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Applicability and scalability of mobile mCHP units in mid-size battery electric vehicles and detached houses with different energy standards

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Abstract

In battery electric vehicles (BEVs) the thermal conditioning of the battery pack and the passenger compartment needs special consideration. In an ongoing research project, micro-combined heat and power unit (mCHP unit) concepts with a mechanical power in the range of 1 to 15 kW have been investigated. The mCHP units are plants for combined generation of electrical energy and usable heat for domestic-hot-water (DHW) and space heating in residential buildings. Additionally, the mCHP unit can be combined with heat generators (boilers or suchlike to cover peak loads), heat storages (heating buffer storage and DHW storage) and switchgear including instrumentation and control. A power conditioning unit (PCU), a special mCHP unit concept from the IAV Ltd (Gifhorn, Germany), upgrades a normal mCHP to a trigeneration of power, heat and cold. This concept is integrated into the energy and thermo management of BEV and not in use during parking periods, therefore a mobile integration and additional application of the PCU in adjacent fields could increase the overall sustainability in energy utilization. It is intended to transfer the CO_2-reduction potential of a BEV to the owner's house and the PCU enables independence and self-sufficiency in order to increase the acceptance of BEVs. To introduce the dual use of PCU in residential buildings, it is necessary to characterize the typology of buildings and the respective standards of heat insulation, as well as the common energy requirements. Additionally, with a simulation tool based on the VDI 4655 and German Meteorological Service data it is calculated, which unit size belongs to which type of BEV and residential building and whether the use of a PCU could decrease it´s CO_2-emissions. In Germany, 42% of residential buildings are detached houses [1]. Furthermore, in 2014, 48% of registered vehicles belonged to mid-size and compact class vehicles [2]. Using the example of an average family of three persons living in a detached house and driving a mid-size class battery electric vehicle including a PCU, the applicability, dual use and benefits are investigated. To summarize, the analysis shows that the dual use of a PCU is possible, efficient, reduces CO_2-emissions and could increase the acceptance of BEVs. Keywords: mCHP, mobile micro-CHP, combined heat and power, range extender, power conditioning unit, electric mobility

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1. Introduction

Battery electric vehicles have not been successfully established in the car market in Germany because there is still a lack of acceptance among customers. There are still challenges like low range, missing or bad comfort, like the insufficient heating, ventilation, and air conditioning (HVAC) of the passenger compartment and the higher price in comparison with similar conventional vehicles. The maximum range of BEV depends on the size and capacity of the battery, and is furthermore influenced by topological, thermodynamical, and dynamical driving effects. This gap could be closed by the use of a range extender (RE) with a combustion engine connected to a generator-unit, which can be used for charging the traction battery while driving. The PCU of the IAV Ltd is a further development which upgrades a normal RE to a trigeneration of power, heat and cold and is integrated into the energy and thermo management of BEVs. This system also uses wasted heat to either heat the battery packs or the passenger compartment of BEV and produces electricity in order to charge the traction battery to reach a higher comfort and range. Furthermore, this system is upgraded with additional couplings and a cooling compressor. That is why the PCU also enables the cooling of the interior or the traction battery (Figure 1 and 2). Therefore a continuous temperature equalization of the battery and the passenger compartment is possible.

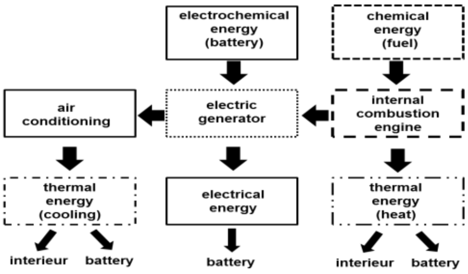

Figure 1. Internal connections of the PCU

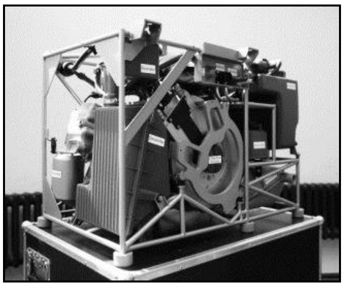

Figure 2. PCU trade fair model

The PCU offers the possibility of a more efficient use of the energy derived from fuel. It can also raise the comfort of the BEV and lead to a higher efficiency of electro mobility which could in turn increase the customer's acceptance of BEVs. To achieve the goal of the government (1 million registered BEVs in Germany until 2020) a combined use of mCHP units in BEVs and buildings could help support the successful achievement of this target. The scalability of mobile mCHP units is currently a research topic at the University of Applied Sciences and Arts Hanover, Germany. The main intention is to minimize the above mentioned lack of acceptance among customers, the problems of BEVs (low range, low comfort etc.) and the CO_2-emissions from a vehicle and/or building.

2. Scenario for a dual use of a PCU in buildings and BEV

The present study examines if the dual use of a PCU in BEVs and residential buildings is possible and efficient. The duration of use of the PCU depends on the type of fuel, the energy demand of the building itself and the user's attitude. In the German residential building sector, detached houses are the most common type (42% of all buildings) [1]. To model the possible integration of a BEVs with mCHP/PCU into the building management, only this building type has been examined. A detailed analysis of the detached house model shows different energy demands resulting from different building ages. Upcoming strict regulations for heat insulation and rising energy prices lead to a re-evaluation in Germany regarding thermal and energetic efficiency. During the oil crisis in the 1970s, better insulation standards for buildings were introduced to decrease heat costs. Since then, insulation standards have been further developed up to the standard Passive house (PHPP), a type of house which needs no active or only minimal additional heating. Consequently, there is a variety of different heat insulation standards and heat requirements in buildings. To model the heat requirements for a possible use of PCU in buildings in Germany, representative insulation standards widely used in detached houses were chosen (Tab. 1) [2].

Thermal insulation standard	Heat requirement [kWh/m²a]
Housing stock Germany (1960 – 1980)	**≤ 300**
Average Germany (Ø Germany)	**≤ 160**
KfW Efficiency House 85	**≤ 55**
KfW Efficiency House 70	**≤ 45**
KfW Efficiency House 55	**≤ 35**
Passive house (PHPP)	**≤ 15**

Table 1. Heating demand depending on the thermal insulation standard of a detached house

The actual Energy Saving Ordinance (EnEV) defines maximum limits for heat requirements to be followed in new buildings. For comparison reasons with the EnEV mapping is necessary. A building with the thermal insulation standard "KfW Efficiency House 85" (KfW 85) needs 85 % of the energy of a comparable new building according to EnEV [3]. The insulation standard "average Germany" (Ø Germany) takes all existing insulation standards into account and provides a reference. The thermal insulation standard Passive house however, provides the optimal thermal insulation standard in this simulation [4]. In order to analyse this dual use a hypothetical model was created. For this model an average family of three persons, living in a detached house with 100 square meters of living space and driving a mid-size class battery electric vehicle has been chosen. Furthermore, the PCU with a thermal power of 2,4 kW is chosen as a result of a previous paper where this is the efficient size for a PCU of a mid-size battery electric vehicle [5]. Moreover, in 2014, 48% of registered vehicles belonged to mid-size and compact class vehicles [2]. Other usage profiles will be examined in future. As a result of another previous paper the calculated average using time of a car is 14 hours. Consequently, the car would be in the garage for 10 hours per day [6]. During this maximum time delay of the PCU, 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. The following tables (Tab. 2, Tab. 3) show the fixed and variable parameters for the simulation.

Parameter	Description
building type	detached house
living space	100 square meters
type of car	mid-size class battery electric vehicle
thermal power of the PCU	2,4 kW
electrical power of the PCU	1,2 kW
maximum time delay of the PCU	10 h
Number of peoples in the household	3
Test reference year for climate zone	TRY03, North-West German Lowlands

Table 2. Fixed parameters for the simulation example

Parameter	Description/variations
Thermal insulation (energy) standard	Housing stock (1960 – 1980),Average Germany (Ø Germany), KfW 85,KfW 70 and KfW 55, Passive house (PHPP)
Typical day	Transition-Workday-Fine (ÜWH),Transition-Workday Cloudy (ÜWB), Transition-Sunday-Fine (ÜSH),Transition-Sunday-Cloudy (ÜSB), Summer Workday (SWX),Summer Sunday (SSX), Winter-Workday-Fine (WWH),Winter-Workday-Cloudy (WWB), Winter-Sunday-Fine (WSH),Winter-Sunday-Cloudy (WSB),

Table 3. Variable parameters for the simulation example

3. Simulation tool for a thermal energetic building simulation

In order to find out which unit size belongs to which type of BEV and residential building and whether the use of PCU could decrease its CO_2-emissions, a simulation tool for a thermal energetic building simulation has been created. This tool is based on the VDI 4655 standard and German Meteorological Service data and enables the determination of annual and daily energy demand values. The following figure shows the graphic user interface of the simulation tool.

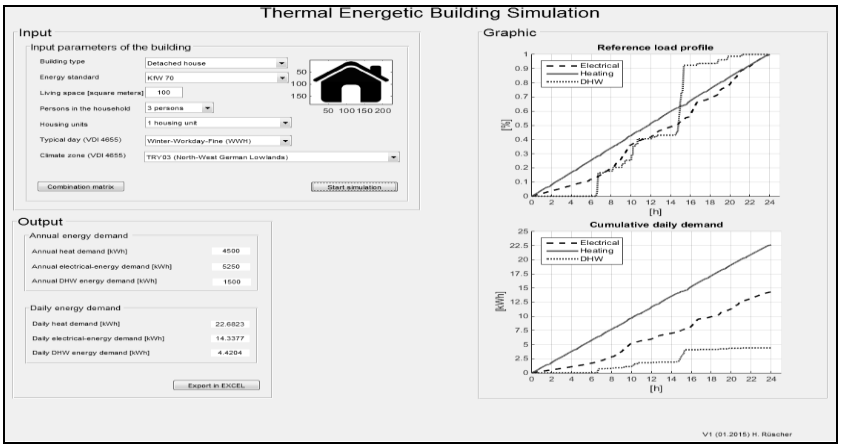

Figure 3. Graphic user interface of the thermal energetic building simulation tool

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, like 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 combinations are displayable. The following figures (Figure 4 and 5) show the reference load profile and the cumulative daily demand of a detached house with the energy standard KfW 70 on the typical day “Winter-Workday-Fine”.

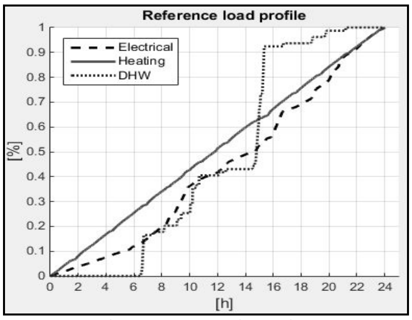

Figure 4. Reference load profile (KfW 70)

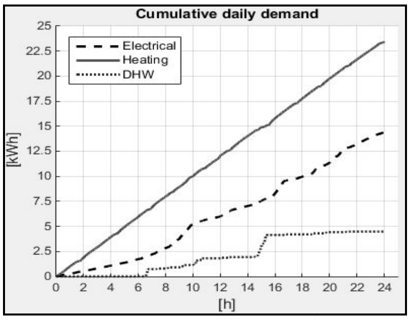

Figure 5. Cumulative daily demand (KfW 70)

The following figures (Figure 6 and 7) present the annual load duration curve of a detached house with the energy standard KfW 70 and the CO_2 savings subject to heating-energy demand.

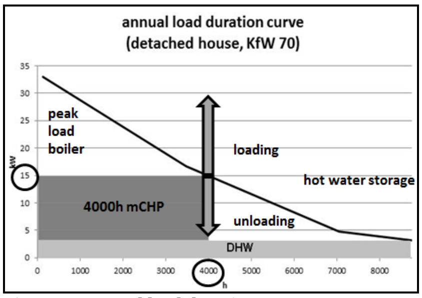

Figure 6. Annual load duration curve

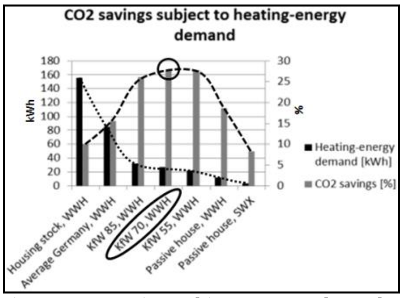

Figure 7. CO_2 savings subject to energy demand

The calculation proves that a detached house with the energy standard KfW 70 is the best building type regarding to the CO_2 savings potential. On a typical Winter-Workday-Fine (WWH) a PCU can reduce the CO_2-emissions up to 28% via CHP technology, compared to a conventional condensing boiler and a standard power connection in a building. In the following table the data (energy source) for the calculation of the CO_2-emissions is shown.

Energy source	CO_2-emissions [g CO_2/kWh]
“Strommix Germany”	**576**
condensing boiler	**260**
MCHP (natural gas)	**200**

Table 4. Basis for calculating CO_2 –emissions

4. Conclusions

A combined use of a mCHP unit in battery electric vehicles and in buildings could reduce the CO_2-emissions in the building effectively up to 28% in comparison to a conventional condensing boiler and a standard power connection. The energy requirements of the building and the energy produced by the PCU match each other; therefore optimal utilization of the CHP-effect is possible. With the help of this simulation tool further studies will examine if the PCU could also be integrated in other building types, such as office buildings, and cover its cooling requirements while the BEV is being charged. Furthermore, the potential of CO_2-reduction by the use of alternative fuels will be addressed within the scope of a doctoral thesis focussing on multi fuel capability of mobile mCHP.

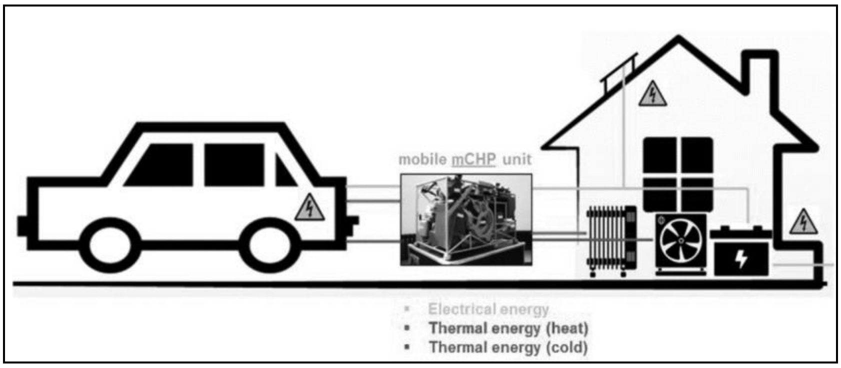

Figure 8. Scheme – Applicability mCHP unit

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