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The benefits of (automatic) pre-conditioning of e-buses

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Before electric buses are going into daily public transport service, energy-consuming activities like heating the bus interior should be done at the bus depot while the bus is still connected to the grid, using energy that would otherwise be at the expense of the batteries and therefore the range. Hence, pre-conditioning of e-buses is important for daily public transport service.

Having a good start

In electric bus operation, the pre-conditioning (often referred to as pre-heating) of electric buses is a widely known practice to extend the range. It usually includes pre-heating the bus interior, or cooling, if necessary, as well as pre-heating the battery. All of these while the bus is still connected to the power supply from the grid (plugged-in) at the depot before departure.

The reason behind it is simple and based on two facts: first, heating the bus interior requires plenty of energy and drains the battery when done after leaving the depot. And second, the battery cannot store as much electricity in cold as in warm conditions. The optimal temperature for the battery to have its maximum charging capacity is +25°C (inside the battery, not ambient temperature). Various studies indicate that the power output from lithium batteries reduces in the order of 10% at 0°C, 20% at -20°C up till 25% at -30°C. Thermal management systems keeping the battery pack warm consume a significant amount of energy (up to 30kW) reducing the vehicle's operational range.

By pre-heating the bus interior and the battery before drive-off, a decrease in driving range can be avoided. The heating can be carried out along with the battery recharging, thus bringing up charging capacity and at the same time not draining the battery for interior heating after leaving the depot. If pre-conditioning is not performed, under extreme conditions driving range is reduced by approximately one third.

Win-win or lose-lose

In other words, either you lose charging capacity (due to the battery being cold) and lose energy from the battery for heating the bus interior or you start the tour with a warm interior and 100% charging level.

Charging a Linkker bus in Turku harbour depot.
Photo by Markku Ikonen

The following calculation illustrates the effects of non-pre-heating, as cold (winter) conditions are more often an issue in e-bus operation.

Two more factors decrease the driving range at cold ambient temperatures. First, maintaining the bus interior temperature needs energy too, however much less than during the warm-up phase. And second, due to increased friction (in the bearings of the motor, in the bearings and gearwheels of the gearbox, in bearings of the drive shafts and bearings of the wheels), the bus needs roughly an extra 10% of driving energy to make it move, at least for some time after drive-off. However, these factors cannot be avoided by pre-heating, so they are not the core of this article.

The power of the bus interior heater can easily be as much as 30 kW. If the ambient temperature is -10°C, about 30 minutes of full power heating is needed to reach a comfortable interior temperature of between 15°C to 18°C. This means that 15 kWh of electricity will be used for this purpose. If the bus has a heater utilizing modern heat pump technology, the amount of energy needed can be cut down to one third in best cases. However, this calculation uses the worst-case scenario, meaning the use of a traditional resistive electric heater.

The ability of the electric battery to store electricity lowers down to approximately 85% when the battery temperature is -10°C instead of +25°C. In many cases of bus operation, the bus is inoperative only a few hours during the night, which means that the battery temperature may be higher than the ambient air when starting the bus operation in the morning. However, in this article, the calculation is based on the assumption that the battery temperature is -10°C to start with.

The calculation below for the influence of not pre-heating is based on the following presumptions:

• Ambient temperature	-10°C
• Bus electricity consumption	1.0 kWh/km (under warm conditions)
• Additional energy needed in cold environment	+10%
• Average driving speed (city conditions)	20 km/h
• Battery capacity left at -10°C	85%
• Interior heater max. power	30 kW
• Interior heater max. power usage time	30 min.

Battery size kWh	Range @ +25 °C km	Range @ -10 °C km	Range decrease %
100	90	59	-34
125	113	77	-32
150	135	94	-31
175	158	111	-30
200	180	129	-29
250	225	163	-28
300	270	198	-27

Calculation by Markku Ikonen, Turku University of Applied Sciences.

The results show the effects of non-pre-heating on the range of the bus. The relative decrease in range caused by not pre-heating lowers along with increasing battery size. This is caused by the interior heating energy that does not depend on battery size.

In this article, we describe how pre-conditioning is being done in different partner regions of the Interreg Europe eBussed project and what the pros and cons are.

Breaking new ground in Hamburg

In Hamburg, Germany we spoke to an expert on the topic from VHH, one of two transport operators in the city who have e-buses in their fleet. In accordance with the experience of other transport operators, VHH had noticed that the range was reduced during winter.

First, pre-conditioning was done manually by the bus drivers. When they arrived at the depot, they started the process before they got ready for their shift. Thus, the buses got approximately half an hour for pre-conditioning.

As part of the overall e-mobility transition at VHH, in December 2020, they ran the first tests with an interface to the charging infrastructure for automatic pre-conditioning that uses an IPV6 Internet connection. The programme is a collaboration with Hamburg's grid provider Stromnetz Hamburg who provides the backend. Since the beginning of 2021, more regular test are being executed. An interface to the e-bus dispositioning system will come before the end of 2021. Then, the timetables for the departure of the buses will be updated automatically every five minutes. The idea is that pre-conditioning of each individual e-bus will start according to its deployment on that particular day including any spontaneous changes if need be. In the final stage, all IT systems will be connected. The aim is to develop open standards, independent of manufacturers.

Sensors in the vehicles autonomously and individually decide what kind of pre-conditioning is needed and how long before the next tour it needs to be started. There are differences for buses from different manufacturers. The battery pack and the interior of the bus are pre-heated to optimal temperatures. After leaving the depot, if the outside temperature is below 5° C, additional diesel heaters are used regularly to heat the bus interior during driving.

Pre-cooling can become necessary as buses are not only charged during the night but during the daytime too. Especially in summer when buses run so-called shared shifts, they return to the depot in the early afternoon and are being pre-cooled while charging before setting off again.

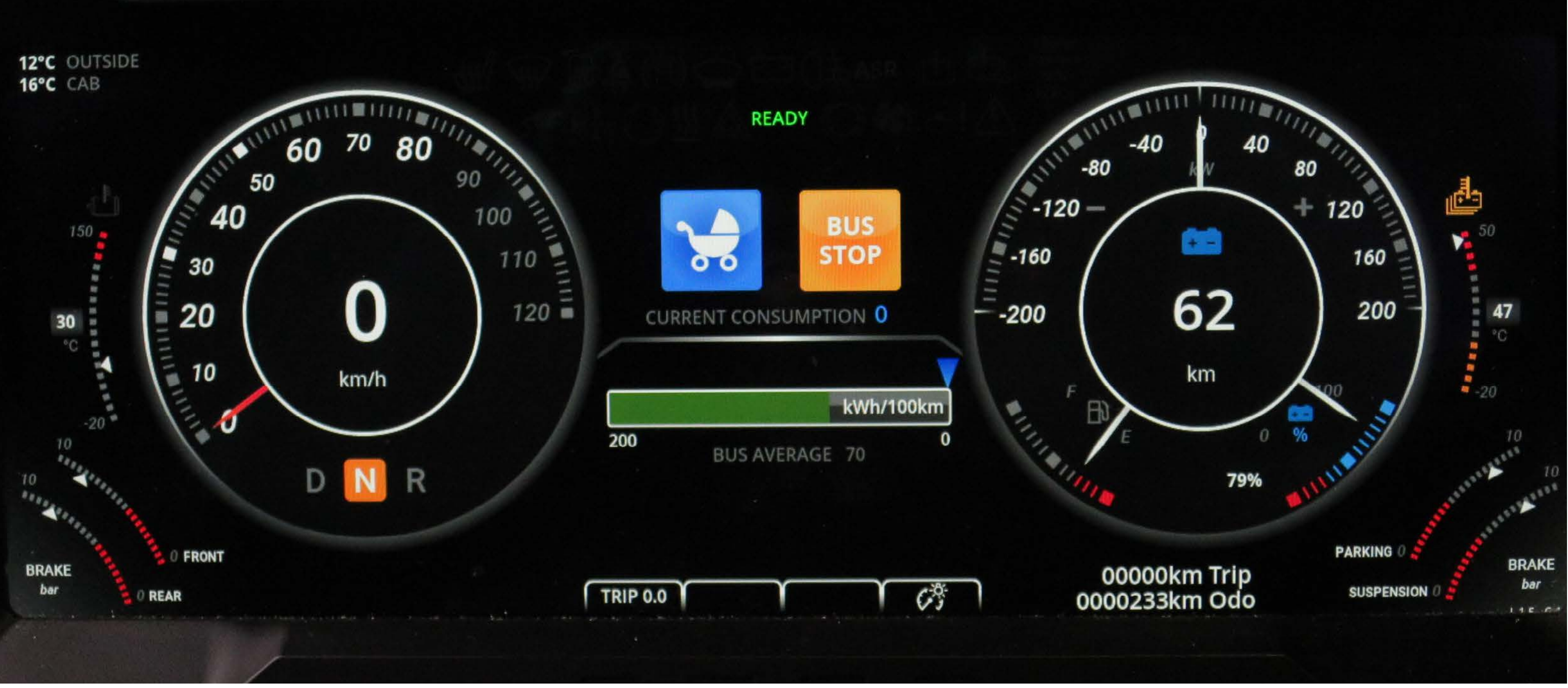
Under normal conditions, pre-heating of the battery pack does not start from whatever ambient temperature prevails. Often the battery has not completely cooled down before the next charging procedure. This is also relevant when looking at recent battery development. Solid-state batteries (e.g., Mercedes) have an optimal operating temperature of 80 °C. What sounds like higher consumption of energy for pre-heating is in fact not. The delta between the temperature at the beginning of pre-heating and reaching the optimal temperature is very similar to that of lithium-ion batteries.

Heating and charging in Turku

In Turku, in Southwestern Finland, six electric buses have been in use since October 2016. The buses are charged with cable equipped 22 kW and 50 kW depot chargers and with opportunity chargers of 300 kW (inverted pantographs) at both ends of the about 13 km long bus line. These buses are used only on this line.

In terms of pre-conditioning, bus interior preheating is a more relevant need under Finnish conditions than pre-cooling. These buses start their daily work very early in the morning, so precooling is usually not necessary even in summer.

There is no automation related to the preheating. The person in charge of bus



Instrumentation of a Linkker e-bus.
Photo by Markku Ikonen

preparations at the depot turns the preheating on manually one hour before the departure time. At the same time, the bus battery charging starts. Electricity for heating and charging is taken from the grid. For some reason, the charging is possible only when the power of the bus is turned on. The batteries are most likely not preheated, but exact information about this is not available.

Simultaneous heating and recharging cause a problem. The electricity supply does not allow the use of 50 kW of power for all six buses at the same time. Due to this, three out of the six chargers are configured to deliver only 22 kW instead of 50 kW. In the case of the lower-powered chargers, priority must be given to recharging. This means that bus interior preheating is not in every case possible.

However, there are plans to update the electricity supply so that 50 kW would in the future be available for all six buses. This would make both preheating and recharging possible at the same time.

A different view from Utrecht

In the depot in Utrecht buses are pre-heated by the electrical grid to which they are connected. The charging management software is designed to allow pre-conditioning but it was time-consuming to set it up properly: it works differently for each type of bus. It is still a complicated process: After the batteries of a bus are fully charged at night, the pre-heating system will be activated. The charging system needs to be (automatically) reset. It is a two steps procedure. The buses' batteries drain considerably on heating batteries and interiors but charging is faster than draining. Ultimately, the buses can leave the depot with full batteries and at operating temperature. The driver of the bus, however, has no actions to take in this procedure.

Heating while driving also consumes a lot of energy. If it was done entirely by the onboard batteries, it cost so much energy that the range would be reduced by more than 30%. Therefore, most electric buses in the Netherlands (>60%) have a small diesel engine onboard for heating the interior. This diesel engine produces few emissions, and the diesel tank is filled with biodiesel (HVO or GTL, while HVO emits virtually no CO2).

Although the Province of Utrecht would like the buses to be completely emission-free, the state of the art does not yet permit them. A diesel engine for interior heating is therefore accepted. In terms of policy, this is accepted as long as the onboard batteries are not fully suitable for heating en route. It is likely that in the future batteries will have the capacity to keep the interior at a comfortable temperature, even en route. If that is a proven technology, the Province of Utrecht will not hesitate to prescribe these buses for new concessions. At the same time, existing electric buses will not be written off prematurely for this reason: after all, that’s not sustainable either.

While the process of pre-conditioning the e-buses is similar to that in Turku or Hamburg, our project partners have interviewed a Dutch e-bus manufacturer on this topic to learn more about their perspective.

For e-bus developer and builder Tribus in Utrecht in the Netherlands good thermo-management is the solution to the design of economically attractive e-buses (special isolating glass, heat pump etc.). Most bus manufacturers are currently initiating programs to test the e-bus to its limits in special climate rooms, mimicking extremely cold and hot conditions to gather data about the thermo ‘leakages’ e.g., opening entrance doors, the impact of the presence of passengers etc.

Charging screen at the Pohjola liikenne depot in Helsinki.
Photo by Markku Ikonen

Onboard heat exchangers are an interesting innovation. In general, e-bus manufacturers are interested in getting the full picture of the various onboard heating and cooling processes and holistically optimise them. For instance, can the released heat of onboard devices that need cooling (via radiators) be used elsewhere?

On-roof solar panels installed on an e-bus are solely sufficient for the onboard 24-volt battery providing power for (essential) support systems to allow the bus to ride. Solar panels however cannot be used for power-consuming systems such as HVAC (heating, ventilation, air-conditioning). 24-volt systems such as the on-board ticketing system, CCTV system, infotainment system etc. may benefit, although this will not significantly affect the range of the e-bus.

E-bus manufacturers and operators ‘buy’ kWh performance for several years (commonly 10 years) from the battery pack manufacturers. Faster depletion or a shorter lifespan of the battery pack as caused by the HVAC system and more frequent recharging is not relevant.

Conclusions

Pre-conditioning can significantly extend the range of an e-bus. Independent of whether a diesel heater is being used for en-route heating of the bus interior, the charging capacity of the battery increases with an optimal operating temperature.

In our view, it largely depends on the number of e-buses that are being operated if the investment in an IT solution is reasonable or whether pre-conditioning can be done manually.

The integration of different IT systems becomes more important with operating e-buses compared to running a fleet of diesel buses. There will be solutions available on the market offering automated pre-conditioning which can be integrated into existing IT solutions for depot management and smart charging.

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