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State-of-the-art vehicle and demo-vehicle benchmark report

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Author(s)

Name	Organisation	Name	Organisation
Clemens Schwaiger	MAGNA		

Reviewers

Name	Organisation	Date
Alexander Kospach	VIF	2024-11-27, 2024-12-16
Alen Kuyumcu	TOGG	2024-12-09

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1 Executive Summary

EFFEREST aims to explore the holistic user-centric efficiency, cost, and lifetime optimization potentials of future Electric Vehicles (EVs). The project involves developing user-centric solutions for the electric powertrain and Heating, Ventilation, and Air Conditioning (HVAC) systems, as well as novel design methodologies. The workflow within the project is divided into six Work Packages (WPs). The work includes measurements (WP2, WP3), simulation and development (WP3, WP4, WP5), and demonstration of the novel solutions in a demonstrator vehicle (WP6).

Deliverable 2.2 is linked to Task 2.2 ("Benchmark state-of-the-art vehicles and definition of base vehicle") of WP2. The benchmark's main objective is to compare and rate the current market products based on the novel user-centric Key Performance Indicators (KPIs) relevant to this project.

The deliverable reports on three state-of-the-art EVs benchmarked on a chassis dynamometer under different environmental conditions and driving cycles. It provides an analysis of comfort and efficiency.

Keywords: Benchmark, Measurement, Chassis dynamometer, Efficiency, Energy Flow, Consumption, Cold conditions, Hot conditions

2 Objectives

The benchmarking activities in EFFEREST are directly linked to objective O1 ("Achieve innovative and holistic user-centric solutions to make EVs more attractive for the mass market"). More specifically, it is linked to objective O1.1 ('Better understanding of user-centric requirements for design/solutions by means of novel indicators that quantify how the technical solutions influence the vehicle operation by the user'), because knowing the market situation allows better understanding on the needed user-centric solutions. Benchmarking is crucial to gain insights into how state-of-the-art EVs perform in terms of comfort and efficiency, as this knowledge is essential in making EVs more appealing to the mass market.

In the EFFEREST Project, the focus of benchmarking is primarily on the thermal comfort of users. This focus is particularly important in cold climate conditions for two reasons:

1. Cabin heating in EVs significantly reduces their range since the absence of waste heat, unlike Internal Combustion Engines (ICEs), necessitates the use of electric energy to heat the cabin, resulting in increased energy consumption.
2. In Europe, heating cases are more relevant than cooling cases [1].

Three state-of-the-art EVs, including a B-Segment vehicle, are benchmarked, considering both homologation and real driving cycles in various environments. The real driving cycles are defined in Task 2.1 ("User Data Analysis and use-case definition based on fleet data").

3 Description of Work

3.1 Key Performance Indicators (KPIs)

The requirements outlined in D2.3 (Vehicle, user-centric control strategy, cloud, and comfort requirements report) specify the targets set forth in the project [2]. The relevant requirements for benchmarking are as follows:

- StH1.1: Achieve a 20% increased range at 0°C ambient temperatures.
- StH2.2: Demonstrate real-world range increase with novel vehicle functions.
- StH1.2: Enhance the effectiveness of comfort functions.

Therefore, the key performance indicators (KPIs) for the benchmarking process will primarily focus on comfort and range. These measurements will not be conducted directly on a chassis-dyno test. Since comfort cannot be directly measured for all benchmarked vehicles, the KPI related to comfort will be the cabin temperature and air quality after 10, 20, and 30 minutes. The second KPI that provides insights into the range of a vehicle is the consumption, specifically the electric energy consumption in kWh per 100 km. Charging losses and preconditioning functions are not taken into account for this benchmark.

3.2 Chassis-Dyno Tests

3.2.1 Test Cycles/Conditions

The test plan includes performing chassis-dynamometer tests for all three vehicles at temperatures of 0°C, 20°C, and 35°C. The test cycles consist of the Worldwide harmonized Light vehicles Test Cycle (WLTC) as well as real driving cycles defined in Task 2.1 by BOSCH. The real driving cycles are categorized into three types: a short trip cycle (6km), a typical commuting cycle (20km), and a long trip cycle (94km). These cycles were designed to represent different regions of Europe, in order to encompass various climate zones. The focus of the EFFEREST project is to increase EV range especially in cold climatic conditions without compromising thermal comfort. Due to limited availability of the chassis-dynamometer, not all cycles from Task 2.1 can be tested. The focus is on ensuring comparability between temperatures and vehicles, with an emphasis on cold climate scenarios. To have comparability between temperatures and vehicles and to have a focus on the cold climate, the test plan shown in Table 3-1 for all three vehicles was developed:

Table 3-1: Overview of tests done with each vehicle.

Test Nr.	Ambient conditions	Test cycle
1	0 °C	WLTC
2	0 °C	Helsinki commute
3	0 °C	Helsinki short
4	0 °C	Helsinki long
5	20 °C	WLTC
6	20 °C	Helsinki commute
7	35 °C	WLTC
8	35 °C	Helsinki commute

The chassis-dynamometer used for benchmarking is located on the MAGNA site in St. Valentin (Austria). The vehicles are soaked in a climate chamber before the tests, to ensure the same starting conditions for all benchmarking activities.

3.2.2 Vehicle Settings

For the chassis-dyno tests the vehicles settings are adjusted so the results are as comparable as possible. During the test, climatization is activated. Climatization is activated together with the start of the first vehicle acceleration phase in the cycle. If other climatization was available (e.g. seat heating, special HVAC mode etc.) it was turned off. In Table 3-2, the settings are shown.

Table 3-2: Overview of vehicle settings for the tests.

Category	Setting
HVAC mode	“Auto”
Cabin set temperature	22 °C
Multiple zone climatization	OFF
Recirculation (if not set by HVAC mode)	35 °C tests – ON 20/0 °C tests – OFF
Recuperation	Maximum
Drive mode	Standard/Comfort

3.3 Benchmarked Vehicles

Three vehicles for benchmarking were agreed upon together in the consortium. The EVs represent different market segments. In Table 3-3 the tested vehicles are listed with vehicle segment and vehicle indication name used in this report.

Table 3-3: Overview of the benchmarked vehicles.

Vehicle	Vehicle Indication Name
B-Segment vehicle	EV1
J-Segment vehicle 1	EV2
J-Segment vehicle 2	EV3

3.4 Vehicle Instrumentation

For chassis-dyno tests, several sensors are mounted inside the vehicle cabin with focus on thermal comfort. This means measuring Carbon Dioxide (CO2), humidity, and temperatures inside the cabin. Furthermore, the On-Board Diagnosis (OBD) port CAN-Bus was reverse engineered to be able to know key indicators for performance (e.g. Battery current, …). Additionally, the HVAC Box of two vehicles was instrumented with several sensors. An overview of the sensors inside the cabin can be seen in Figure 1.

3.5 Cabin/HVAC Air Characterization

To determine the air mass flow in the cabin of the vehicles, measurements with a duct leakage tester device are executed. This measurement enables the characterization of the air pressure increase at different air volume flows through the cabin. Furthermore, it enables to characterize the air mass flow at different HVAC blower and flap settings.

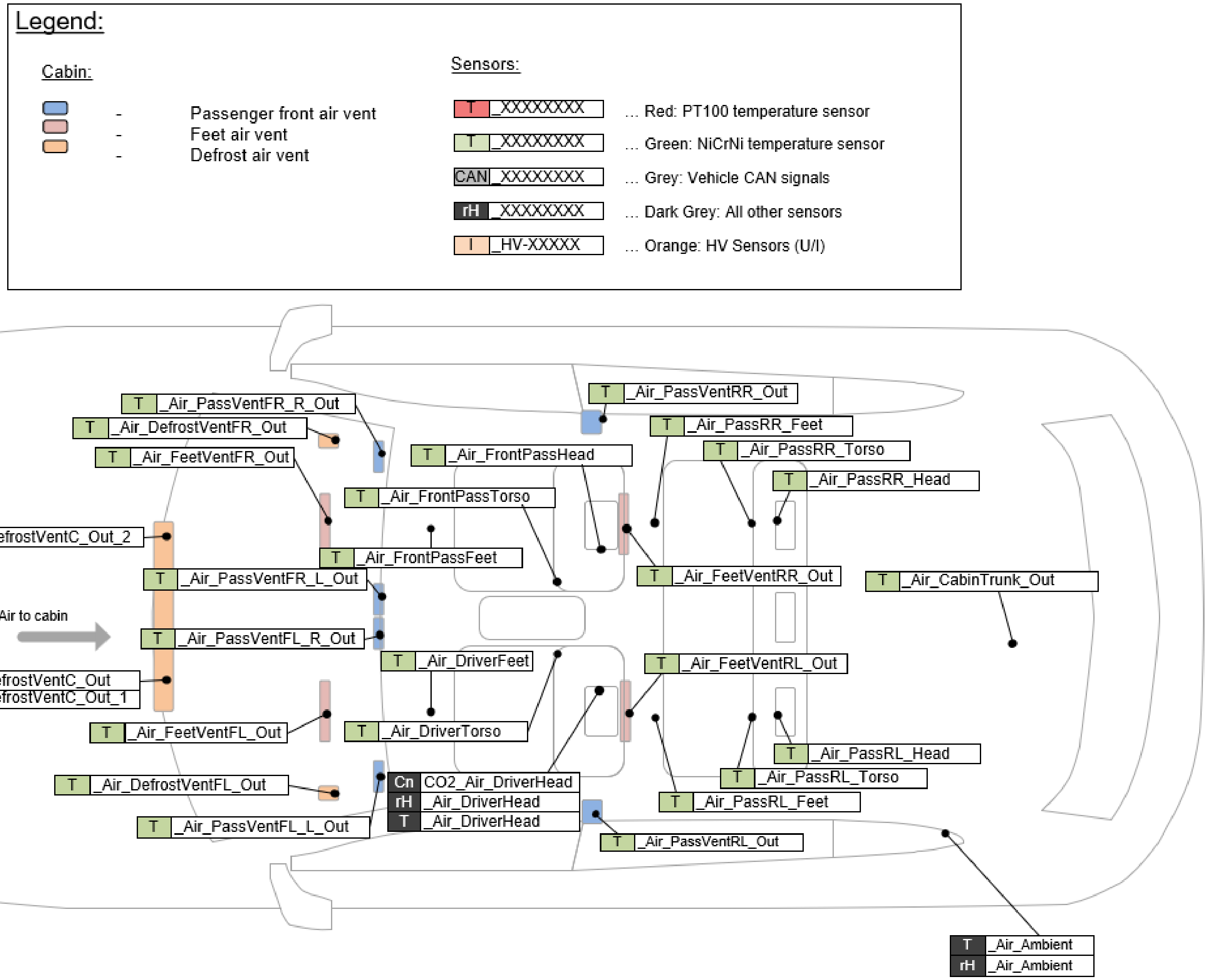

Figure 1: Cabin instrumentation schematic.

3.6 Benchmark Results

In this section the results of the chassis-dyno benchmarks are shown. To have comparable results for all three ambient temperature points, the WLTC and the Helsinki Commute cylces are averaged in terms of consumption and average cabin temperatures after 0, 10, 20 and 30 minutes. This illustration demonstrates the impact of varying levels of heating and cooling on a vehicle's consumption.

3.6.1 EV1 Results

In Figure 2, the averaged consumption of EV1 over the tested cycles is shown. The Increase in consumption at higher and lower ambient temperatures can be seen. This increase is directly linked to cooling and heating of the cabin as can be seen in Figure 3. The cabin set temperature of 22 °C is not reached in any of the three tested scenarios. The temperature inside this vehicle is especially far away from the target at 0 °C ambient temperature. This reduces the consumption tremendously. It is remarkable, that the cabin was cooled below 20 °C cabin temperature even when the setpoint was higher and the ambient temperature was 20 °C. The consumption at the 20 °C ambient point was only 82% of the maximum consumption at 0 °C ambient temperature.

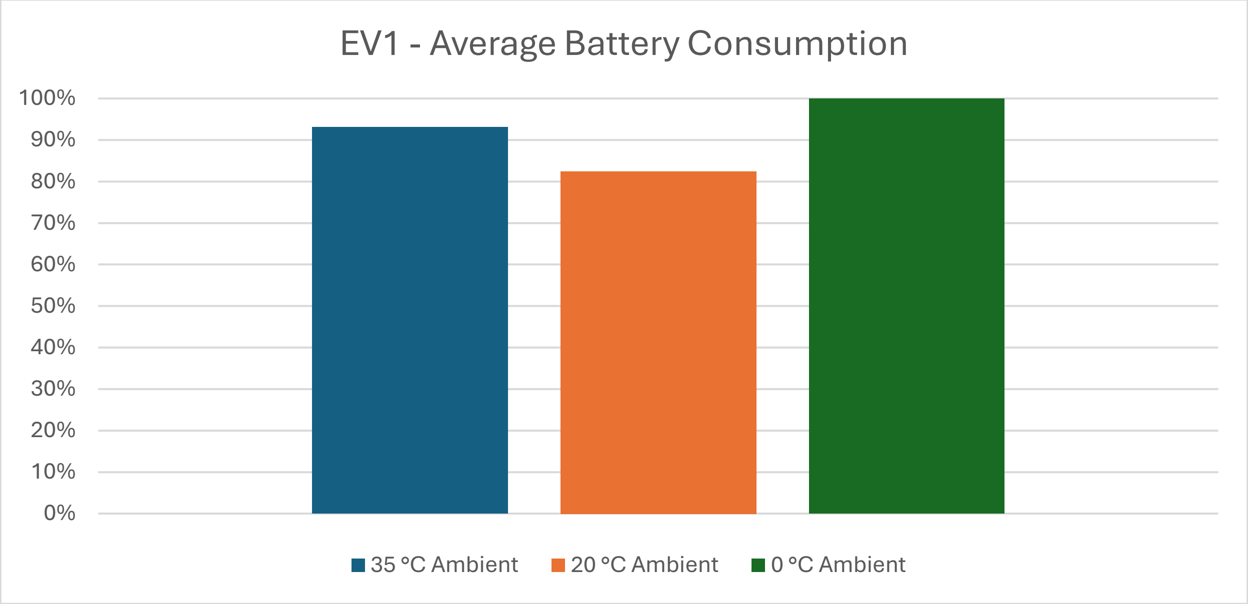

Figure 2: Average Battery Consumption as a Percentage of Maximum Average Consumption EV1 for soaked WLTC and Helsinki Commute cycles at different ambient temperatures.

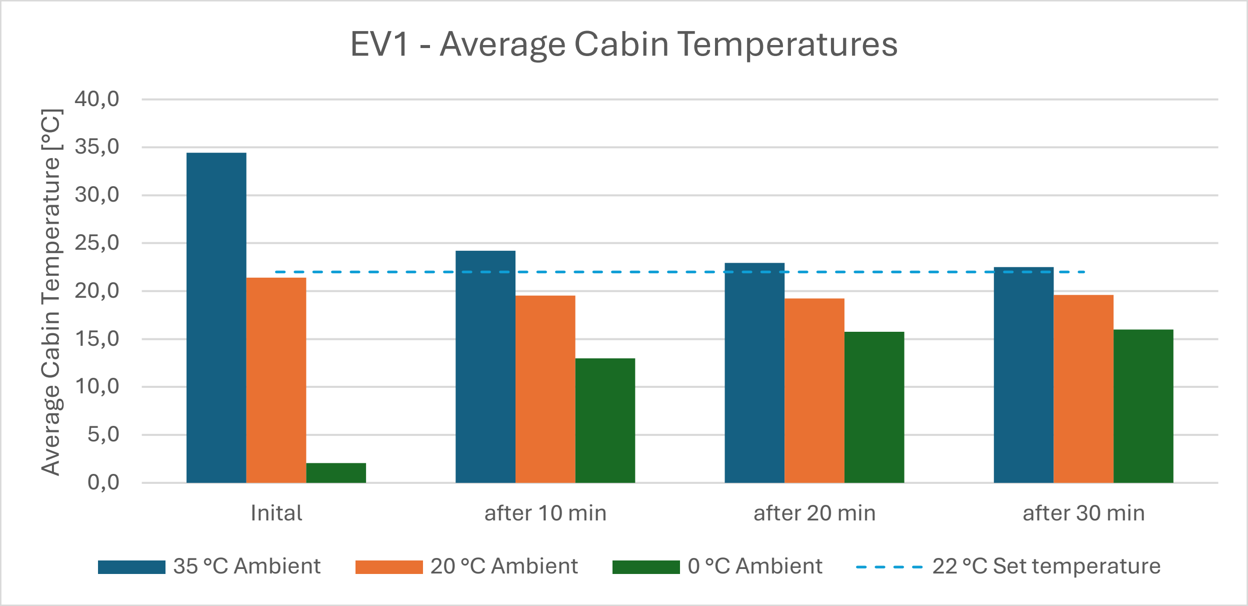

Figure 3: Average cabin temperatures of EV1 for soaked WLTC and Helsinki Commute cycles at different ambient temperatures.

3.6.2 EV2 Results

In Figure 4, the averaged consumption of EV2 over the tested cycles is shown. The lowest consumption was measured at 35 °C ambient temperature. The lower consumption for cooling at 35 °C ambient temperature compared to 20 °C ambient temperature is noteworthy. The active reheat at 20 °C in this vehicle seems to be demanding more energy compared to the cooldown. The consumption at 20 °C and 35 °C ambient conditions is only 65 % and respectively 58 % of the consumption at 0 °C ambient temperature. The average cabin temperatures during the measurements are shown in Figure 5. Due to technical reasons the initial temperature is slightly increased compared to the other vehicles for the 20 °C and 0 °C measurements.

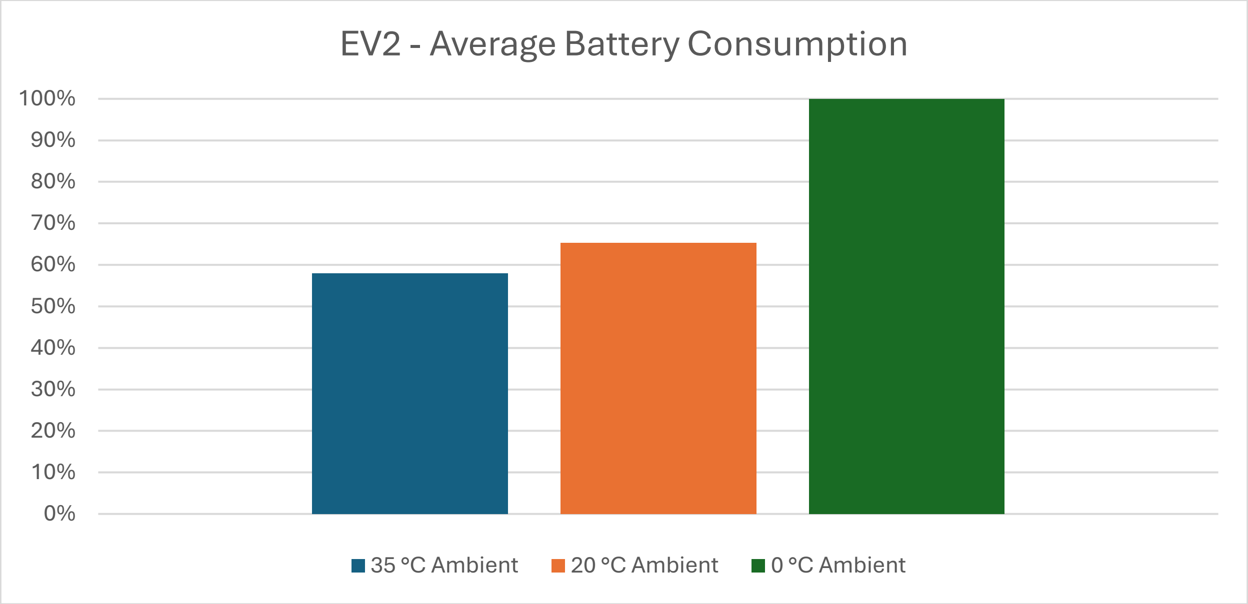

Figure 4: Average Battery Consumption as a Percentage of Maximum Average Consumption EV2 for soaked WLTC and Helsinki Commute cycles at different ambient temperatures.

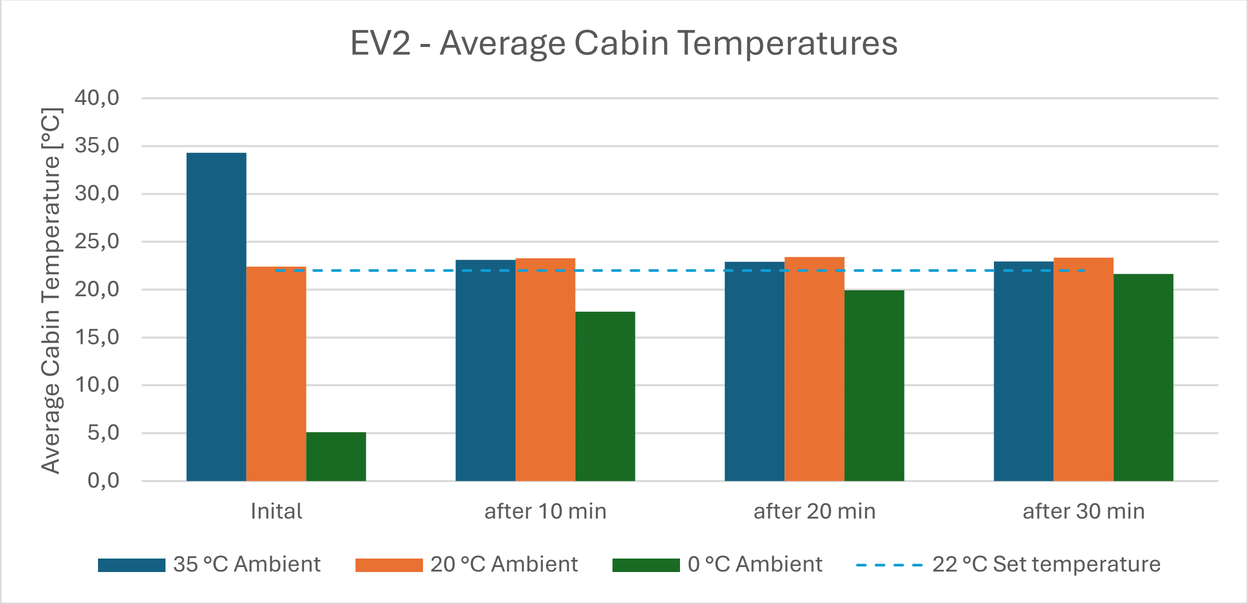

Figure 5: Average cabin temperatures of EV2 for soaked WLTC and Helsinki Commute cycles at different ambient temperatures.

3.6.3 EV3 Results

In Figure 6, the averaged consumption of EV3 over the tested cycles is shown. This vehicle has the highest consumption in all operating points. Due to constant reheat during the 20 °C ambient temperature tests, the consumption is as high as the dedicated cooling case at 35 °C ambient temperature. For the heating case at 0 °C ambient temperature the consumption is the highest. For both 20 °C and 35 °C ambient conditions the consumption is only 74% of the consumption at the 0 °C ambient temperature point. This vehicle reaches the desired temperature rather fast and holds it steadily. The average cabin temperatures during the measurements are shown in Figure 7.

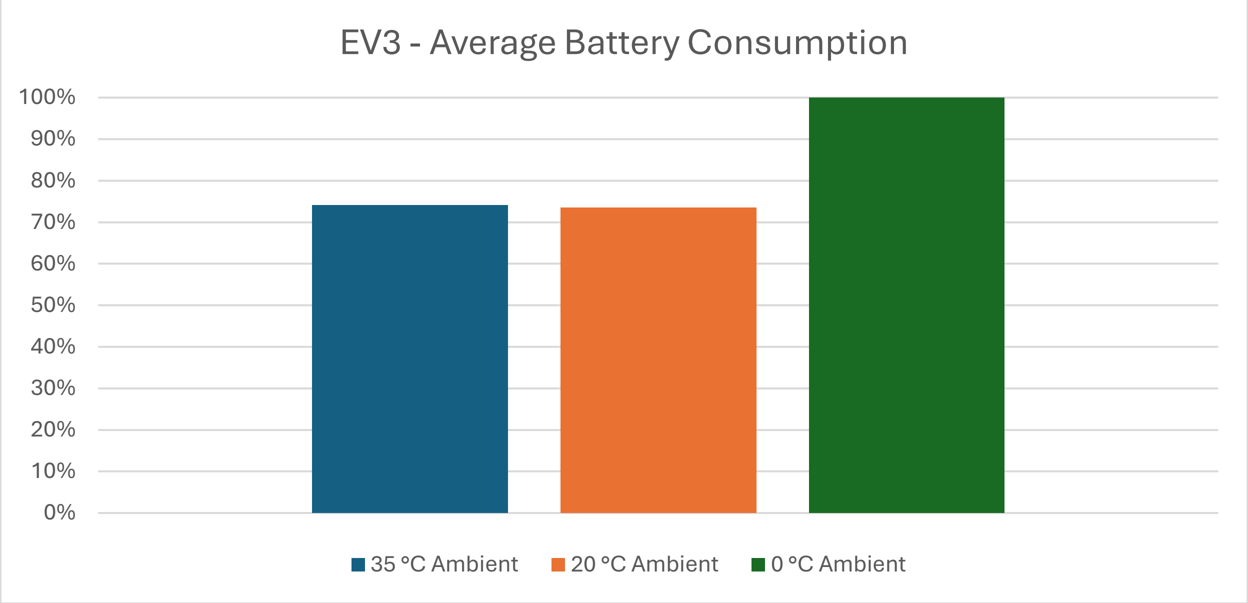

Figure 6 Average Battery Consumption as a Percentage of Maximum Average Consumption EV3 for soaked WLTC and Helsinki Commute cycles at different ambient temperatures.

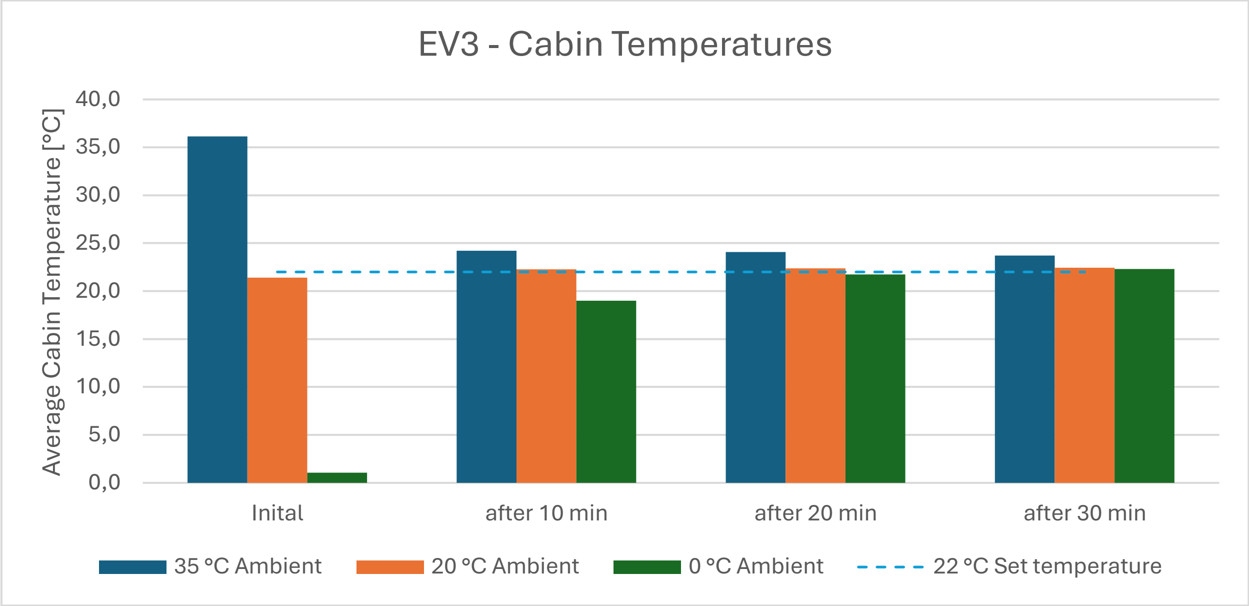

Figure 7: Average cabin temperatures of EV3 for soaked WLTC and Helsinki Commute cycles at different ambient temperatures.

4 Conclusion

In this report, the benchmark activities within the EFFEREST project are summarized. The benchmark activities involved testing three vehicles at three different climatic points on a chassis-dynamometer to evaluate the KPIs of comfort and consumption. The vehicles belonged to different market segments and were benchmarked using the WLTC and real driving cycles developed within the project in Task 2.1.

The results demonstrate a clear correlation between consumption and comfort, particularly in cold climatic conditions. The desired cabin temperature of 22°C was set for all vehicles during the benchmarking. However, only EV1 reached this temperature during the 35°C tests. During the 0°C tests, the temperature inside the cabin of EV1 was only around 16°C at the end of the tests, indicating a compromise in comfort to achieve better consumption results. This can be observed in the relatively low consumption increase of 22% from the 20°C tests to the 0°C tests for this vehicle.

In comparison, EV2 and EV3 experienced tremendous consumption increases between the 20°C and 0°C tests but did not compromise comfort. This highlights the decision-making process that original equipment manufacturers (OEMs) face in today's market - whether to prioritize comfort and compromise consumption or to reduce consumption at the expense of comfort. This emphasizes the potential of a holistic user-centric approach in EFFEREST, where consumption can be reduced without compromising comfort. The new tools developed in the project offer a better understanding of comfort and how to achieve it in an energy efficient way.

5 Abbreviations

Term	Definition
CO2	Carbon Dioxide
EFFEREST	Efficient User-Centric Energy Management Systems for Optimized Electric Vehicles
EV	Electric Vehicle
HVAC	Heating, Ventilation and Air Conditioning
ICE	Internal Combustion Engine
KPI	Key Performance Indicator
OBD	On-Board Diagnosis
WLTC	Worldwide harmonized Light vehicles Test Cycle
WP	Work Package

6 References

[1] H. G. a. C. Böttcher, "Elektrisch betriebene Pkw," in *Pkw-Klimatisierung*, Springer Vieweg, Berlin, Heidelberg, 2020.

[2] Manuel Ruf, Jürgen Barthlott, Nikolai Ebinger, Sajib Chakraborty, Aldo Sorniotti, "Vehicle, user-centric control strategy, cloud and comfort requirements report," BOSCH, 2024.