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# TEST REPORT
# ANSI/CAN/UL 9540A:2019
## Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

| | | |
|---|---|---|
| Report Reference No. | : | 220702483SHA-001 |
| Tested by (name + signature) | : | Chuanhui Xie |
| Approved by (name + signature) | : | Robin Xu |
| Total number of pages | : | 59 |
| Date of issue | : | 2023-01-10 |

| | | |
|---|---|---|
| Testing Laboratory | : | Intertek Testing Services Shanghai |
| Address | : | Building No.86, 1198 Qinzhou Road (North), Shanghai 200233, China |
| Testing procedure | : | Witness testing |
| Testing location/ address | : | No. 158, Changbangcun Road, Fengxian District, Shanghai, China. |

| | | |
|---|---|---|
| Applicant's name | : | Soluna（Shanghai）Co.,Ltd |
| Address | : | 2nd Floor, No. 979, Yunhan Road, Lingang New Area, China |

| | | |
|---|---|---|
| Test specification: | | |
| Standard | : | ANSI/CAN/UL 9540A:2019 ( Fourth Edition ) + UL CRD's |
| Test procedure | : | Unit level test (clause 9.1-9.8) |
| Non-standard test method | : | N/A |

| | | |
|---|---|---|
| Test Report Form No. | : | ANSI/CAN/UL 9540A unit level_TTRF |
| Test Report Form(s) Originator | : | Intertek |
| Master TRF | : | 2022-01-14 |



| | | |
|---|---|---|
| Test item description | : | Residential Battery ESS (BS+PCS) |
| Trade Mark | : | SOLUNA |
| Manufacturer | : | DLG Energy (Shanghai) Co., Ltd |
| Model/Type reference | : | Soluna 15K Pack HV (L-E), Soluna 10K Pack HV (L-E), Soluna 6K Pack HV (L-E) |
| Ratings | : | See unit information |

**General disclaimer:**

**List of attachments:**

Attachment 1 – Photos

Attachment 2 – Sample preparation of the test

Attachment 3 – Arrangement of the unit

Attachment 4 – Thermal runaway preparation

Attachment 5 – Observations and records

Attachment 6 – Temperature measurements

Attachment 7 – Heat flux measurements (N/A)

Attachment 8 – Chemical heat release rate measurement

Attachment 9 – Convective heat release rate measurement

Attachment 10 – Gas generation measurement

Attachment 11 – Smoke release rate measurement

Attachment 12 – Equipment list

Test video 220702483SHA-001.mp4 was provided in addition to this test report.

**Summary of testing:**

| | |
|---|---|
| The thermal runaway initiation method*) ..... : | Heating |
| Thermal Runaway Propagation ..... : | Yes |
| Maximum Temperature of Target BESS (°C) ..... : | 26.7°C |
| Maximum Temperature of Wall Surface (°C) ..... : | 59.0°C |
| Maximum Heat Flux on target wall surfaces (kW/m$^2$) ..... : | N/A |
| Maximum Heat Flux on target BESS units (kW/m$^2$) ..... : | N/A |
| Vent gas composition ..... : | See attachment 10 |
| Peak Chemical Heat Release (kW) ..... : | 1.2 kW |
| Peak Convective Heat Release Rate (kW) ..... : | 0 kW |
| Peak Smoke Heat Release Rate (m$^2$/s) ..... : | 0.0365 m$^2$/s |
| Total Smoke Heat Release Rate (m$^2$) ..... : | 9.13 m$^2$ |
| Maximum Heat Flux on Egress Path (kW/m$^2$) ..... : | N/A |
| External Flaming from BESS ..... : | Not observed |
| Flying debris or explosive discharge of gases ..... : | Not observed |
| Sparks, electrical arcs, or other electrical events ..... : | Not observed |
| Re-ignitions ..... : | Not observed |

*) The thermal runaway initiation method was based on the same thermal runaway method for the UL 9540A cell level test (report no. 220401842SHA-001, issued by Intertek Testing Services Shanghai.)

Conclusion:

The performance criteria of the unit level test as indicated in 9.8 of UL 9540A 4th edition has been met.

The deflagration protection analysis is not done in this report, it shall be evaluated based on the final installation condition. (with the reference to procedure in UL9540A Figure A.3)

| | |
|---|---|
| **Possible test case verdicts:** | |
| - test case does not apply to the test object..... : | N/A |
| - test object was not evaluated for the requirement..... : | N/E |
| - test object does meet the requirement..... : | Pass (P) |
| - test object does not meet the requirement ..... : | Fail (F) |
| **Testing:** | |
| Date of receipt of test items ..... : | August 1st, 2022 |
| Date(s) of performance of tests ..... : | August 20th, 2022– August 25th, 2022 |

**General remarks:**

"(see Attachment #)" refers to additional information appended to the report.

"(see appended table)" refers to a table appended to the report.

The tests results presented in this report relate only to the object tested.

This report shall not be reproduced except in full without the written approval of the testing laboratory.

List of test equipment must be kept on file and available for review.

Additional test data and/or information provided in the attachments to this report.

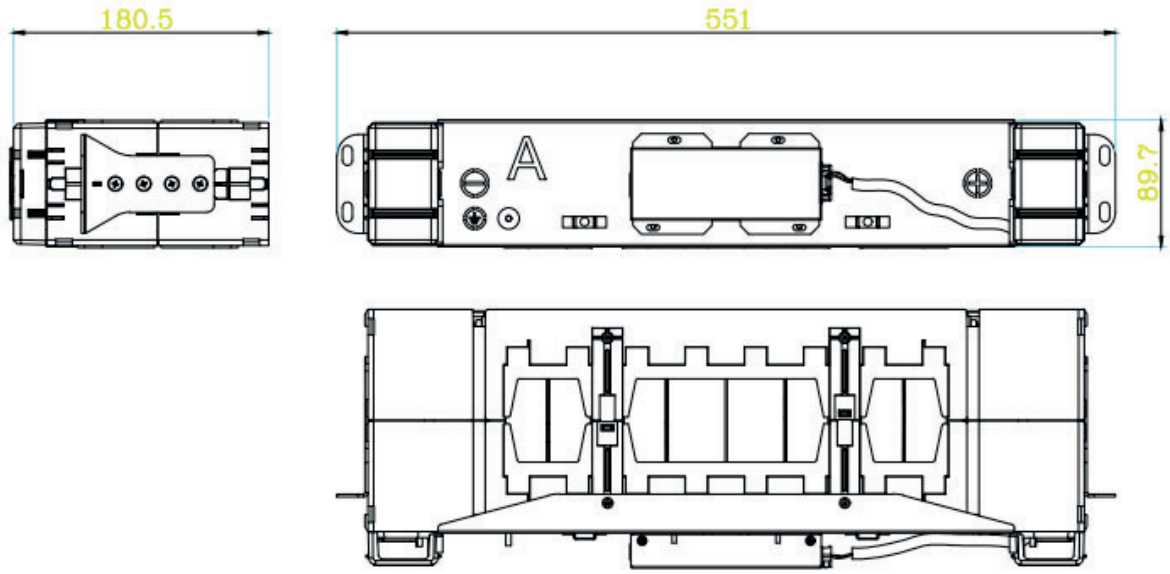
Throughout this report a ☐ comma / ☒ **point** is used as the decimal separator.

Determination of the test results includes consideration of measurement uncertainty from the test equipment and methods.

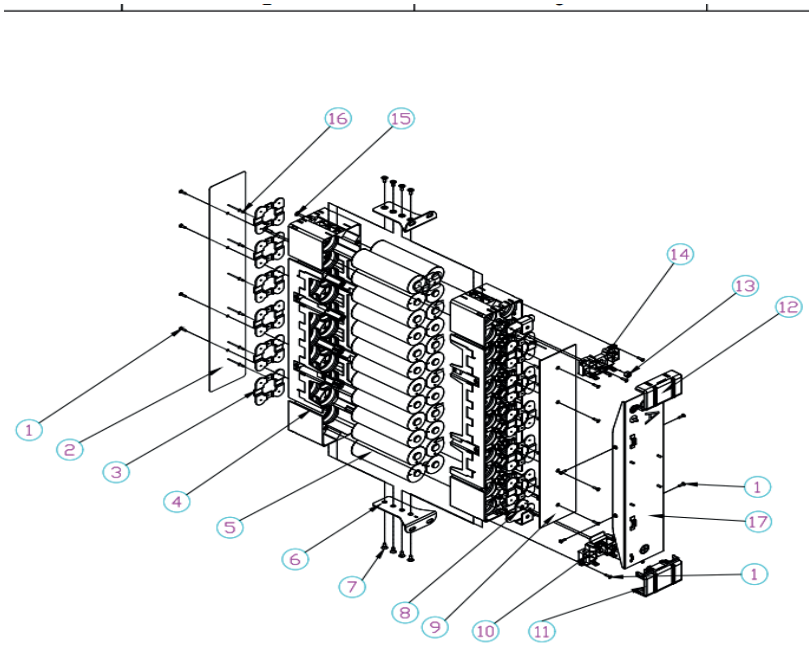
| | | |
|---|---|---|
| **Product information:** | | |
| **Cell information** | | |
| Manufacturer | : | EVE POWER Co., Ltd |
| Model name | : | IFR40135 (C40) |
| Chemistry | : | $LiFePO_4$ |
| Physical configuration | : | Cylindrical |
| Dimension (W*L*H) | : | |
| Weight | : | 374 g |
| Nominal voltage | : | 3.2 Vdc |
| Rated capacity | : | 20 Ah |
| If the cell compliance with UL 1973 | : | Certificate is ongoing. |
| **Standard charge method** | | |
| Charge current | : | 10 A |
| End of charge voltage | : | 3.65 V |
| Cut off current | : | 1 A |
| **Standard discharge method** | | |
| Discharge current | : | 10 A |
| End of discharge voltage | : | 2.5 V (T>0°C)<br>2.0 V (T<=0°C) |
| **Test result from cell level 9540A test report** | | |
| Cell level test report | : | 220401842SHA-001 |
| Average cell venting temperature | : | 222.6°C |
| Average cell thermal runaway onset temperature | : | 264°C |
| Gas volume | : | 9.7L |
| Gas composition | : | CO: 10.76%, $CO_2$:22.25%, $H_2$:54.64%, Hydrocarbon:12.35% |
| LFL at ambient temperature | : | 6.5% at 24±2°C and 101±3kPa |
| LFL at cell venting temperature | : | 5.3% at 222.6±1°C and 101±3kPa |
| Burning velocity ($S_u$) | : | 0.828m/s |
| $P_{max}$ | : | 116.0psi (0.80MPa) at 24±2°C and 101±5kPa |

| | | |
|---|---|---|
| **Module information**[*)] | | |
| Manufacturer | : | DLG Energy (Shanghai) Co., Ltd |
| Model name | : | Soluna Module HV (L-E) |
| **Physical configuration** | | |
| Enclosure material | : | Metal |
| Dimension (W*L*H) | : | |
| Weight | : | 10.2 kg |
| Cells in series/parallel: | : | 2P12S |
| Total number of cells: | : | 24 cells |
| Cooling method | : | Natural |
| Separation between cells | : | 2mm |
| **Electrical rating** | | |
| Rated capacity | : | 40 Ah |
| Rated energy | : | 1530 Wh |
| Nominal voltage | : | 38.4 Vdc |
| Standard charge method | | |
| Charge current | : | 20 A |
| End of charge voltage | : | 42 Vdc |
| Standard discharge method | | |
| Discharge current | : | 20 A |
| End of discharge voltage | : | 33.6 Vdc |
| If the module compliance with UL 1973 | : | Certificate is ongoing. |

**Diagram of module with overall dimension (unit: mm)**

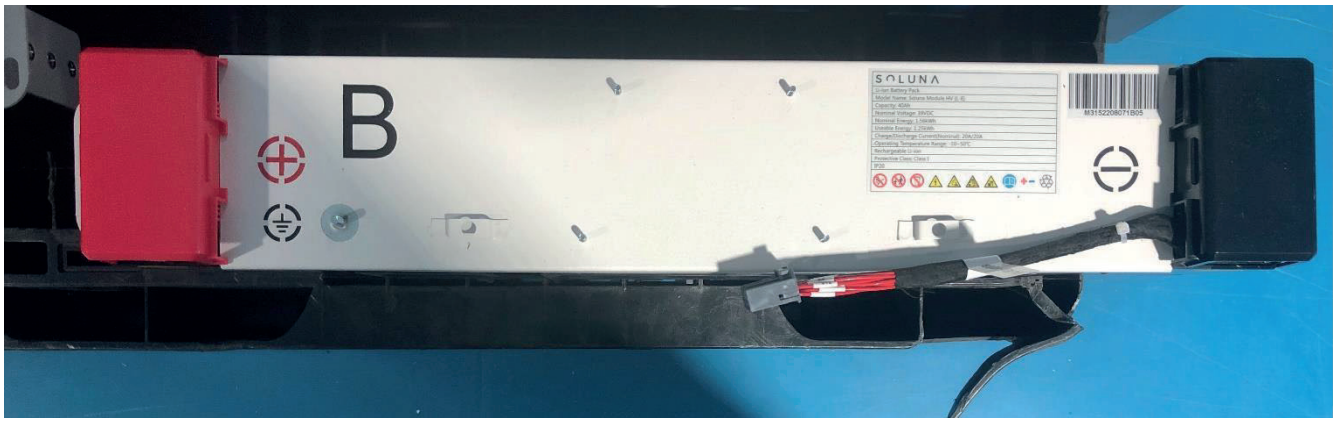


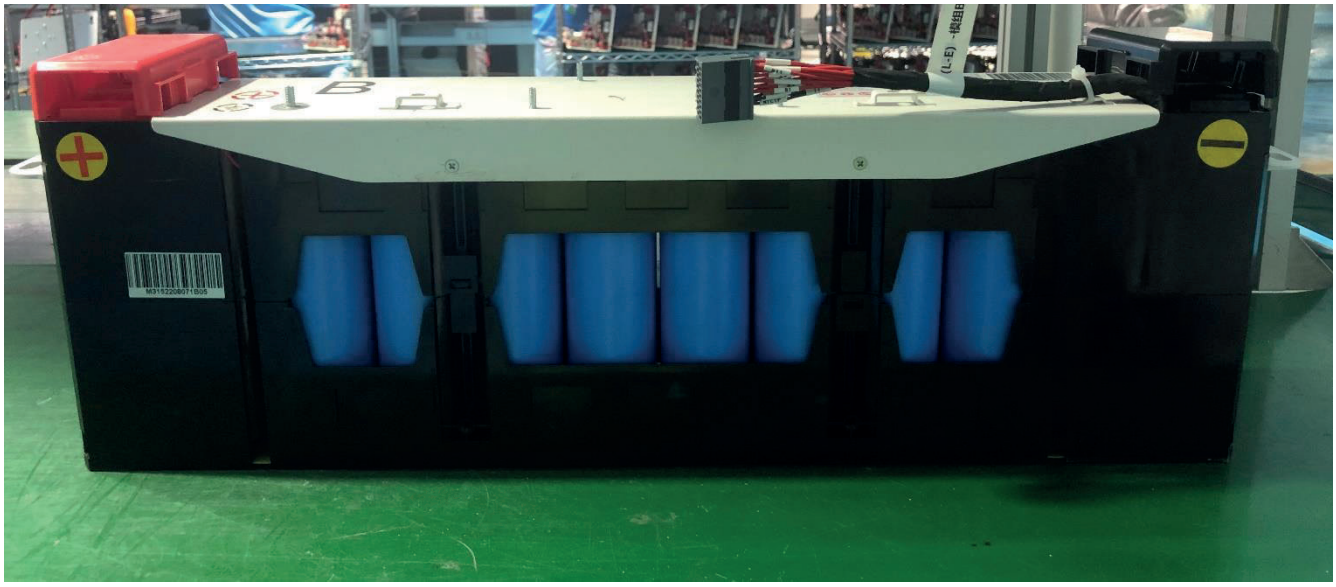

**Contents (main components) of the module**




| 序号 | 零件名称 | 数量 | 单位 |
|---|---|---|---|
| 1 | 十字螺钉 | 18 | PCS |
| 2 | 纤维板2 | 1 | PCS |
| 3 | 铝排01 | 11 | PCS |
| 4 | 电芯支架 | 2 | PCS |
| 5 | 电芯 | 24 | PCS |
| 6 | 模组固定支架 | 2 | PCS |
| 7 | 十字螺钉 | 8 | PCS |
| 8 | 铝排02 | 2 | PCS |
| 9 | 纤维板1 | 1 | PCS |
| 10 | 正极底座 | 1 | PCS |
| 11 | 正极盖帽 | 1 | PCS |
| 12 | 负极盖帽 | 1 | PCS |
| 13 | 螺母 | 2 | PCS |
| 14 | 负极底座 | 1 | PCS |
| 15 | 十字螺钉 | 8 | PCS |
| 16 | 铆钉 | 11 | PCS |
| 17 | 从控支架 | 1 | PCS |

**Photo of module**



| **Unit information** | |
|---|---|
| Manufacturer: | DLG Energy (Shanghai) Co., Ltd |
| Model name: | Soluna 15K Pack HV (L-E),<br>Soluna 10K Pack HV (L-E),<br>Soluna 6K Pack HV (L-E) |
| Type of system: | ☐ Battery System (BS) ☒ Battery ESS |
| Intended use location: | ☒ Residential ☐ Non-residential<br>☐ Non-residential rooftop<br>☐ Non-residential open garage use |
| Type of installation: | ☒ Indoor ☒ Outdoor<br>☐ Wall mounted ☒ Floor/ground mounted |
| Enclosure material: | ☒ Metal ☐ Non-metal<br>☐ Open rack |
| Weight: | 141 kg for Soluna 15K Pack HV (L-E)<br>96 kg for Soluna 10K Pack HV (L-E)<br>66 kg for Soluna 6K Pack HV (L-E) |
| Module series and/or parallel configuration: | 2P120S for Soluna 15K Pack HV (L-E)<br>2P84S for Soluna 10K Pack HV (L-E)<br>2P48S for Soluna 6K Pack HV (L-E) |
| Total number of battery stacks: | N/A |
| Total number of modules: | 10 for Soluna 15K Pack HV (L-E)<br>7 for Soluna 10K Pack HV (L-E)<br>4 for Soluna 6K Pack HV (L-E) |
| Total number of cells: | 240 for Soluna 15K Pack HV (L-E)<br>168 for Soluna 10K Pack HV (L-E)<br>96 for Soluna 6K Pack HV (L-E) |
| Min. spacing between modules: | 0.78"(2cm) vertical spacing |
| Smallest volume room installations specified. (only for Residential Indoor Use) *: | 35 $m^3$ |

| | |
|---|---|
| **Electrical rating** | |
| Rated energy (kWh) .....: | 15 for Soluna 15K Pack HV (L-E)<br>10 for Soluna 10K Pack HV (L-E)<br>6 for Soluna 6K Pack HV (L-E) |
| Nominal voltage (V) .....: | 384Vdc for Soluna 15K Pack HV (L-E)<br>268.8Vdc for Soluna 10K Pack HV (L-E)<br>153.6Vdc for Soluna 6K Pack HV (L-E) |
| **Standard charge method** | |
| Charge current (A) .....: | 20 |
| End of charge voltage (V) .....: | 420Vdc for Soluna 15K Pack HV (L-E)<br>294Vdc for Soluna 10K Pack HV (L-E)<br>168Vdc for Soluna 6K Pack HV (L-E) |
| **Standard discharge method** | |
| Discharge current (A).....: | 20 |
| End of discharge voltage (V) .....: | 336Vdc for Soluna 15K Pack HV (L-E)<br>235.2Vdc for Soluna 10K Pack HV (L-E)<br>134.4Vdc for Soluna 6K Pack HV (L-E) |
| Rest time between charge and discharge (min).....: | 0 |
| Integrated fire protection system in the unit .....: | ☒ No |
| If the unit compliance with UL 1973 or UL 9540.....: | UL 1973 certificated, test report No. 220700946SHA-001 |

Model difference

The model Soluna 10K Pack HV (L-E) and Soluna 6K Pack HV (L-E), are identical to model Soluna 15K Pack HV (L-E), except the quantity of battery modules and size of metal enclosure.

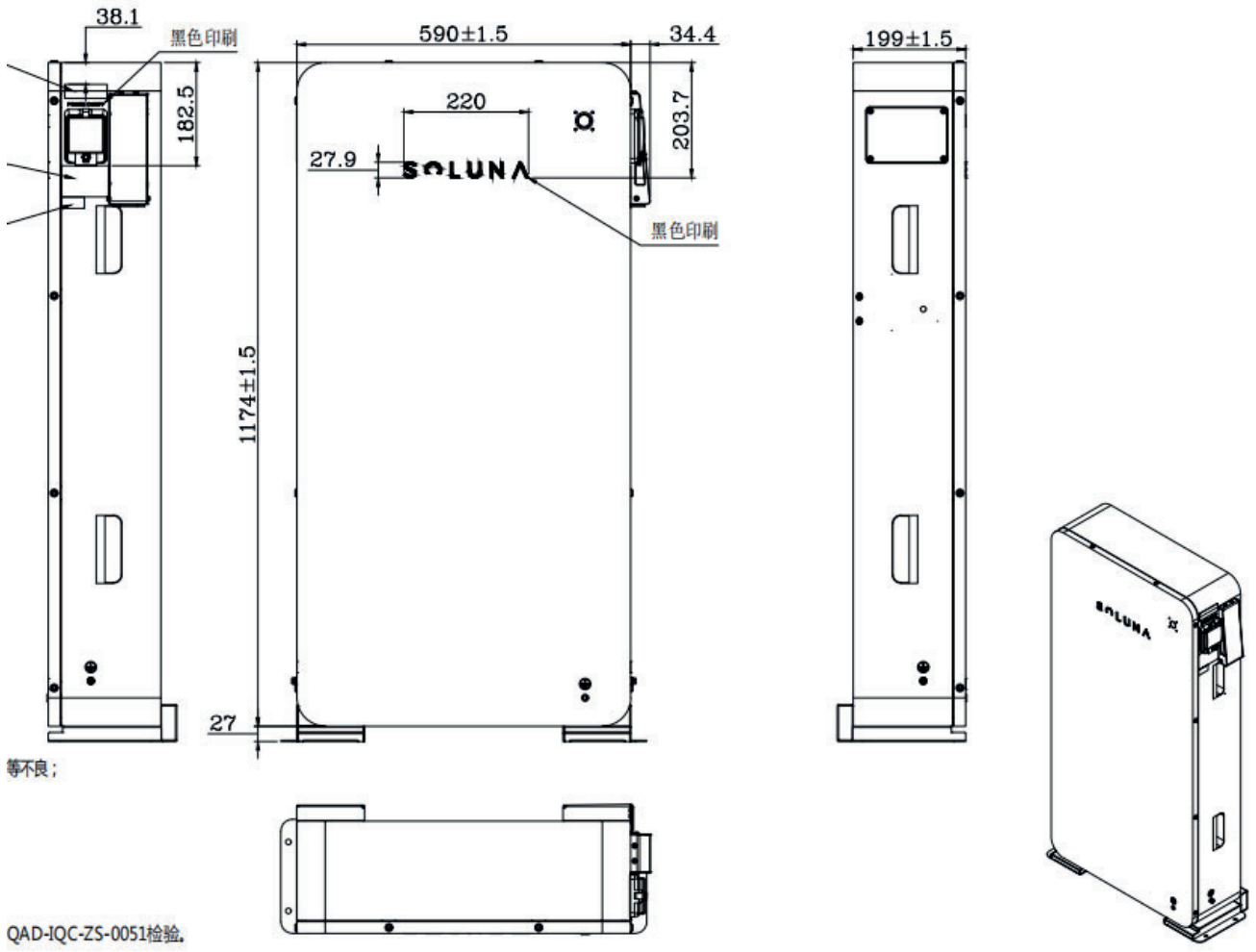
All the test and measurement were performed on model Soluna 15K Pack HV (L-E), it is valid for other models.

Note:

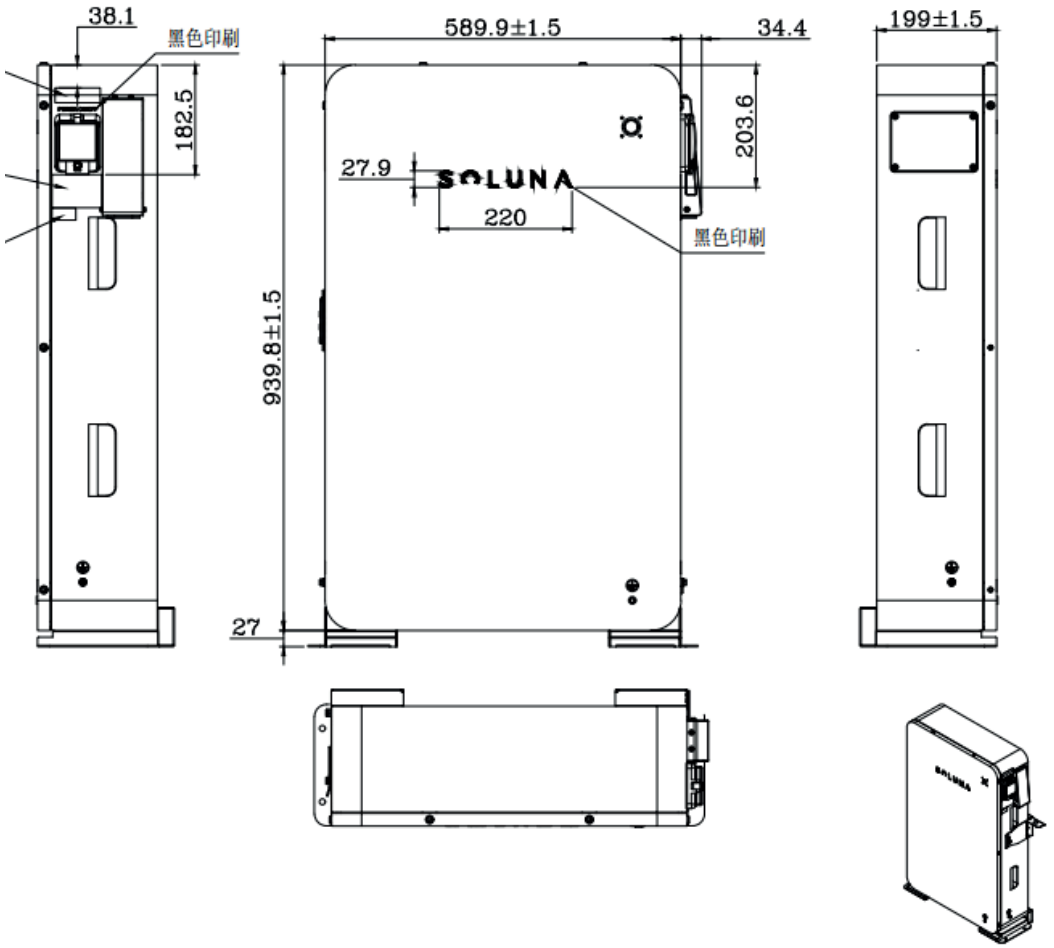
*) the LFL value at ambient temperature in cell level report and number of cells thermal runaway at unit level test was considered.

Additional ventilation device shall be used if the volume room installed is less than the smallest volume room installations specified.

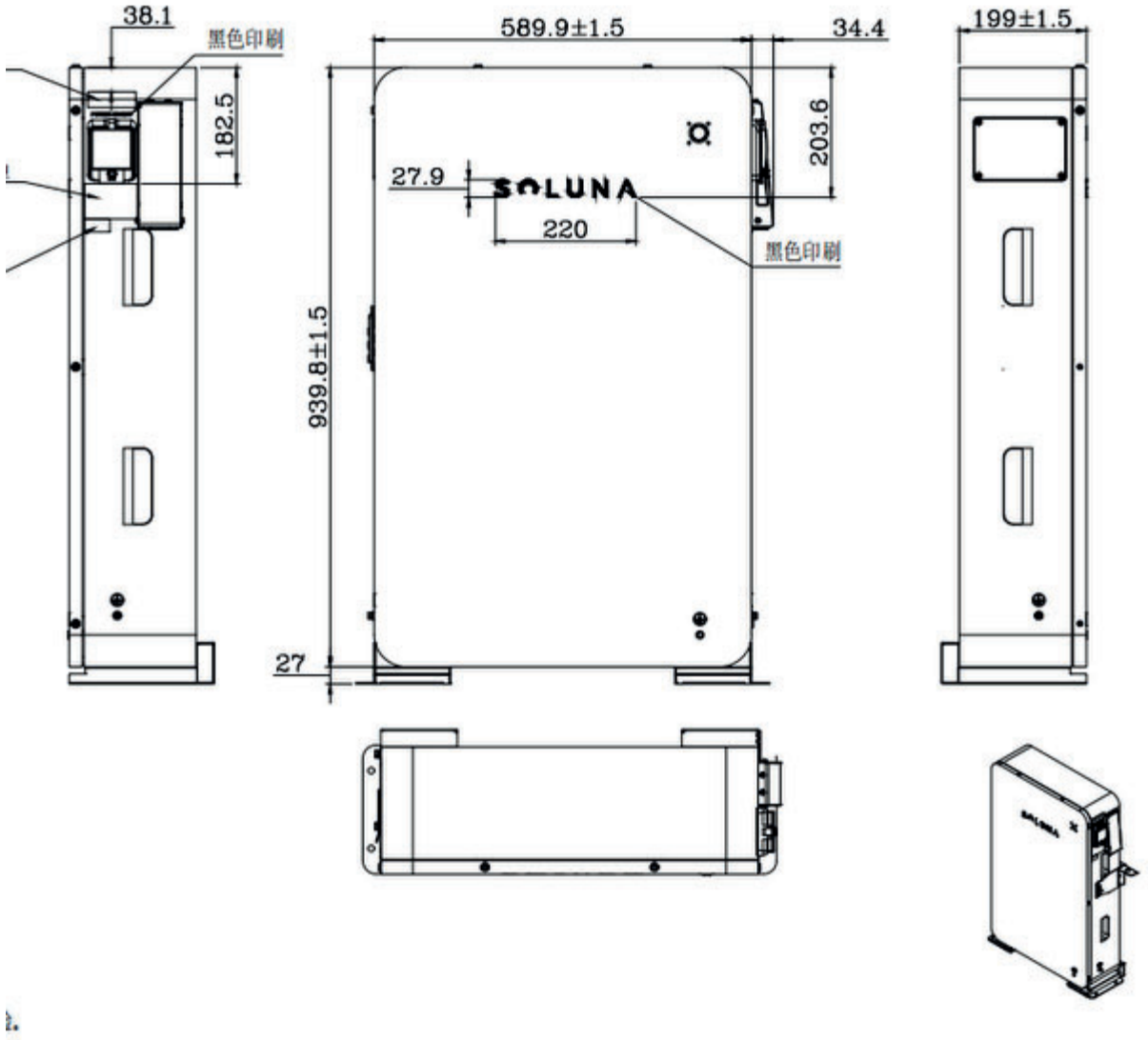
**Diagram of unit with overall dimension (unit: mm)**




Model: Soluna 15K Pack HV (L-E)

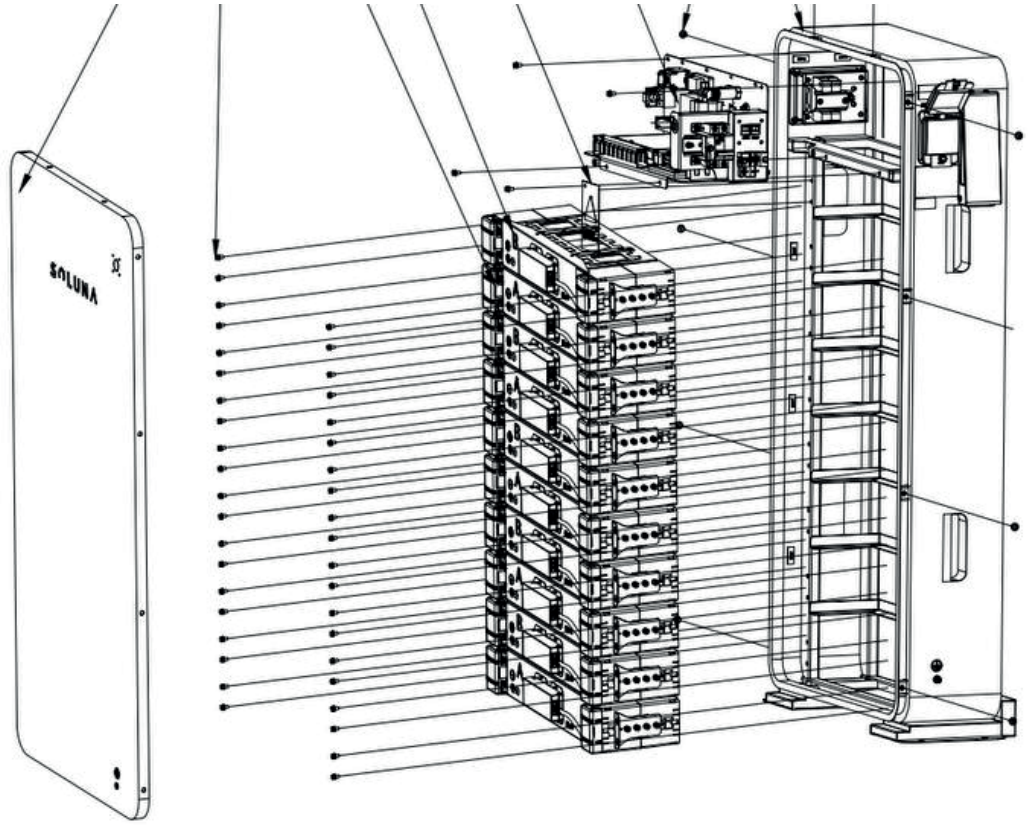



Soluna 6K Pack HV (L-E)

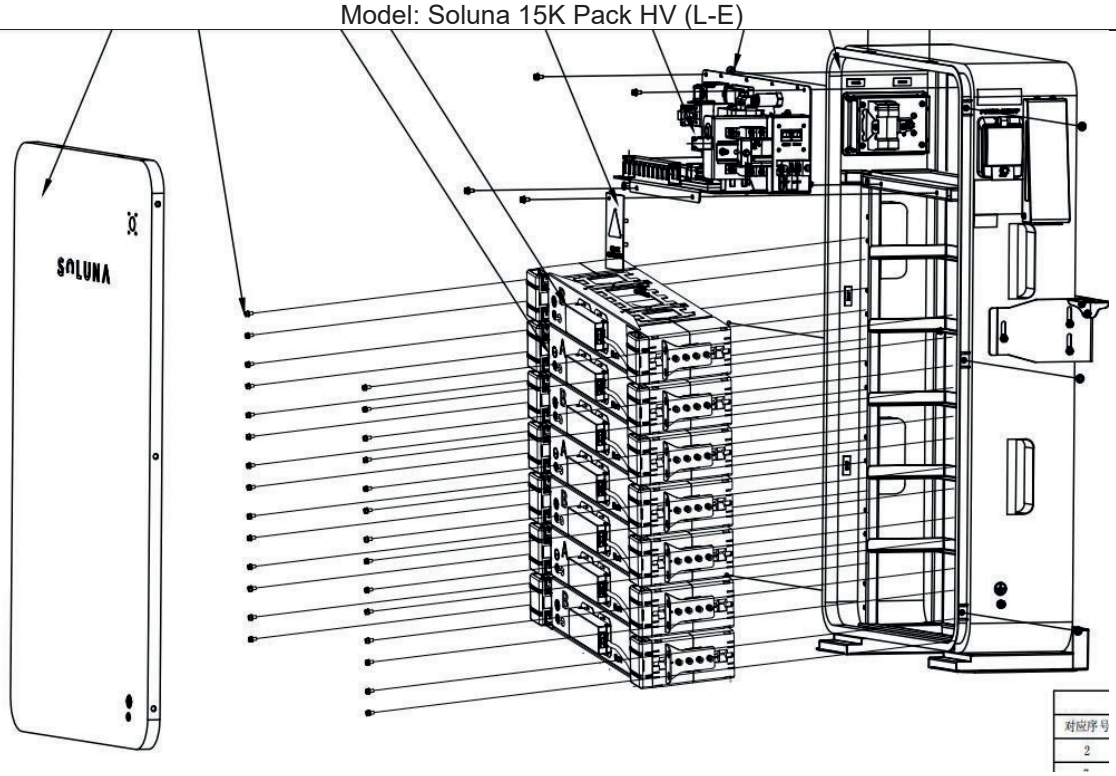



Model: Soluna 10K Pack HV (L-E)

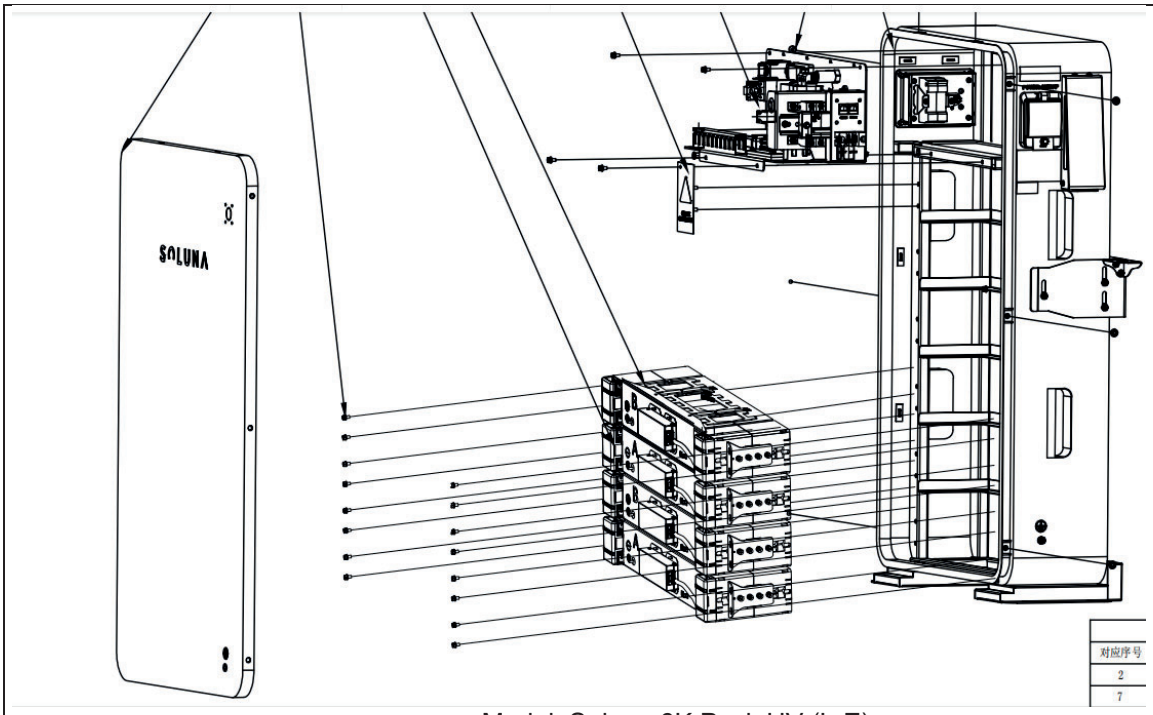
**Construction of battery unit**




Model: Soluna 15K Pack HV (L-E)

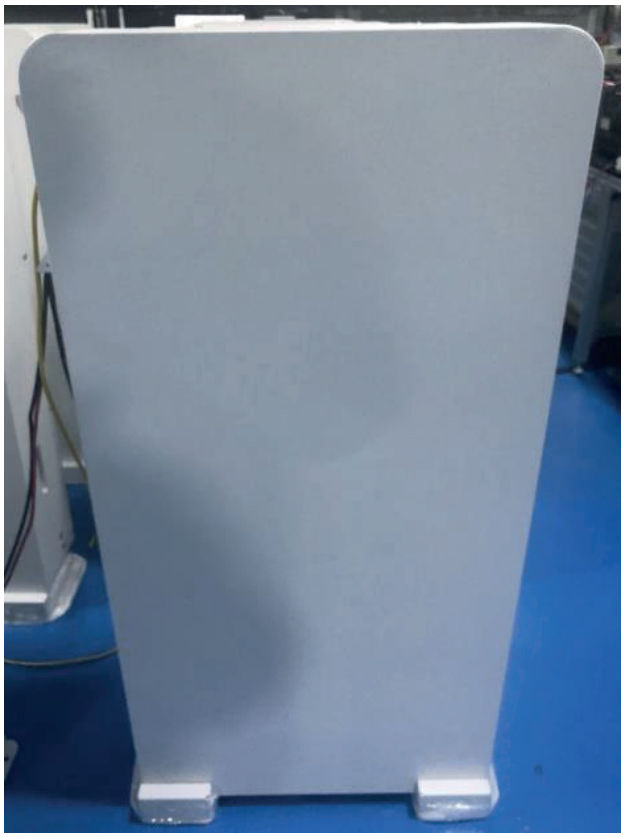



Model: Soluna 10K Pack HV (L-E)




Model: Soluna 6K Pack HV (L-E)

**Photo of the unit**

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| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| **5** | **Construtions – General** | | |
| **5.1** | **Cell** | | -- |
| 5.1.1 | The cell info associated with the BESS includes: | | P |
| | • cell chemistry (e.g. NMC, LFP); | LFP | P |
| | • the physical format of the cell; | Cylindrical | P |
| | • the cell electrical rating in capacity and nominal voltage; | 20 Ah, 3.2Vdc | P |
| | • the overall dimensions of the cell, and weight. | | P |
| 5.1.2 | The cells associated with the BESS comply with ANSI/CAN/UL 1973 or not. | | |
| 5.1.3 | Further details included in the cell level test report. | | P |
| **5.2** | **Module** | | -- |
| 5.2.1 | The modules info associated with the BESS includes: | | P |
| | • the generic enclosure material; | Metal | P |
| | • the general layout of the module contents; | | P |
| | • the electrical configuration of the cells in the modules and the modules in the BESS. | 2P12S | P |
| 5.2.2 | The modules associated with the BESS comply with UL 1973 or not. | Certified by Intertek, certificate no. xxxxx | P |
| 5.2.3 | Further details included in the module level test report. | | P |
| **5.3** | **Battery energy storage system unit** | | -- |
| 5.3.1 | The BESS unit info includes: | | -- |
| | • the units comply with UL 9540 or not; | | P |
| | • the manufacturer and model number; | See Unit information | P |
| | • electrical ratings; | See Unit information | P |
| | • energy capacity of all BESS. | See Unit information | P |
| 5.3.2 | For BESS units, which UL 9540 compliance cannot be determined, to include: | | -- |
| | • the number of modules in the BESS; | See Unit information | P |
| | • electrical configuration of the module; | See Unit information | P |
| | • physical layout of the modules in the BESS; | See Unit information | P |
| | • battery management system (BMS); and | See Unit information | P |
| | • other major components of the BESS; | See Unit information | P |
| | • the BESS enclosure overall dimensions and generic material; | See Unit information | P |
| | • battery system(s) may be tested as representative of the BESS; | See Unit information | P |
| | • battery system complies with UL 1973 or not. | See Unit information | P |
| 5.3.3 | Any fire detection and suppression systems that are an integral part of the BESS. | No integral fire detection and suppression system | N/A |
| 5.3.4 | Further details included in the unit level and if applicable, installation level test reports. | | N/A |
| **5.4** | **Flow Batteries** | | -- |
| 5.4.1 | For flow batteries, to include the following info: | | N/A |

| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| | • the chemistry; | Not flow battery | N/A |
| | • a generic description of the electrolyte (s); | Not flow battery | N/A |
| | • the overall dimensions of the individual stack; | Not flow battery | N/A |
| | • the electrical rating in capacity and nominal voltage of the cell stack. | Not flow battery | N/A |
| | And the Information of the complete flow battery system: | | N/A |
| | • the manufacturer's name and model number of the system; | Not flow battery | N/A |
| | • the electrical rating in volts and rated storage capacity in Ah or Wh; | Not flow battery | N/A |
| | • the number of cells and stacks in the system; | Not flow battery | N/A |
| | • the maximum volume of electrolyte(s) for the system. | Not flow battery | N/A |
| 5.4.2 | The flow battery system complies with UL 1973 or not. | Not flow battery | N/A |
| 5.4.3 | Further details included in the flow battery thermal runaway determination level test report. | Not flow battery | N/A |
| **6** | **Performance – General** | | |
| 6.1 | The tests in this standard are extreme abuse conditions conducted on electrochemical energy storage devices, which may result in various kind of hazards. | Considered | P |
| 6.2 | At the conclusion of testing, samples discharged in accordance with the manufacturer' specifications. | Considered | P |
| | All samples disposed of in accordance with local regulations. | Considered | P |
| **9** | **Unit Level** | | |
| **9.1** | **Sample and test configuration** | | **--** |
| 9.1.1 | The unit level test shall be conducted with BESS units installed as described in the manufacturer's instructions and this section. | Indoor wall mounted residential use BESS | P |
| 9.1.2 | The unit level test requires one initiating BESS unit and target adjacent BESS units representative of an installation. | An internal fire condition as in the module level test is initiated | P |
| | (modified by UL CRD-2020.10.21)<br>Tests conducted for indoor floor mounted installations for residential BESS may be considered representative of both indoor floor mounted and outdoor ground mounted installations. | Test configurations are shown in attachment 3 | P |
| | Exception: Testing can be conducted outdoors for outdoor only installations with controlled environment. | | N/A |
| 9.1.3 | Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), this testing to determine fire characterization can be done at the battery system level. | Determined based upon the overall design of the BESS and an analysis of the battery system | N/A |
| 9.1.4 | The initiating BESS unit shall contain components representative of a BESS unit in a complete installation. Combustible components that interconnect the initiating and target BESS units shall be included. | | P |
| 9.1.5 | Target BESS units shall include the outer cabinet, racking, module enclosures, and components that | | P |

| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| | retain cells components. The target BESS unit module enclosures do not need to contain cells. | | |
| 9.1.6 | The initiating BESS unit shall be at the maximum operating state of charge (MOSOC) for conducting the tests in this standard. After charging and prior to testing, the initiating BESS shall rest for a maximum period of 8 h at room ambient. | | P |
| 9.1.7 | If a BESS unit includes an integral fire suppression system, there is an option of providing this with the DUT. If the BESS unit is provided with an optional integral fire suppression system, the system shall not be provided on the DUT. | No integral fire supprsssion sysem | N/A |
| 9.1.8 | Electronics and software controls such as the battery management system (BMS) in the BESS are not relied upon for this testing. | BMS function disabled | P |
| | This does not include a fire suppression control in accordance with UL 840 that is external to the BESS but provided as part of an integral fire suppression system per 9.1.7 | No fire suppression control sysem | N/A |
| **9.2** | **Test method – Indoor floor mounted BESS units** | The information in this clause is for the test method- indoor wall mounted unit, see clause 9.4. | **--** |
| 9.2.1 | During the test, the test room environment shall be controlled to prevent drafts that may affect test results. | Ambient temperature 27°C | P |
| 9.2.2 | Any access door(s) or panels on the initiating BESS unit and adjacent target BESS units shall be closed, latched and locked. | | P |
| 9.2.3 | The initiating BESS unit shall be positioned adjacent to two instrumented wall sections. | see photo documentaion | P |
| 9.2.4 | Instrumented wall sections shall extend not less than 0.49 m(1.6 ft) horizontally beyond the exterior of the target BESS units. | See attachment 3 | P |
| 9.2.5 | Instrumented wall sections shall be at least 0.61 m(2 ft) taller than the BESS unit height, but not less than 3.66m(12 ft) in height above the bottom surface of the unit. | See attachment 3 | P |
| 9.2.6 | The surface of the instrumented wall sections shall be covered with 16-mm (5/8-in) gypsum wall board and painted flat black. | | P |
| 9.2.7 | The initiating BESS unit shall be centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter. | Sample was centered under the smoke collection hood, see photo documention | P |
| 9.2.8 | The light transmission in the calorimeter's exhaust duct shall be measured for the duration of the test, and the smoke release rate shall be calculated. | Using a white light source and photo detector | P |
| 9.2.9 | The chemical and convective heat release rates shall be measured for the duration of the test, respectively. | see 8.2.11 and 9.2.12 | P |
| 9.2.10 | The heat release rate measurement system shall be calibrated using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane. | Using an atomized heptane diffusion burner | P |
| 9.2.11 | The convective heat release rate shall be measured using a thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct. | see 9.2.12 | P |

| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| 9.2.12 | The convective heat release rate shall be calculated using the following equation: $HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$ | | P |
| 9.2.13 | The physical spacing between BESS units (both initiating and target) and adjacent walls shall be representative of the intended installation. | | P |
| 9.2.14 | Separation distances shall be specified by the manufacturer for distance between: | | P |
| | a) The BESS units and the instrumented wall sections; and | See attachment 3 | P |
| | b) Adjacent BESS units. | See attachment 3 | P |
| 9.2.15 | Wall surface temperature measurements shall be collected for BESS intended for installation in locations with combustible construction. | | P |
| | If the intended installation is composed completely of noncombustible construction in which wall assemblies, cables, wiring and any other combustible materials are not to be present in the BESS installation, then the report should note that the installation shall contain no combustible construction and that surface temperature rises can be deemed not applicable. | | N/A |
| 9.2.16 | Wall surface temperatures shall be measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections. | Using #24-gauge or smaller, Type-K exposed junction thermocouples | P |
| | The thermocouples for measuring the temperature on wall surfaces shall be horizontally positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit. | | P |
| 9.2.17 | Thermocouples shall be secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires. | | P |
| | The thermocouple tip shall be depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement and held in thermal contact with the surface at that point by the use of pressure-sensitive paper tape. | | P |
| 9.2.18 | (Modified by UL CRD-2022.01.04)<br>Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter or Gardon gauges at the surface of each instrumented wall: | | P |
| | a) Both are collinear with the vertical thermocouple array; | Cheesecloth used | N/A |
| | b) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and | Cheesecloth used | N/A |
| | c) One is positioned at the elevation estimated to receive the greatest heat flux during potential propagation of thermal runaway within the initiating BESS unit. | Cheesecloth used | N/A |
| 9.2.18.1 | (added by UL CRD-2021.03.26)<br>Heat flux measurements on walls may be waived for residential units that are tested with the cheesecloth indicator of 9.2.22. | Cheesecloth used. | P |

| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| 9.2.18.2 | (added by UL CRD-2021.03.26)<br>With reference to 9.2.18, if b) and c) are deemed to be at the same location, only one gauge may be installed on the wall for the measurement. | | N/A |
| 9.2.19 | Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit: | | P |
| | a) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating BESS; and | The cheesecloth used. | N/A |
| | b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating BESS. | The cheesecloth used. | N/A |
| 9.2.19.1 | (added by UL CRD-2021.03.26)<br>Heat flux measurements on target units may be waived for residential units that are tested with the cheesecloth indicator of 9.2.22. | The cheesecloth used. | P |
| 9.2.19.2 | (added by UL CRD-2021.03.26)<br>With reference to 9.2.19, if a) and b) are deemed to be at the same location, only one gauge may be installed on the target unit for the measurement. | | N/A |
| 9.2.20 | (modified by UL CRD-2022.01.04)<br>For non-residential use BESS, heat flux shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter or Gardon gauge positioned at the mid height of the initiating unit or the point where the majority of off-gas venting is expected from the initiating unit in the center of the accessible means of egress. | Tested as indoor wall mounted residential use BESS | N/A |
| 9.2.21 | Measure the temperature of: | #24-gauge, type-K exposed TC | P |
| | the surface proximate to the cells and between the cells and exposed face of the initiating module; | See temperature data attached | P |
| | Each non-initiating module enclosure within the initiating BESS unit; | | P |
| | convoluted enclosure interior geometries. | | P |
| 9.2.22 | For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator. | | P |
| 9.2.23 | An internal fire condition in accordance with the module level test shall be created within a single module in the initiating BESS unit: | | P |
| | a) The position of the module shall be selected to present the greatest thermal exposure to adjacent modules, based on the results from the module level test; and | | P |
| | b) The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module shall be the same as that used to initiate and propagate thermal runaway within the module level test (Section 8). | | P |
| 9.2.24 | The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct as in 8.2.10. | Via the testing system which has the sensors in the exhuast duct | P |

| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| | The hydrocarbon content of the vent gas shall be measured using flame ionization detection. | Integerated FID in the testing system used | P |
| | Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor. | Considered | P |
| 9.2.25 | (modified by UL CRD-20200110)<br>The hydrocarbon components of the vent gas composition may additionally be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 $cm^{-1}$ and a path length of at least 2 m, or an equivalent gas analyzer. | Considered | P |
| 9.2.26 | The test shall be terminated if: | | P |
| | a) Temperatures measured inside each module within the initiating BESS unit return to ambient temperature; | Considered | P |
| | b) The fire propagates to adjacent units or to adjacent walls; or | | N/A |
| | c) A condition hazardous to test staff or the test facility requires mitigation. | | N/A |
| 9.2.27 | For residential use systems, the gas collection data shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air. | The smallest volume of installation room: 35$m^3$<br>Gas concentration:0.56% (20 cells thermal runaway, refer to module level report, issued by Intertek Shanghai.<br>25%$LFL_{amb}$: 1.625% (refer to cell level report, issued by Intertek Shanghai) | P |
| **9.3** | **Test method – Outdoor ground mounted units** | | -- |
| 9.3.1 | Outdoor ground mounted non-residential use BESS being evaluated for installation in close proximity to buildings and structures. | The test method described in section 9.2 | N/A |
| | If intended for outdoor use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured. | | N/A |
| 9.3.2 | (modified by UL CRD-20220104)<br>Outdoor ground mounted residential use BESS being evaluated for installation in close proximity to buildings and structures shall use the test method described in Section 9.2 except as noted in 9.3.3 and | | N/A |
| | Heat flux measurements for the accessible means of egress. | | N/A |
| | If intended for outdoor use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured. | | N/A |
| 9.3.3 | Test samples shall be installed as shown in Figure 9.2 in proximity to an instrumented wall section. | | N/A |
| | The sample shall be mounted on a support substrate and spaced from the wall in accordance with the minimum separation distances specified by the manufacturer. | | N/A |

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|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| | Exception: If the manufacturer requires installation against non-flammable material, the test setup may include manufacturer recommended backing material between the unit and plywood wall. | | N/A |
| 9.3.4 | (modified by UL CRD-20220104)<br>Heat flux measurements for the accessible means of egress shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter or Gardon gauge positioned at the mid height of the initiating unit or the point where the majority of off-gas venting is expected from the initiating unit in the center of the accessible means of egress in accordance with 9.2.20. If intended for outdoor use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured.<br>*Exception: The heat flux measurement for the accessible means of egress was waived for outdoor ground mounted residential use BESS if the BESS was draped with cheesecloth in accordance with 9.4.7.* | | N/A |
| **9.4** | **Test Method – Indoor wall mounted units** | | N/A |
| 9.4.1 | Testing of indoor wall mounted BESS shall be in accordance with Section 9.2, except as modified in this section. | N/A | P |
| 9.4.2 | Conduct testing in a standard NFPA 286 fire test room (12 x 8 x 8-ft) high, with a 2-1/2 x 7-ft high opening. | N/A | N/A |
| 9.4.2.1 | (added by UL CRD-2020.10.21)<br>BESS intended for residential installations only may be tested using instrumented wall sections not less than 2.44m (8-ft) in height & width instead of the test room. | N/A | P |
| 9.4.3 | The initiating BESS unit shall be positioned on the wall opposite of the door opening, with the center located 4-ft above the floor, and halfway between adjacent walls. | N/A | P |
| 9.4.3.1 | (added by UL CRD-2020.10.21)<br>When residential BESS are tested in accordance with 9.4.2.1, the initiating BESS unit shall be positioned with the center located 1.22m (4-ft) above the floor, and halfway between adjacent walls. | N/A | P |
| 9.4.4 | Target BESS shall be installed on the wall on each side of the initiating BESS, at the same height above the floor as the initiating BESS. | N/A | P |
| 9.4.5 | The wall on which the initiating and target BESS units are mounted shall be instrumented. | N/A | P |
| 9.4.6 | For residential use systems, the gas collection data gathered in 9.2 shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air. | | N/A |
| 9.4.7 | For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator. | See equipmmnt list | N/A |
| 9.4.8 | (added by UL CRD-2020.10.21)<br>When testing BESS for residential only installations, the criteria in 9.2.9. 9.2.18 and 9.2.19 may be waived. | Considered. | N/A |
| **9.5** | **Test Method – Outdoor wall mounted units** | | **P** |

| ANSI/CAN/UL 9540A | | | |
|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| 9.5.1 | Testing of outdoor wall mounted BESS shall be in accordance with Section 9.2, except as modified in this section. | The results of indoor test in this report can also be applicable for an outdoor installation. | N/A |
| | If intended for outdoor use only wall mount installations, the smoke release rate, the convective and chemical heat release rate; and the content, velocity and temperature of the released vent gases need not be measured. | | N/A |
| 9.5.2 | Test samples shall be mounted on an instrumented wall (undersurface of the eave shown in Figure 9.4). | The results of indoor test in this report can also be applicable for an outdoor installation. | N/A |
| 9.5.3 | The initiating BESS unit shall be positioned on the instrumented wall, with its center located 4-ft above the floor, and halfway between wall edges. | The results of indoor test in this report can also be applicable for an outdoor installation. | N/A |
| 9.5.4 | Target BESS shall be installed on the wall on each side of the initiating BESS, at the same height above the floor as the initiating BESS and keep the min. separation distances specified by the manufacturer. | The results of indoor test in this report can also be applicable for an outdoor installation. | N/A |
| 9.5.5 | The wall on which the initiating and target BESS units are mounted shall be instrumented. | The results of indoor test in this report can also be applicable for an outdoor installation. | N/A |
| 9.5.6 | For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator. | The results of indoor test in this report can also be applicable for an outdoor installation. | N/A |
| **9.6** | **Rooftop and open garage installations** | | -- |
| 9.6.1 | Testing of BESS intended for non-residential use rooftop or open garage installations shall be in accordance with 9.2. | | N/A |
| 9.6.2 | If intended for rooftop and open garage use only installations, the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases need not be measured. | | N/A |
| **9.7** | **Unit level test report** | | -- |
| 9.7.1 | The report on the unit level testing shall identify the type of installation being tested, as follows: | | P |
| | a) Indoor floor mounted non-residential use BESS; | | N/A |
| | b) Indoor floor mounted residential use BESS; | | N/A |
| | c) Outdoor ground mounted non-residential use BESS; | | N/A |
| | d) Outdoor ground mounted residential use BESS; | | N/A |
| | e) Indoor wall mounted non-residential use BESS; | | N/A |
| | f) Indoor wall mounted residential use BESS; | | P |
| | g) Outdoor wall mounted non-residential use BESS; | | N/A |
| | h) Outdoor wall mounted residential use BESS; | | P |
| | i) Rooftop installed non-residential use BESS; or | | N/A |
| | j) Open garage installed non-residential use BESS. | | N/A |
| 9.7.2 | If testing is intended to represent more than one installation type, this shall be noted in the report. | See unit information | P |

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|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| 9.7.3 | The report shall include the following, as applicable: | | P |
| | a) Unit manufacturer name and model number (and whether UL 9540 compliant); | See unit information | P |
| | b) Number of modules in the initiating BESS unit; | See unit information | P |
| | c) The construction of the initiating BESS unit per 5.3; | See unit information | P |
| | d) Fire protection features/detection/suppression systems within unit; | See unit information | P |
| | e) Module voltage(s) corresponding to the tested SOC; | See module information | P |
| | f) The thermal runaway initiation method used; | See attachment 4 | P |
| | g) Location of the initiating module within the BESS unit; | See attachment 3 | P |
| | h) Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits; | See attachment 3 | P |
| | i) Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension; | See attachment 5 | P |
| | j) Chemical and convective heat release rate versus time data; | See attachment 8 and 9 | P |
| | k) Separation distances from the initiating BESS unit to target walls (A and C in Figure 9.1); | See attachment 3 | P |
| | l) Separation distances from the initiating BESS unit to target BESS units (D and H in Figure 9.1); | See attachment 3 | P |
| | m) The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple; | See attachment 6 | P |
| | n) The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple; | Instrumented wall used | N/A |
| | o) The maximum incident heat flux on target wall surfaces and target BESS units; | Cheesecloth used. | N/A |
| | p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test; | Cheesecloth used. | N/A |
| | q) Gas generation and composition data | See attachment 10 | P |
| | r) Peak smoke release rate and total smoke release data; | See attachment 11 | P |
| | s) Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred; | | N/A |
| | t) Observation of flying debris or explosive discharge of gases; | See attachment 5 | P |
| | u) Observation of re-ignition(s) from thermal runaway events; | See attachment 5 | P |
| | v) Observation(s) of sparks, electrical arcs, or other electrical events; | See attachment 5 | P |
| | w) Observations of the damage to: | See attachment 5 | P |
| | 1) The initiating BESS unit; | See attachment 5 | P |
| | 2) Target BESS units; | See attachment 5 | P |

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|---|---|---|---|
| Clause | Requirement – Test | Result - Remark | Verdict |
| | 3) Adjacent walls, ceilings, or soffits; and | See attachment 5 | P |
| | x) Photos and video of the test. | See video file 220702483SHA-001.mp4 | P |
| **9.8** | **Performance at unit level testing** | | P |
| 9.8.1 | Installation level testing in Section 10 is not required if the performance conditions outlined in Table 9.1 are met during the unit level test. | See table 9.1 | -- |

| Table 9.1 | Unit Level Performance Criteria | P |
|---|---|---|
| **1. Non-Residential Installations** | | **Result** |
| (1) Indoor Floor Mounted | a) Flaming outside the initiating BESS unit is not observed. | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | N/A |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | N/A |
| | e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m$^2$. | N/A |
| (2) Outdoor Ground Mouted | a) If flaming outside of the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test. | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation near exposures, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | N/A |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | N/A |
| | e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m$^2$. | N/A |
| (3) Indoor Wall Mounted | a) Flaming outside the initiating BESS unit is not observed; | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | N/A |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | N/A |
| | e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m$^2$. | N/A |
| (4) Outdoor Wall Mounted | a) Flaming outside the initiating BESS unit is not observed; | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation on walls with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | N/A |

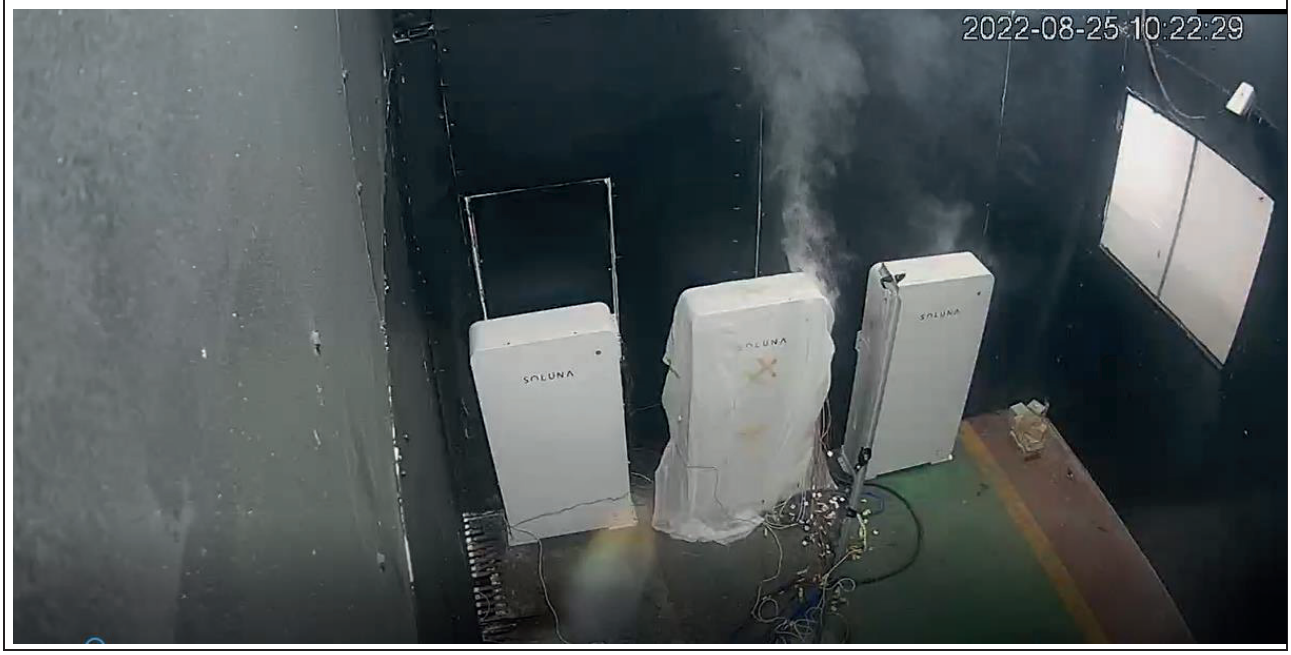
| | | |
|---|---|---|
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | N/A |
| | e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m$^2$. | N/A |
| (5) Rooftop and Open Garages | a) If flaming outside the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test; | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | N/A |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | N/A |
| | e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m$^2$. | N/A |
| **2. Residential Installations** | | **Result** |
| (1) Indoor Floor Mounted | a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator. | P |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | P |
| | c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | P |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | P |
| | e) The concentration of flammable gas does not exceed 25% LFL in air for the smallest specified room installation size. | P |
| (2) Outdoor Ground Mounted | a) If flaming outside the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test.<br>If tested with cheesecloth draped on the unit per the exception to 9.3.2, flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator;<br>(modified by UL CRD-20220104) | P |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | P |
| | c) For BESS units intended for near exposures, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | P |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | P |

| | | |
|---|---|---|
| | e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m$^2$.<br>If tested with cheesecloth draped on the unit per the exception to 9.3.2, this measurement is waived;<br>(modified by UL CRD-20220104) | P |
| (3) Indoor Wall Mounted | a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator; | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; | N/A |
| | d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and | N/A |
| | e) The concentration of flammable gas does not exceed 25% LFL for the smallest intended room installation size. | N/A |
| (4) Outdoor Wall Mounted | a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator; | N/A |
| | b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; | N/A |
| | c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15; and | N/A |
| | d) Explosion hazards are not observed, including deflagration, detonation, or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases. | N/A |
| Note(s):<br>*) No deflagration observed during test. Further evaluation of the potential deflagration by vented gas inside BESS enclosure may necessary. | | |

**Attachment 1 Photos**

All units

Unit during test

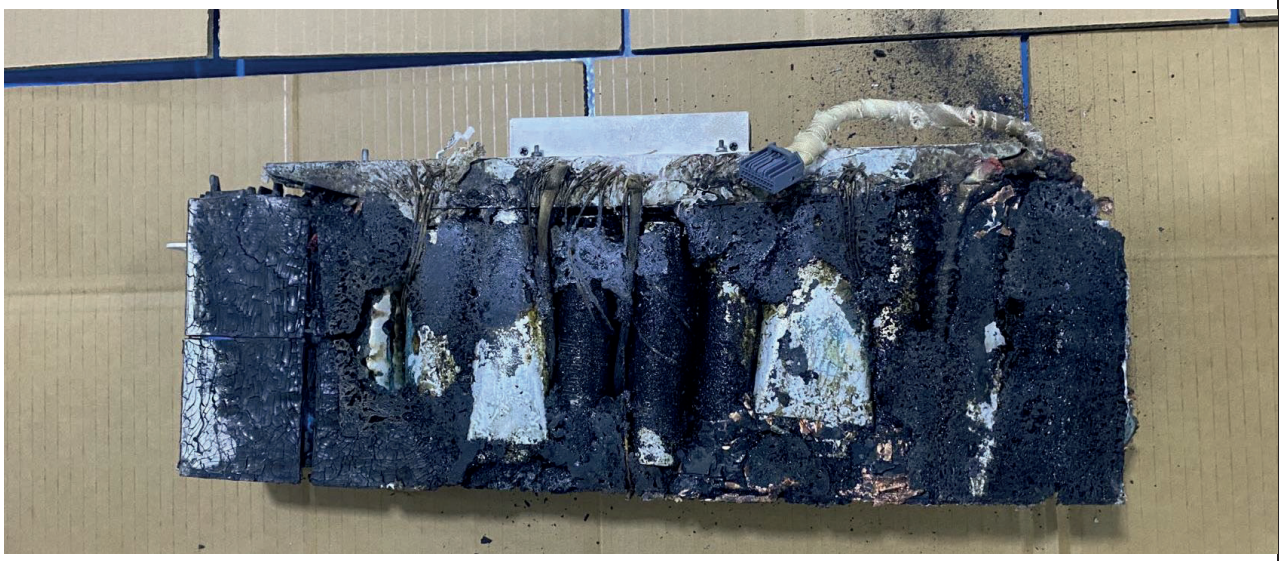



Unit after test


All units


Initiating unit

Initiating module after test



**Attachment 2 Sample preparation of the test**

The module was conditioned, prior to testing, through charge and discharge cycles for 2 cycles using a manufacturer specified methodology to verify that the module is functional.

As manufacturer specified, the initiating unit was charged with 15A current to end charge voltage 410V, then the unit was charged with 5A to end charge voltage 412V, then keep the unit stabilized for 60 minutes. After being stabilized, the unit was discharged with 25A current to module end discharge voltage 380V, then keep the unit stabilized for 60 minutes.

After repeat the cycle above twice and then unit was fully charged to end charge voltage 412V, and before testing, the module was stabilized for about 5 hours.During conditioning the ambient temperature was maintained at 25 ±5°C and 50 ±25% RH.

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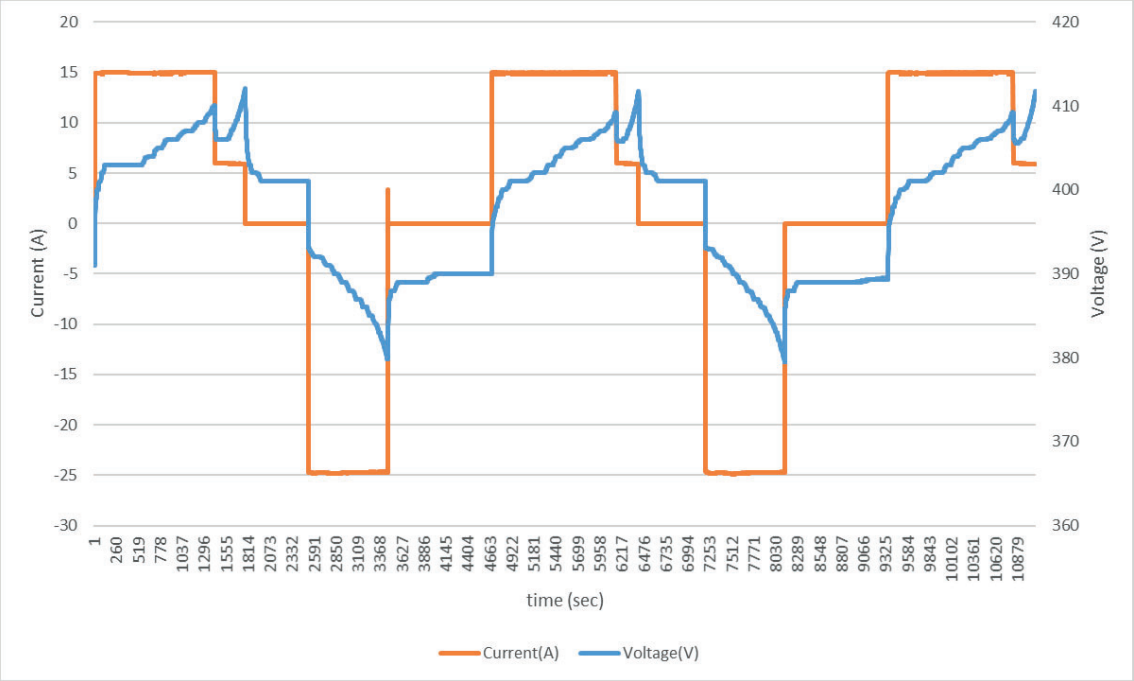



Charge and discharge voltage/current profiles

**Attachment 3 Arrangement of the unit**

The installation information was provided by the client as below.

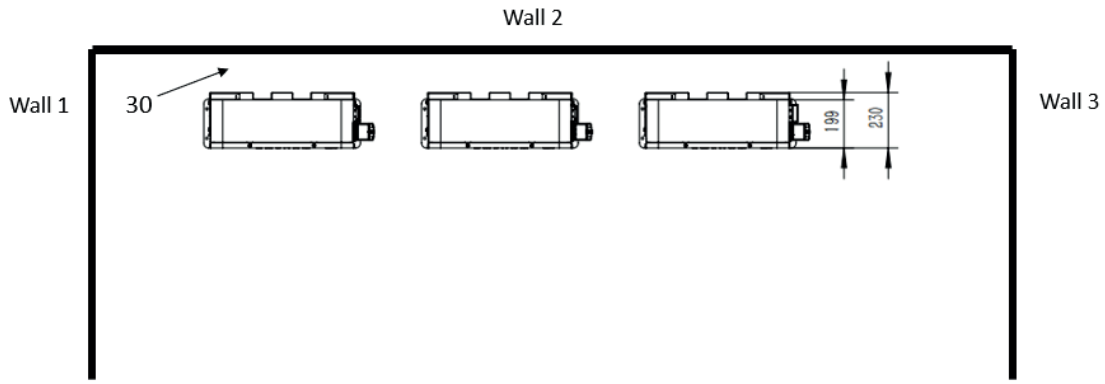
| | | |
|---|---|---|
| Intended use location .....: | ☒ Residential | ☐ Non-residential |
| | ☐ Non-residential rooftop | |
| | ☐ Non-residential open garage use | |
| Type of installation .....: | ☒ Indoor | ☒ Outdoor |
| | ☒ Floor/ground mounted | ☐ Wall mounted |
| Row(s) of installation | ☒ Single | ☐ Multiple |

The test was conducted on indoor, wall mounted unit.

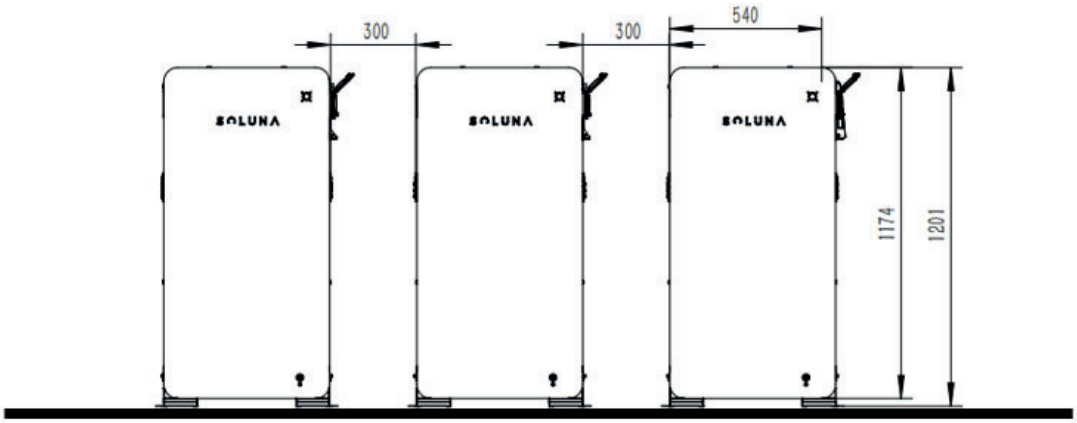
Three instrumented walls (wall1, wall2 and wall3) with 3.68 m height and 4.29m /3.3 m width form a right angle. Walls were constructed of 16 mm (5/8-inch) gypsum painted flat black.

Three BESSs were used for the purpose of the test. The BESSs arrangement is side to side. The middle column of the BESS is defined as initiating unit (unit B) with full cells. The initiating unit was positioned between the two instrumented walls. The adjacent unit A and unit C were defined as target unit. Minimum separation distance between units were provided by the client. The mounting bracket was close to the wall 2, distance 0cm.

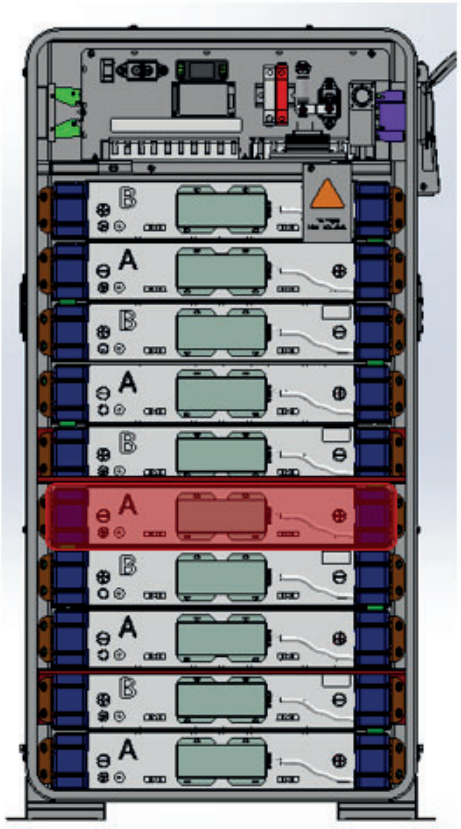
The view of the unit's arrangement is shown in figure below.




Top view of the unit's arrangement



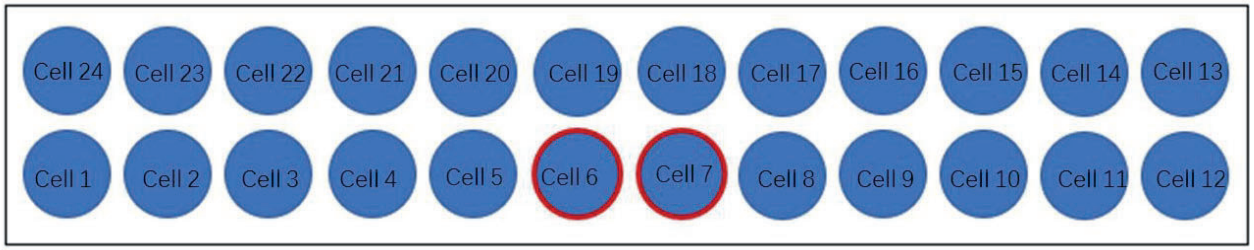

Front view of unit's arrangement




Layout of initiation module in initiation unit

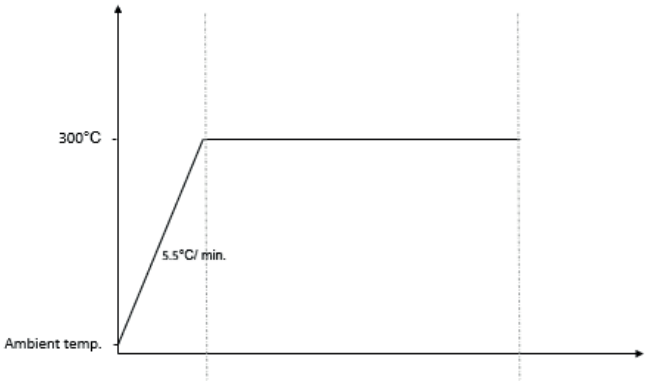
**Attachment 4 Thermal runaway preparation**

External heating method was used to initiate thermal runaway in the unit. 2 heaters were installed as below figure (red circuit).




Layout of heaters

A PID controller was used to control the voltage supply to the heater and maintain a 5.5°C/min heating rate. When thermal runaway occurred, the heater will de-energized immediately.



**Attachment 5 Observations and records**

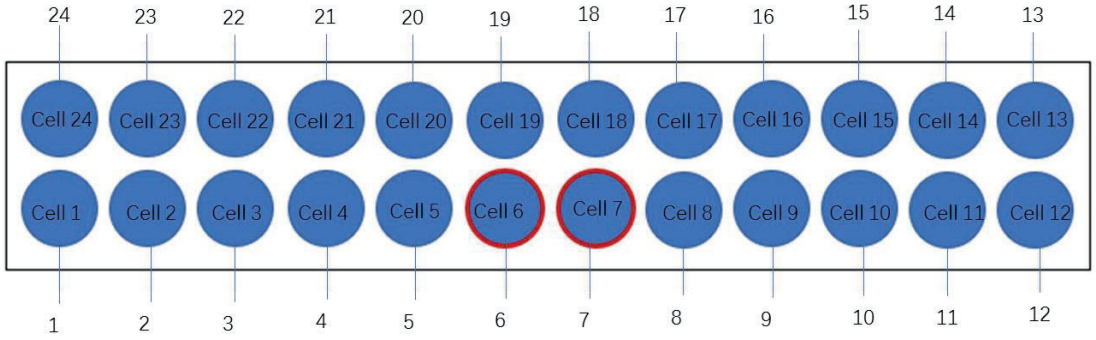
Cell 6 and cell 7 were heated as the target cell at a rate of 4°C-7°C per minute until thermal runaway was occurred.
Below table summarizes the details:

| | | | | |
|---|---|---|---|---|
| Ambient conditions at the initiation of the test: | 27°C 60%RH | | | |
| Module voltage before test: | 39.9 V | | | |
| Module voltage after test: | 4.9 V | | | |
| Time when test was initiated: | 9:46 | | | |
| Observations during test: | 1st vented | 10:17 | 1st thermal runaway | 10:22 |
| | 2nd vented | 10:17 | 2nd thermal runaway | 10:22 |
| | 3rd vented | 10:22 | 3rd thermal runaway | 10:23 |
| | 4th vented | 10:23 | 4th thermal runaway | 10:36 |
| | 5th vented | 10:28 | 5th thermal runaway | 10:38 |
| | 6th vented | 10:36 | 6th thermal runaway | 10:39 |
| | 7th vented | 10:38 | 7th thermal runaway | 10:45 |
| | 8th vented | 10:38 | 8th thermal runaway | 10:51 |
| | 9th vented | 10:39 | 9th thermal runaway | 11:01 |
| | 10th vented | 10:40 | 10th thermal runaway | 11:01 |
| | 11th vented | 10:45 | 11th thermal runaway | 11:05 |
| | 12th vented | 10:51 | 12th thermal runaway | 11:12 |
| | 13th vented | 10:58 | 13th thermal runaway | 11:15 |
| | 14th vented | 10:59 | 14th thermal runaway | 11:20 |
| | 15th vented | 11:05 | 15th thermal runaway | 11:20 |
| | 16th vented | 11:07 | 16th thermal runaway | 11:26 |
| | 17th vented | 11:08 | 17th thermal runaway | 11:30 |
| | 18th vented | 11:08 | 18th thermal runaway | 11:33 |
| | 19th vented | 11:35 | 19th thermal runaway | 11:47 |
| | 20th vented | 11:37 | 20th thermal runaway | 11:47 |
| | 21st vented | Not observed | 21st thermal runaway | Not observed |
| | No flying debris or explosive discharge of gases.<br>No sparks, electrical arcs, or other electrical events.<br>No external flaming was observed | | | |

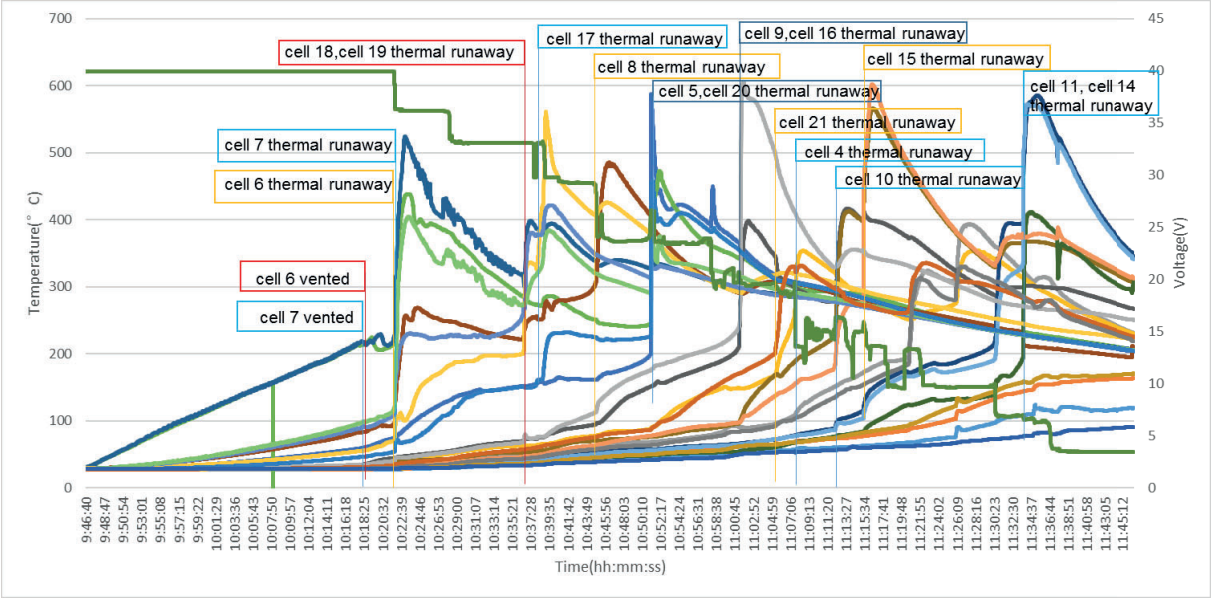
| | |
|---|---|
| Post-test evaluation: | No charring of the cheesecloth indicator<br><br>Surface temperatures of target BESS adjacent to the initiating BESS did not exceed the temperature at which thermally initiated cell venting occurs<br><br>BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces did not exceed 97K<br><br>In initiating unit, no thermal runaway propagation from initiating module to rest modules in initiating unit.<br><br>No damage on instrumental walls.<br><br>No damage on target units.<br><br>In initiating module, Cell 6 and cell 7 went to thermal runaway due to external heating.<br><br>Cell 3 to Cell 5, Cell 8 to Cell 22 went to thermal runaway due to thermal runaway propagation. |

**Attachment 6 Temperature measurements**

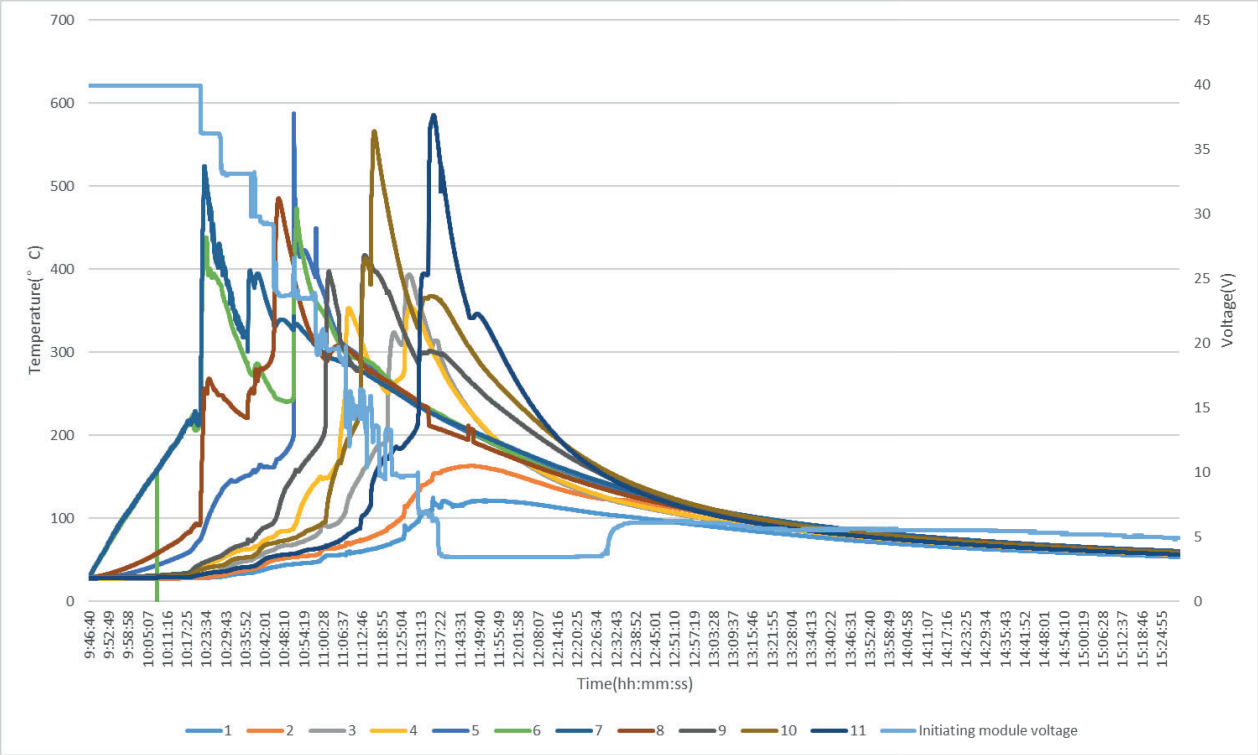
To monitor the cells temperature inside the initiating module, 24 thermocouples, Type K, were attached on the centre of cell surface inside the module. See below figure and table for detail location of thermocouples (No. 1 to No.24).




Temperature describing cell to cell propagation and module voltage are show in below figure



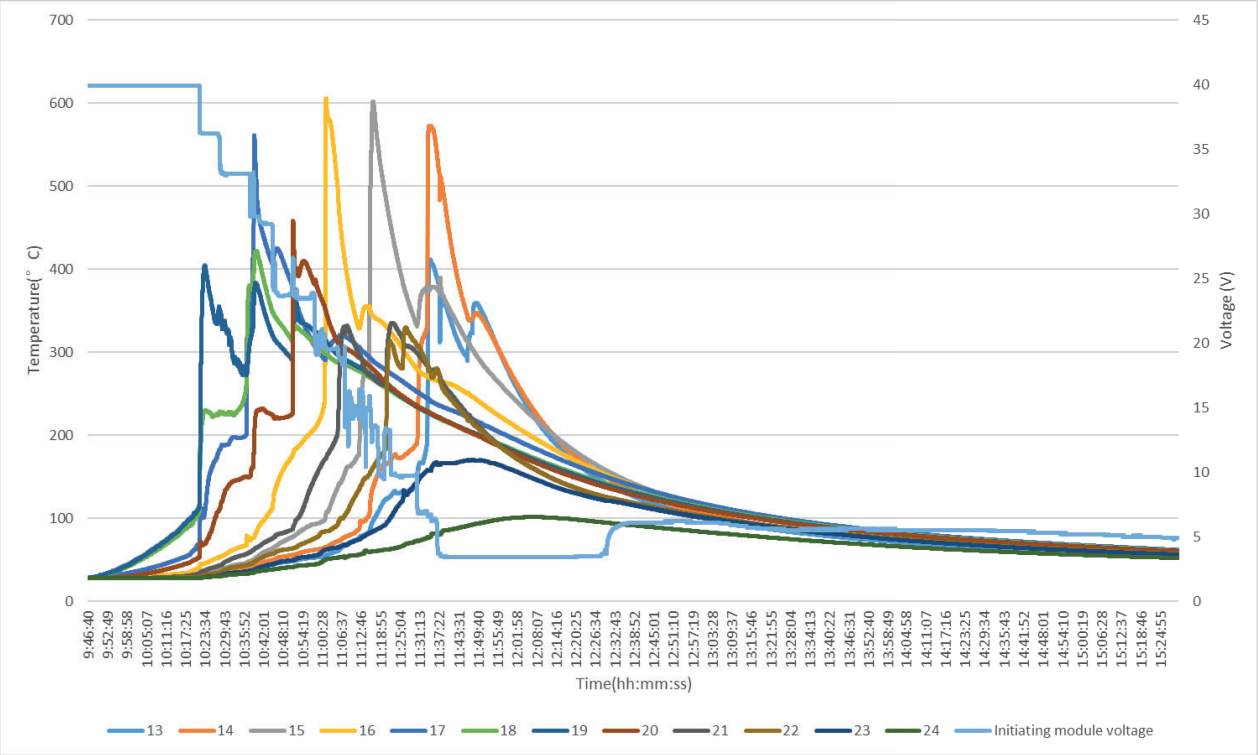
The measured temperature of cell 1 to cell 12 in the initiating module during the test are shown in below figure. Thermocouple No.12 was damaged during the test and hence not shown in below figure.




Maximum measured temperature of each location is shown in below table

| Thermocouple No. | Location | Max. measured temperature (°C) |
|---|---|---|
| 1 | Middle of longitudinal axis of cell 1, face module bottom | 124.4 |
| 2 | Middle of longitudinal axis of cell 2, face module bottom | 163.7 |
| 3 | Middle of longitudinal axis of cell 3, face module bottom | 393.8 |
| 4 | Middle of longitudinal axis of cell 4, face module bottom | 355.5 |
| 5 | Middle of longitudinal axis of cell 5, face module bottom | 587.5 |
| 6 | Middle of longitudinal axis of cell 6, face module bottom | 473.0 |
| 7 | Middle of longitudinal axis of cell 7, face module bottom | 523.8 |
| 8 | Middle of longitudinal axis of cell 8, face module bottom | 485.3 |
| 9 | Middle of longitudinal axis of cell 9, face module bottom | 416.6 |
| 10 | Middle of longitudinal axis of cell 10, face module bottom | 566.1 |
| 11 | Middle of longitudinal axis of cell 11, face module bottom | 585.4 |
| 12 | Middle of longitudinal axis of cell 12, face module bottom | N/A (damaged) |

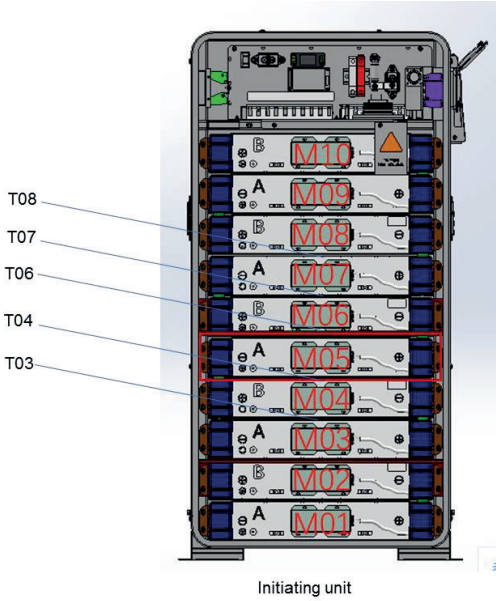
The measured temperature of cell 13 to cell 24 in the initiating module during the test are shown in below figure.



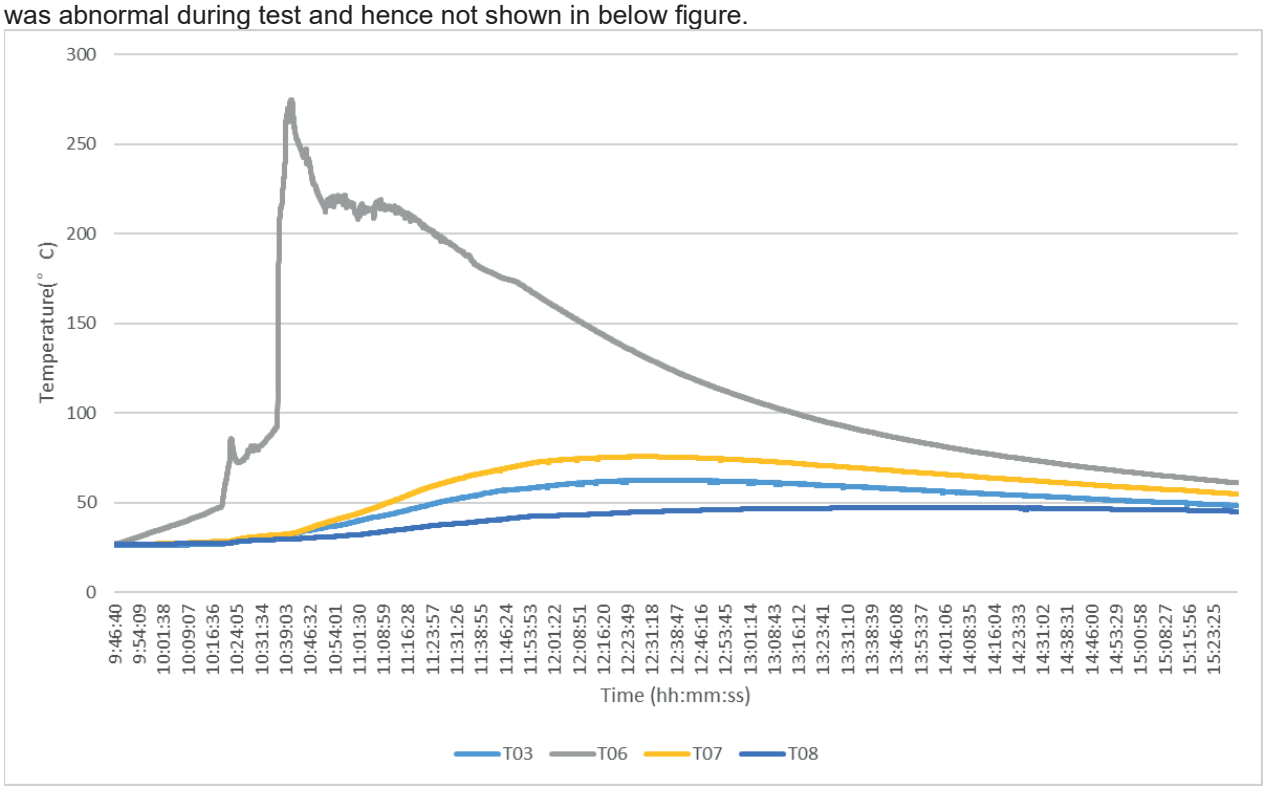

Maximum measured temperature of each location is shown in below table

| Thermocouple No. | Location | Max. measured temperature (°C) |
|---|---|---|
| 13 | Middle of longitudinal axis of cell 13, face module top | 412.0 |
| 14 | Middle of longitudinal axis of cell 14, face module top | 572.7 |
| 15 | Middle of longitudinal axis of cell 15, face module top | 602.2 |
| 16 | Middle of longitudinal axis of cell 16, face module top | 605.6 |
| 17 | Middle of longitudinal axis of cell 17, face module top | 561.3 |
| 18 | Middle of longitudinal axis of cell 18, face module top | 421.5 |
| 19 | Middle of longitudinal axis of cell 19, face module top | 412.1 |
| 20 | Middle of longitudinal axis of cell 20, face module top | 458.4 |
| 21 | Middle of longitudinal axis of cell 21, face module top | 335.5 |
| 22 | Middle of longitudinal axis of cell 22, face module top | 330.2 |
| 23 | Middle of longitudinal axis of cell 23, face module top | 170.6 |
| 24 | Middle of longitudinal axis of cell 24, face module top | 101.4 |

To monitor the internal temperature of initiating unit, 5 thermocouples were attached on the surface of modules as below figure.



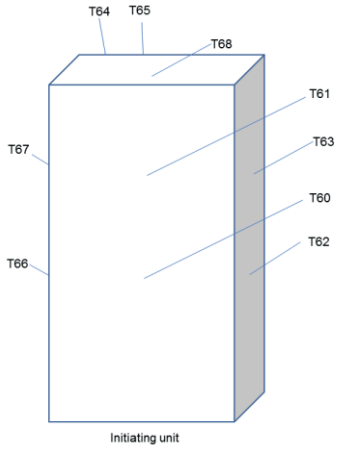

The measured temperature in the initiating unit during the test are shown in below figure. Thermocouple T04 was abnormal during test and hence not shown in below figure.



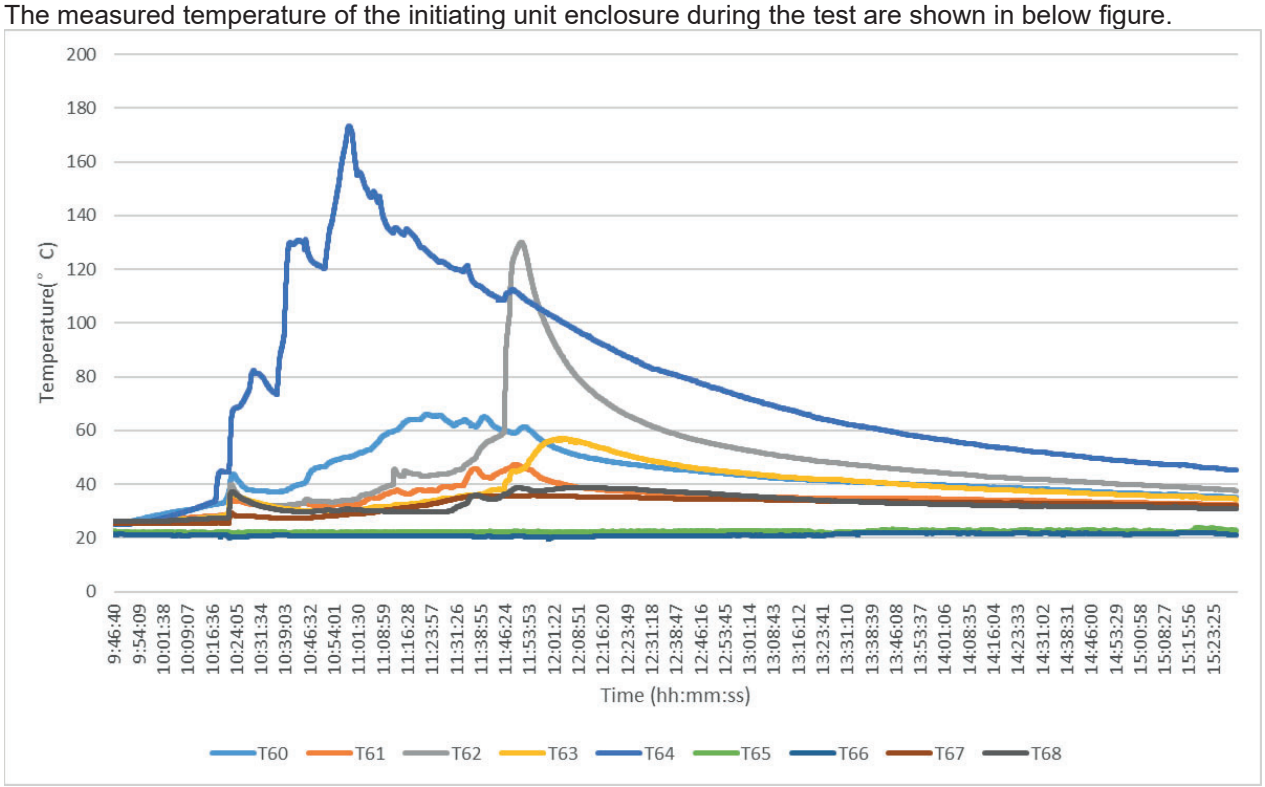
Maximum measured temperature of each location is shown in below table

| Thermocouple No. | Location | Max. measured temperature (°C) |
|---|---|---|
| T03 | Center of upper side of model M03 | 62.5 |
| T04 | Center of upper side of model M04 | N/A (abnormal) |
| T06 | Center of bottom side of model M06 | 275 |
| T07 | Center of bottom side of model M07 | 75.7 |
| T08 | Center of bottom side of model M08 | 47.1 |

To monitor the temperature of initiating unit enclosure, 9 thermocouples (T60-T68) were attached on the surface of initiating unit as below figure.



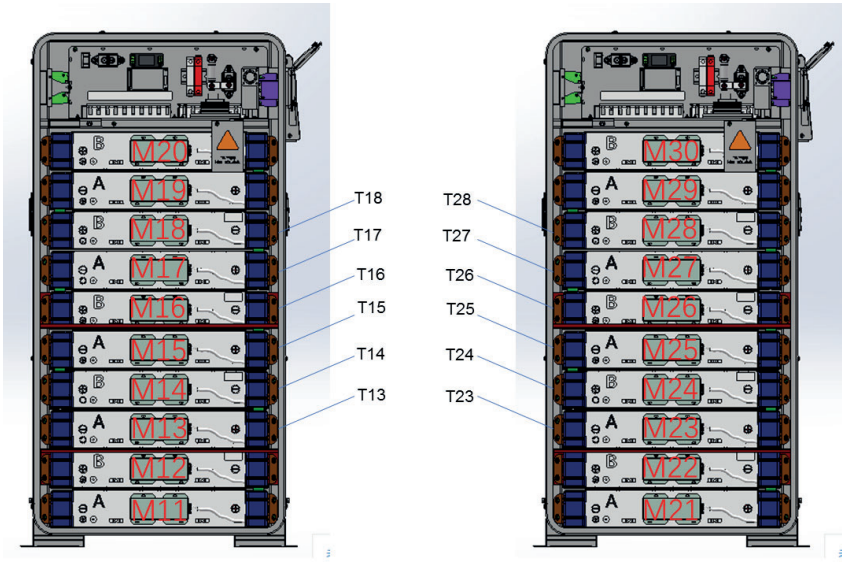

The measured temperature of the initiating unit enclosure during the test are shown in below figure.



Maximum measured temperature of each location is shown in below table

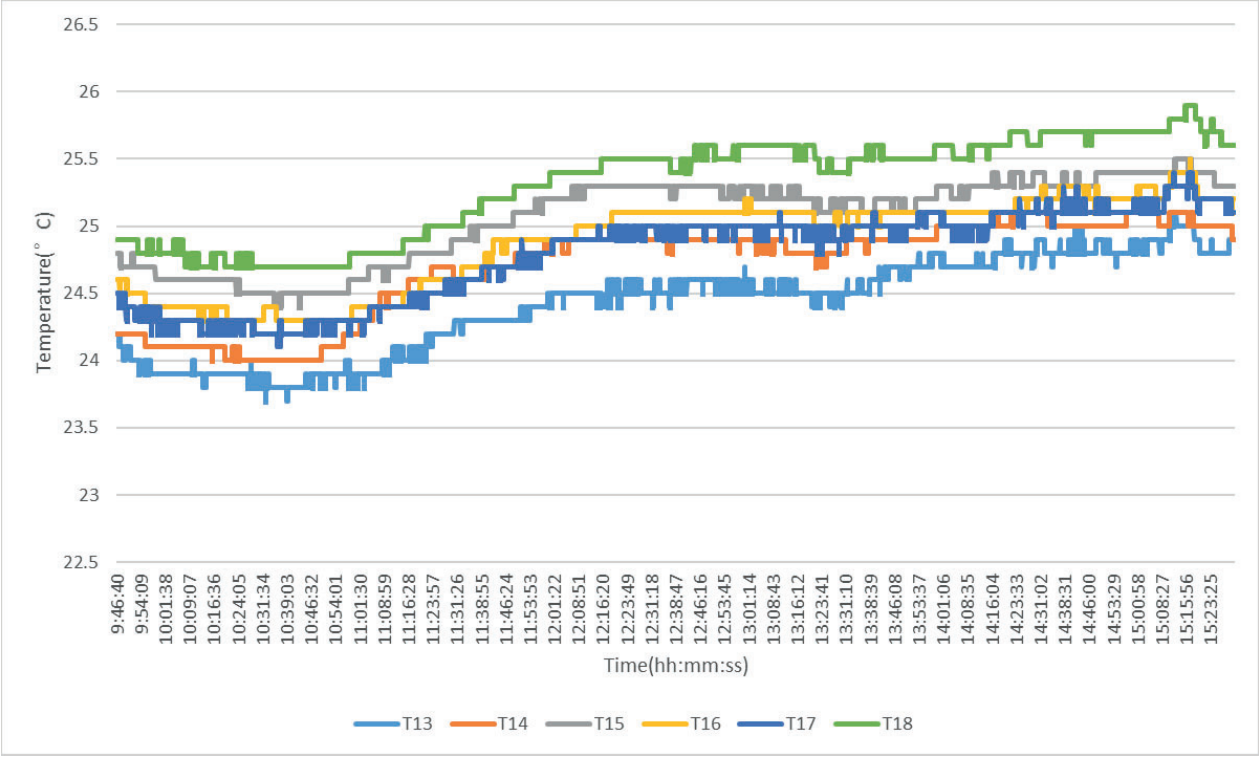
| Thermocouple No. | Location | Max. measured temperature (°C) |
|---|---|---|
| T60 | Centre line of front surface, height equal to module M5 top surface | 66.0 |
| T61 | Centre line of front surface, height equal to module M8 top surface | 47.4 |
| T62 | Centre line of right surface, height equal to module M5 top surface | 130.0 |
| T63 | Centre line of right surface, height equal to module M8 top surface | 56.9 |
| T64 | Centre line of rear surface, height equal to module M5 top surface | 173.3 |
| T65 | Centre line of rear surface, height equal to module M8 top surface | 23.8 |
| T66 | Centre line of left surface, height equal to module M5 top surface | 22.1 |
| T67 | Centre line of left surface, height equal to module M8 top surface | 35.8 |
| T68 | Centre of top surface | 38.8 |

To monitor the temperature of adjacent target unit 1 and unit 2, thermocouples (T13-T18) were attached on the side surface of modules inside the target unit1 which toward the initiating unit and thermocouples (T23-T28) were attached on the side surface of modules inside the target unit 2 which toward the initiating unit




Target unit 1 Target unit 2

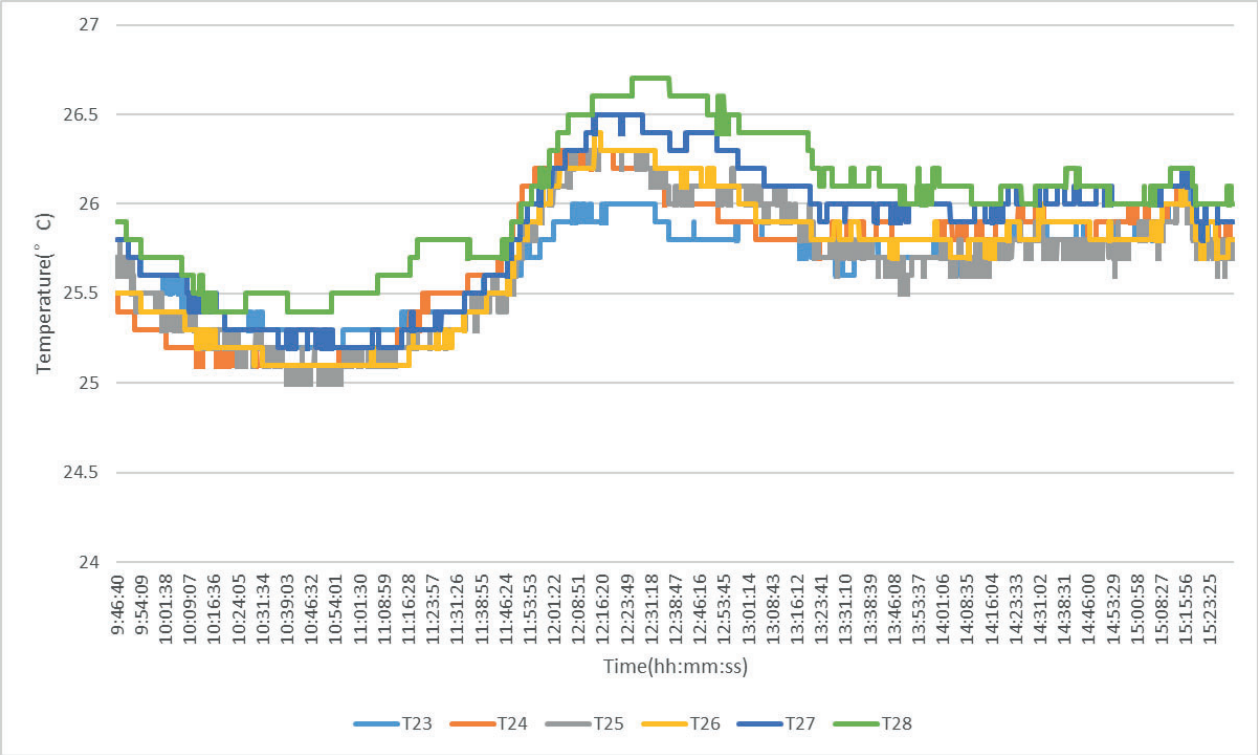
The measured temperature in the target unit 1 during the test are shown in below figure.



Maximum measured temperature of each location is shown in below table

| Thermocouple No. | Location | Max. measured temperature (°C) |
|---|---|---|
| T13 | Center of right surface of model M13 | 25.1 |
| T14 | Center of right surface of model M14 | 25.1 |
| T15 | Center of right surface of model M15 | 25.5 |
| T16 | Center of right surface of model M16 | 25.5 |
| T17 | Center of right surface of model M17 | 25.4 |
| T18 | Center of right surface of model M18 | 25.9 |

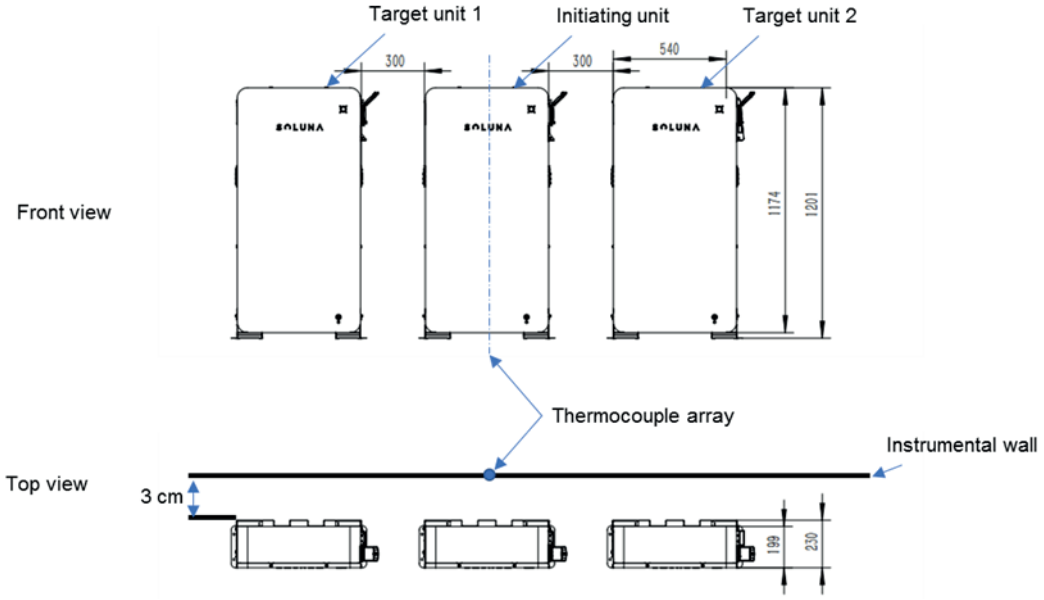
The measured temperature in the target unit 2 during the test are shown in below figure.



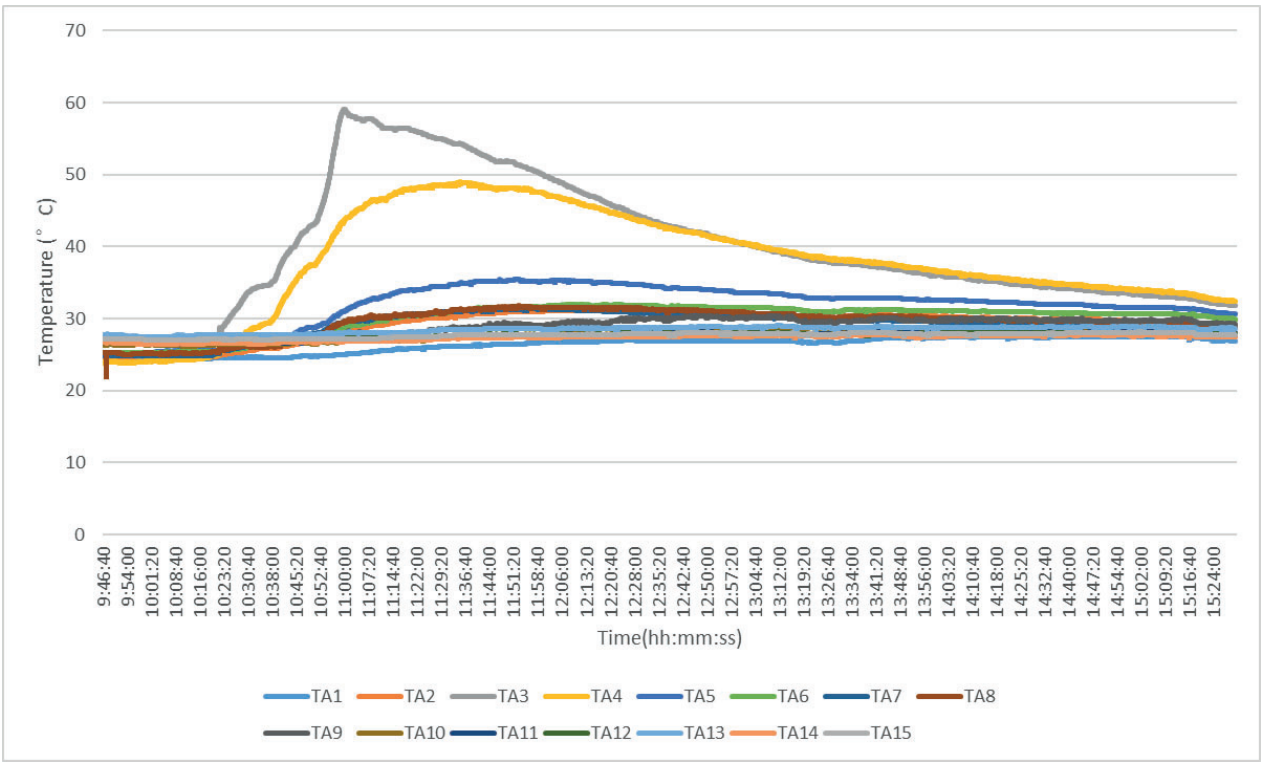

Maximum measured temperature of each location is shown in below table

| Thermocouple No. | Location | Max. measured temperature (°C) |
|---|---|---|
| T23 | Center of left surface of model M23 | 26.1 |
| T24 | Center of left surface of model M24 | 26.3 |
| T25 | Center of left surface of model M25 | 26.3 |
| T26 | Center of left surface of model M26 | 26.4 |
| T27 | Center of left surface of model M27 | 26.5 |
| T28 | Center of left surface of model M28 | 26.7 |

To monitor instrumental wall surface temperatures, the instrumental wall was measured in vertical array at 152 mm intervals for the full height of the instrumented wall sections using Type K, 30 AWG thermocouples. The detail location of the thermocouples was shown in figure below




The first thermocouple starts from 152 mm from ground. Total 15 thermocouples were used for each array. The thermocouples were numbered from low to high as TA1 to TA15.
The measured surface temperature of instrumental wall A during test is shown in below figure.



Maximum measured temperature of each location is shown in below table

| Thermocouple No. | Max. measured temperature (°C) | Thermocouple No. | Max. measured temperature (°C) |
|---|---|---|---|
| TA1 | 27.5 | TA9 | 30.4 |
| TA2 | 31.2 | TA10 | 28.6 |
| TA3 | 59.0 | TA11 | 28.3 |
| TA4 | 49.0 | TA12 | 28.2 |
| TA5 | 35.4 | TA13 | 29.0 |
| TA6 | 31.9 | TA14 | 27.8 |
| TA7 | 31.4 | TA15 | 28.2 |
| TA8 | 31.8 | | |

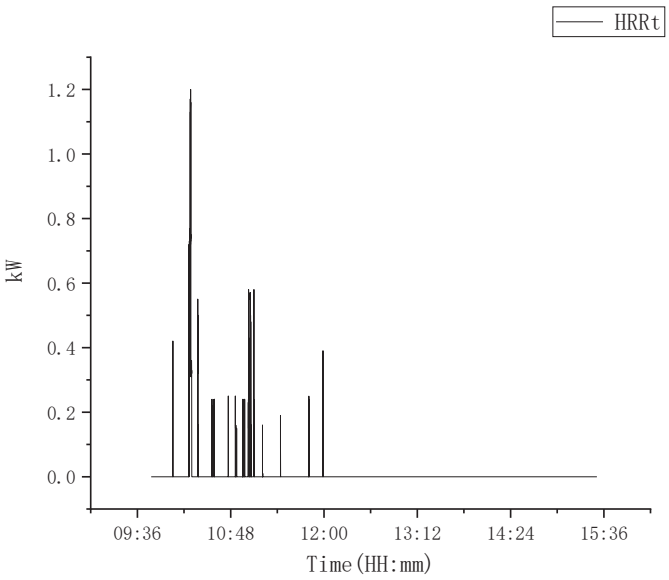
**Attachment 7 Heat flux measurements**

N/A

**Attachment 8 Chemical heat release rate measurement**

The chemical heat release rate was measured by a measurement system consisting of a paramagnetic oxygen analyser, non-dispersive infrared carbon dioxide and carbon monoxide analyser, velocity probe, and a Type K thermocouple. The instrumentation was located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influence of bends or exhaust devices.

Measured peak chemical heat release rate HRR: 1.2 kW




HRR Curve

**Attachment 9 Convective heat release rate measurement**

The convective heat release rate were measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.
The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

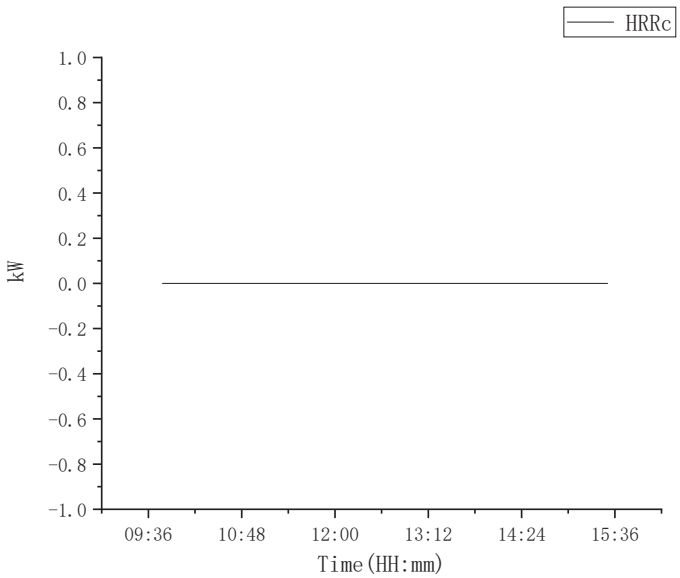
Where:

$HRR_c$ = The convective heat release rate (kW)
$V_e$ = The exhaust velocity (m/s)
$A$ = The exhaust duct cross sectional area ($m^2$)
$T_e$ = The temperature at the location where exhaust velocity is measured (K)
$353.22/T_e$ = The density of air at the velocity measurement location (kg/m3)
$T_o$ = The ambient temperature (K) in the test room
$T$= The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

$Cp$ = Specific heat of air (kJ/kg-K), given as $Cp = A0 + A1T + A2T2 + A3T3$, where:
$A0 = 0.9950$
$A1 = -5.29933E-05$
$A2 = 3.21022E-07$
$A3 = -1.22004E-10$

The measured peak convective heat release rate HRRc was 0 KW




HRRc curve

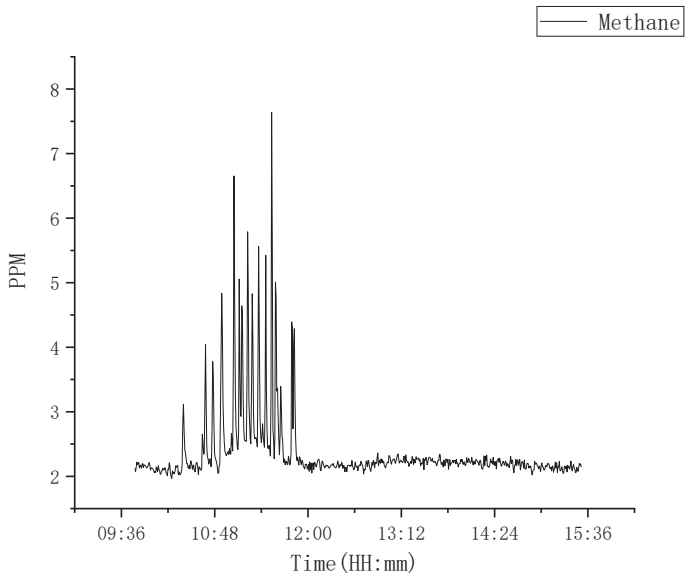
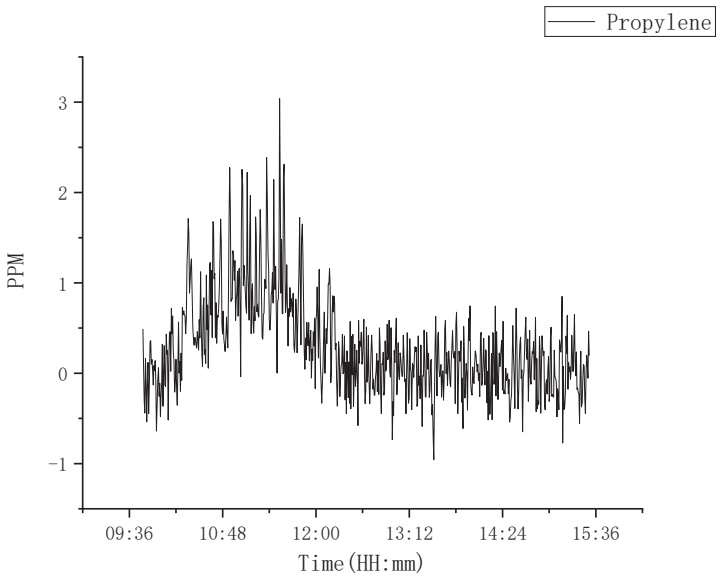
**Attachment 10 Gas generation measurement**

Vent gas composition were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 0.5 $cm^{-1}$ and a path length of 5.11 m within the calorimeter's exhaust duct. And the composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

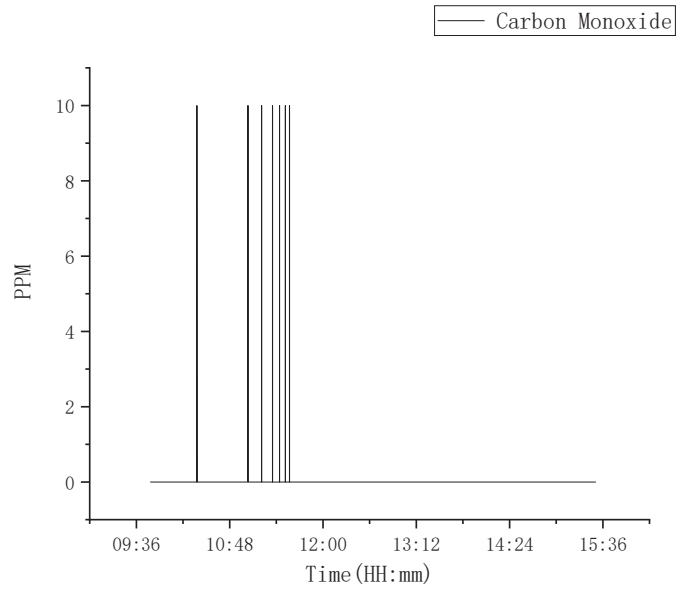
The hydrocarbon content of the vent gas was measured using flame ionization detection.
The hydrogen content was measured with a palladium-nickel thin-film solid state sensor and electrochemistry sensor. The hydrogen was not detected by the palladium-nickel thin-film solid state sensor, the value in below table was measured by electrochemistry sensor.

| Gas type | Gas components | | Volume of gas (L) |
|---|---|---|---|
| Hydrocarbon species | Methane | $CH_4$ | 6.5 |
| | Propylene | $C_3H_6$ | 9.5 |
| Others | Carbon Monoxide | CO | 1.2 |
| | Carbon Dioxide | $CO_2$ | 125.4 |
| | Hydrogen (detected by palladium-nickel thin-film solid state sensor) | $H_2$ | 116.2 |
| | Hydrogen (detected by electrochemistry sensor) * | $H_2$ | 0 |
| Total Hydrocarbons（equivalent to $C_3H_8$, measured by FID) | | | 28.5 |
| *) the measurement result of hydrogen detected by electrochemistry sensor was for reference only. | | | |

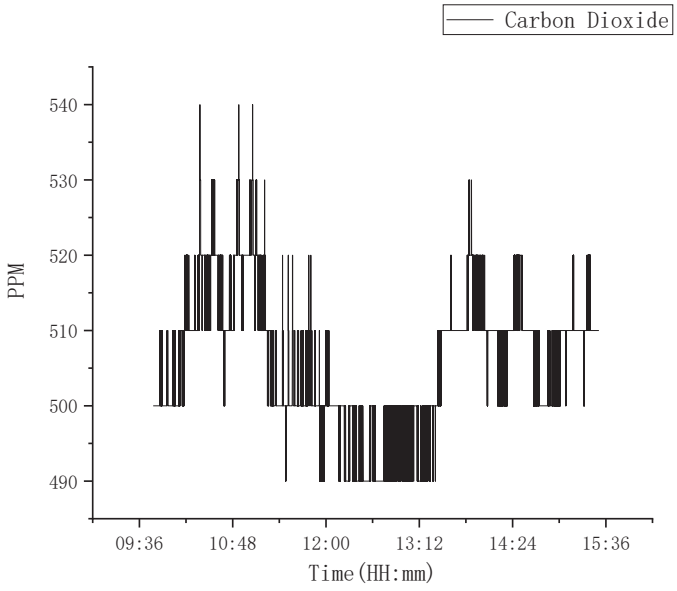
Concentration of different gas components according to gas species classification was displayed as following graphs:

| Hydrocarbon species |
| --- |
|  |
| Concentration of $CH_4$ |
|  |
| Concentration of $C_3H_6$ |

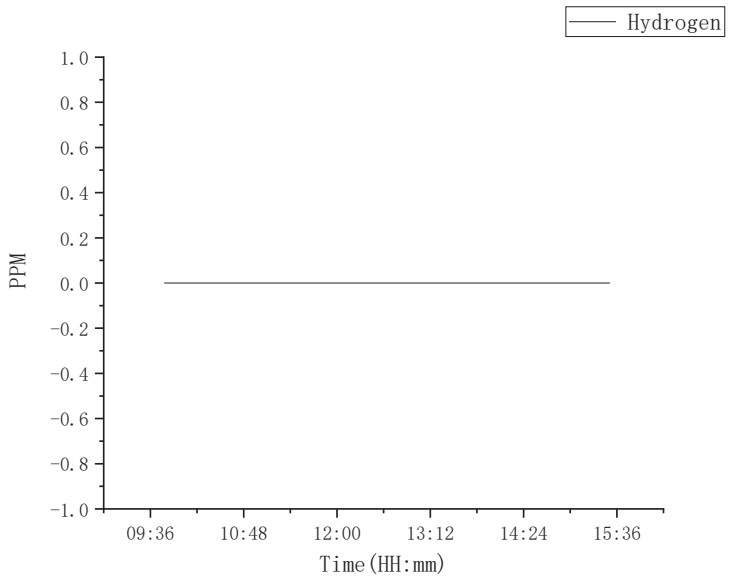
Other species



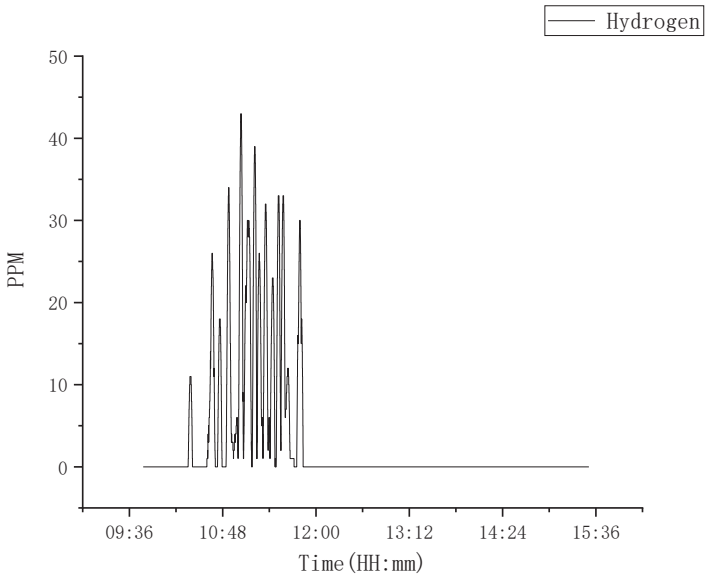

Concentration of CO




Concentration of $CO_2$

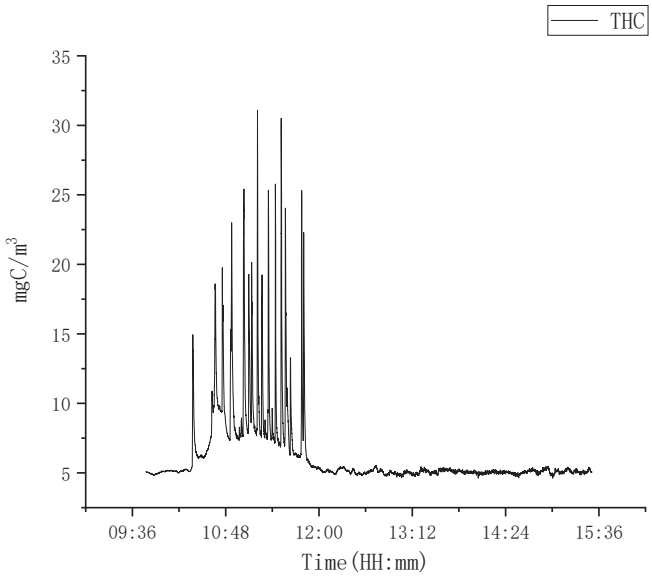



Concentration of $H_2$ (detected by palladium-nickel thin-film solid state sensor)




Concentration of $H_2$ (detected by electrochemistry sensor)

Total Hydrocarbons (measured by FID)




Concentration of total hydrocarbons (measured by FID)

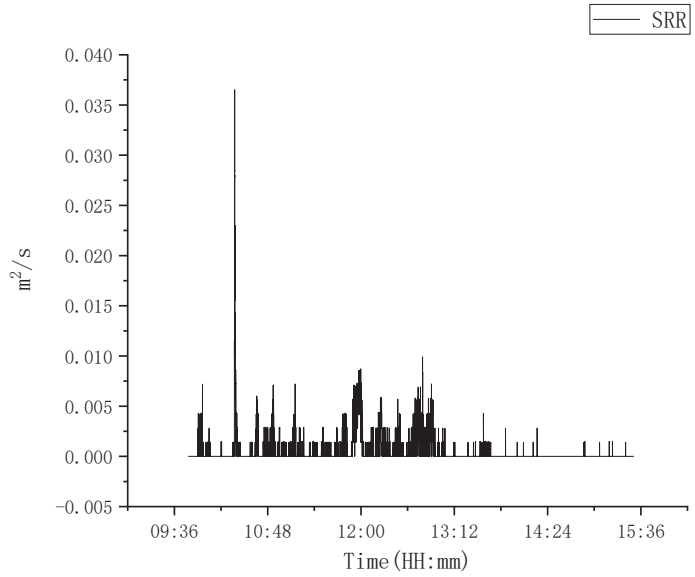
**Attachment 11 Smoke release rate measurement**

Smoke release rate shall be calculated as follows:

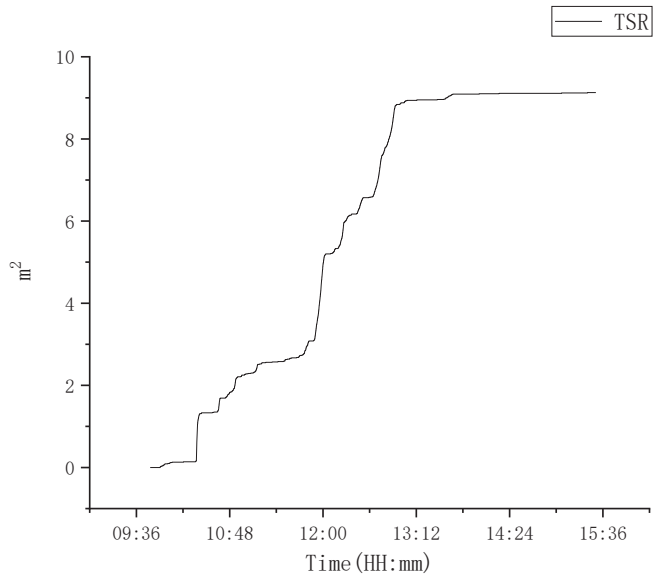
$$SRR = 2.303\left(\frac{V}{D}\right) Log_{10}\left(\frac{I_o}{I}\right)$$

Where:
SRR = Smoke release rate ($m^2/s$)
V = Volumetric exhaust duct flow rate ($m^3/s$).
D = duct diameter (m).
Io = Light transmission signal of clear (pre-test) beam (V)
I = Light transmission signal during test (V)

Peak smoke release rate SRR: 0.0365 $m^2/s$
Total smoke release rate TSR: 9.13 $m^2$




SRR curve




TSR curve

**Attachment 12 Equipment list**

| No. | Equipment | | Model | Rating | Inventory no. | Last Cal. date |
|---|---|---|---|---|---|---|
| 1 | Ambient monitor | | WSB-2-H1 | 0-40°C，10-90%RH | S-044 | 2022.04.25 |
| 2 | Data acquisition equipment | | ADAM-4117<br>ADAM-4118<br>MT4W | 0-10V<br>0-1000°C<br>0-100V | S-060-1<br>S-060-2<br>S-060-(4-7) | 2022.08.09<br>2022.08.09<br>2022.08.09 |
| 3 | Digital multi-meter | | FLUKE101 | 0-600V | S-038 | 2022.04.02 |
| 4 | Tape | | 1000mm<br>5000mm | 0-1000mm<br>0-5000mm | S-040<br>S-042 | 2022.04.22 |
| 5 | Electronic scale | | TCS-500 | 0-500kg | S-039 | 2022.04.19 |
| 6 | Oxygen consumption calorimeter measurement system | Paramagnetic oxygen analyzer | SERVOMEX MultiExact 4100 | $O_2$：0-21%<br>CO2:0-10%<br>CO:0-1% | S-024 | 2022.01.12 |
| | | CO and CO2 sensor | | | | |
| | | Velocity probe | WIKA | 0~0.4MPa | S-024-5 | 2022.01.12 |
| | | Thermopile | ANHUI ANKANG INSTRUMENT(GROUP) CO., LTD | 0~200°C | S-062-(1~3) | 2022.01.12 |
| | | Photo detector | DP101MD | -100~100Pa | S-062-4 | 2022.01.12 |
| | | Light filter | -- | 25%, 50%, 75% | S-024-6<br>S-024-7<br>S-024-8 | 2022.01.12 |
| 7 | Palladium-nickel thin-film solid state sensor | | H2scan 740B | 500ppm-100% | S-023-1 | 2022.01.13 |
| 7-1 | Electro-chemistry sensor | | H240000/H21000 | 0-4%/0-0.1% | S-023-2～3 | 2022.01.13 |
| 8 | Fourier-Transform Infrared Spectrometer | | MG6000 | 0.01ppm-100% | S-019 | 2022.01.12 |
| 9 | Flame Ionization Detector | | ABB AO2000 | 0-3000ppm | S-025 | 2022.01.13 |
| 10 | Thermopile | | OMEGA TT-K-24 | 0-260°C | S-026-(1-10) | 2022.04.23 |
| 11 | The cheesecloth | | -- | 26.9m2/kg with a count of 31 treads in either direction within a 6.45 $cm^2$ area | -- | 2022.08.15 |
| 12 | Battery charging/discharging system | | RCDS-100V300A | 100V 300A | S-045 | 2022.04.21 |

---------- End of test report ----------