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Challenges for air conditioning and heating solutions in electrobuses

The energy supply to electric buses remains a major challenge. Against a background of limited energy resources in traction batteries, the use and interconnection of highly efficient individual components and intelligent thermal management are a major prerequisite for the achievement of acceptable operating ranges.

For some time now public service buses with electrical drive components have been in daily operation for many transport undertakings as hybrid buses, and meanwhile also as pure electrobuses. The key challenge here is still the energy supply to the vehicle as a whole, including all auxiliary users, since the operating range in electrically powered buses is directly dependent on the available energy budget, i.e. traction battery. As shown in Fig. 1, the operating range depends, among other things, on the power requirements of the auxiliary consumers and the ambient temperature /1/.

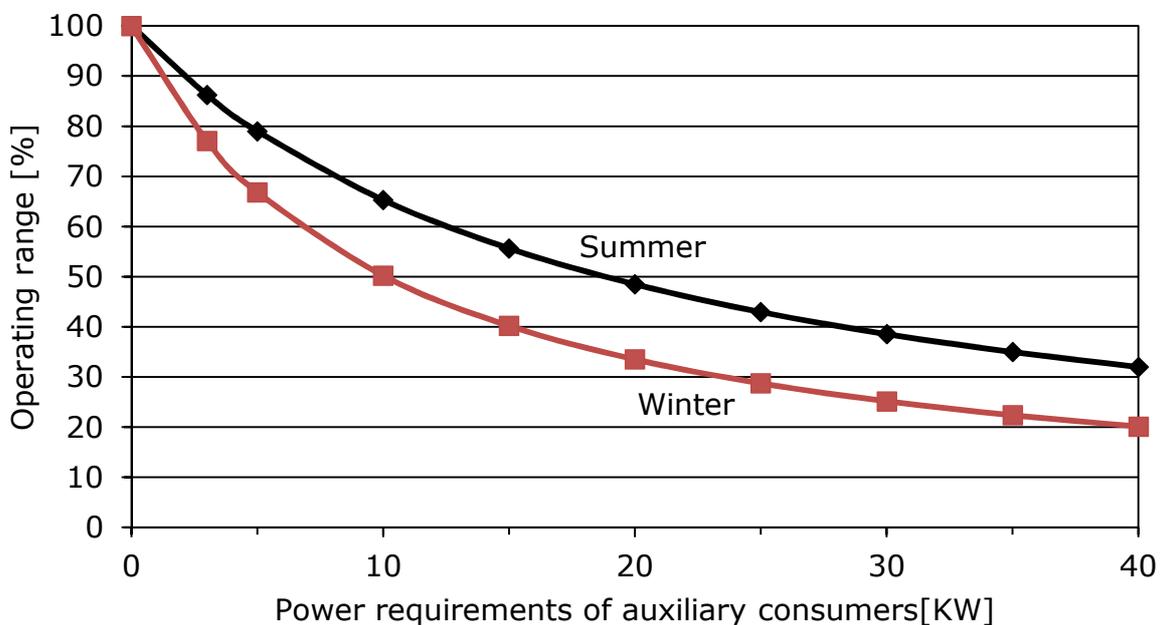


Fig. 1: Operating range as a factor of power requirements of auxiliary consumers

Due to the lower energy density of today's traction batteries and the limited supply of useable waste heat, a basic energy deficit exists in HVAC applications (heating, ventilation, air conditioning) in electrobuses /2/. To compensate for this energy deficit, innovative solutions must be sought in which the air conditioning

and heating systems make the best possible use of the existing energy resources. This will result in a sustained increased efficiency of buses and thus an increased operating range.

Extending the operating range for electric buses

There are thus two prerequisites for mobility in the future: firstly, we must achieve peak efficiency with optimum individual efficiency factors for all auxiliary appliances, such as heating and air conditioning systems and their components. Secondly, we must avoid as far as possible of energy losses inherent to the vehicle, e.g. due to high heat transmission coefficients of the bodywork, disadvantageous thermal masses and excess weight.

Furthermore, if we consider the specific requirements placed on an electrobus, optimised heating and cooling strategies can be developed for these vehicles. Intelligent and energy-efficient system interconnection (air conditioning system, heat pump, heaters, etc.) and a holistic, load-synchronous thermal management serve as a basis for optimum use of the finite energy resources of the vehicle optimal and maximize its operating range.

Optimum individual efficiency factors of the climate control components should at this point be assumed for the purposes of this essay, which does not mean that further optimisation is not possible in future.

Energy requirements for heating and cooling

Experimentally determined power requirements for heating in daily operations demonstrate that essentially a distinction can be made between two operating states /3/: the pre-heating prior to operations and booster heating to maintain the set interior temperature. The energy requirements for pre-heating at the start of operations are disproportionately higher than for booster heating while on the move. Against this background, pre-conditioning of the vehicle from a so-called off-board energy supply takes on particular importance, as this can significantly extend the vehicle battery life.

In normal operation the energy requirements result from transmission losses, warming of the inflowing cold fresh air while passengers are boarding and exchange flows when the doors are opened at bus stops. The required amount of energy for heating is directly dependent on the ambient temperature. Basically, this also applies to cooling /4/.

In Fig. 2 the different heating output demands are shown as a factor of ambient temperature. Considerable potential for reducing heating demands lies in the area of transmission heat losses. Energy losses through the entire bodywork, doors, windows and their joints due to thermal bridges can be substantially reduced by improving vehicle insulation and glazing – similar to the advances in building insulation.

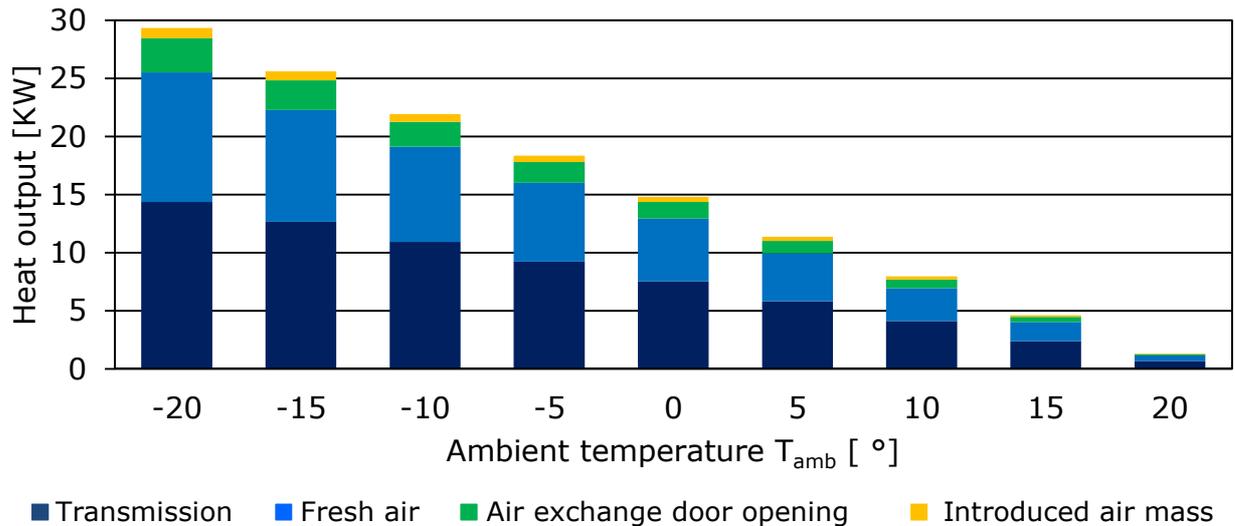


Fig. 2: Heating output requirements as a factor of outside temperature

In addition, disadvantageous thermal masses can be reduced, e.g. by the appropriate choice of material and composition of the seats and interior panelling.

Buses are ventilated with 100% fresh air, not only for hygienic reasons. A further essential point is the dehumidification of the air in the vehicle interior by introducing cold and thus dry ambient air. This ensures that the window panes, in particular the windscreen, do not fog up. Depending on the outside temperature, however, a substantial amount of energy is required to heat up the cold fresh air (outside air) to the temperature level of the interior.

Goal-oriented ventilation strategies, e.g. recirculation and parking ventilation, can help to reduce the amount of energy required. In the first case, the fresh air supply can be coupled with the air quality actually measured in the interior. CO₂ content is monitored and evaluated by sensors, and fresh air is “added” accordingly. In doing so, it should be ensured that the driver’s zone is separate from the passenger compartment. The use of humidity sensors likewise creates further savings potential. When at a standstill, demand-actuated solar-powered ventilation units can be used to lower the interior temperature before setting out.

Electrobus: specific requirements and strategies for the energy supply

Lithium-ion batteries have proved to be the best method of energy storage for use in electrically powered vehicles. The optimum operating temperature is between 20 and 30°C, i.e. the battery must already be cooled after only a short period of operation /5/. Because the majority of today’s vehicles have an air conditioning system, the most obvious solution is to integrate the battery cooling into the existing refrigerant circuit. The latter essentially consists of an electric compressor, condenser and evaporator with fan and expansion valve. The battery cooling is connected to the refrigerant circuit via a plate heat exchanger. This refrigerant circuit is supplemented by an external heat exchanger, so that the air conditioning system does not need to be operated for cooling the battery at lower outside temperatures.

As shown in Fig. 3, the air conditioning system can also be operated by reverse circulation as a heat pump, for efficient and energy-conserving regulation of the temperature in the passenger compartment at moderate outside temperatures.

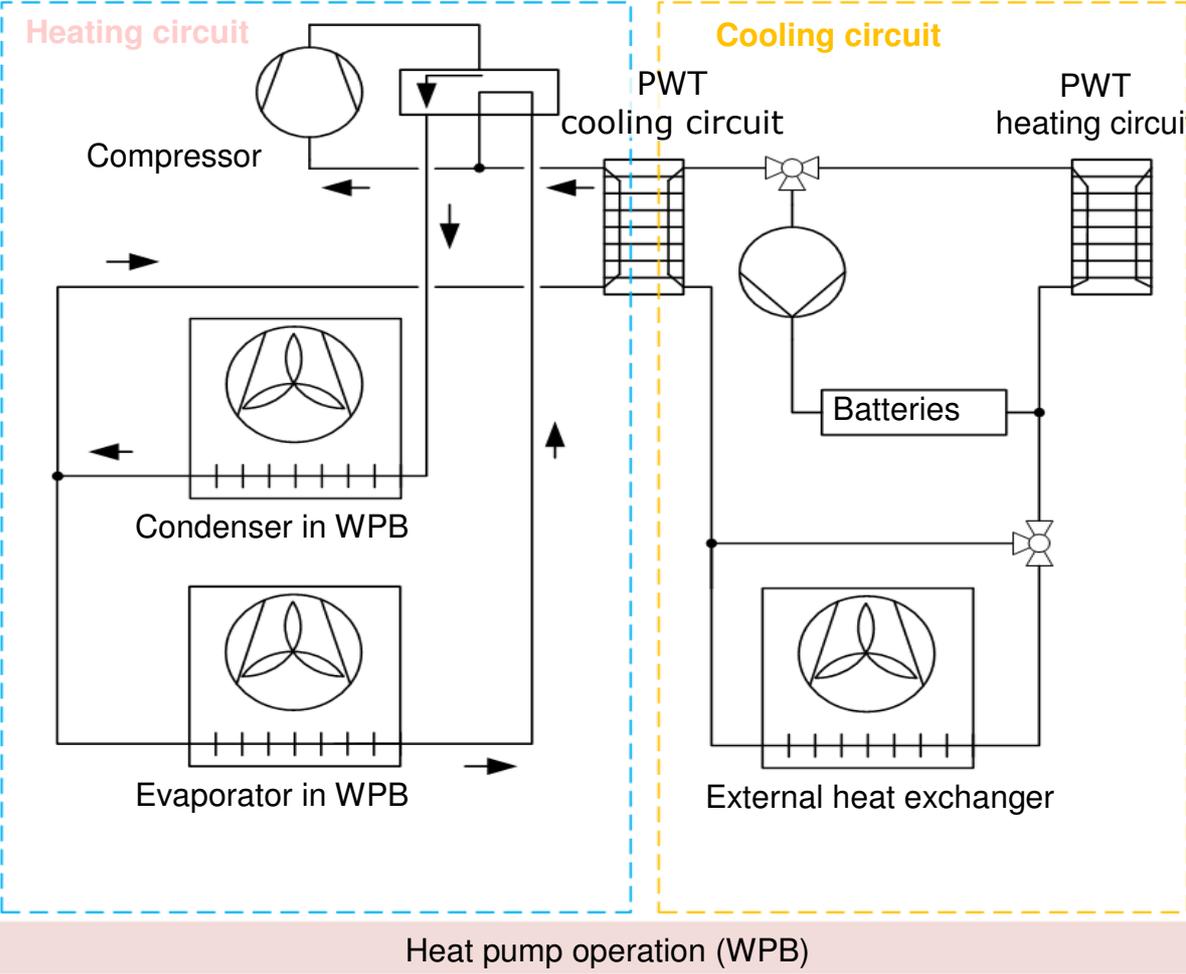


Fig. 3: Diagram of system interconnection for heat pump operation /6/

Unfortunately, when the outside temperature drops, i.e. with increasing heating power demand, the thermal efficiency (COP = coefficient of performance) of the heat pump also decreases. If the heat pump is operated at outside temperatures below approx. 7° C, there is a risk of icing of the heat exchanger. The water vapour in the air condenses and freezes; ice forms on the fins. The ice layer reduces heat transfer and air velocity, causing a further drop in the evaporation temperature. A defroster – expensive and susceptible to malfunctioning – is needed for continued operation of the heat pump. A further reversal of circulation switches the system back to air conditioning mode. Hot gas (condenser in air conditioning mode) flows through the heat exchanger (evaporator in heat pump mode) and de-ices it. In the process, the COP of the heat pump may fall below the value of ONE, which is no longer energy efficient operation. The principal COP gradient of a heat pump as a factor of the evaporating temperature, taking into account a defroster, is shown in Fig. 4.

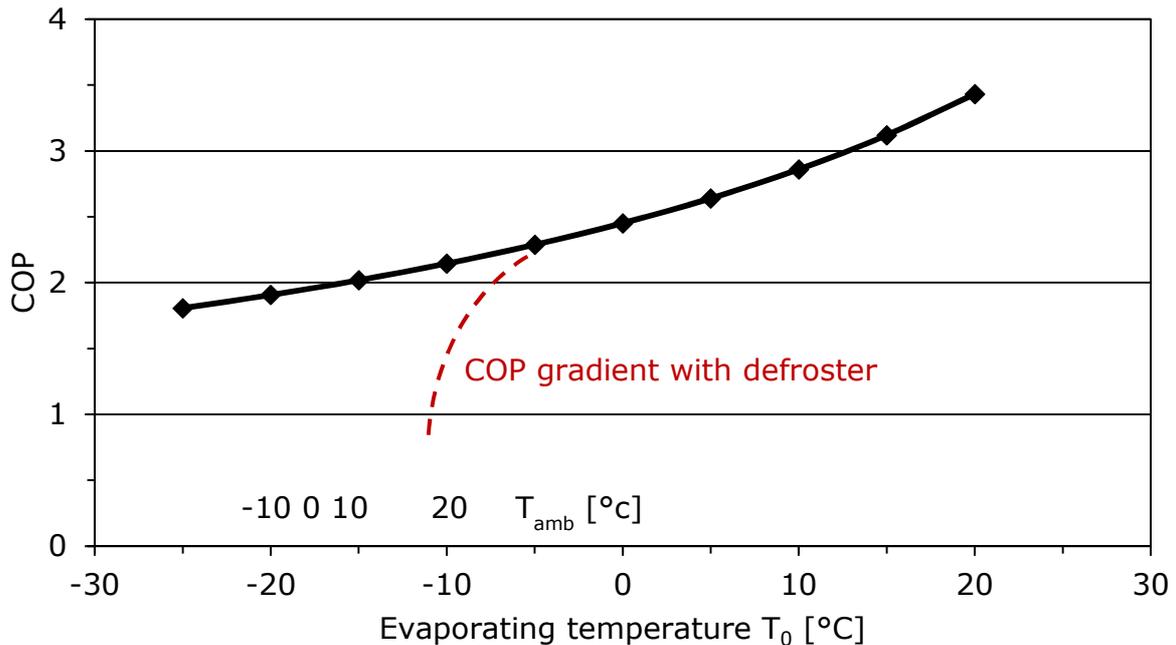


Fig. 4: COP gradient of the heat pump as a function of evaporating temperature

Under certain environmental conditions so-called flash fogging /4/ may occur in these combined systems. By this we mean the accumulation of water on the evaporator fins when the air conditioning is in operation. This water evaporates very quickly upon switchover to heat pump operation. Warm air injected into the interior immediately forms condensation on contact with the cold windscreen that restricts visibility for the driver. There are considerable disadvantages involved with exclusive use of these combined systems to heat the vehicles in heat pump mode. Safety risks cannot be ruled out and the systems are not truly suitable for preheating the vehicle at low temperatures (cold start). Nevertheless, the battery must also be brought up to operating temperature on a cold start. Although this may be achieved by an electrical booster heater, the necessary energy must be drawn from the battery at low temperatures. This results in faster discharging and reduced service life.

Possible booster heating concepts and their evaluation

As stated in the previous section, a heating concept based exclusively on a heat pump for colder regions, e.g. Germany, must be deemed insufficient. The following alternatives must be considered as a necessary supplement. Firstly, the Thermo AC/DC electric heater, a water booster heater, provides both an off- and on-board energy supply. The vehicle can thus be brought up to a comfortable temperature at the depot prior to the start of the journey with a heating capacity of 20 kW without emissions, smells or noise. In residential areas this is an enormous advantage. The power is drawn from the local mains network; the traction battery does not need to be used.

Along the line the Thermo AC/DC is used as a booster heater during the journey at low outside temperatures. However, the required energy must be provided by the traction battery, which in turn causes a direct reduction in the vehicle's operating range.

Against this background, the fuel-powered Thermo S heater can be considered as a further alternative. This heater operates virtually independently of the existing battery capacity, is integrated into the hot water circuit and can be regarded as a self-sufficient bus heating concept for pre- and booster heating. It operates with a high level of efficiency and is diagnosable. With the different appliance versions a heating range between 16 and 40 KW can be covered for efficient interior heating. The Thermo S normally runs on diesel, but can also be operated on a number of alternative fuels (e.g. biodiesel, rape oil and ethanol). In a comparison of the specific energy content (KWh/kg) the advantages of fossil-fuelled heaters are apparent compared to the energy consumption from traction batteries. Whereas about 30kg of fuel (diesel) is required for vehicle heating on cold days, a traction battery of about 2000 kg would have to be installed for the same amount of energy.

Opportunities for a holistic thermal management

A holistic view of all energy flows required for heating and cooling during the course of daily bus operation and their optimum control results in comprehensive thermal management and thus energy-efficient vehicle operation.

For this purpose, the bus is brought into an efficient operating state at the depot before starting out. In the cold season the vehicle and traction battery are heated up by an electric heater supplied by off-board power and the window panes are de-iced as needed. No disturbing noises and no harmful emissions occur. Likewise, at high temperatures the vehicle interior can be cooled by an air conditioner, driven by an electrical compressor, without placing a strain on the energy reserves of the vehicle.

Once the bus leaves the depot, the optimised bus bodywork, selective ventilation strategy and booster heating by heat pump are adequate at moderate outside temperatures. If the temperature drops, the use of a fuel-powered heater is expedient and necessary.

In the warmer seasons an electrical compressor can provide the cooling capacity as needed, thereby saving energy. Ventilation along the line is selectively achieved via a sensor-controlled air circulation, the parking ventilator via solar-powered fan.

Consistent use of the described thermal management permits an impressive energy savings potential of 45%. As much as 20% can be achieved alone by measures such as a reduction in energy losses depending on the vehicle (weight, transmission losses, on-demand fresh air intake) and optimization of the individual efficiency factors of all auxiliary appliances. A further 10% can be saved at moderate temperatures by means of a heat pump booster heating. It goes without saying that all options for the use of the existing waste heat should be exploited. The use of so-called predictive options results in load-synchronous thermal management and offers an additional 15% energy saving potential. The energy flows are control on the basis of information supplied by a global positioning system (GPS).

Mobility of the future will most certainly include the subject of electromobility. Against a background of limited energy resources in traction batteries, the use and interconnection of highly efficient individual components and intelligent thermal management are a major prerequisite for the achievement of acceptable operating ranges.

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Dr.-Ing. Robert Basile (47) studied automotive engineering / theoretical mechanical engineering in Munich and Siegen. Subsequently he worked as a research associate at the Institute for Fluid- and Thermodynamics of the University of Siegen and received his Ph.D. in the field of computational fluid mechanics in turbo-machineries. Afterwards Dr. Basile was employed by an international automotive supplier, where he was responsible for simulation and testing, occupant protection/vehicle safety and process development. In mid-2011 Dr. Basile joined Spheros GmbH, manufacturer of bus heating/air conditioning systems and