

CUSTOMER REPORT

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Donut Battery Module Low Temperature Performance Test

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Summary The objective of this project was to conduct independent performance testing of energy storage device supplied by the customer. The work reported herein focused on low temperature performance testing of a battery module at -30 °C. An initial capacity test was performed at +25 °C, followed by a discharge test at -30 °C. In the initial capacity test at +25 °C, performed within the recommended voltage range using a discharge rate of 1C, the measured capacity was 27.77 Ah and 1353.9 Wh. The subsequent low-temperature discharge test was performed at -30 °C using a discharge rate of 1C. The measured capacity at -30 °C was 26.821 Ah and 1253.9 Wh.	
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Contents

- 1. Description and objectives 4
- 2. Methods 5
 - 2.1 Capacity tests at +25 °C.....5
 - 2.2 Discharge test at –30 °C 6
- 3. Results 10
 - 3.1 Capacity tests at +25 °C.....10
 - 3.2 Discharge tests at –30 °C 10
- 4. Conclusions and summary 10



1. Description and objectives

The objective of the project was to conduct independent performance testing of energy storage devices supplied by the customer. One battery module, designated DL module 1, was provided for the testing described in this report. The module consisted of 14 cells connected in series. The module was equipped with a battery management system but did not include heating or cooling elements.

Two temperature sensors were installed on the module. One sensor was installed inside the module on the seventh cell from the negative side and attached to the cell surface at the positive-terminal end, adjacent but not in contact with the positive tab. The second sensor was installed on the surface of the module near its centre.

The module was connected to the VTT battery tester using the customer-provided cable, shown in orange in Figure 1. The voltage measurement connection was made at the junction between the customer-provided cable and the VTT tester cable. The specification of the device under test is presented in Table 1. Testing was performed according to the customer's test plan using a PEC SBT10055 battery tester, with the module placed free-standing inside a climate test chamber. The test setup is shown in Figure 1. The specifications of the battery tester and climate test chamber are presented in Table 2 and Table 3, respectively.

Table 1. Preliminary specification of the device under test, as provided by the customer.

Module type	Donut Battery Module
Cell type	Donut Battery V1
Module configuration	14S1P
Nominal capacity	29 Ah
Recommended voltage range	37.8–58.1 V
Charging method	CC–CV @ 1C (29 A), 58.1 V, CV cut-off 0.05C (1.45 A)
Discharge cut-off voltage	38.0 V

Table 2. Specification of the battery tester.

Product	PEC SBT10050 tester, 12 channels
Output voltage	0–100 VDC
Voltage measurement accuracy	0.03% FSD
Voltage measurement resolution	< 1 mV (8–100 V)
Automatically switched current ranges	0–50 mA, 50–500 mA, 0.5–5 A, 5–50 A
Current measurement accuracy	0.03% FSD (each current range)

Table 3. Specification of the climate test chamber.

Product	Vötsch VC ³ 7060
Test space volume nominal	600 litres
Test space dimensions H x W x D	950 x 800 x 800 mm
Temperature range	–72 °C to +180 °C
Temperature rate of change	4.0 K/min (heating); 2.5 K/min (cooling)
Temperature deviation in time	±0.1 K to ±0.5 K

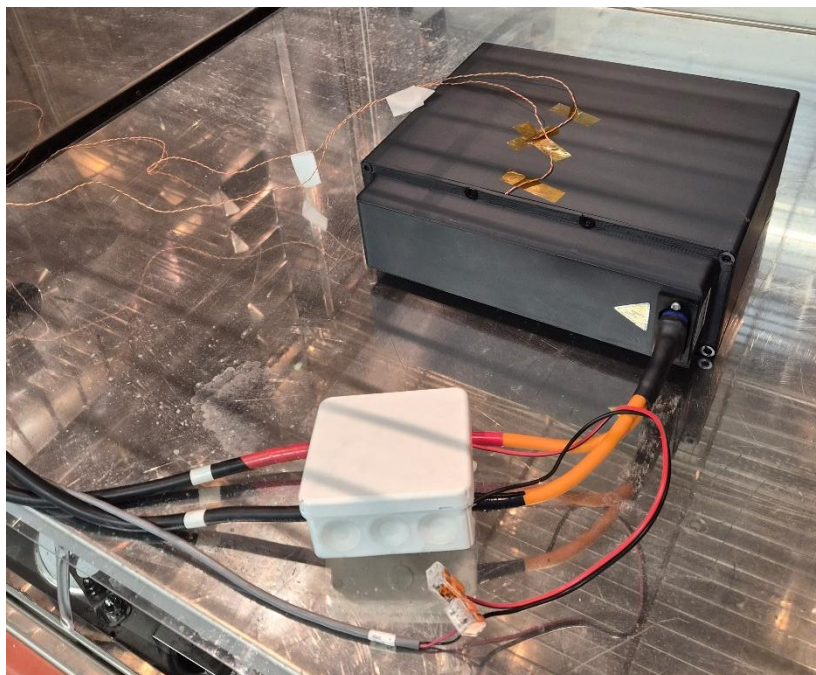


Figure 1. Test setup showing the module positioned inside the climate test cabinet, with one VTT temperature sensor attached inside the module and one on the surface of the module.

2. Methods

2.1 Capacity tests at +25 °C

Start: The climate chamber temperature setpoint was set to +25 °C. After the module temperature had stabilised, the module was charged at a rate of 1C (29 A) until the highest recommended voltage of 58.1 V was reached, followed by constant-voltage charging at 58.1 V until the current decreased to 0.05C (1.45 A).

Cycles 1–2 (capacity test at +25 °C using a rate of 1C): After approximately 5 hours of temperature stabilisation, the module was discharged at a rate of 1C (29 A) until the low cut-off voltage of 38.0 V was reached. After approximately 6 hours of temperature stabilisation, the module was charged at a rate of 1C (29 A) until the highest recommended voltage of 58.1 V was reached, followed by constant-voltage charging at 58.1 V until the current rate decreased to 0.05C (1.45 A). This cycle was performed twice.

After completion of the capacity tests, the module was discharged to approximately 50 % SOC using a discharge rate of 1C (29 A). The measured voltage, current, charge capacity, discharge capacity, ambient temperature, module inside temperature and module surface temperature during the capacity test at +25 °C are shown in Figure 2.



2.2 Discharge test at $-30\text{ }^{\circ}\text{C}$

Start: The climate chamber temperature setpoint was set to $+25\text{ }^{\circ}\text{C}$. After the module temperature had stabilised, the module was charged at a rate of 1C (29 A) until the highest recommended voltage of 58.1 V was reached, followed by constant-voltage charging at 58.1 V until the current decreased to 0.05C (1.45 A).

Cycles 1–2 (discharge test at $-30\text{ }^{\circ}\text{C}$ using a rate of 1C): The climate chamber temperature setpoint was set to $-30\text{ }^{\circ}\text{C}$. After approximately 5 hours of temperature stabilisation, the module was discharged at a rate of 1C until the low cut-off voltage of 38.0 V was reached. The climate chamber temperature setpoint was then changed to $+25\text{ }^{\circ}\text{C}$. After approximately 6 hours of temperature stabilisation, the module was charged at a rate of 1C (29 A) until the highest recommended voltage of 58.1 V was reached, followed by constant-voltage charging at 58.1 V until the current rate decreased to 0.05C (1.45 A). This cycle was performed twice.

After completion of the test, the module was discharged to approximately 50 % SOC using a discharge rate of 1C (29 A). The measured voltage, current, charge capacity, discharge capacity, ambient temperature, module inside temperature and module surface temperature during the discharge tests at $-30\text{ }^{\circ}\text{C}$ are shown in Figure 3 and Figure 4.

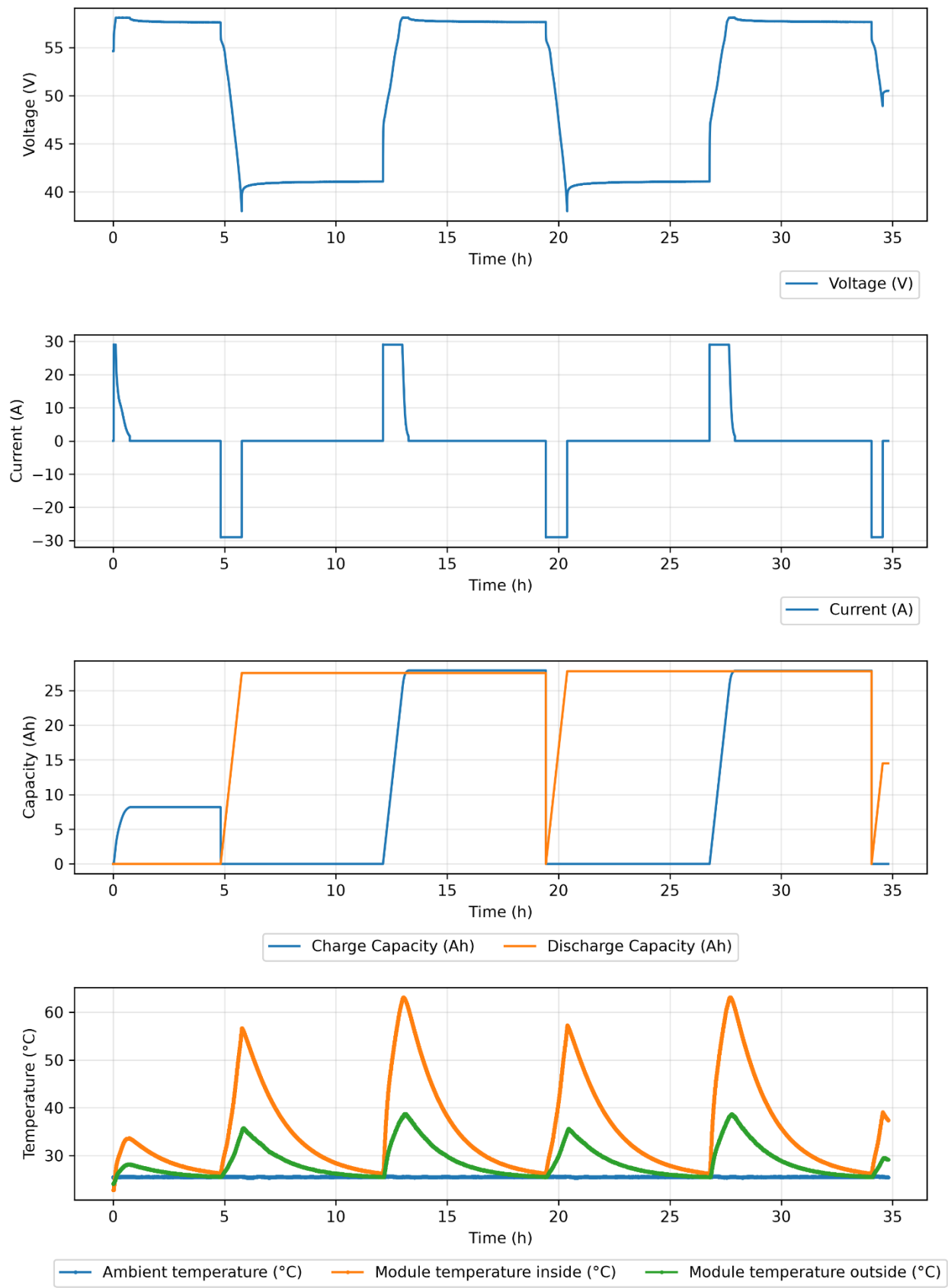


Figure 2. Measured voltage, current, charge capacity, discharge capacity, ambient temperature, module inside temperature and module surface temperature during the capacity test at +25 °C.

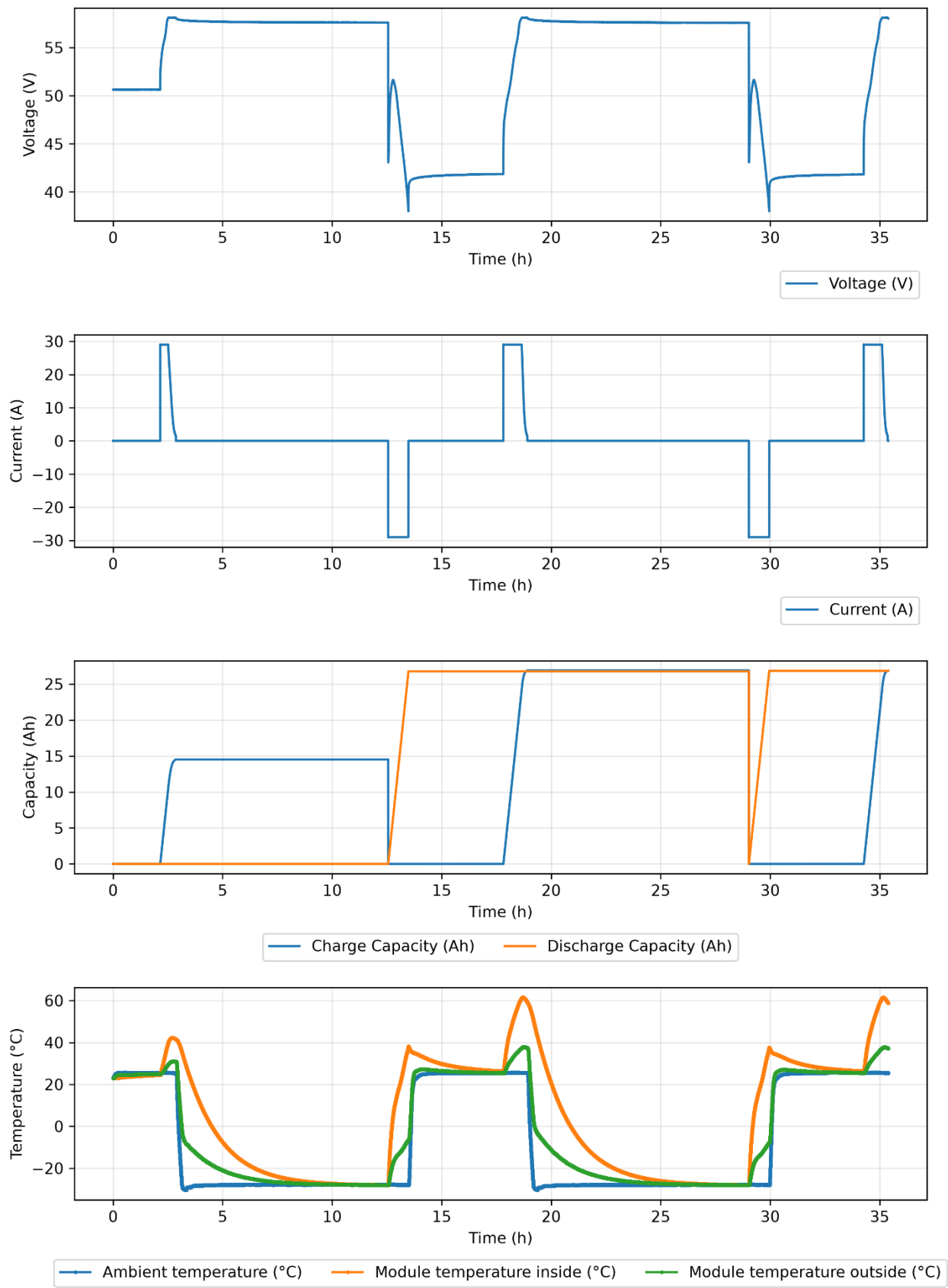


Figure 3. Measured voltage, current, charge capacity, discharge capacity, ambient temperature, module inside temperature and module surface temperature during the discharge tests at -30 °C.

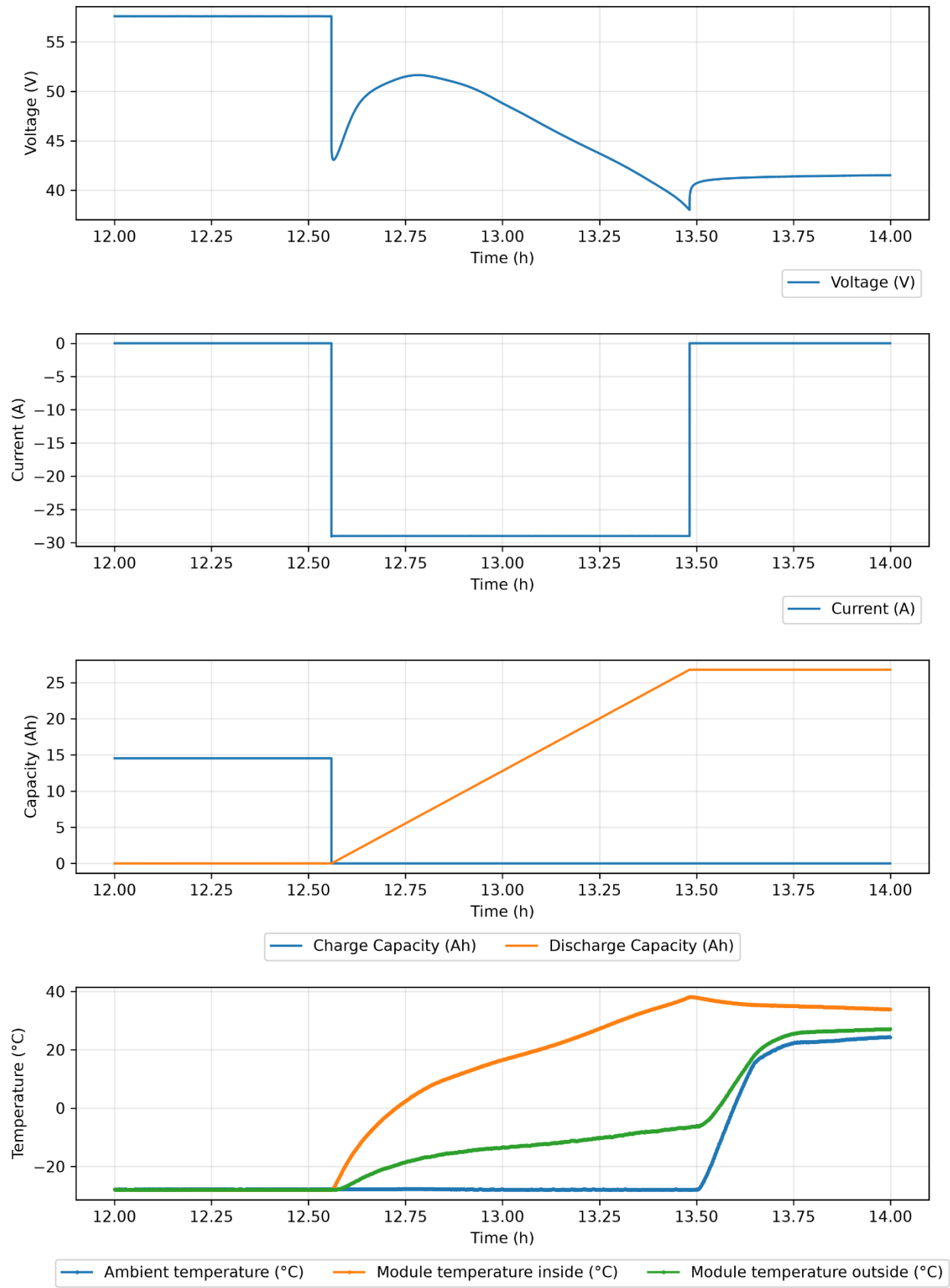


Figure 4. Detailed view of discharge test at -30 °C between 12 and 14 hours.



3. Results

3.1 Capacity tests at +25 °C

The measured capacities are presented in Table 4. The results from the second cycle were used as the reported capacity values. The internal module temperature reached approximately +57 °C during both discharge and charge. The module surface temperature reached approximately +36 °C during discharge and +38 °C during charge.

Table 4. Measured capacity and energy during the capacity test at +25 °C

	Discharge capacity	Charge capacity	Discharge energy	Charge energy
Cycle 1	27.519 Ah	27.884 Ah	1341.7 Wh	1482.1 Wh
Cycle 2	27.770 Ah	27.847 Ah	1353.9 Wh	1479.9 Wh

3.2 Discharge tests at –30 °C

The measured capacities are presented in Table 5. The second cycle was used for the reported capacity values. The internal module temperature reached approximately +38 °C during discharge and +63 °C during charge. The module surface temperature reached approximately –6 °C during discharge and +38 °C during charge. Following completion of the test, the module remained operational and could be charged and discharged normally. No observable changes to the module were detected.

Table 5. Measured capacity and energy during the discharges at –30 °C and charging at +25 °C

	Discharge capacity	Charge capacity	Discharge energy	Charge energy
Cycle 1	26.763 Ah	26.882 Ah	1249.3 Wh	1434.0 Wh
Cycle 2	26.821 Ah	26.850 Ah	1253.9 Wh	1432.0 Wh

4. Conclusions and summary

The battery module was subjected to capacity testing at +25 °C and discharge testing at –30 °C in accordance with the customer’s test plan. The measured capacity at +25 °C was 27.77 Ah and 1353.9 Wh.

At –30 °C, the measured capacity was 26.821 Ah and 1253.9 Wh. Capacity, energy and module temperatures were recorded during the low-temperature discharge test.