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Application scenarios for a dual use of a portable micro-CHP unit in a BEV and building

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Abstract

Within the scope of worldwide discussions regarding CO_2-reduction, the electrification of electric drive trains and the number of battery electric vehicles (BEVs) increases. However, there is still a lack of acceptance among customers due to the existing challenges such as low range, insufficient battery charging infrastructure, the higher price in comparison with similar conventional vehicles and customer flexibility. The scope of this paper is to analyse whether a portable micro-combined heat and power unit (pmCHP unit), investigated in an ongoing research project, could be used as a plant for combined generation of electrical energy and usable heat in residential buildings (domestic-hot-water & space heating) and in BEVs (range extender and thermal conditioning unit).

A mobile integration and alternative application of the pmCHP unit in adjacent fields could increase the overall sustainability in energy utilization. Furthermore, its independency and self-sufficiency could increase the acceptance of BEVs. To clarify the application of a pmCHP unit in residential buildings and BEVs, it is necessary to characterize the typology of buildings and the respective standards of heat insulation, as well as the common energy requirements regarding BEVs and buildings.

Additionally, with the utilization of various narrative scenarios and simulation tools developed at the IKME, the applicability, dual use and benefits of the pmCHP unit are investigated. To summarize, the analysis shows that the dual use of a pmCHP unit is possible, efficient, reduces CO_2-emissions and could increase the acceptance of BEVs.

Keywords: pmCHP, combined heat and power, range extender, electric mobility

1. Introduction

There is still a lack of acceptance among consumers regarding BEVs due to the existing challenges such as low range, insufficient charging infrastructure and consumer flexibility.

The maximum range of BEVs depends on the size and capacity of the battery and is furthermore influenced by topological, thermodynamical and dynamic driving effects. This gap could be closed by the use of a pmCHP unit which upgrades a normal state of the art range extender (RE) to a portable power unit with a combined generation of power and heat, integrated into the energy and thermal management of BEVs and buildings. The pmCHP unit consists of a combustion engine connected to a generator-unit, which can be used for charging the traction battery and for heating the battery packs or passenger compartment while driving, by using wasted heat. This enables a higher comfort and range.

The pmCHP unit offers the possibility of a more efficient use of fuel. It can also raise the comfort of the BEV and lead to a higher efficiency for electro mobility which could in turn increase consumer acceptance of BEVs. Furthermore, upcoming strict regulations for heat insulation and rising energy prices lead to a re-evaluation at least in Germany regarding thermal and energetic efficiency and CO_2-emissions.

The scalability of mobile micro-CHP units is currently a research project at the IKME in Hanover, funded by the Land of Lower Saxony (the so-called "Niedersächsisches Vorab") and the Ministry of Science and Culture.

The main intention is to minimize the above mentioned lack of acceptance among consumers and the problems regarding BEVs (low range, low comfort etc.). Hence, the identification of the possibilities for the dual use of a pmCHP unit in BEVs & buildings and the reduction of the CO_2-emissions from a vehicle and/or building are investigated.

2. Methodology

All necessary data will be gathered through different simulation tools in Matlab/Simulink and indicative measurements (test benches & measurement vehicle). Furthermore the development of a parameter space, including the specific parameters of the *Building & environment*, *BEV* and *Behaviour*, is necessary in representing the possibilities and establishing the probabilities.
The structure of the *TripleB* parameter space, developed at the IKME within an ongoing doctoral project, is shown in the following figure 1.

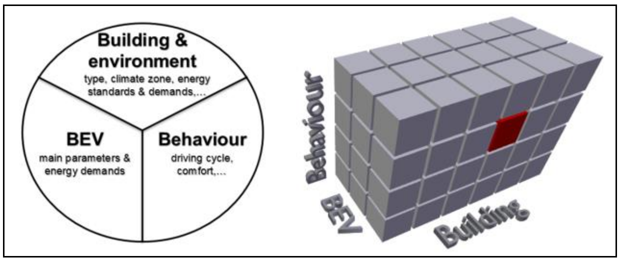

Figure 1. TripleB parameter space & rectangle

As a part of this paper, specific narrative scenarios and one combination (building & BEV) were chosen in order to clarify and examine the dual use of a pmCHP unit in buildings and BEVs.

3. Simulation tools

In order to find out if the dual use of the pmCHP unit in BEVs and residential buildings is possible and whether the use of this unit could decrease CO_2-emissions, three different simulation tools, developed at the IKME, have been used.

<u>Thermal energetic building simulation (Bsim)</u>
Simulation tool for a thermal energetic building simulation based on the VDI 4655 standard and German Meteorological Service data [1] enables the determination of annual and daily energy demand values.
Ten different reference load profiles of the normalized energy demand in terms of the three energy forms, electrical energy, heating energy and DHW energy are presentable for every building type with different specific parameters, including living space, energy standard and climate zone. Furthermore the reference load profile, the cumulative daily demand curve and the annual load duration curve for every specific parameter combination is displayable.

<u>Physical BEV simulation (BEVsim)</u>
Simulation tool for a physical simulation of longitudinal dynamics of BEVs (including roll, air and acceleration resistance) based on vehicle parameters (weight, front surface, battery capacity etc.) and dynamic consumptions (supply of electric auxiliary consumers, driving & consumer cycles).

<u>Physical energy supply unit simulation (ESUsim)</u>
Simulation tool for a physical simulation of an energy supply unit consisting of a modulating CHP unit, a modulating condensing boiler to act as a backup heater, a heat storage tank and a domestic hot water tank. This tool is based on the thermal components from the CARNOT toolbox library provided by the Solar-Institute Juelich (SIJ). For the simulation executed the energy supply unit was combined with the energy demand values resulting from the Bsim and controlled by a heat-led control strategy in order to satisfy the thermal demands in a building. In the simulated energy supply unit, effects like the warming and cooling phase of the power generation equipment, the temperature profiles in the storage tanks and the overall thermal losses and internal electrical consumption are considered. The superordinate energy management system that is used in the simulations to control the output energy of the power plants makes sure that the heat demand and temperature levels of the heating and DHW circuits are satisfied of any time. Thereby the strategy is to always prioritize the power generation by the CHP unit and only revert to the backup heater when the CHP unit on its own cannot meet the temperature levels.

4. Scenarios for a dual use of a pmCHP unit in buildings and BEVs

The present study examines if the dual use of a portable mCHP unit in BEVs and residential buildings is possible and efficient. The duration of use of the pmCHP unit depends on the energy demand of the building itself and the user's attitude.

A pmCHP unit with an electrical power of 2,8 kW and a mechanical power of 3,8 kW (test bench at the IKME) are chosen, due to the limit on portable weight (< 25 kg) [2]. The usage in a detached house could start, while the battery of the vehicle is being charged and requirements for thermal energy in the building exist.

In the German residential building sector, detached houses are the most common type (42 % of all buildings) [3]. Hence, to model the possible integration of a BEV with pmCHP into the building management, only this building type has been examined. The actual Energy Saving Ordinance (EnEV) defines maximum limits for heat requirements to be followed in new buildings. For reasons of comparison with the EnEV, mapping is necessary. Consequently, after a preselection regarding unit size and energy demands (Bsim) the "KfW Efficiency House 70" (KfW 70) is chosen due to its fitting energy demands.
A building with the thermal insulation standard KfW 70 needs 70 % of the energy of a comparable new building according to EnEV [4]. The heat requirement is 45 kWh/m²a [5]. Furthermore, different narrative scenarios for the daily mobility demand and the behaviour of the possible customers were chosen in order to analyse the dual use of the pmCHP unit. Within this context three different consumer types have been chosen.

<u>Scenario 1:</u>
Two Adults living in a detached house with 114,6 m^2 of living space [6].

<u>Scenario 2:</u>
A family of four persons (two adults, two children) living in a detached house with 137,6 m^2 of living space [6].

<u>Scenario 3:</u>
A multigenerational family of six persons (two adults, two children and two retired persons) living in a detached house with 206,4 m^2 of living space [6].

As primary car (BEV), all three types of consumers drive a VW eGolf. The heat storage tank size is 750 l and the location of the house is North-West German Lowlands (Test reference year TRY03) [1]. During a workday the total daily driving distance is 56,1 km and 34,8 km at the weekend. Furthermore, a driving (NEFZ) and demand cycle for electric loaders in a BEV are considered [7]. A professionally active person leaves the house at 7:00 a.m. and returning at 5:30 p.m..

Figure 2 shows the total distances split into individual route sections by trip purpose, based on [7]. These distances are used in the BEVsim.

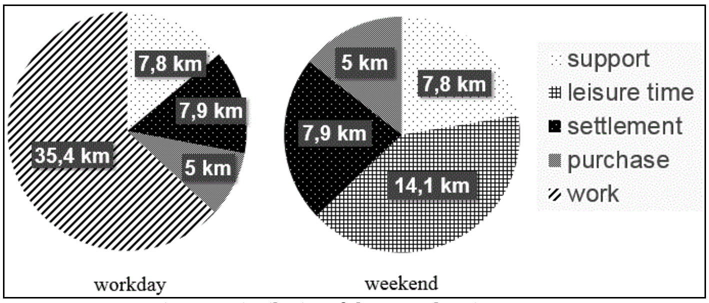

Figure 2. Distribution of the routes by trip purpose

For the calculation the CO_2-emissions of the different energy supply systems *power grid* (576 gCO_2/kWh_{el}, Electricity Mix Germany), *condensing boiler* (260 gCO_2/kWh_{th}, running on NG) and *pmCHP unit* (417 gCO_2/kWh_{el}, running on petrol) have been considered.

5. Results

Figure 3 shows the energies generated (Q_{chp}, P_{chp}) and consumed (Q_{heat}, Q_{dhw}, $P_{consumption}$) in kW and running time of the pmCHP unit in h (Scenario 1 + 7:00 a.m. – 5:30 p.m. pmCHP unit as backup system in the BEV) on a typical Winter-Workday-Fine (WWH) to standard VDI 4655 [1].

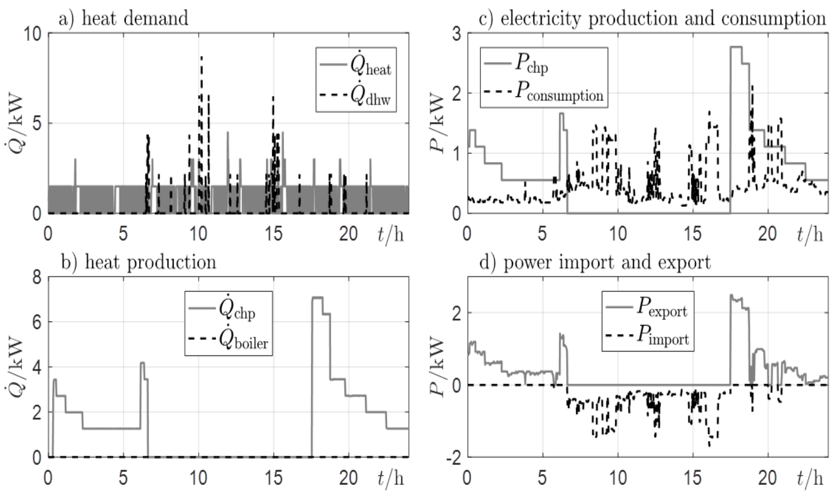

Figure 3. Energies generated (b, c, d) and consumed (a, c, d)

P_{export} is the generated electrical surplus (used for charging the battery of the BEV) and P_{import} the grid imported electricity. This ensures an efficient charging of the battery (BEV). Table 1 shows the most important parameters.

Energy generated / consumed	electrical / thermal energy
Q_{chp} (used th. Energy/pmCHP)	**31,38 kWh_{th}**
P_{chp} (generated el. Energy/pmCHP)	**13,40 kWh_{el}**
P_{import} (grid imported electricity)	**6,18 kWh_{el}**
P_{export} (generated electrical surplus)	**8,39 kWh_{el}**
$P_{consumption}$ (building incl. water pumps)	**11,20 kWh_{el}**
P_{BEV} (energy demand BEV during workday)	**10,83 kWh_{el}**

Table 1. Generated and consumed energies

6. Conclusions

During the absence of the pmCHP unit (working time, backup system for unexpected mobility needs/range) the energy demand is satisfied by the available energy in the storage tank (charged by the pmCHP unit during the running time in the building) and grid imported electricity (figure 3). The calculations prove that a combined use of a pmCHP unit in a BEV and a building (figure 4) could reduce the CO_2-emissions effectively by up to 49 % in comparison to a conventional condensing boiler and a standard power connection. The energy requirements of the building & BEV and the energy produced by the pmCHP unit match each other (table 2); hence the efficiency increases. Further studies will examine if the pmCHP unit could also be integrated into other application areas, such as camping and leisure market.

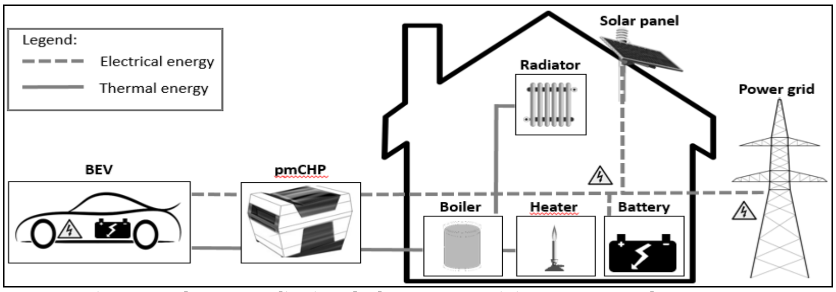

Figure 4. Scheme – Application/ dual use mCHP unit in BEV & smart home system

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