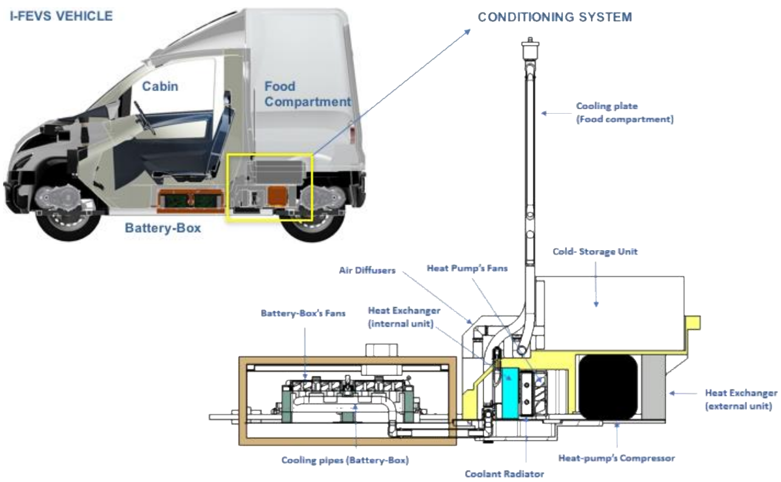

Fig.7: View of the complete integrated conditioning system and its positioning in the vehicle.

8. Assigned priorities for energy management and systems control

The three compartments and the cold storage unit are brought at the desired temperatures while the vehicle is plugged in. During the typical two-hour mission of food delivery the temperatures of three compartments are monitored and reconditioned in a 5 minutes loop. When the cold storage unit and-or the battery capacity are below defined critical values, the energy management system according to set priorities decides how to manage the temperature levels in the three compartments. The energy management unit is perfomed by an automotive grade electronic board (Infineon Aurix based platform) whose operation can be set through a smart phone remote control. The overall view of the implemented scheme is shown in figure 8.

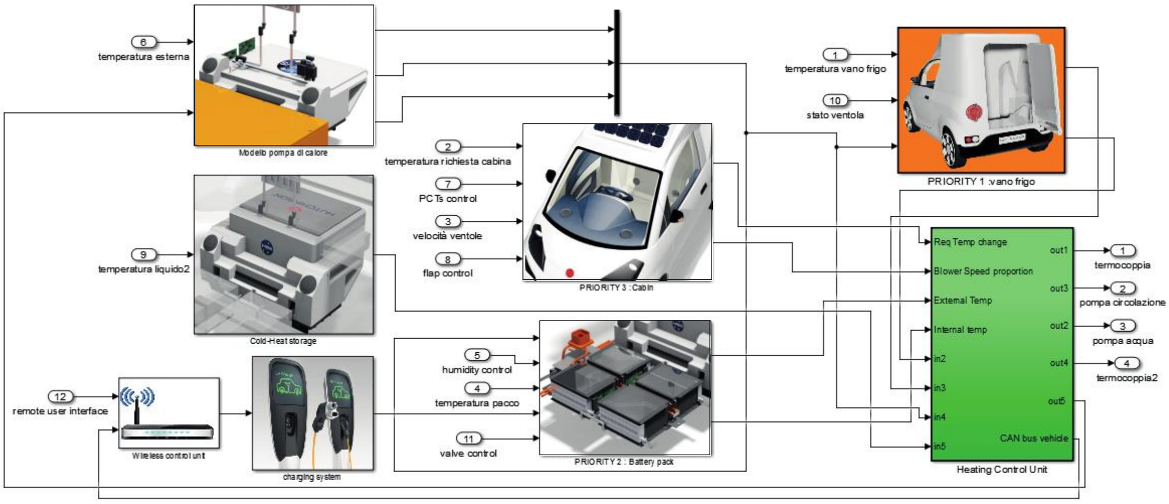

Fig.8: The Matlab-Simulink based energy management system with its remote control unit.

9. Results and Conclusions

Starting the typical two hour mission with the three compartments preconditioned at the desired temperatures, the tests show that with outdoor temperatures ranging from 30^{O}C to 37^{O}C the temperatures inside the three compartments can be maintained at their initial nominal values using only about 1 kWh of the battery capacity.

The advanced thermal systems designed-developed and integrated in the OSEM-EV demo vehicle can be exploited in a variety of other vehicles.

10. References

1 P.Perlo et al “Towards Full Electromobility: Energy and Power Systems”, Chapter published on Catalysis for Sustainable Energy Production, Wiley 2010, P. Barbaro and C. Bianchini (eds).

2 Gi-Heon Kim, Jeffrey Gonder, Jason Lustbader, and Ahmad Pesaran, Thermal Management of Batteries in Advanced Vehicles Using Phase-Change Materials, The World Electric Vehicle Journal, Vol 2, Issue 2.

3 Torregrosa, B.; Payá, J.; Corberán, J.M. Modeling of mobile air conditioning systems for electric vehicles. In Proceedings of the 4th European Workshop—Mobile Air Conditioning and Vehicle Thermal Systems, Torino, Italy, 1–2 December 2011.

4 Lohse-Busch, H., Duoba, M., Rask, E., and Meyer, M., *Advanced Powertrain Research Facility AVTA Nissan Leaf Testing and Analysis*. Argonne, IL: Argonne National Laboratory Report, Oct. 2012. http://www.transportation.anl.gov/D3/data/2012_nissan_leaf/AVTALeaftestinganalysis_Major%20summary101 212.pdf, accessed Feb. 2014.

5 Lee, D. Experimental study on the heat pump system using R134a refrigerant for zero-emission vehicles. Int. J. Automot. Technol. 2015, 16, 923–928.