World Electric Vehicle Journal

MDPI

Article

Analysis of the Specific Energy Consumption of Battery-Driven Electrical Buses for Heating and Cooling in Dependence on the Technical Equipment and Operating Conditions

Louis Heß [1,†], Daniela Dimova [1,*,†], Jakub Wit Piechalski [1], Stefan Rusche [1], Pascal Best [2] and Michael Sonnekalb [2]

[1] Department of Engineering, RheinMain University of Applied Sciences, Am Brückweg 26, 65428 Rüsselsheim, Germany; louis.hess@hs-rm.de (L.H.); jakub.piechalski@student.hs-rm.de (J.W.P.); stefan.rusche@hs-rm.de (S.R.)

[2] Konvekta AG, 34613 Schwalmstadt, Germany; PascalBest@konvekta.com (P.B.); MichaelSonnekalb@konvekta.com (M.S.)

* Correspondence: daniela.dimova@hs-rm.de; Tel.: +49-6142-898-4329

† These authors contributed equally to this work.

Abstract: This paper analyzes methods of heating battery-driven electrical buses. The examined buses were two identical airport transport buses and two buses used in local transportation. To heat the first buses, an electrical water heater with a heating capacity of 20 kW, and for air conditioning, a rooftop air conditioner with a cooling capacity of 20.6 kW was installed. Climate control in the city buses was achieved using an R744 heat pump with a cooling capacity of 25 kW and a heating capacity between 14 and 21 kW, along with an electrical water heater with a capacity of 32 kW. During the project, the measurement data of the buses described above were taken for a full year and evaluated. The analysis of the measurement data brought insights into the specific electrical energy consumption of climate control in the buses in real operating conditions at outdoor temperatures between 2 °C and 36 °C. The results of this project additionally provide information on the optimization potential for the climate control of buses.

Keywords: battery-driven electrical bus; specific energy consumption; HVAC systems; CO_2 heat pump; electric water heater

check for updates

Citation: Heß, L.; Dimova, D.; Piechalski, J.W.; Rusche, S.; Best, P.; Sonnekalb, M. Analysis of the Specific Energy Consumption of Battery-Driven Electrical Buses for Heating and Cooling in Dependence on the Technical Equipment and Operating Conditions. *World Electr. Veh. J.* **2023**, *14*, 126. https://doi.org/10.3390/wevj14050126

Academic Editors: Michael Fowler and Joeri Van Mierlo

Received: 10 March 2023
Revised: 11 April 2023
Accepted: 12 May 2023
Published: 14 May 2023

1. Introduction

In its Climate Protection Act, the German government stipulated a 65% reduction in greenhouse gas emissions by 2030 in comparison to 1990 [1]. Companies are also formulating their own individual goals in the reduction of CO_2 emissions; for example, the members of the German Air Transportation Association [2]. To achieve these aims, it is necessary to transition away from combustion engines in transportation and to adopt electrical engines. One partial task is to convert bus fleets belonging to cities and companies to electricity. By the end of December 2021, there were 1066 buses powered solely by electrical batteries in Germany [3]. However, the conversion to electrical engines poses new problems for the bus operators. As they can cover large distances, diesel buses can be used flexibly. For electrical vehicles, the energy consumption plays a decisive role in operational planning and must be determined as accurately as possible in advance. The charging time for batteries is significantly greater than the time required to pump fuel into a diesel bus. In addition, buses running on electrical batteries (e-buses) generally cover shorter distances than similar buses with combustion engines. Battery-powered vehicles with depot charging have high-voltage (HV) batteries, with a typical capacity of between 200 and approximately 500 kWh, which means a distance of 100–240 km, depending on the operating conditions [4].

A major factor influencing the distance covered by e-buses is the heating and air conditioning (HVAC) of the buses. The HVAC systems are generally run using electricity from the vehicle's batteries, thus directly reducing the distance covered by the buses. Problems regarding the distance covered are more than just an annoyance in challenging conditions [5–8]. The selection of the HVAC system plays an important role in ensuring the comfort of the passengers, and at the same time, keeping energy consumption low. Previous studies have examined the effects on the comfort of passengers [9]. The energy consumption of the HVAC systems is mainly dependent on the bus design, the HVAC technology, and the HVAC system's control technology. The operational settings of the HVAC systems are based on the guideline of VDV-Schrift 236 [10]. Possible systems for heating buses are heat pumps or electrical resistance heaters (e-heaters). The studies conducted thus far have used simulation models to determine the specific energy consumption (spec. energy consumption) of the buses for various HVAC technologies. This has shown that e-heaters can lead to a reduction in the distance covered of approximately 50% and heat pumps of up to approximately 20% [11,12]. This means that the use of heat pumps reduces the specific energy consumption in comparison to e-heaters, and thus increases the distance the buses can cover; therefore, heat pumps can be seen as a recommended equipment feature [8]. This paper will build on the previous papers in which the specific energy consumption was derived using simulation models or in which only the overall consumption was measured [13]. T. and W. Pamula compared estimated values with measured values without making differences in the thermal equipment of the buses, and they used only four different weather conditions instead of discrete temperatures. M. Vehviläinen et al. [14] calculated the energy consumption of five electric city buses as a function of temperature; however, even with this knowledge, it is difficult to predict the distances covered for buses under different operation conditions. In this project, the actual specific energy consumption of various heating systems in different operating conditions was recorded and analyzed. The insights from this paper can be used to provide a foundation for the optimization of HVAC systems for e-buses and for simulation models in the future.

2. Experimental Setup

Two identical airport transport buses (operated by Fraport AG at the Frankfurt Airport) and two buses used in city transportation, operated by the Verkehrs-Aktiengesellschaft in Nuremberg and the Verkehrs-Betriebe GmbH in Offenbach, Germany, were examined. Table 1 shows the differences between the two bus types. The airport transport buses are used to transport passengers and crew members. They are heated using an e-heater with a heating capacity of 20 kW and cooled using a rooftop air conditioner with a cooling capacity of 20.6 kW. The electrical energy required for this is taken from the traction battery. The capacity of the LTO battery is 99 kWh. The city buses have a 240 kWh lithium-ion battery. For the climate control of the passenger space, a CO_2 heat pump, made by Konvekta, and an e-heater are used. The heat pump has a cooling capacity of 25 kW and a heating capacity between 14 and 21 kW. The e-heater has a maximum capacity of 32.4 kW and features four capacity levels. The driver's cab is also climate-controlled using the CO_2 heat pump, but only if the passenger compartment is also heated. When necessary, this heat supply is supplemented using an e-heater with a capacity of 10 kW.

Table 1. Comparison of characteristic data for the city bus and the airport transport bus.

Data	Airport Transport Bus	City Bus
Desired temperature for the passenger space	10 °C | 24 °C	22 °C
Operational mode	70% motionless	Driving (doors open)
Occupation	70% empty	Almost fully occupied
HVAC system	Water heater and rooftop air conditioner	CO_2 heat pump and water heater
Floor surface	30 m^2	30.6 m^2
Spatial allocation	Driver's cab separate	Driver's cab in passenger space

2.1. Measurement Techniques and Control Technology in the Airport Transport Bus

The measurement data were taken using a FLEETlog2 data logger and an M-THERMO2 thermal module made by Ipetronik GmbH and Co. KG (76532 Baden-Baden, Germany). They were connected to the vehicle using a CAN bus. Eight thermal elements were connected to the thermal module. The passenger space temperature was measured near the ceiling and floor; the inflow and outflow temperatures of the electrical water heater and the outdoor temperature were also measured. The CAN bus made it possible to additionally determine the measurement duration, the distance of the test drive, the specific energy consumption of the vehicle as a whole, the specific energy consumption of the HVAC system, and the charging status of the battery. The measurement data were subsequently entered into a Python script and evaluated.

The determining quantity for the control technology governing the climate control of the passenger space is the temperature in the passenger space. The temperature was measured using a temperature detector near the ceiling. If it falls below the threshold value of 10 °C, the e-heater is turned on, which heats the water in the heating circuit. The heat energy is then emitted into the passenger space via the water/air heat exchanger near the ceiling. If the temperature rises above 24 °C, the rooftop air conditioner is turned on, cooling the passenger space. The threshold values for the activation of climate control in the passenger space are fixed. However, the heating of the passenger space can be deactivated by the driver during trips without passengers. If the inside temperature is between 10 °C and 24 °C, the passenger space is merely ventilated.

The driver's cab is separated from the passenger space by a partition, and the climate control can be operated individually by the driver. The heating for the driver's cab is provided by the e-heater. Cooling is provided by an additional rooftop air conditioner, which is independent of the passenger space and used solely for climate control in the driver's cab.

2.2. Measurement Techniques and Control Technology in the City Bus

The measurement data were taken by connecting a data logger to the vehicle's climatization CAN bus. It was possible to access all of the data relevant to calculating the energy uptake of the HVAC system. Temperature sensors (Pt100) were used to measure the hot water and hot air temperature inside the bus and the driver's cab, the inside temperature (average value from three temperature sensors), and the outdoor temperature. The data were stored in a cloud via the cell phone network in order to avoid interrupting passenger services. The evaluation of the measurement data was carried out using a Python script.

In addition, in this case, the temperature of the passenger space is the determining value of the control technology for the passenger space. The desired temperature in the passenger space is approximately 22 °C. In fact, the VDV regulation [10] contains target values for the temperatures in the passenger compartment that depend on the outside temperature and are automatically set by the HVAC control.

Heat is provided by the CO_2 heat pump, which is supplemented by an e-heater (32.4 kW) when necessary. In the temperature range between 18 and 22 °C, the passenger space is only provided with fresh-air ventilation (ventilation function) and is only actively cooled at temperatures above 22 °C. The temperature of the driver's cab can be separately adjusted by the driver, even though the driver's cab is not spatially separated from the passenger space. The driver's cab is cooled and heated using the HVAC system for the passenger space and, when necessary, with an additional 10 kW e-heater.

3. Results of the Experiment and Discussion

In the following section, the evaluated measurement data from the electric buses will be presented, enabling a comparison between the two HVAC systems. In the analysis, it will be possible to separate the specific energy consumption by the driver's cab and the passenger space from each other.

3.1. Specific Energy Consumption by the Airport Transport Bus

In the following, detailed descriptions will be given of trips taken by the buses of the eCobus2700 type on the landing field of the Frankfurt Airport between April 2021 and April 2022. The overall measurement duration was 985 h. The distances traveled and the duration of the test drives varied. The buses in question were used to transport passengers and crew members. Either before or after, a trip without passengers was made. Using these measurements, it was possible to determine that the buses are not in motion for 70% of their operating time; in these periods, the driver is generally waiting for passengers. For this reason, it was decided not to relate the energy consumption to the distance driven, but rather to the time the buses were used.

Figure 1 shows the measured specific energy consumption in dependence on the outdoor temperature, with the outdoor temperature divided into temperature segments of 2 °C. The temperature segments presented between 2 and 36 °C each have at least five measurement hours and can thus be viewed as being representative. In addition, the specific energy consumption is allocated to the individual consumers. The measurement data show a significant increase in the specific energy consumption as the temperatures decrease below an outdoor temperature of 10 °C (heating), and the energy consumption increases when the temperatures rise above 24 °C (air conditioning).

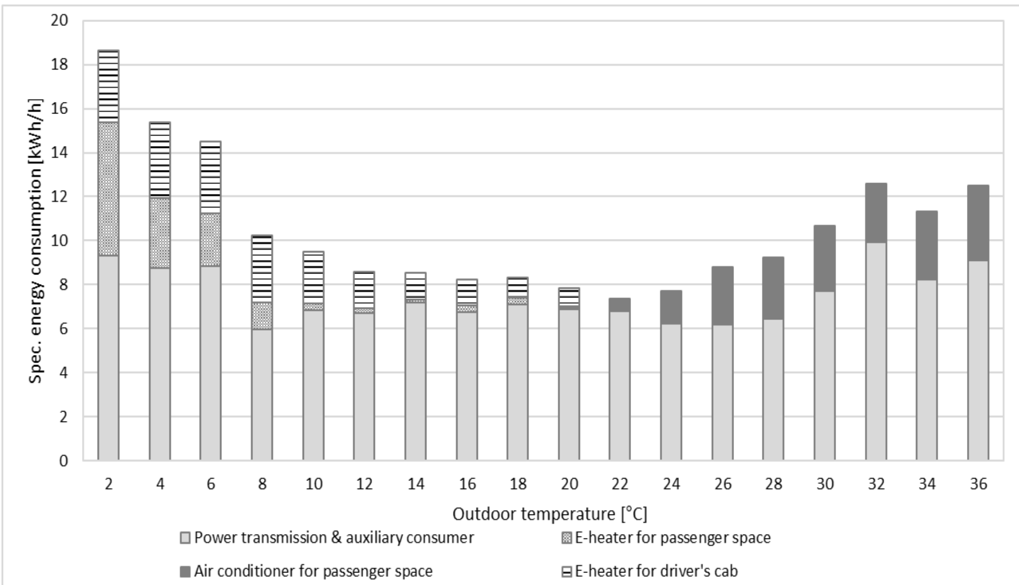

Figure 1. Specific energy consumption of the airport transport bus's HVAC system at varying outdoor temperatures.

At indoor temperatures between 10 and 24 °C, the passenger compartment is neither heated nor cooled, it is only ventilated. At even lower temperatures, the specific energy consumption of the passenger space rose continuously, while the consumption for the driver's cab remained relatively constant on a high level. The driver's cab is spatially separated from the passenger space and the desired temperature can be individually adjusted. In the temperature range between 2 and 10 °C, the driver's cab accounted for between 35% and 88% of the overall specific energy consumption of the HVAC system. In this temperature range, the proportion of the HVAC system is between 39% and 50% of the vehicle's overall energy consumption. One reason for this is that it takes approximately 20 min for the heating system to initially heat up the water circuit. This process always requires a similar amount of energy, independent of the ambient temperature. This is due to the energy required to heat all the water in the heating system to 70 °C. The temperature of the water when operation begins is never lower than 2 °C. This means that the initial temperature of the water when it is first heated is similar for all the measurements. The energy required for the initial heating procedure is approximately 2 kWh.

Further reasons for the large impact of the heating on the overall energy consumption are the slow movement of the bus during operation on the apron and the aforementioned high percentage of time spent waiting for passengers.

At an outdoor temperature above 22 °C, the specific energy consumption increased linearly. The proportion of the climate control of the passenger space to the overall specific energy consumption amounted to 26% for these trips. For the purposes of this project, only the capacity consumption of the air conditioner in the passenger space was determined. No data are available for the air conditioner in the driver's cab, so its energy consumption is part of the consumption of the "power transmission and auxiliary consumer".

In summary, it can be said that the heating of the eCobus2700 with an e-heater and a two-level controller requires a great deal of energy, even though the temperatures tolerated in the passenger compartment can be significantly lower than the indoor temperature of city buses recommended in [15] (between 22.4 °C and 28.9 °C).

3.2. Specific Energy Consumption by the City Bus

The measurement data for the city buses of the Solaris Urbino 12 electric type with a CO_2 heat pump were collected between June 2021 and December 2021. The overall measurement duration in the city transportation was 564 h. Figure 2 shows the measured specific energy consumption in dependence on the outdoor temperatures during the trip. The temperature segments displayed between 4 and 34 °C each have at least five measurement hours and can thus be viewed as being representative. Using the collected measurement data, it was possible to determine the specific energy consumption of the CO_2 heat pump and the e-heater. In the case of the e-heater, it was additionally possible to determine whether the energy was consumed by the e-heater for the driver's cab or by the e-heater for the passenger space. In these vehicles, there is no spatial separation between the driver's cab and the passenger space. The passenger space is indirectly heated along with the driver's cab when the desired value for the inner temperature in the driver's cab is higher than 22 °C.

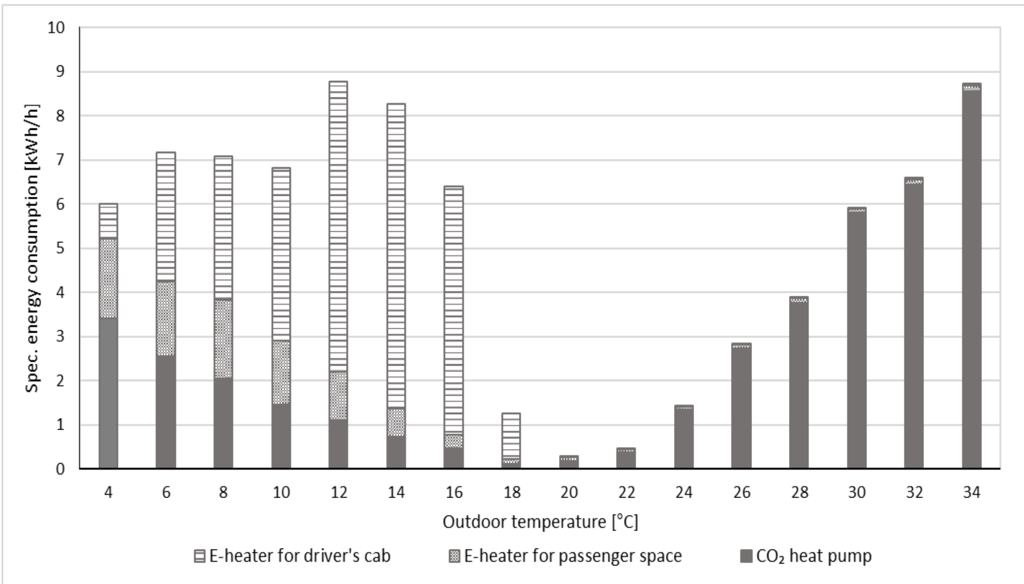

Figure 2. Specific energy consumption by the city bus's HVAC system at varying outdoor temperatures.

As expected, the specific energy consumption by the heat pump increased as the temperature either increased or decreased, at which point either cooling or heating is required. The significantly higher specific energy consumption by the heat pump while cooling was immediately apparent. At temperatures over 22 °C, the HVAC's cooling function, which is provided solely by the heat pump, is turned on. The specific energy consumption increased at a constant rate as the outdoor temperatures rose. At 22 °C, it was

0.4 kWh/h, and reached its maximum at 34 °C, with a specific energy consumption by the cooling function of 8.6 kWh/h.

The lowest specific energy consumption was in the temperature range between 20 and 22 °C. This was due to the desired temperature of 22 °C in the passenger space. In this range, the heat pump was mainly operated for ventilation purposes.

In the temperature range below 20 °C, the heating function of the HVAC system is turned on and the specific energy consumption of the heat pump and e-heater for the passenger space increased at a constant rate. In comparison, the specific energy consumption by the e-heater for the driver's cab rose significantly, especially between 12 and 18 °C. At 12 °C, the maximum specific energy consumption of the HVAC system's heating function was reached at 8.8 kWh/h. The e-heater of the driver's cab accounted for 75% of the overall consumption. On average, the e-heater for the driver's cab accounted for 81.7% of the overall specific energy consumption in the temperature range between 12 and 18 °C. Below 12 °C, the specific energy consumption by the e-heater for the driver's cab decreased significantly. The proportion of the overall specific energy consumption required by the e-heater for the driver's cab decreased as the outdoor temperature fell. In the temperature range between 6 and 10 °C, this proportion was 48%.

The measurement results clearly show that the highest specific energy consumption can be attributed to the electrical heater for the driver's cab, even though it is the least powerful of all the heating appliances. Due to a lower degree of effectiveness compared to the heat pump, this indicates room for improvements concerning the HVAC's control technology. For heating up the passenger space, a heat pump is provided. If a driver sets a higher temperature in his cabin than that which is automatically provided for in the passenger compartment, the heating water of the entire bus must be heated, even if the passenger compartment does not yet need to be heated. Further investigations showed that starting the operation of the heat pump with higher priority, although there is no heating demand in the passenger compartment, leads to clear energy savings.

3.3. Comparison between Airport Transport Bus and City Bus

The city bus and the airport transport bus were compared based on the specific energy consumption of the HVAC systems. The comparison was drawn for the outdoor temperature range between 4 and 18 °C because, in this range, the driver's cab and/or the passenger space are heated in both vehicles.

The airport transport bus is heated using a central e-heater. The city bus is heated using a CO_2 heat pump, an e-heater for the passenger space, and an e-heater for the driver's cab. The desired temperature for the passenger space of both buses is stored in their HVAC controls. The desired temperature of the driver's cab can be freely adjusted by the driver in both buses. The airport transport bus has a clear spatial separation between the driver's cab and the passenger space, while the city bus has none. The floor space of both buses is approximately 30 m^2. The city bus is almost fully occupied and often opens its doors to allow passengers to enter or leave the bus at bus stops. The airport transport bus is unoccupied and not in motion 70% of the time; this was shown by the measurement data. This is a result of long waiting times at the airport gate. The trip distances are relatively short and the number of passengers is very small, ranging between one person (a service trip or a trip without passengers) and 13 to 26 people (transport of crew members and/or passengers).

Figure 3 shows the variation in the specific energy consumption values between the airport transport bus and the city bus in the temperature range between 4 and 18 °C. Between 10 and 18 °C, in the airport transport bus, only the driver's cab was heated because the temperature in the passenger compartment is then higher than the stored minimum target value of 10 °C. In this range, the specific energy consumption by the city bus was significantly higher than that of the airport transport bus. This is due to the higher desired temperature in the passenger space of the city bus, which is about 22 °C (see above). Accordingly, in the range between 10 and 18 °C, in the city bus, both the passenger space and the driver's cab are heated using the e-heater and the CO_2 heat pump. An additional, but less important, cause of the increased specific energy consumption by the city bus could be the fact that it opens and closes its doors more frequently than the airport transport bus.

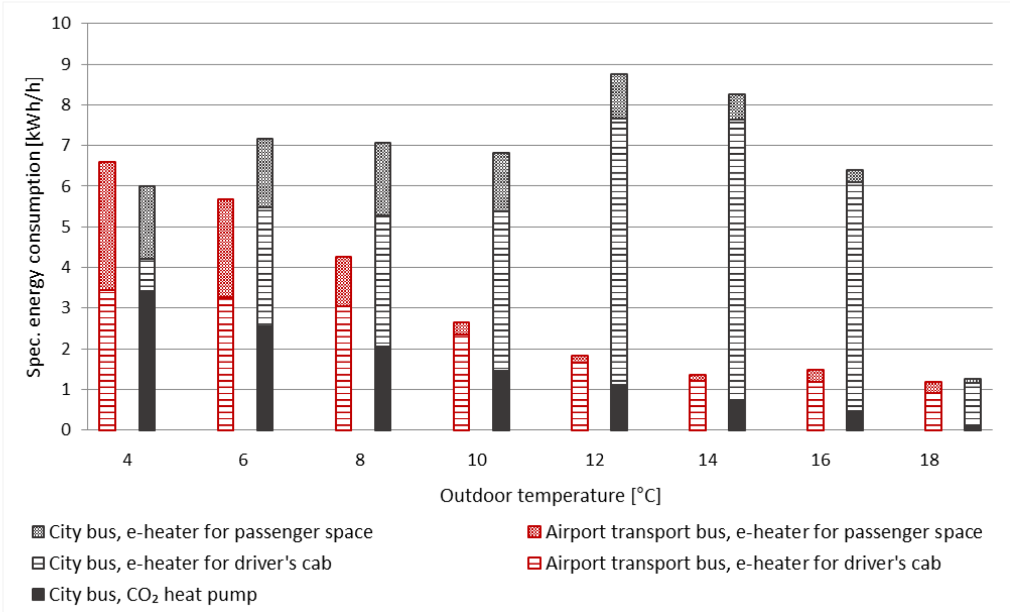

Figure 3. Comparison of the specific energy consumption values of the HVAC systems of the airport transport bus and the city bus at outdoor temperatures between 4 and 18 °C.

Between 4 and 10 °C, the passenger space and the driver's cab are both heated in both of the buses. This results in the specific energy consumption values of the two buses approaching each other. In the range between 6 and 10 °C, despite the CO_2 heat pump, the specific energy consumption of the city bus is greater than that of the airport transport bus. On one hand, this is due to the significantly higher desired temperature, and on the other hand, it can be attributed to the large proportion of energy consumed by the e-heater compared to that of the heat pump. This is shown clearly in Section 3.2. Beginning at an outdoor temperature of 4 °C, the specific energy consumption of the city bus is lower than that of the airport transport bus. The reason for this is that, beginning at this outdoor temperature, the city bus is mainly heated using the CO_2 heat pump. It is clear that an HVAC system with a heat pump has a lower specific energy consumption than an HVAC system with an e-heater, despite having a desired temperature in the passenger space that is about 12 K higher.

In both buses, when the HVAC system is turned off, the remaining heat energy in the system, which amounts to approximately 2 kWh in the airport transport bus, is released into the surrounding environment. This energy could be saved using thermal storage devices and then re-used during the initial heating of the HVAC system; this would reduce the HVAC system's overall consumption.

4. Optimization of the HVAC Control Technology for the City Bus

Based on the analysis of the measurement data from 2021, the control technology for the city bus's HVAC system could be optimized. The measurement data show that the proportion of energy consumption by the e-heater for the driver's cab is high compared to that of the heat pump and to that of the passenger space. After implementing the change in the priorities of the heating appliances for heating up the bus after certain heating demands (Section 3.2), tremendous energy savings could be realized. With the new control technology, the e-heater of the driver's cab is mainly activated for additional heating using the defrost or reheat buttons.

Figure 4 shows the measurement data for the city bus with the old and new control technology for the temperature range between 2 and 20 °C. The measurement duration for the measurement data with the old control technology was 2781 h; for the new control technology, it was 916 h. Optimizing the control technology can reduce the specific energy consumption of the e-heater for the driver's cab by an average of 72%, and that of the e-heater for the passenger space by 75%. At the same time, the specific energy consumption of the heat pump increased by 226%, from an average of 1.3 kWh/h to 2.9 kWh/h. These changes led to a reduction in the overall specific energy consumption by the HVAC system, from an average of 5.8 kWh/h to 4.1 kWh/h. The reason for this is that the heat pump has a higher COP than the e-heaters. The largest energy savings were in the temperature range between 10 and 20 °C, where it was possible to reduce the overall specific energy consumption by an average of 50%. There are two reasons for this: First, the e-heaters are rarely turned on in this temperature range, and second, the heat pump in this temperature range has a COP between 2.7 and 4.3. In the temperature range between 0 and 5 °C, the heat pump has a COP between 2.4 and 2.7. The optimization of the control technology led to energy savings for the city bus, and thus increased its distance covered, with the desired temperature of the passenger space remaining unchanged.

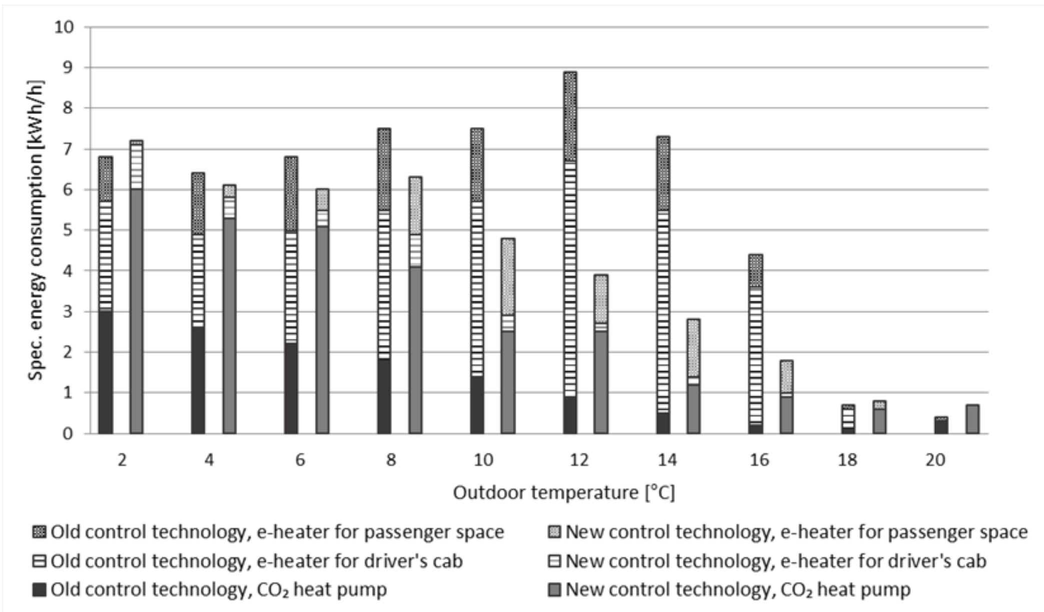

Figure 4. Comparison of the city bus's HVAC system with new and old control technology at outdoor temperatures between 2 and 20 °C.

5. Conclusions

The collection of measurement data regarding the specific energy consumption by the HVAC systems of battery-driven electrical buses leads to the following conclusions: The individually adjustable temperature in the driver's cab (in contrast to the automatic climate control in the passenger space) has a very large effect on the overall specific energy consumption of the HVAC systems. In the temperature range between 2 and 10 °C, its proportion for the airport transport buses amounted to between 35% and 88%. The consumption by the e-heater for the driver's cab in the city bus had the highest values in the temperature range between 12 and 18 °C. Its proportion of the overall specific energy consumption amounted to 81.7%, and this had to be improved because direct electric heating is less efficient than the use of a heat pump, which was also installed.

In a direct comparison between the specific energy consumption of the two HVAC systems, it was immediately apparent that the specific energy consumption by the airport transport bus was lower than that of the city buses, although the latter are equipped with a heat pump. The clear structural separation between the passenger space and the driver's cab, as well as the fact that the passenger space is only ventilated, neither heated nor cooled, when the temperature is in the range between 10 and 24 °C, create consumption advantages for the airport transport bus.

For the city buses, it was possible to significantly reduce the specific energy consumption by optimizing the control parameters of the HVAC system. Accordingly, the heat pump has already been prioritized as a provider of the heating requirements in the city buses. The use of CO_2 heat pumps, instead of e-heaters, for the heating and cooling of battery-driven electrical buses leads to a reduction in the overall consumption, and thus to an increase in the distance covered. In addition, in the future, it will be possible to further reduce energy losses using thermal storage devices, in which the remaining energy in the heating circuit can be stored.

Author Contributions: Conceptualization, L.H. and D.D.; software, D.D., L.H. and P.B.; validation, D.D., L.H., J.W.P. and P.B.; formal analysis, L.H. and D.D.; investigation, D.D. and P.B.; data curation, D.D. and P.B.; writing—original draft preparation, L.H. and D.D.; writing—review and editing, S.R. and J.W.P.; visualization, D.D., L.H. and J.W.P.; supervision, S.R. and M.S.; project administration, S.R. and M.S.; funding acquisition, S.R. and M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This project (HA project no. 768/19-88) was financed using funding from the "Elektromobilität in Hessen" (E-mobility in the German state of Hessen) funding program. Open Access funding was provided by the Open Access Publication Fund of the RheinMain University of Applied Sciences.

Data Availability Statement: Data are available upon request due to restrictions, such as privacy or ethical reasons. Data presented in this study are available upon request from the corresponding author. Due to confidentiality agreements, data are not freely available and cannot become public.

Acknowledgments: The authors thank the project partners for the valuable discussions and their support.

Conflicts of Interest: The authors declare no conflict of interest. Authors Louis Heß and Daniela Dimova are to be considered the first authors. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Bundesregierung. Available online: https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzgesetz-2021-1913672 (accessed on 11 February 2022).
2. Bundesverband der Deutschen Luftverkehrswirtschaft e.V. Available online: https://www.bdl.aero/de/themen-positionen/nachhaltigkeit/klimaschutz/ (accessed on 2 November 2022).
3. Statista. Available online: https://de.statista.com/statistik/daten/studie/1048269/umfrage/anzahl-der-elektrobusse-in-deutschland-nach-antriebsart/ (accessed on 14 November 2022).
4. Sphera Solutions GmbH. *Emissionsfreie Energie- und Antriebskonzepte für Stadtbusse zur Umsetzung der europäischen Clean Vehicles Directive*; Verband Deutscher Verkehrsunternehmen e.V.: Köln, Germany, 2020.
5. Aurich, J.; Baumgart, R.; Danzer, T.; von Unwerth, T. *Untersuchungen zur Energieeffizienten Klimatisierung von Hybrid- und Elektrofahrzeugen, Wärmemanagement des Kraftfahrzeugs VIII*; expertVerlag: Essen, Germany, 2012; pp. 167–175.
6. Konz, M.; Lemke, N.; Försterling, S.; Eghtessad, M. *Spezifische Anforderungen an das Heiz-Klimasystem Elektromotorisch Angetriebener Fahrzeuge; FAT-Schriftreihe 233*; Berlin, Forschungsvereinigung Automobiltechnik e.V.: Berlin, Germany, 2011.
7. Lorenz, M.; Spinnler, M.; Sattelmayer, T. *Reduzierung des Heizbedarfs von Elektrofahrzeugkabinen Durch Alternative Scheibentechnik, Wärmemanagement des Kraftfahrzeugs*; expertVerlag: Essen, Germany, 2012; pp. 1–13.
8. Karle, A. *Elektromobilität Grundlagen und Praxis*; Carl Hanser Verlag München: Munich, Germany, 2018.
9. Cigarini, F.; Fay, T.-A.; Artemenko, N.; Göhlich, D. Modeling and Experimental Investigation of Thermal Comfort and Energy Consumption in a Battery Electric Bus. *World Electr. Veh. J.* **2021**, *12*, 7. [CrossRef]
10. Verband Deutscher Verkehrsunternehmen e.V. VDV-Schrift Nr. 236. Klimatisierung von Linienbussen der Zulassungsklassen I (Stadtbus) und II (Überlandbus), für konventionell angetriebene Diesel- und Gasbusse als auch für Hybrid-, Brennstoffzellen- und Elektrobusse. VDV-Schrift, 2018.
11. Peteranderl, C. *Heizen und Klimatisierung von Batterieelektrischen Stadtbussen durch Umschaltbare R744-Wärmepumpenmodule*; Technische Universität Carolo-Wilhelmina zu Braunschweig: Braunschweig, Germany, 2022.
12. Jefferies, D.; Ly, T.; Kunith, A.; Göhlich, D. Energiebedarf verschiedener Klimatisierungssysteme für Elektro-Linienbusse. In Proceedings of the DKV-Tagung, Dresden, Germany, 18–20 November 2015.

13. Pamuła, T.; Pamuła, W. Estimation of the Energy Consumption of Battery Electric Buses for Public Transport Networks Using Real-World Data and Deep Learning. *Energies* **2020**, *13*, 2340. [CrossRef]
14. Vehviläinen, M.; Lavikka, R.; Rantala, S.; Paakkinen, M.; Laurila, J.; Vainio, T. Setting Up and Operating Electric City Buses in Harsh Winter Conditions. *Appl. Sci.* **2022**, *12*, 2762. [CrossRef]
15. Lin, T.; Hwang, R.; Huang, K.; Sun, C.; Huang, Y. Passenger thermal perceptions, thermal comfort requirements, and adaptions in short-and long-haul vehicles. *Int. J. Biometeorol.* **2010**, *54*, 221–230. [CrossRef] [PubMed]