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Increasing the driving range of electric vehicles using secondary energies – a review

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Abstract – The on-going electrification of the mobility sector requires intensive research studies on several topics, such as energy storage systems and electric charging infrastructure as well as sustainable air conditioning. In winter performance losses reduce capacity and range of battery electric vehicles (BEVs) extremely. Furthermore, heating the passenger compartment exacerbates this. Hence,a lot of research is going on, regarding the support of the heating system in BEVs. The subject of this review is the state of the art of air conditioning systems. Alternative energy supplying concepts, which will provide the BEV with secondary, auxiliary energy (heating, cooling, and electricity) are discussed. Fuel operated heaters (FOHs) run by renewable bioethanol seem to make a great prospect to future air conditioning (heating and cooling). Subsequently, a view is given on alternative air conditioning concepts, such as area or layer heaters. Researches show that air conditioning systems have to work more decentralized and directly, saving energy consumptions and thus increase the range. The most promising and explored approaches are discussed. The paper closes with a conclusion and an outlook.

***Keywords** – battery electric vehicles, air conditioning, heating, cooling, fuel operated heater, secondary energy, renewable energy. bioethanol*

I. INTRODUCTION

Due to a high efficiency, advantageous torsional characteristics as well as no local emissions, electrified drive systems are a promising alternative for mobility purposes.

The success of Battery Electric Vehicles (BEVs) goes hand in hand by the range of the car, the costs of battery manufacturing and required acclimatization comfort. Passenger compartment heating in combustion vehicles is usually operated using and transforming the waste heat of the combustion engine. In particular, modern diesel engines and BEVs/HEVs (Hybrid Electrical Vehicles) do not produce enough waste heat. So the heating is supported nowadays by different auxiliary heating systems.

The air conditioning of the passenger compartment of battery electric vehicles offers a new and wide field of research, in conventional and technical ways. Several research studies figure out that energy intensive consumers (mainly the air conditioning) reduce efficiency and range of battery electric vehicles up to 50 percent during winter [1-4].

Fig. 1 clearly shows the achievable ranges of our research vehicle (Fig 2: Renault ZOE R240, 2015)in different driving scenarios. According to NEDC (New European Driving Cycle) the range of the Zoe R240 with a 22 kWh battery is said to be 240 km. The NEDC consists of four urban driving cycles and on extra-urban driving cycle, which shall represent typical usage of cars in Europe [5].

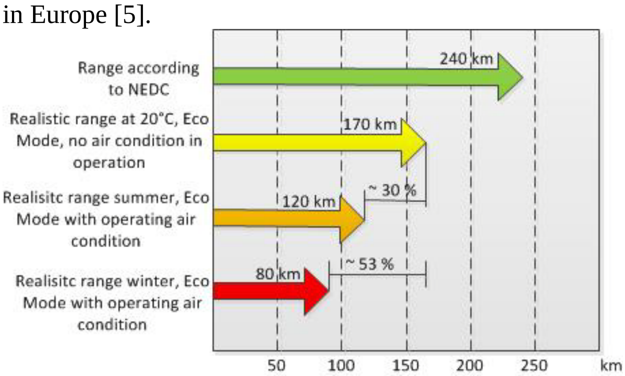

Fig. 1. Range of Renault ZOE R240

Based on our experience, ranges of max.170 km are realistic when driving at 20 °C in *ECO-Mode* (max. speed is reduced to 93 km/h, max. air condition performance is reduced, no operating air condition).In hot summers, when the passenger compartment is cooled, still 120 km are reachable. In winter (with operating air heating) the range decreases to 80 km. The effect of the outdoor temperature increases in winter since the capacity of the battery is significantly lower at cold temperatures than at standard test conditions of 20 °C. According to NEDC the round trip from Ansbach to our partner university in Nuremberg (100 km) should be easily done with our Renault Zoe R240without a stop to recharge the battery.

Unfortunately, the real situation today is somewhat different. Only, at a moderate ambient temperature of about 20 °C and driving *ECO-Mode*, the detailed round trip can be achieved without charging. However, if the temperature differs from 20°C (and even worse the air conditioning of the passenger compartment is activated), the range of the ZOE decreases up to 30 % in summer time and 53 % in winter. UMEZU et al. [6] point out, that in studies with a MITSUBISHIi-MiEV, heating reduced the range even as much as 68 %.

Fig. 2. Research vehicle Renault ZOE R240

Important technical data of our BEV are detailed in table 1 [7].

Table1. Technical data Renault ZOE R240

Technical data	Renault Zoe R240
Electrical drive	Three phase synchronous generator
Cooling system	Air cooled
Battery	22 kW
NEDC-Range	240 km
Power	65 kW (88 HP)
Max. torque	220 Nm
Max. speed	135 km/h
Consumption	14.6 kWh/100km

In consequence, the aim of our research activities is to increase the range of the electric vehicle by relieving the battery pack from the air conditioning by using secondary energies, with regard to polluting emissions, preferably renewable energies.

In this paper, we present a detailed review of the current state of the art in academic research and industrial development concerning approaches on air conditioning and ventilation in electric vehicles and further adaptions and the application of renewable energies.

The review focuses on several different aspects arising in our research. Three of those are:

1. State of the art on air conditioning concepts in battery electric vehicles
2. Alternative research concepts on operating the air condition of a battery electric vehicle
3. Research activities for air conditioning beyond mobility

The following sections II to IV give a brief view on selected work in these three fields.

II. STATE OF THE ART – AIR CONDITIONING IN ELECTRIFIED VEHICLES

Cooling the passenger compartment of BEVs is mainly still done by common air conditioning systems of combustion cars. The range reduction maximizes in wintertime, depending on low capacity of the battery, too less waste heat and the high amount of required electrical energy for the heating system. Since greatest savings can be achieved in winter and providing heat is easier than coldness, most research projects only focus on relieving the battery by supplying heat for the compartment. Further studies focus on provide heating capacity for the battery, too.

Currently, three heating concepts are in use for BEVs (see Fig. 3):

1. electrical high voltage (HV) air heaters
2. electrical HV water heaters
3. heat pump heaters (HPH)

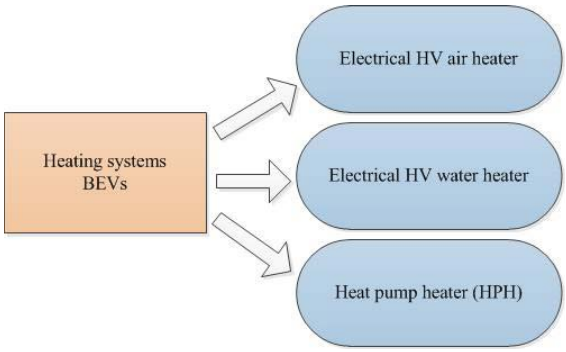

Fig.3. Common heating systems BEVs

A. Electrical high voltage heaters

Electrical high voltage (HV) heaters are one sort of electric heater, which are supplied by battery-energy. These are applied in air- and water-cooled vehicle systems. High voltage water heaters allow an energy efficient usage, but reduce the range up to 40 % [8].

B. Heat pump heaters

Heat pump heaters (HPHs) have remarkably high energy efficiency, but still need electric power for running. This advanced technology can provide heating as well as cooling capacity for the electric vehicle. [9] Recent developments in multiple heat pump systems are carried out to enhance the heat pump system efficiency. Our research vehicle, the Renault Zoe R240, is equipped with a heat pump system for heating and cooling.

In both cases (HV heaters and HPHs) the capacity of the battery is reduced by the electric consumption and affects directly the range of the BEV. Due to these effects, research projects follow up with the question, how the supply of secondary auxiliary energy can relieve the battery and enhance an adequate air conditioning.

SHIMADA details that the air conditioning by using renewable energies is a strong criterion on buying an electric vehicle nowadays and in the future [10].Furthermore, this assessment is supported by RAMANA et al. in [11]. They clearly point out that the use of renewable energies is the most efficient approach for air conditioning in closed rooms.

Depending on the applied process, the production of renewable thermal and/or electrical energy can help to increase the range: secondary supplied warmth can support or overtake the heating of the compartment in winter. Generated electrical energy can be used to run secondary heating and/or cooling systems, ventilation concepts in the compartment or feed the battery [12]. Due to transformation losses the most efficient way is to produce the heat directly from burning fuel.

III. STATE OF THE ART – ALTERNATIVE CONCEPTSFOR AIR CONDITIONING IN ELECTRIFIED VEHICLES

A. State of the art – alternative energy supply

In this review we took a closer look on alternative energy concepts for supporting the air conditioning system with heat or generated electricity. The most promising and best explored are shown in Fig. 4.

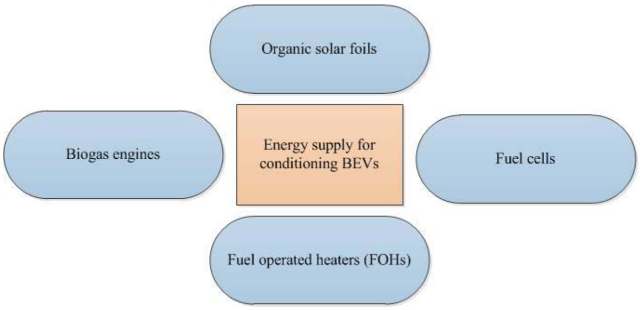

Fig. 4. Alternative energy supply for auxiliary systems in BEVs

i. Biogas engine

A discussed option is the implementation of a biogas engine for conditioning the passenger compartment or generating required electricity [9]. Several studies (such as [10]) show that there is a huge field of applications for biogas engines in electric and hybrid vehicles.

Furthermore, JAGUAR and BLADON JETS developed a range-extended electric car that is equipped with electricity by operating two small biogas engines. This application seems useful if small size, light weight and high output delivery is significant. The BLADON JETS micro gas turbines generate 140 kW to charge the batteries – extending the range of the car to a remarkable 900 km. [13]

ii. Fuel cells

Another research scope is the usage of fuel cells for generating energy and heat. Fuel cells generate about 40 percent waste heat which can be used for cabin heating [14, 15]. However, generating hydrogen (which is necessary for the fuel cell operation) is still very expensive and energy intensive. Today, hydrogen is mainly produced in pilot plants and thus not available in a sufficient amount for driving or supporting electrified vehicles adequately.

iii. Solar panels and foils

Mounted solar panels on car roofs for generating energy, are still available on the market. WEBASTO manufactures solar sunroofs, which provide additional electricity. Since the production of common solar panels needs rare earth, latest studies focus on the usage of so-called organic solar foils. For air conditioning the passenger compartment, organic solar foils can be easily implemented on car roofs and if they are translucent, also on windows. The generated electric power can operate several small fans, which will lead to a continuously fresh air supply to cool down the passenger compartment. Even more these solar foils help to reduce the direct radiation on the car. Organic solar foils can also contribute to recharge the battery. Although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar system decreases.

iv. Fuel operated heaters

A further promising approach – the auxiliary heating using biofuels – can support or adopt the air conditioning of BEVs. In contrast to high voltage heaters, the use of fuel operated heaters (FOHs) does not have a strong impact on the battery since the heat production is mostly independent. Heat will be directly generated by burning fuel.

BEETZ et al. [16] point out that the most efficient usage of the battery electricity is the implementation of fuel operated heaters with a heating power from 900 kW to 4.000 kW. Some manufacturers (such as VOLVO) already implement FOHs in their electric vehicle prototypes. Mostly FOHs can be implemented directly into the air conditioning system of the vehicle. Similar to today's BEVs battery cooling systems, there are two possibilities for FOHs: water heater or air heater.

Fig. 5 and Fig. 6 show the main structure of FOHs. FOHs can be easily installed in the engine compartment, in the passenger compartment or at the exterior of the vehicle.

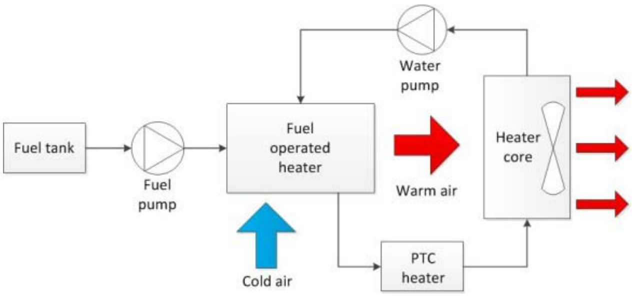

Fig. 5. Water circuit including FOH

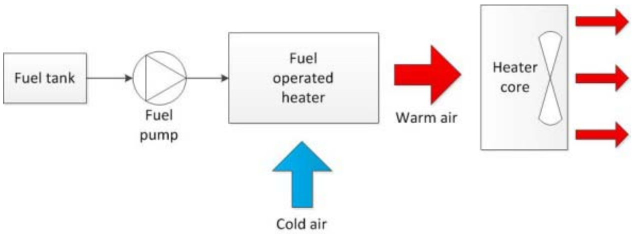

Fig.6. Air circuit including FOH

MIMURU et al. compare different possibilities for air conditioning in [17]. They show that FOHs can provide a workable solution to the range difficulty. Considering the discussion about CO_2 emissions, they even point out that biofuels would be more sensible to run the FOHs. It is still unclear whether customers would accept a fuel burned heater in an electric driven car.

Nevertheless several manufacturers are working on fuel operated heaters for electrified cars. EBERSPÄCHER already implemented a FOH-prototype in a MITSUBISHIi-Miev. The company even manufactures a FOH (Monofuel Hydronic-E-Mobility E4S, based on ethanol E100), which leads to an emission free operation [18].

KOHLE et al. [19] reveal in their study, that the energy savings by using an ethanol fuel operated heater instead of an electrical heater comes up to 30 %. This value was figured out by testing a BEV at an ambient temperature of -7 °C according to the TÜV SÜD Electric Car Cycle (TSECC). This car cycle defines the velocity profile as a combination of three street types [20]. The applied fuel heater was a Hydronic-E-Mobility E4S heater, operated with 100 % ethanol. The range benefit was calculated according to the energy consumption. For the entire distance, the energy consumption sums up to 15.72 kWh. During this test the heating power of the FOH was 3.17 kWh. If the required energy would be supplied by the electrical heater, with an efficiency of 85 %, 3.7 kWh would be needed.

Due to the uncomplicated production and high availability of bioethanol as well the easy implementation of the heater and auxiliary systems in the vehicle, bioethanol FOHs seem to offer a good contribution to the heating systems of the future.

B. state of the art – alternative air conditioning concepts for electric vehicles

Despite alternative energy concepts being the focus of on-going research, even more and more issues on air conditioning the passenger compartment are addressed. Few studies discuss new concepts, mainly for heating and well-feeling of every passenger. The most promising approaches are listed in Fig 7.

i. Area heaters

Cold areas in the passenger cabin can be heated by using area heaters, such as resistance heating foils, which will lead to a higher comfortable temperature for the passengers. The required electricity can be generated by solar cells, mounted on the car exterior.

ACKERMANN et al. [21] analyze in their study how area heaters contribute to a well-feeling of the passenger and an energy efficient HVAC (Heating, Ventilation and Air Conditioning) system. They show that area heaters shall be mounted close to the body to achieve a perfect heat distribution to the body.

KLASSEN et al. developed an acclimatization concept using area heaters and reducing the energy consumption up to 50 % for each passenger. The basic idea of their concept is only to heat up the area around the passenger. Since passengers just feel the direct air temperature around them, it is more energy-efficient and cheaper to distribute the heat around the passenger. A major aspect is the decentralization of the future HVAC system in vehicles. In this case, each passenger can control the private ambient acclimatization individually. This would relate to more energy savings [22]. HYUNDAI is working on a special HVAC system, which only operates the occupied zones in the cabin [11].

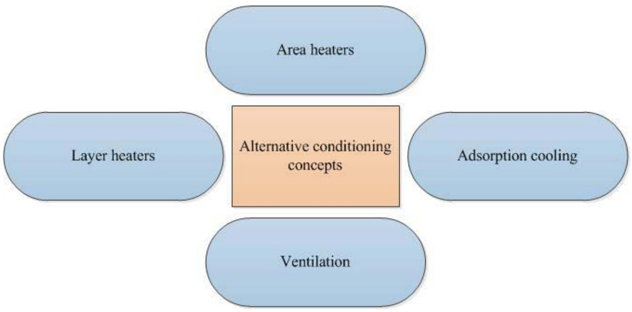

Fig. 7. Alternative conditioning concepts for BEVs

ii. Layer heater

Layer heaters, a further development of common high voltage heaters, are already in use in different industrial applications. When they are admitted by electricity, they emit heat. The work of CAP et al. [23] points out, that the efficiency of these layer heaters achieves up to 99 %. Compared to a common PTC (Positive Temperature Coefficient) water heater, the compartment target temperature was reached earlier – after 6.1 min instead of

10.8 min. Furthermore, the energy consumption was reduced by 18 %. This heating system can be also used as auxiliary heating and for battery air conditioning.

iii. Ventilation

Generated sun power can support continuously ventilation in the compartment, which will lead to a continuously fresh air supply and lowered heating in the car cabin.

iv. Adsorption cooling

Finally, adsorption cooling shows potential for efficient use in electric vehicles. It has not reached a common usage nowadays, due to of a few limitations such as low capacity of the most currently adsorbents. ABDULLAH et al. point out, that adsorption cooling will be common if further improvements are achieved [24].

IV. STATE OF THE ART – AIR CONDITIONING CONCEPTS BESIDES MOBILITY

Heating of residential and agricultural buildings by running a biogas engine is state of the art in rural landscapes. Accruing biomass is gasified and turned into biogas. This renewable energy can produce heat or electricity due to combustion.

Darkening foils still help to reduce the solar radiation on cars and the faces of building. This application leads to a lower indoor temperature. Solar foils use this effect too. Furthermore, the converted sun power can relieve the internal consumption of buildings.

LEVINSON et al. [25] show in their study that the adoption of solar reflective coatings for opaque surfaces of the vehicle shell can decrease the indoor temperature of the compartment of a vehicle parked in the sun. An experimental comparison of a black and silver car (same model) indicates that the required cooling capacity to cool the compartment to 25 C within 30 min in the silver car is 13% less than the required energy in the black car.

The face greening of building is a more and more considered aspect relating to air conditioning of facilities. However, the transfer of this interesting research to the electrified mobility seems not doable.

KIM et al. present in [26] a state of the art review of different technologies to deliver refrigeration from solar energy. Topics that are covered are solar electric and solar thermal technologies. Comparisons are made between the different technologies both from the point of view of energy efficiency and economic feasibility. However, more detailed research has to be done. Until now this technology is mainly used in the field of sorption systems for buildings.

Regenerative air conditioning systems using water or ice as a cooling storage medium have been widely adopted. A new field of experience is an air conditioning system using hydrate slurry for cooling. The cooling medium (developed in the work of OGOSHI et al. [27]) is a fluid of a mixed solid-liquid phase type, consisting of fine particles and an aqueous solution of clathrate hydrate slurry (CHS). As it has a high thermal density in the temperature range of 5 C – 12 C, this cooling storage medium is well-suited to air conditioning and shows excellent properties for pumping and transportation. A significant reduction in pumping power consumption and other advantages can be expected with CHS. It is also expected to make contributions to CO_2 reduction by saving energy and leveling load in electric power consumption.

V. CONCLUSION

With a continual rise in petroleum fuel costs and the important discussion about emissions, increasing attention has to be paid to the development and utilization of renewable energy technologies. The ongoing electrification of the power train is a great challenge for the thermal management in BEVs.

With the precondition that heating has no negative impact on the range, the usage of FOHs operated with biofuels, seems one of the most promising alternatives to other heating systems. Mainly biofuels have a huge spectrum of raw material and are renewable. In combination with organic solar foils which generate electricity for ventilation, the fuel heating systems seem to be a good alternative for air conditioning of the passenger compartment.

Next steps of our research will include the implementation of a biofuel operated heater (E100) into our research vehicle and the mounting of organic solar foils on to the car roof. Extensive field tests and experimental drives and simulations [28] will then allow quantifying the energy-savings of the primary drive and thus the achievable range extension of the BEV.

It is still to be clarified whether costumers of BEVs accept a fuel operated heater due to environmental aspects. For the future it seems, that a combination of several of the presented technologies will be still necessary to achieve an adequate approach powering the electrified mobility going further.

VI. ACKNOWLEDGMENT

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