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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..... :	240913052GZU-002
Tested by (name + signature) ..... :	5.1.2e Engineer
Approved by (name + signature) ..... :	5.1.2e Reviewer
Total number of pages..... :	58
Date of issue..... :	13 November 2024

5.1.2e

Testing Laboratory..... :	Intertek Testing Services Shenzhen Ltd. Zengcheng Branch
Address..... :	C2-1, Heping Xu, Yongning Street, Zengcheng District, Guangzhou, China
Testing location/ procedure ..... :	Lab test
Testing location/ address..... :	Intertek Testing Services Shenzhen Ltd. Zengcheng Branch C2-1, Heping Xu, Yongning Street, Zengcheng District, Guangzhou, China
Applicant's name ..... :	Shanghai SIGEN New Energy Technology Co., Ltd.
Address..... :	No.175 Weizhan Road, Lingang New Area, China (Shanghai) Pilot Free Trade Zone, 201304, Shanghai, P.R.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
Test Report Form(s) Originator ..... :	Intertek
Master TRF..... :	2022-01

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Test item description ..... :	Energy storage system
Trade Mark ..... :	Sigenergy
Manufacturer..... :	Shanghai SIGEN New Energy Technology Co., Ltd.
Model/Type reference..... :	1*Sigen Battery, 2*Sigen Battery, 3*Sigen Battery, 4*Sigen Battery, 5*Sigen Battery, 6*Sigen Battery
Ratings..... :	See Unit information for detail

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List of attachments:

Attachment 1 – Photos

Attachment 2 – Sample preparation

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

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 test-1.mp4 to test-8.mp4 were provided in addition to this test report.

Summary of testing:

Thermal Runaway Propagation.....	1 cell vented and thermal runaway due to thermal runaway propagation in the initiating module. No thermal runaway propagation from initiating module to other modules in initiating unit.
Maximum Target BESS Temperature (°C) .....:	30.0°C
Maximum Wall Surface Temperature (°C) .....:	42.2°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
Peak Chemical Heat Release Rate (kW) .....:	41.41kW
Peak Convective Heat Release Rate (kW) .....:	0kW
Peak Smoke Heat Release Rate (m^2/s) .....:	0.0768 m^2/s
Total Smoke Release (m^2) .....:	11.92m^2
Maximum Heat Flux on Egress Path (kW/m^2) .....:	0.031kW/m^2
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

Conclusion:

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

Installation level testing in Section 10 is not required because the performance conditions outlined in Table 9.1 are met during the unit level test.

Possible test case verdicts:

- test case does not apply to the test object.....: N/A
- test object was not evaluated for the requirement.....: N/A
- test object does meet the requirement..... : Pass (P)
- test object does not meet the requirement .....: Fail (F)

Testing:

Date of receipt of test items .....: 26 September 2024

Date(s) of performance of tests.....: 26 September 2024 –29 September 2024

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.

General product information:

This test unit is a residential and non-residential indoor floor and outdoor ground mounted and wall mounted battery system. For outdoor wall mounted, each unit energy does not exceed 20kWh for residential area.

The energy storage system can only play a normal function through the combination method described below, as follows:

Sigen Inverter:

SigenStor EC x SP, Sigen Hybrid x SP, SigenStor AC x SP(x can be 3.0,3.6,4.0,4.6,5.0.6.0.8.0.10.0.12.0), SigenStor EC x SP AU, Sigen Hybrid x SP AU, SigenStor AC x SP AU(x can be 8.0, 10.0, 12.0), SigenStor EC xTP, Sigen Hybrid x TP, SigenStor AC x TP(x can be 5.0, 6.0, 8.0,10.0, 12.0,15.0, 17.0, 20.0, 25.0, 30.0), SigenStor EC x TPLV, Sigen Hybrid xTPLV, SigenStor AC xTPLV(x can be 5.0, 6.0, 8.0,10.0, 12.0), SigenStor EC x TP AU, Sigen Hybrid x TP AU, SigenStor AC x TP AU(x can be 5.0, 6.0, 8.0,10.0, 12.0,15.0, 17.0, 20.0, 25.0, 30.0), SigenStor EC xTP BE, Sigen Hybrid x TP BE, SigenStOr AC x TP BE (x can be 10.0), SigenStor EC x TPLV BE, Sigen Hybrid x TPLV BE, SigenStOr AC x TPLV BE(x can be 10.0)

Sigen EV DC Charging Module:

SigenStor EVDC 12 5S2, SigenStor EVDC 12 7.5S2, SigenStor EVDC 12 10S2, SigenStor EVDC 25 5S2, SigenStor EVDC 25 7.5S2, SigenStor EVDC 25 10S2, SigenStor EVDC 25 5GBT, SigenStor EVDC 25 7.5GBT, SigenStor EVDC 25 10GBT, SigenStor EVDC 12 5GBT, SigenStor EVDC 12 7.5GBT, SigenStor EVDC 12 10GBT.

Sigen Battery:

SigenStor BAT 5.0, SigenStor BAT 8.0.

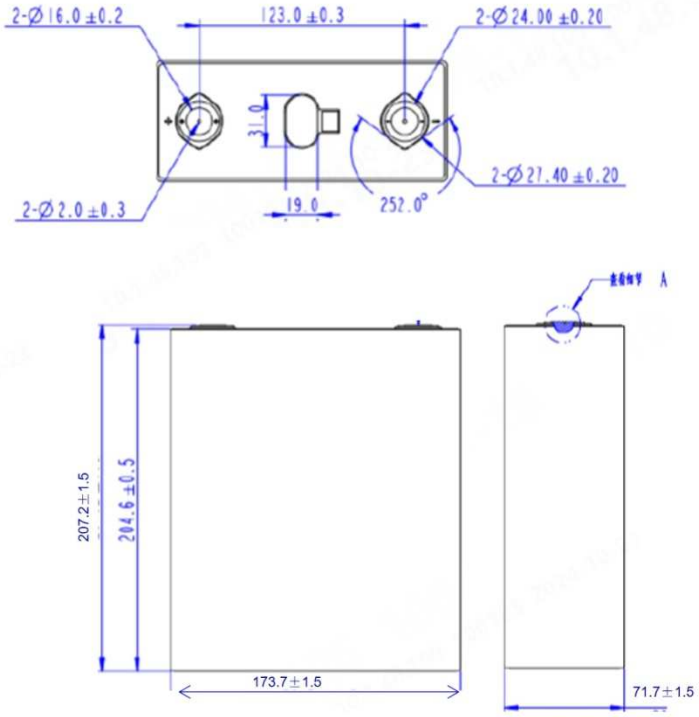
Remark:

Combination 1: Sigen Inverter + n*Sigen Battery (n can be 1-6)

Combination 2: Sigen Inverter + Sigen EV DC Charging Module + n*Sigen Battery (n can be 1-5)

Product information:		
Cell information		
Manufacturer	:	EVE Energy Storage Co., Ltd.
Model name	:	LF280K
Chemistry	:	$LiFePO_4$
Physical configuration	:	Prismatic
Dimension (L*W*T)	:	207.2(±1.5) mm x 173.7(±1.5) mm x 71.7(±1.5) mm
Weight	:	5480(±300) g
Nominal voltage	:	3.2V
Rated capacity	:	280Ah
If the cell compliance with UL 1973	:	Compliance / UL MH66335
Standard charge method		
Charge power	:	448 W
End of charge voltage	:	3.65 V
Cut off current	:	/
Standard discharge method		
Discharge power	:	448 W
End of discharge voltage	:	2.5 V
Test result from cell level 9540A test report		
Cell level test report	:	Issued by UL(Changzhou) Quality Technical Service Co., LTD Report No. 4790830441
Average cell venting temperature	:	168 °C
Average cell thermal runaway onset temperature	:	220 °C
Gas composition	:	See cell level UL9540A test report.
LFL at ambient temperature	:	7.25%
LFL cell venting temperature	:	6.24%
Burning velocity	:	77.21 cm/s
P_{max}	:	96.30 psig

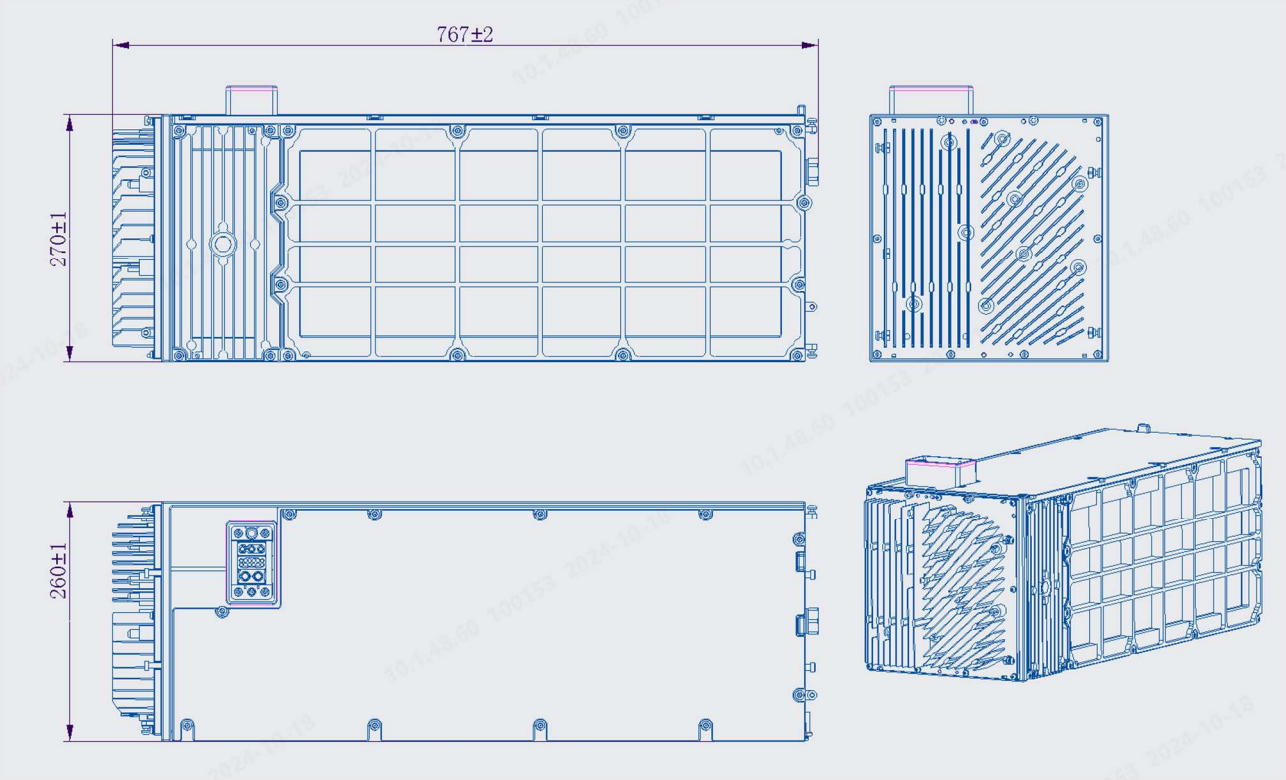
Diagram of cell with overall dimension



Unit: mm

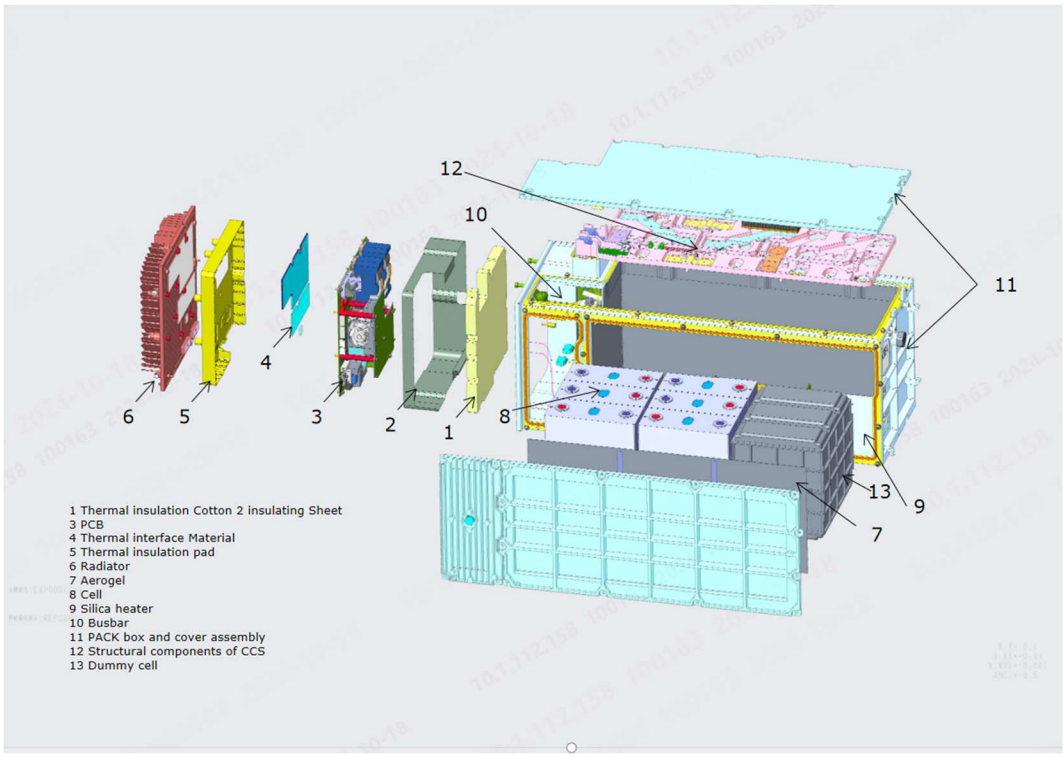
Module information	
Manufacturer ..... :	Shanghai SIGEN New Energy Technology Co., Ltd.
Model name ..... :	SigenStor BAT 5.0, SigenStor BAT 8.0
Physical configuration	
Enclosure material..... :	Metal
Dimension (L*W*H) ..... :	767(±2.0) mm x 260(±1.0) mm x 270(±1.0) mm
Weight..... :	70(+5.0) kg for model SigenStor BAT 8.0 57(+5.0) kg for model SigenStor BAT 5.0
Cells in series/parallel: ..... :	9S1P for model SigenStor BAT 8.0 6S1P for model SigenStor BAT 5.0
Total number of cells: ..... :	9cells for model SigenStor BAT 8.0 6cells for model SigenStor BAT 5.0
Cooling method ..... :	Electric fan
Separation between cells ..... :	2mm by aerogel
Electrical rating	
Rated energy ..... :	8064 Wh for model SigenStor BAT 8.0 5376 Wh for model SigenStor BAT 5.0
Nominal voltage..... :	28.8 V for model SigenStor BAT 8.0 19.2V for model SigenStor BAT 5.0
Standard charge method	
Charge current..... :	4000W for model SigenStor BAT 8.0 2500W for model SigenStor BAT 5.0
End of charge voltage..... :	31.95 V for model SigenStor BAT 8.0 21.30 V for model SigenStor BAT 5.0
Standard discharge method	
Discharge current ..... :	4000W for model SigenStor BAT 8.0 2500W for model SigenStor BAT 5.0
End of discharge voltage ..... :	26.10 V for model SigenStor BAT 8.0 17.4 V for model SigenStor BAT 5.0
If the module compliance with UL 1973 ..... :	N/A
Test result from module level 9540A test report	
Module level test report ..... :	Compliance / Report No. 240913052GZU-001
Peak chemical heat release rate HRR (kW) ..... :	38.0 kW
Peak smoke release rate SRR (m^2/s) ..... :	2.3292 m^2/s
Total smoke release TSR (m^2) ..... :	590.65 m^2
Total Hydrocarbons (equivalent to CH_4, measured by FID) ..... :	15.67 L
Module weight loss (kg)..... :	2.5 kg

Diagram of module with overall dimension

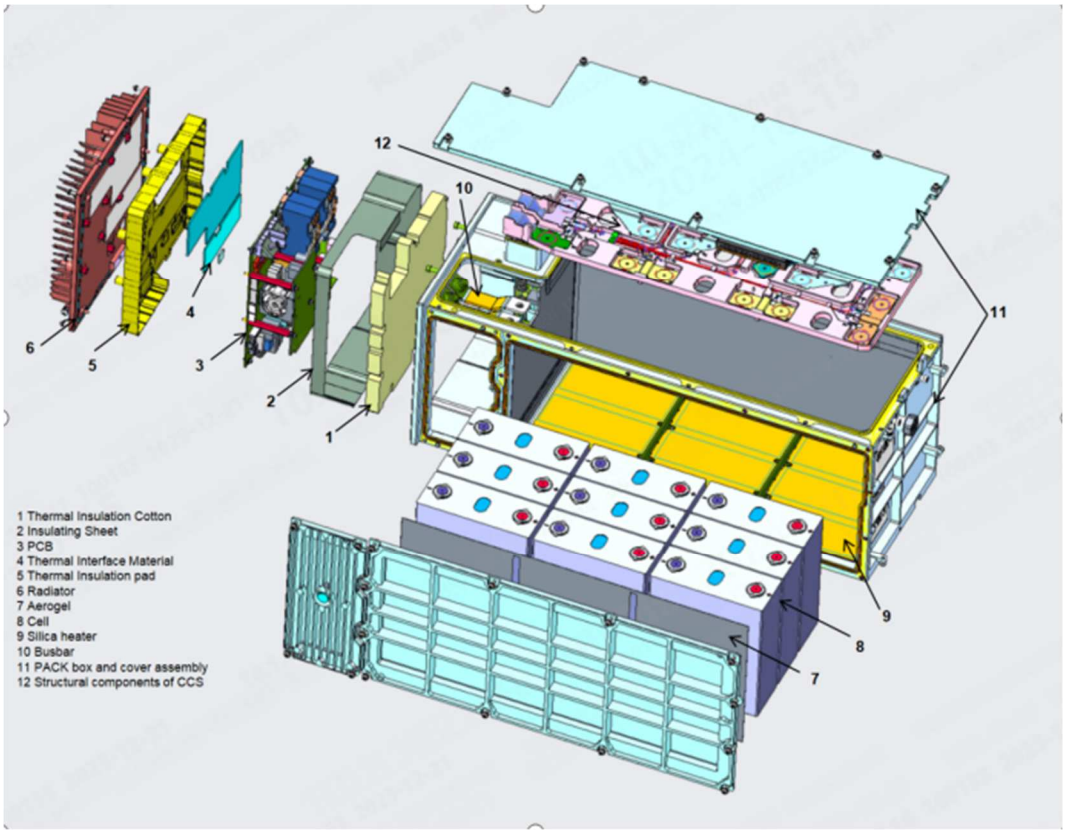


Unit: mm

Contents (main components) of the module

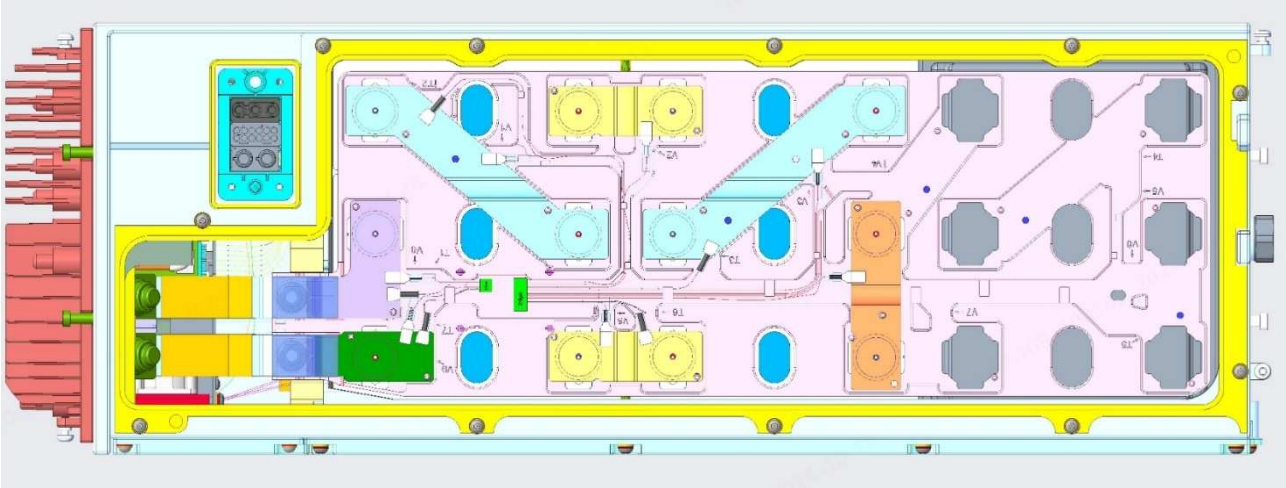


For model SigenStor BAT 5.0

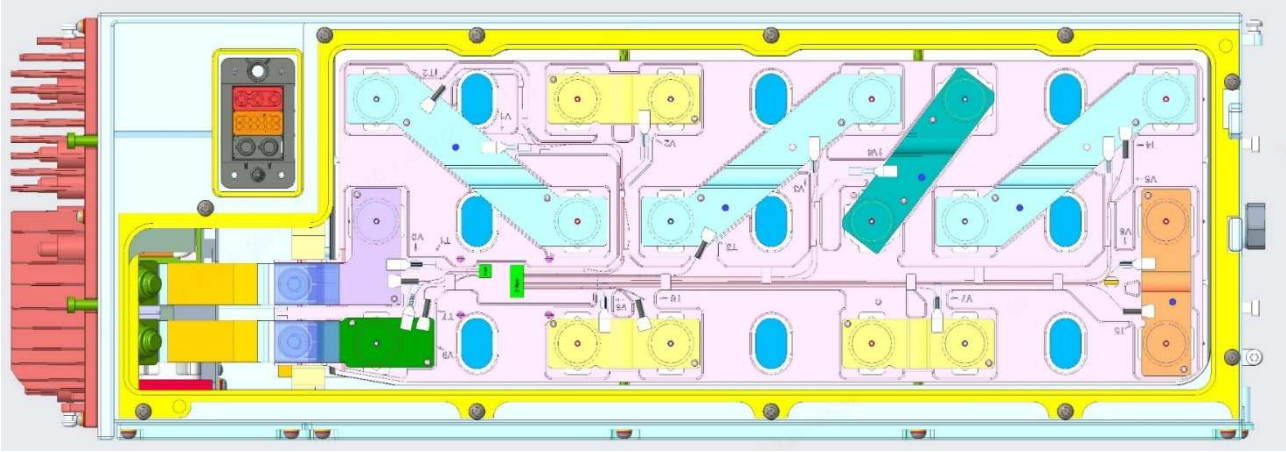


For model SigenStor BAT 8.0

Layout of the module contents

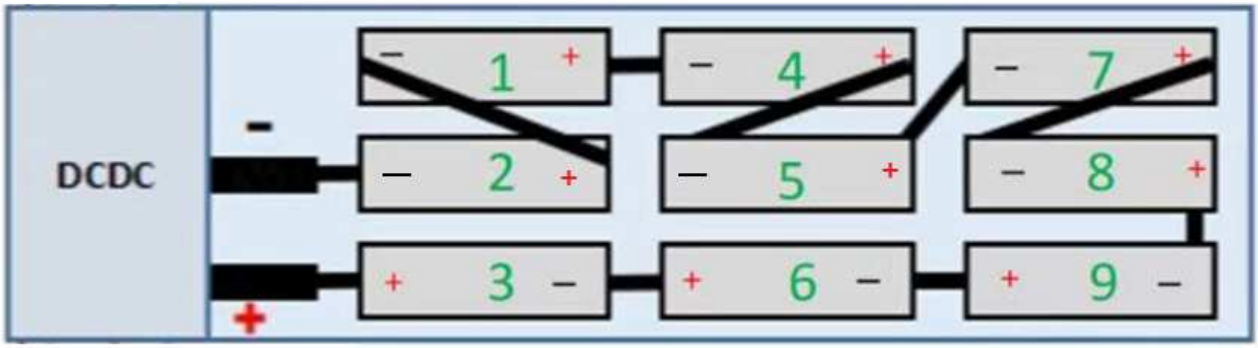


For model SigenStor BAT 5.0

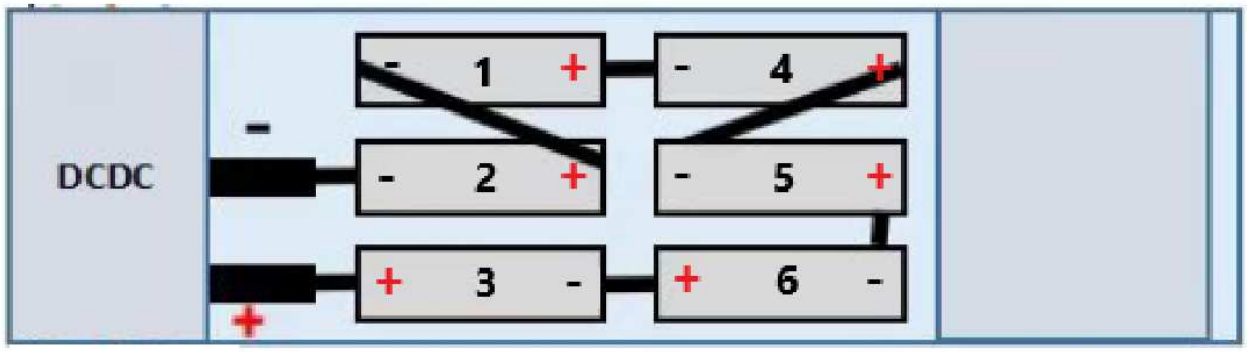


For model SigenStor BAT 8.0

Module structure diagram and cell series and/or parallel configuration (with cell numbered)

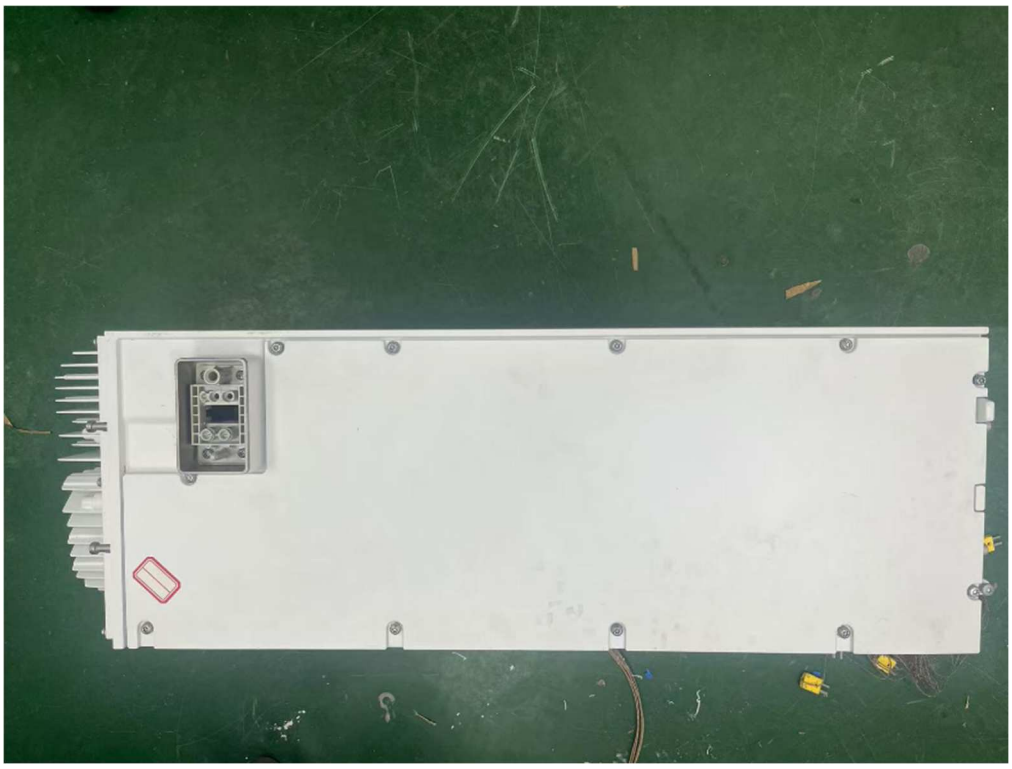


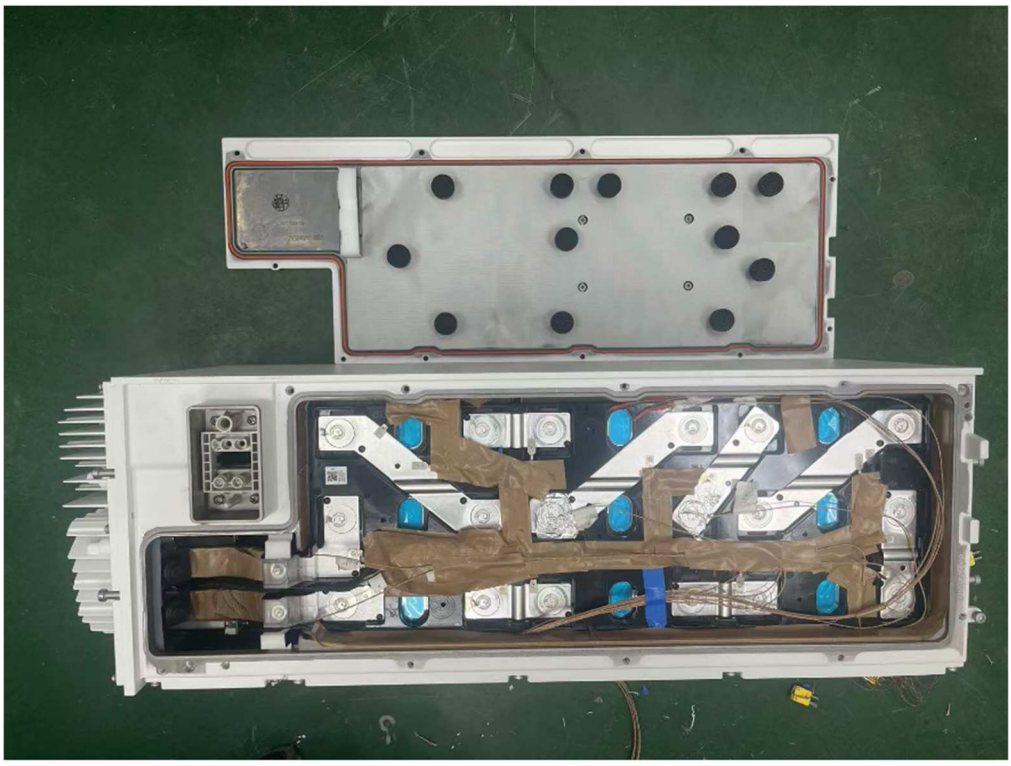
For model SigenStor BAT 8.0



For model SigenStor BAT 5.0

Photo of the module

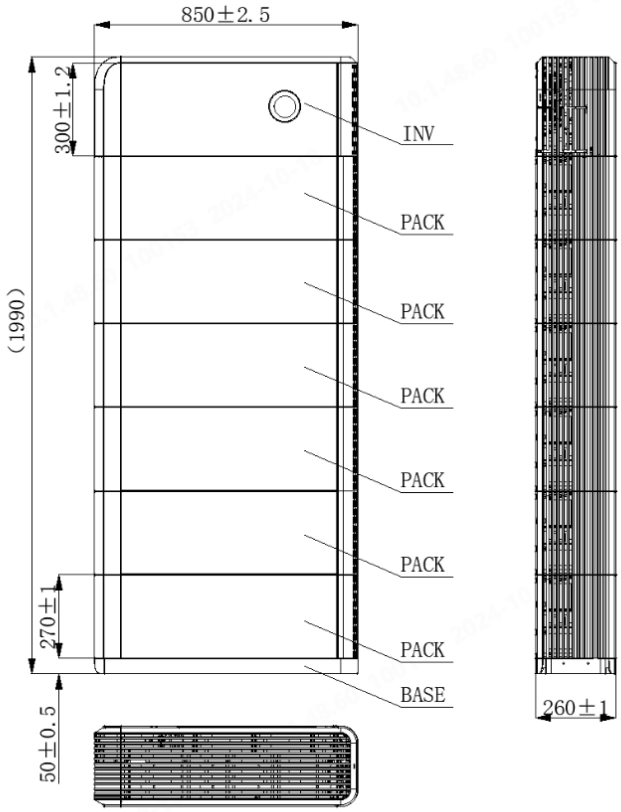


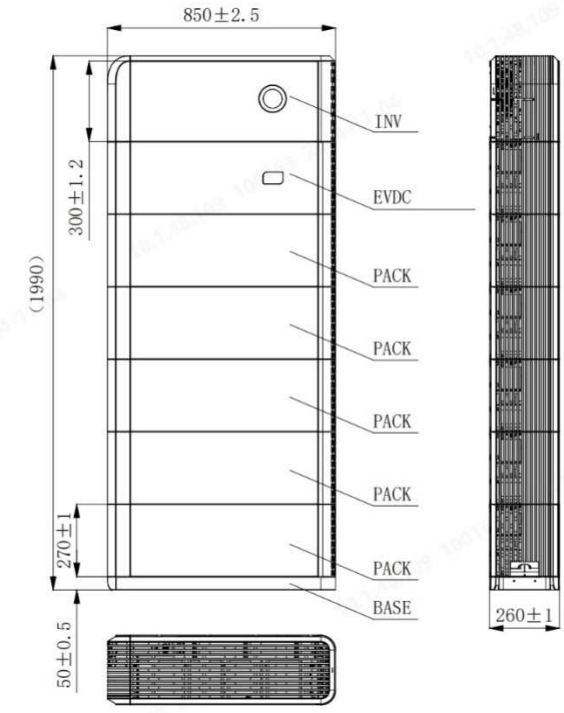


Unit information		
Manufacturer:	Shanghai SIGEN New Energy Technology Co., Ltd.	
Model:	1*Sigen Battery, 2*Sigen Battery, 3*Sigen Battery, 4*Sigen Battery, 5*Sigen Battery, 6*Sigen Battery	
Test model:	6*Sigen Battery	
Type of system:	☐ Battery System (BS)	☒ Battery ESS
Intended use location:	☒ Residential ☐ Non-residential rooftop ☐ Non-residential open garage use	☒ Non-residential
Type of installation:	☒ Indoor floor mounted ☒ Indoor wall mounted	☒ Outdoor ground mounted ☒ Outdoor wall mounted
Enclosure material:	☒ Metal ☐ Open rack	☒ Non-metal
Spacing between modules:	Vertical: 0.7mm	
Integrated fire protection system in the unit	No fire detection and suppression system installed for the unit level test	
If the unit compliance with UL 1973 or UL 9540:	N/A	
Electrical rating		
Model:	n*Sigen Battery	
Rated capacity (Ah):	n*280	
Rated energy (kWh):	n*5.376	n*8.064
Nominal voltage (V):	19.2	28.8
Weight(kg):	n*(57+5)	n*(70+5)
Module series and/or parallel configuration:	1SnP	1SnP
Total number of cells:	n*6	n*9
Standard charge method^:		
Charge power (W):	2500W	4000W
End of charge voltage (V):	21.3V	31.95V
Standard discharge method^:		
Discharge power (W):	2500W	4000W
End of discharge voltage (V):	17.4V	26.1V
Rest time between charge and discharge	N/A	

Remark:
1. ^ represent one module's charge/discharge power and end of charge/discharge voltage. The voltage refers to both ends of the cell group after the DC-DC module depressurization.
2. There are two models of Sigen battery, they are SigenStor BAT 5.0 and SigenStor BAT 8.0. The rated energy of model SigenStor BAT 5.0 is 5.376kWh. The rated energy of model SigenStor BAT 8.0 is 8.064kWh.
3. As for the electrical rating of each unit model, since the product is a unit formed by stacking module components, but there are two models of module and they can be used together arbitrarily, the electrical rating only describes the rating of the two modules, and the parameters of the unit need to be superimposed according to the module model and the number of parallel modules. n represent 1 to 6.

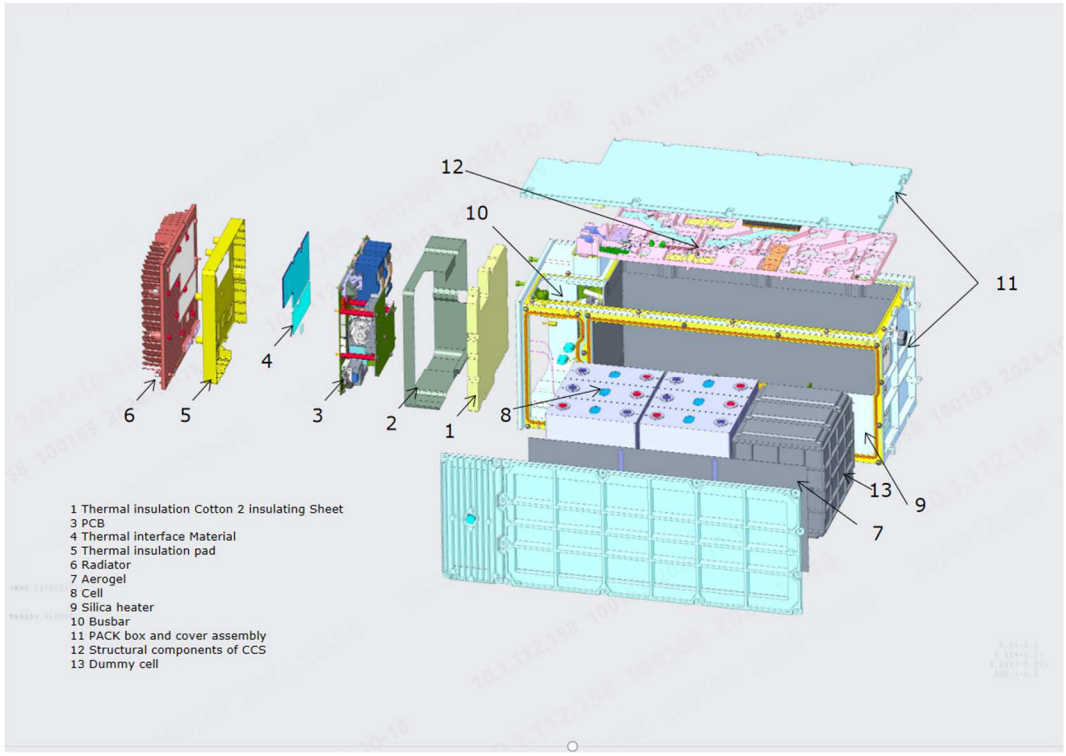
Diagram of unit with overall dimension (Unit: mm)



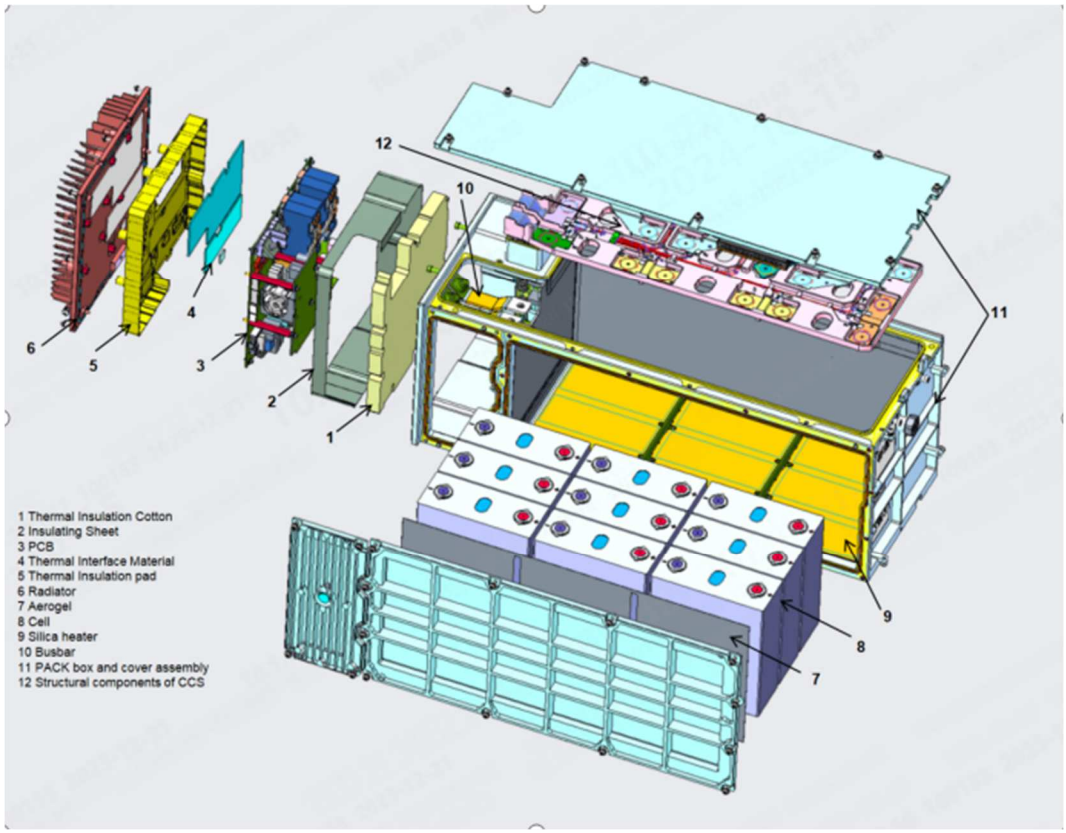


Exploded view of the unit contents (show all components inside the unit. Include battery modules, control module(s), bus bars wires etc.)

Remark: Exploded view of the unit contents is the same as the battery module, the difference is the number of modules stacked.



For model SigenStor BAT 5.0



For model SigenStor BAT 8.0

Photo of the unit



ANSI/CAN/UL 9540A			
Clause	Requirement – Test	Result - Remark	Verdict
5	**Construction – General**		
5.1	**Cell**		**--**
5.1.1	The cell info associated with the BESS includes:		Pass
	• cell chemistry (e.g. NMC, LFP);	$LiFePO_4$	Pass
	• the physical format of the cell;	Prismatic	Pass
	• the cell electrical rating in capacity and nominal voltage;	3.2V, 280Ah	Pass
	• the overall dimensions of the cell, and weight.	See page 4-5	Pass
5.1.2	The cells associated with the BESS comply with ANSI/CAN/UL 1973 or not.	Certificate provided.	Pass
5.1.3	Further details included in the cell level test report.		Pass
5.2	**Module**		**--**
5.2.1	The modules info associated with the BESS includes:		Pass
	• the generic enclosure material;	Metal and non-metal	Pass
	• the general layout of the module contents;	See page 6-10	Pass
	• the electrical configuration of the cells in the modules and the modules in the BESS.	9S1P or 6S1P	Pass
5.2.2	The modules associated with the BESS comply with UL 1973 or not.		Pass
5.2.3	Further details included in the module level test report.	Refer to 8.3	Pass
5.3	**Battery energy storage system unit**		**--**
5.3.1	The BESS unit info includes:		**--**
	• the units comply with UL 9540 or not;		Pass
	• the manufacturer and model number;		Pass
	• electrical ratings;		Pass
	• energy capacity of all BESS.		Pass
5.3.2	For BESS units, which UL 9540 compliance cannot be determined, to include:		**--**
	• the number of modules in the BESS;	Max.6	Pass
	• electrical configuration of the module;	See Unit information (page 12-14)	Pass
	• physical layout of the modules in the BESS;		Pass
	• battery management system (BMS); and		Pass
	• other major components of the BESS;		Pass
	• the BESS enclosure overall dimensions and generic material;		Pass
	• battery system(s) may be tested as representative of the BESS;		Pass
	• battery system complies with UL 1973 or not.		N/A
5.3.3	Any fire detection and suppression systems that are an integral part of the BESS.	No fire detection and suppression system installed for the test.	N/A
5.3.4	Further details included in the unit level and if applicable, installation level test reports.		Pass
5.4	**Flow Batteries**		**--**

ANSI/CAN/UL 9540A			
Clause	Requirement – Test	Result - Remark	Verdict
5.4.1	For flow batteries, to include the following info:		N/A
	• the chemistry;		N/A
	• a generic description of the electrolyte (s);		N/A
	• the overall dimensions of the individual stack;		N/A
	• the electrical rating in capacity and nominal voltage of the cell stack.		N/A
	And the Information of the complete flow battery system:		N/A
	• the manufacturer's name and model number of the system;		N/A
	• the electrical rating in volts and rated storage capacity in Ah or Wh;		N/A
	• the number of cells and stacks in the system;		N/A
	• the maximum volume of electrolyte(s) for the system.		N/A
5.4.2	The flow battery system complies with UL 1973 or not.		N/A
5.4.3	Further details included in the flow battery thermal runaway determination level test report.		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.		Pass
6.2	At the conclusion of testing, samples discharged in accordance with the manufacturer' specifications.		Pass
	All samples disposed of in accordance with local regulations.		Pass
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.		Pass
9.1.2	The unit level test requires one initiating BESS unit and target adjacent BESS unit's representative of an installation.		Pass
	(Modified by UL CRD-2020.10.21) Tests conducted for indoor floor mounted installations for residential BESS may be considered representative of both indoor floors mounted and outdoor ground mounted installations.		Pass
	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.		Pass
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.		Pass

ANSI/CAN/UL 9540A			
Clause	Requirement – Test	Result - Remark	Verdict
9.1.5	Target BESS units shall include the outer cabinet, racking, module enclosures, and components that retain cells components. The target BESS unit module enclosures do not need to contain cells.	No cells in target BESS	Pass
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 8h at room ambient.	See attachment 2: sample preparation.	Pass
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.		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	Pass
	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.		N/A
9.2	**Test method – Indoor floor mounted BESS units**		**--**
9.2.1	During the test, the test room environment shall be controlled to prevent drafts that may affect test results.	See attachment 5	Pass
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.		N/A
9.2.3	The initiating BESS unit shall be positioned adjacent to two instrumented wall sections.	See attachment 3	Pass
9.2.4	Instrumented wall sections shall extend not less than 0.49m horizontally beyond the exterior of the target BESS units.		Pass
9.2.5	Instrumented wall sections shall be at least 0.61m taller than the BESS unit height, but not less than 3.66m in height above the bottom surface of the unit.		Pass
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.		Pass
9.2.7	The initiating BESS unit shall be centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.		Pass
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.		Pass
9.2.9	The chemical and convective heat release rates shall be measured for the duration of the test, respectively.		Pass
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.		Pass
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.		Pass

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: $HRR_c = V_e A \frac{353.22}{T_e} \int_{T_e}^{T} C_p dT$	See attachment 9	Pass
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls shall be representative of the intended installation.	See attachment 3	Pass
9.2.14	Separation distances shall be specified by the manufacturer for distance between:		Pass
	a) The BESS units and the instrumented wall sections; and	See attachment 3	Pass
	b) Adjacent BESS units.	See attachment 3	Pass
9.2.15	Wall surface temperature measurements shall be collected for BESS intended for installation in locations with combustible construction.	See attachment 6	Pass
	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 #30-gauge, Type-K exposed junction thermocouples; See attachment 6	Pass
	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.		Pass
9.2.17	Thermocouples shall be secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires.		Pass
	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.		Pass
9.2.18	Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt- Boelter gauges at the surface of each instrumented wall:	Cheesecloth used, refer to 9.2.18.1, heat flux measurement on walls was not measured.	N/A
	a) Both are collinear with the vertical thermocouple array;		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		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.		N/A
9.2.18.1	Heat flux measurements on walls may be waived for residential units that are tested with the cheesecloth indicator of 9.2.22.	Cheesecloth indicator used.	Pass

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Clause	Requirement – Test	Result - Remark	Verdict
9.2.18.2	(added by UL CRD-2021.03.26) 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:		N/A
	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		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.		N/A
9.2.19.1	(added by UL CRD-2021.03.26) Heat flux measurements on target units may be waived for residential units that are tested with the cheesecloth indicator of 9.2.22.		Pass
9.2.19.2	(added by UL CRD-2021.03.26) 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	(added by UL CRD-2021.03.26) For non-residential use BESS and outdoor ground mounted 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.		Pass
9.2.21	Measure the temperature of:		Pass
	the surface proximate to the cells and between the cells and exposed face of the initiating module;		Pass
	Each non-initiating module enclosure within the initiating BESS unit;		Pass
	Convoluted enclosure interior geometries.		Pass
9.2.22	For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator.		Pass
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:		Pass
	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		Pass
	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).		Pass
9.2.24	The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct.	Via the testing system which has the sensors in the exhaust duct	Pass

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Clause	Requirement – Test	Result - Remark	Verdict
	Gas composition shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer.		Pass
	Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.		Pass
9.2.25	The hydrocarbon components of the vent gas composition shall be measured using flame ionization detection.	Integrated FID in the testing system used	Pass
9.2.26	The test shall be terminated if:		Pass
	a) Temperatures measured inside each module within the initiating BESS unit return to ambient temperature;		Pass
	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: 20.27m^3 25%LFL_{amb}: 1.81% (from cell level test report)	Pass
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)	Pass
	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	Outdoor ground mounted residential use BESS being evaluated for installation in close proximity to buildings and structures.	(The test method described in section 9.2)	Pass
	Heat flux measurements for the accessible means of egress.		Pass
	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.		Pass
	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.		Pass
	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

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Clause	Requirement – Test	Result - Remark	Verdict
9.3.4	Target BESS shall be installed on each side of the initiating BESS and keep the min. separation distances specified by the manufacturer.		Pass
9.4	**Test Method – Indoor wall mounted units**		**--**
9.4.1	Testing of indoor wall mounted BESS shall be in accordance with Section 9.2, except as modified in this section.		Pass
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
9.4.2.1	(Added by UL CRD-2020.10.21) 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.		Pass
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.		Pass
9.4.3.1	(added by UL CRD-2020.10.21) 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.		Pass
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.	(Keep the min. physical spacing between BESS units specified by the manufacturer)	Pass
9.4.5	The wall on which the initiating and target BESS units are mounted shall be instrumented.		Pass
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.	(Gas collection methods per clause 9.2)	Pass
9.4.7	For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator.	cheesecloth indicator used	Pass
9.4.8	(added by UL CRD-2020.10.21) When testing BESS for residential only installations, the criteria in 9.2.9. 9.2.18 and 9.2.19 may be waived.		Pass
9.5	**Test Method – Outdoor wall mounted units**		**--**
9.5.1	Testing of outdoor wall mounted BESS shall be in accordance with Section 9.2, except as modified in this section.		Pass
	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).		Pass
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.		Pass
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.		Pass

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Clause	Requirement – Test	Result - Remark	Verdict
9.5.5	The wall on which the initiating and target BESS units are mounted shall be instrumented.		Pass
9.5.6	For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator.		Pass
9.6	**Rooftop and open garage installations**	**--**	N/A
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:		Pass
	a) Indoor floor mounted non-residential use BESS;		Pass
	b) Indoor floor mounted residential use BESS;		Pass
	c) Outdoor ground mounted non-residential use BESS;		Pass
	d) Outdoor ground mounted residential use BESS;		Pass
	e) Indoor wall mounted non-residential use BESS;		Pass
	f) Indoor wall mounted residential use BESS;		Pass
	g) Outdoor wall mounted non-residential use BESS;		Pass
	h) Outdoor wall mounted residential use BESS;		Pass
	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.		Pass
9.7.3	The report shall include the following, as applicable:		Pass
	a) Unit manufacturer name and model number (and whether UL 9540 compliant);	See unit information (page 12)	Pass
	b) Number of modules in the initiating BESS unit;	See Attachment 3	Pass
	c) The construction of the initiating BESS unit per 5.3;	See unit information (page 13-14)	Pass
	d) Fire protection features/detection/suppression systems within unit;	No fire detection and suppression system installed for the test.	N/A
	e) Module voltage(s) corresponding to the tested SOC;	See Attachment 2	Pass
	f) The thermal runaway initiation method used;	See Attachment 4	Pass
	g) Location of the initiating module within the BESS unit;	See Attachment 3	Pass
	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	Pass
	i) Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	See Attachment 5	Pass

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Clause	Requirement – Test	Result - Remark	Verdict
	j) Chemical and convective heat release rate versus time data;	See Attachment 8 and attachment 9	Pass
	k) Separation distances from the initiating BESS unit to target walls (A and C in Figure 9.1);	See Attachment 3	Pass
	l) Separation distances from the initiating BESS unit to target BESS units (D and H in Figure 9.1);	See Attachment 3	Pass
	m) The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	See Attachment 6	Pass
	n) The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;	See Attachment 6	Pass
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	Cheesecloth used, refer to 9.2.18.1, heat flux measurement on walls was not measured.	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, refer to 9.2.18.1, heat flux measurement on walls was not measured.	N/A
	q) Gas generation and composition data	See Attachment 10	Pass
	r) Peak smoke release rate and total smoke release data;	See Attachment 11	Pass
	s) Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	No fire detection and suppression system installed for the test.	N/A
	t) Observation of flying debris or explosive discharge of gases;	No observation.	Pass
	u) Observation of re-ignition(s) from thermal runaway events;	No observation.	Pass
	v) Observation(s) of sparks, electrical arcs, or other electrical events;	See Attachment 5	Pass
	w) Observations of the damage to:	See Attachment 1	Pass
	1) The initiating BESS unit;	See Attachment 1	Pass
	2) Target BESS units;	See Attachment 1	Pass
	3) Adjacent walls, ceilings, or soffits; and	See Attachment 1	Pass
	x) Photos and video of the test.	See Attachment 1 and test-1.mp4 to test-8.mp4	Pass
9.8	**Performance at unit level testing**		**--**
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.		Pass
	Non-Residential Installations		**--**
Indoor Floor Mounted	a) Flaming outside the initiating BESS unit is not observed;		Pass
	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;		Pass
	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;		Pass

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Clause	Requirement – Test	Result - Remark	Verdict
	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		Pass
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m2.		Pass
Outdoor Ground Mounted	a) If flaming outside of the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test.	No observed.	Pass
	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;		Pass
	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;		Pass
	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		Pass
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m2.		Pass
Indoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed;	No observed.	Pass
	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;		Pass
	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;		Pass
	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		Pass
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m2.		Pass
Outdoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed;	No observed.	Pass
	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;		Pass
	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;		Pass

ANSI/CAN/UL 9540A			
Clause	Requirement – Test	Result - Remark	Verdict
	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		Pass
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m2.		Pass
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/m2.		N/A
	Residential Installations		--
Indoor Floor Mounted	a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator;	No observed.	Pass
	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;		Pass
	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;		Pass
	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		Pass
	e) The concentration of flammable gas does not exceed 25% LFL in air for the smallest specified room installation size.		Pass
Outdoor Ground Mounted	a) If flaming outside of the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test.	No observed.	Pass
	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;		Pass

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Clause	Requirement – Test	Result - Remark	Verdict
	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;		Pass
	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		Pass
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m2.		Pass
Indoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator;	No observed.	Pass
	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;		Pass
	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;		Pass
	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		Pass
	e) The concentration of flammable gas does not exceed 25% LFL for the smallest intended room installation size.		Pass
Outdoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed as demonstrated by no flaming or charring of the cheesecloth indicator;	No observed.	Pass
	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;		Pass
	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		Pass
	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.		Pass

Attachment 1 Photos

The battery system before test



Front side

During test



Smoke release from initiating unit

The battery system after test

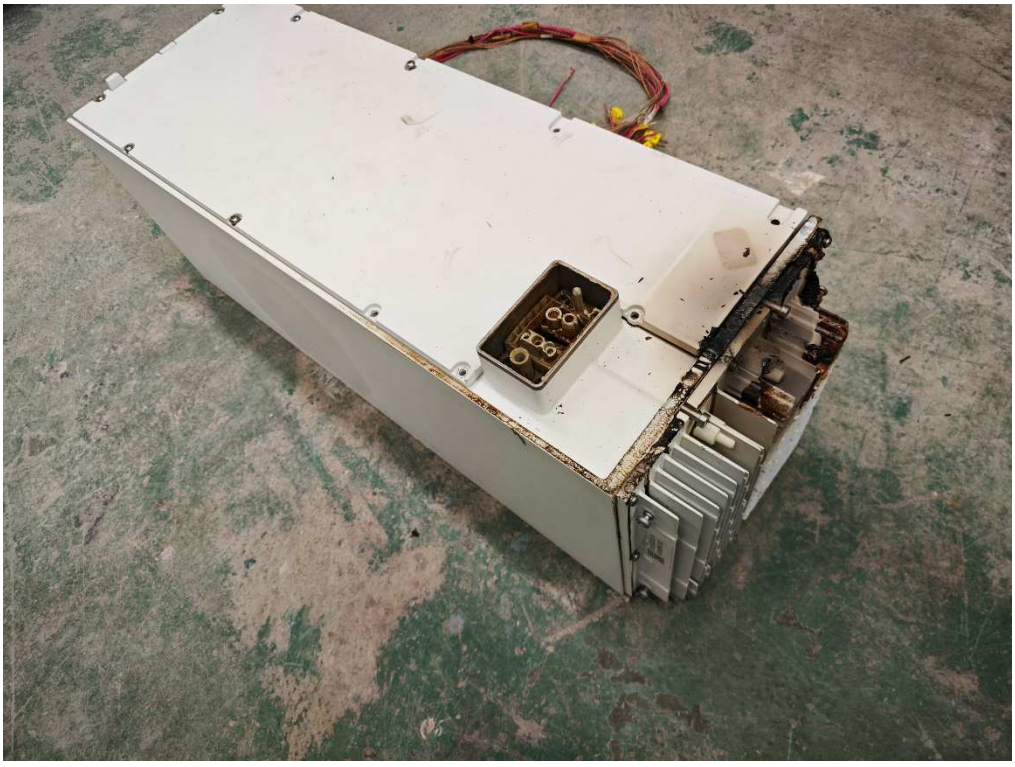


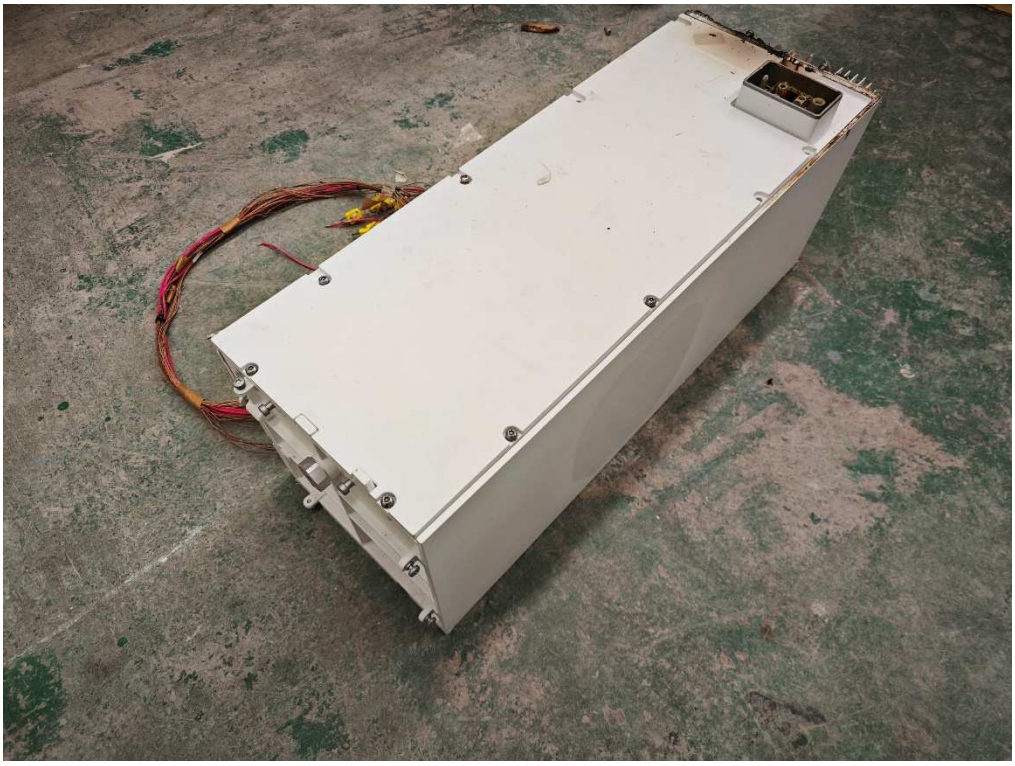






Internal view of initiating module, after test









Attachment 2 Sample preparation

The test energy storage system consists of 6 modules and 6 BMS (inside of each module).

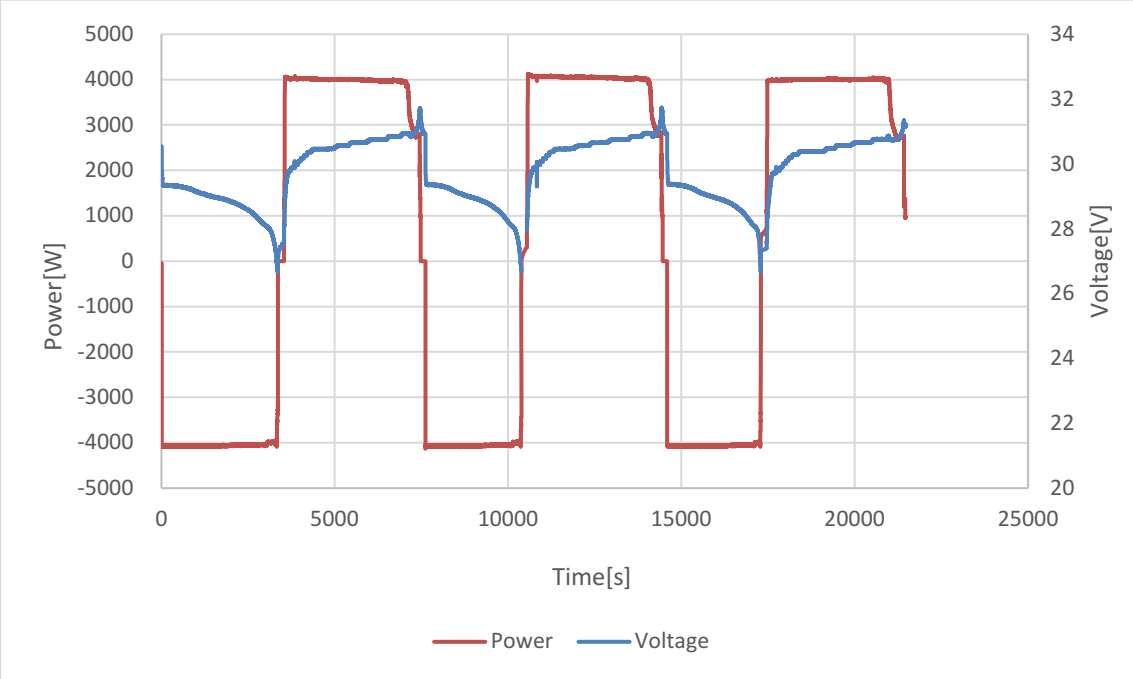
The unit was conditioned, prior to testing, through charge and discharge cycles for 2 cycles per the manufacturer's instructions to verify that the unit was functional.

As manufacturer specified, the unit was charged with the standard charge method (see page 12). After being stabilized, the unit was discharged, the unit used the standard discharge method (see page 12).

After repeating the cycle above twice and then unit was fully charged with 100% SOC, and before testing, the unit was stabilized for about 4 hours.

During conditioning the ambient temperature maintained in 25 ±5°C and 50 ±25% RH.

Cycling curve of the initiating unit is shown below.



Initiating unit charge and discharge voltage/current profiles

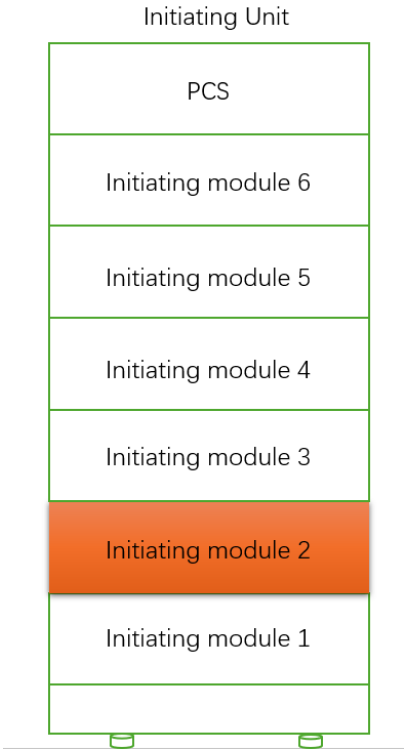
Attachment 3 Arrangement of the unit

The installation information was provided by the client as below.

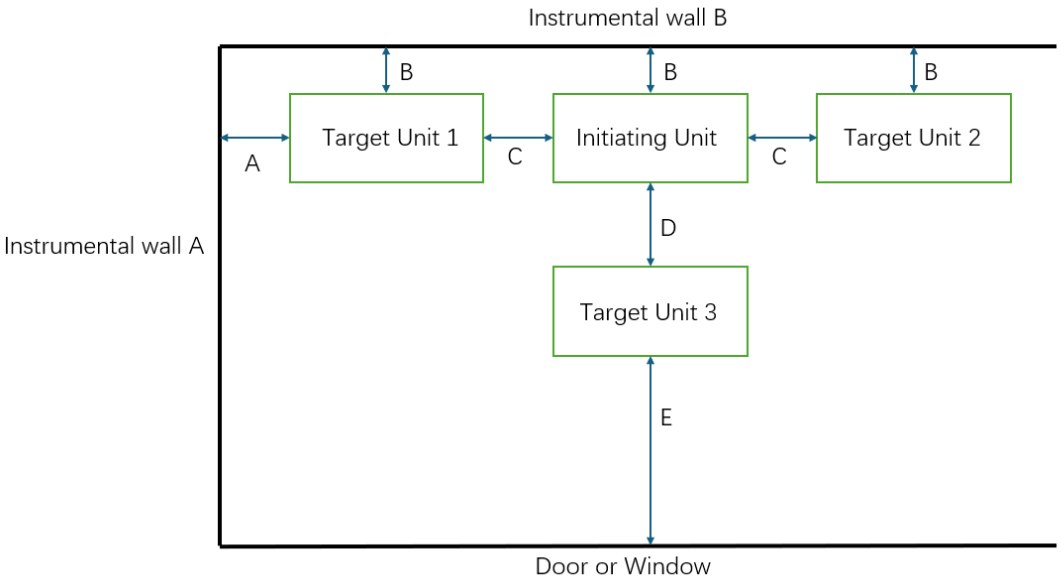
Intended use location .....:	☒ Residential	☒ Non-residential
	☐ Non-residential rooftop	
	☐ Non-residential open garage use	
Type of installation .....:	☒ Indoor floor mounted	☒ Outdoor ground mounted
	☒ Indoor wall mounted	☒ Outdoor wall mounted
Row(s) of installation	☐ Single	☒ Multiple

Walls were constructed of 16 mm (5/8-inch) gypsum painted flat black.

One unit was used for the purpose of the test. To identify the modules in each unit, the modules in each unit were numbered as the figure below.



Minimum separation distance from the units to instrumental walls were shown in below figure. Top view of the unit arrangement and separation distance from units to instrumental walls are shown in below figure. Due the weight and size of the unit, the accuracy of the distance may have a 0.5 cm tolerance.



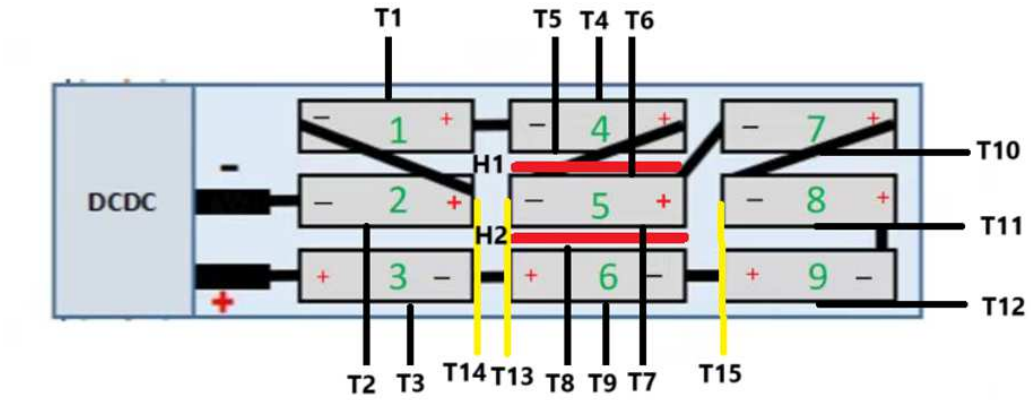
A: Distance from the unit to the left wall: 600mm	B: Distance from the unit to the back wall: 50mm	C: Distance from the unit to other unit in the same row: 600mm	D: Distance from the unit to other unit in the same column: 800mm	E: Distance from exposures and means of egress: 914mm

Attachment 4 Thermal runaway preparation

Module 2 in initiating unit was selected as the initiating module.

The initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

External heating method was used to initiate thermal runaway in the module. 2 flexible film heaters, rated 220VAC/900W each, sized 172mmX195mm, were pasted on cell 5.



Cell 5 was heated as the target cell at a rate of 4°C-7°C per minute until thermal runaway was occurred. When thermal runaway occurred, the heater will de-energized immediately.

Attachment 5 Observations and records

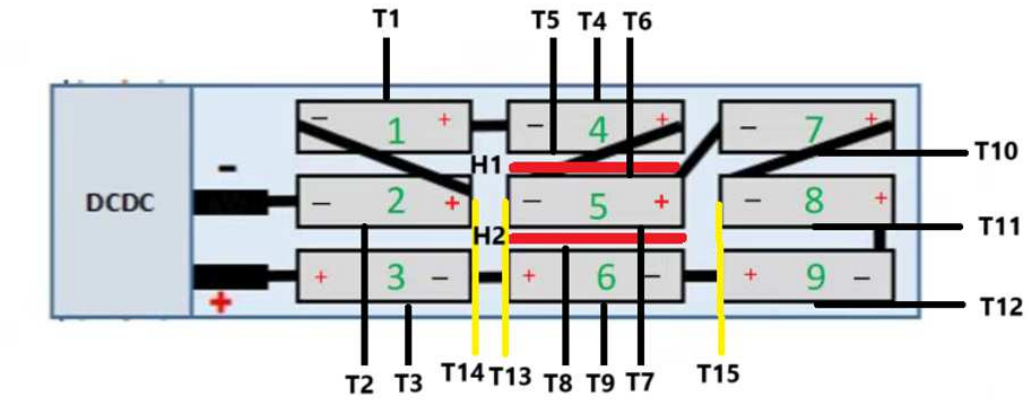
Before the test, the initiating module was charged to 100% SOC and stabilized for about 4 h before the start of the test.

Below table summarizes the details:

Ambient conditions at the initiation of the test:	28.1°C, 65%RH			
Electronics and software controls within the module?	☒ Yes, but not relied upon for this testing ☐ No such controls			
Time when test was initiated:	15 August 2024, 15:32 PM			
Observations during test:	1st vented	17:09	1st thermal runaway	17:10
	2nd vented	17:17	2nd thermal runaway	17:18
	No flying debris or explosive discharge of gases. No sparks, electrical arcs, or other electrical events. No external flaming was observed			
Post-test evaluation:	In initiating unit, no thermal runaway propagation from initiating module to other modules in initiating unit. In initiating module, cell 5 went to thermal runaway, due to external heating. Cell 4 in the initiating module vented and went to thermal runaway due to thermal runaway propagation. No damage on target walls. No damage on target units.			

Attachment 6 Temperature measurements

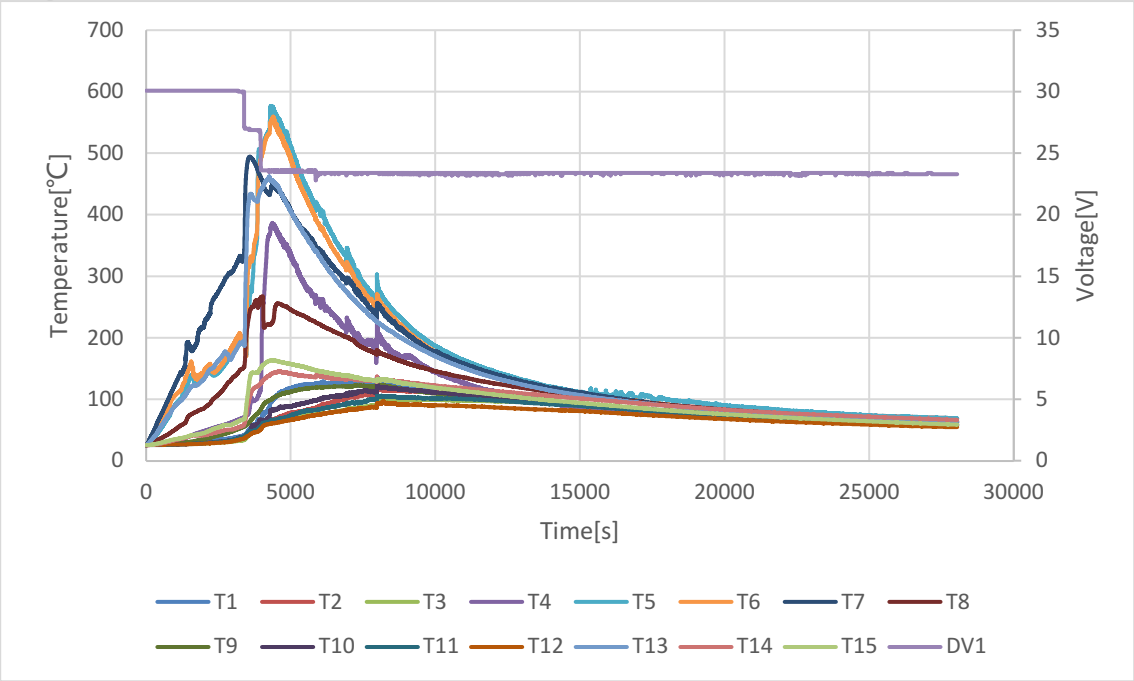
To monitor the cells temperature inside the module, 15 thermocouples, Type K, were used. See below figure and table for detail location of the film heaters and thermocouples.



Heaters and thermocouple location inside the module

Thermocouple No.	Thermocouple location on initiating module 2
T1	Centre of big side of cell 1 facing enclosure
T2	Centre of big side of cell 2 facing cell 3
T3	Centre of big side of cell 3 facing enclosure
T4	Centre of big side of cell 4 facing enclosure
T5	Centre of big side of cell 4 facing heater 1
T6	Centre of big side of cell 5 facing heater 1
T7	Centre of big side of cell 5 facing heater 2
T8	Centre of big side of cell 6 facing heater 2
T9	Centre of big side of cell 6 facing enclosure
T10	Centre of big side of cell 7 facing cell 8
T11	Centre of big side of cell 8 facing cell 9
T12	Centre of big side of cell 9 facing enclosure
T13	Centre of narrow side of cell 5 facing cell 2
T14	Centre of narrow side of cell 2 facing cell 5
T15	Centre of narrow side of cell 8 facing cell 5

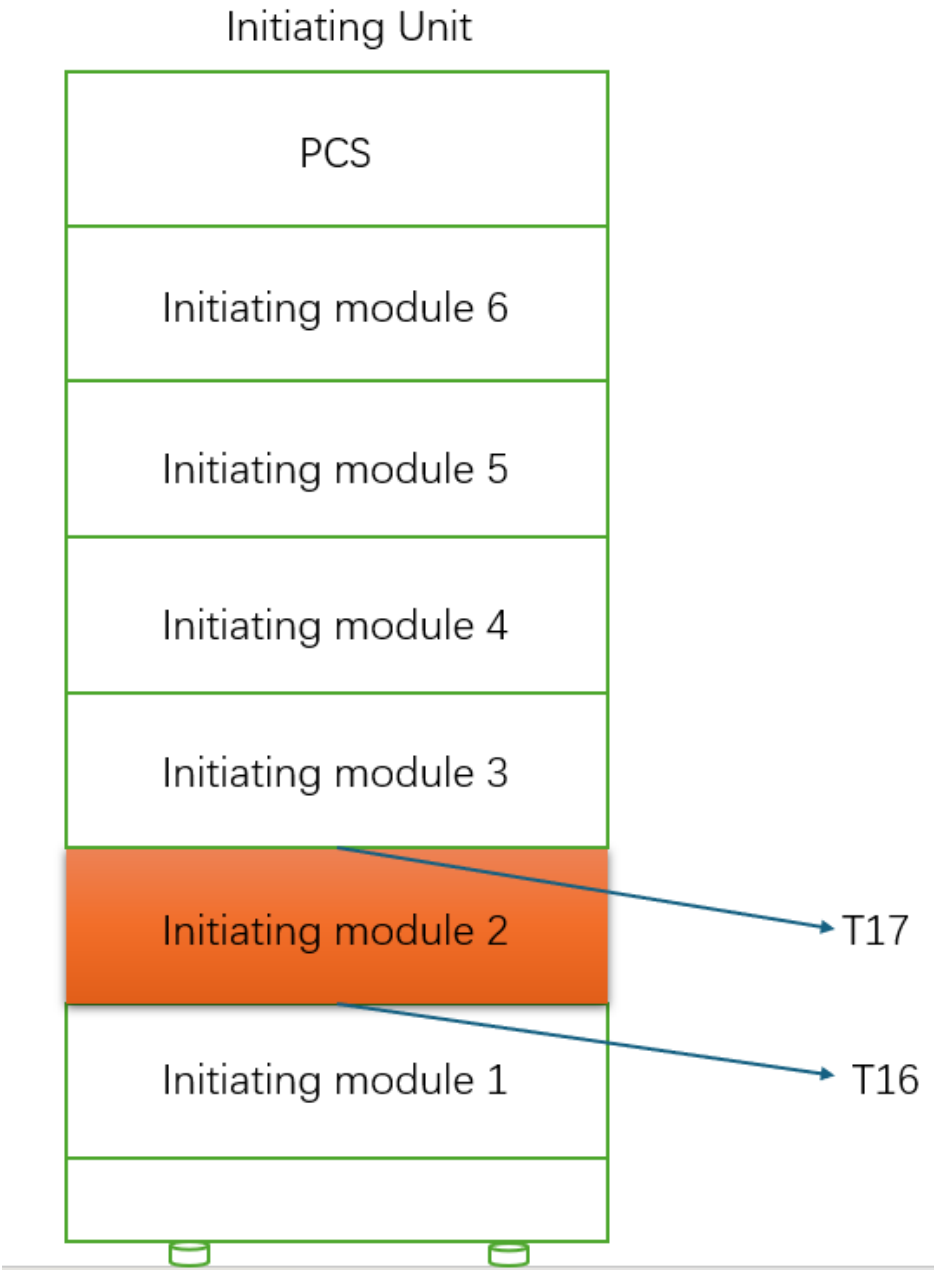
Temperature describing cell to cell propagation in initiating module and initiating unit voltage are show in below figure.



The maximum measured temperature of each location is shown in below table.

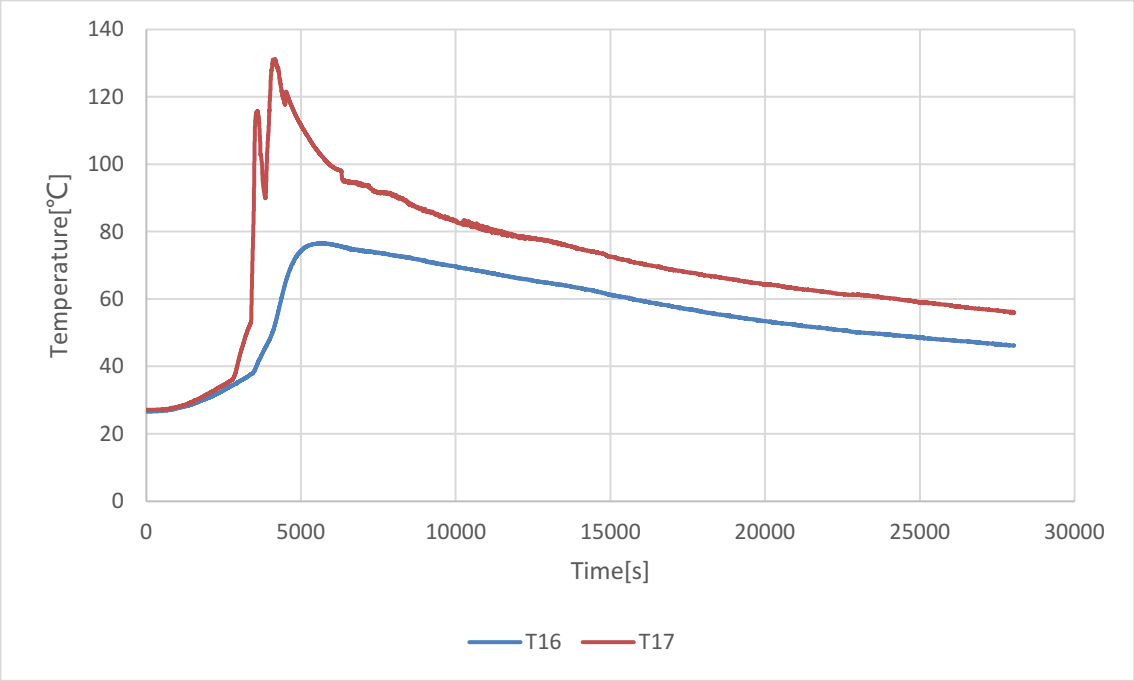
Thermocouple No.	Thermocouple location on initiating module 3	Maximum temperature (°C)
T1	Centre of big side of cell 1 facing enclosure	136.3
T2	Centre of big side of cell 2 facing cell 3	127.4
T3	Centre of big side of cell 3 facing enclosure	101.9
T4	Centre of big side of cell 4 facing enclosure	386.8
T5	Centre of big side of cell 4 facing heater 1	576.6
T6	Centre of big side of cell 5 facing heater 1	559.7
T7	Centre of big side of cell 5 facing heater 2	494.5
T8	Centre of big side of cell 6 facing heater 2	267.7
T9	Centre of big side of cell 6 facing enclosure	125.4
T10	Centre of big side of cell 7 facing cell 8	136.4
T11	Centre of big side of cell 8 facing cell 9	106.0
T12	Centre of big side of cell 9 facing enclosure	97.0
T13	Centre of narrow side of cell 5 facing cell 2	462.2
T14	Centre of narrow side of cell 2 facing cell 5	145.4
T15	Centre of narrow side of cell 8 facing cell 5	163.7
Max. system voltage, after test		
DV1	22.8V	

To monitor the surface temperature of module 1 and module 3 in initiating unit, 2 thermocouples (number T21 and T22) were used, and detail location was shown in below figure and table.



Thermocouple's location in initiating module (Front View)

The measured surface temperature of module 1 and module 3 in initiating unit during test is shown in below figure.



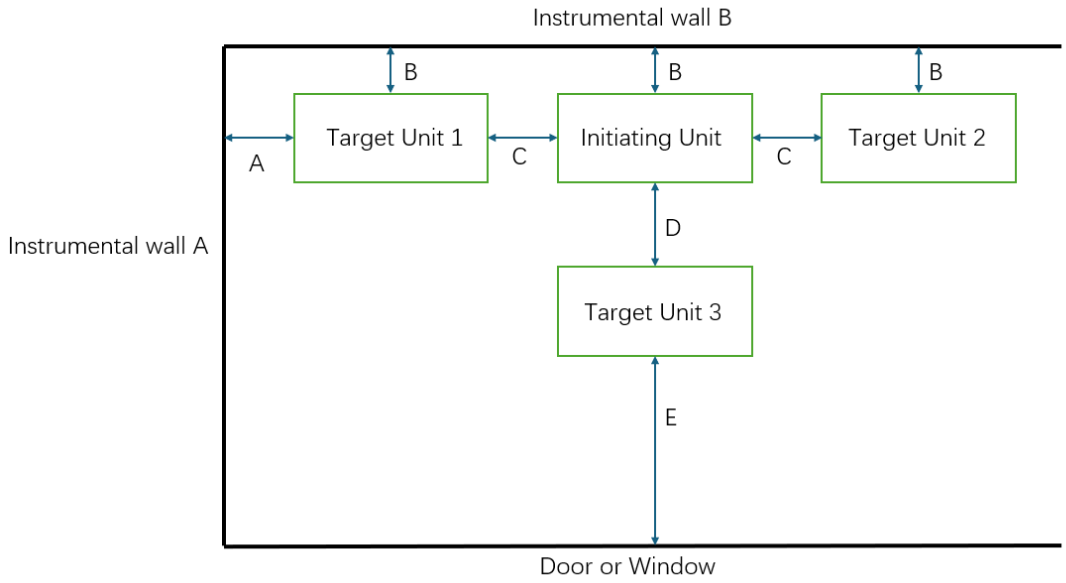
The maximum measured temperature of each location is shown in below table.

Thermocouple No.	Location	Maximum measured temperature (°C)
T16	Metal enclosure, top of the module 1	76.6
T17	Metal enclosure, bottom of the module 3	131.2

To monitor the surface temperature of instrumental walls, vertical array at 152 mm intervals for the full height of the instrumented wall sections using Type K, 30 AWG thermocouples were used.

The thermocouple array A was on the right surface of target unit 1, collinear with vertical central line of initiating unit left surface.
The thermocouple array B was on instrumental wall B, collinear with vertical central line of initiating unit back surface.
The thermocouple array C was on the left surface of target unit 2, collinear with vertical central line of initiating unit right surface.
The thermocouple array D was on the back surface of target unit 3, collinear with vertical central line of initiating unit front surface.

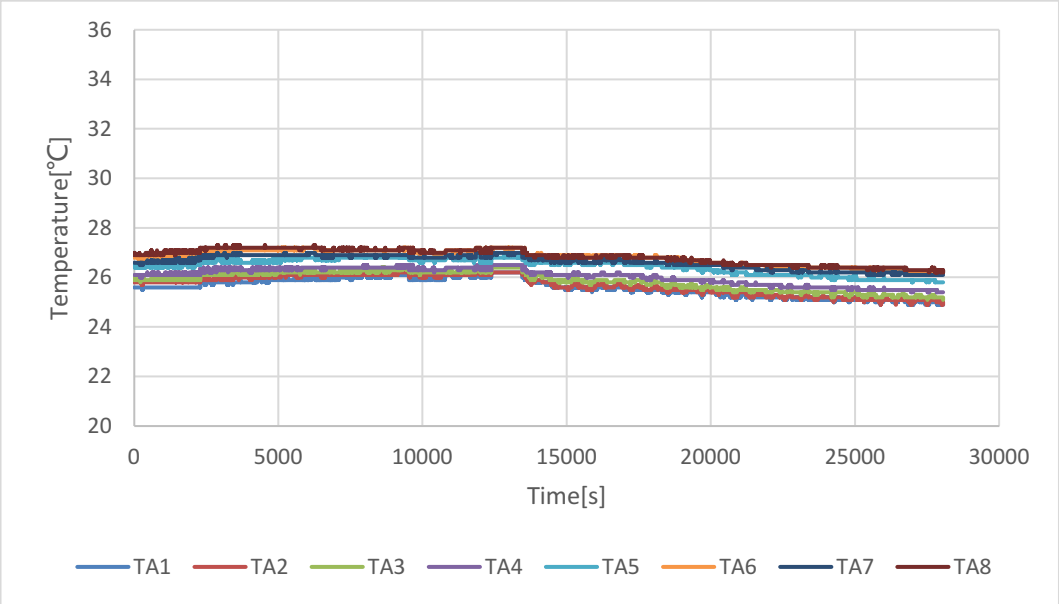
The detailed locations of the thermocouple arrays are shown in the below figure.



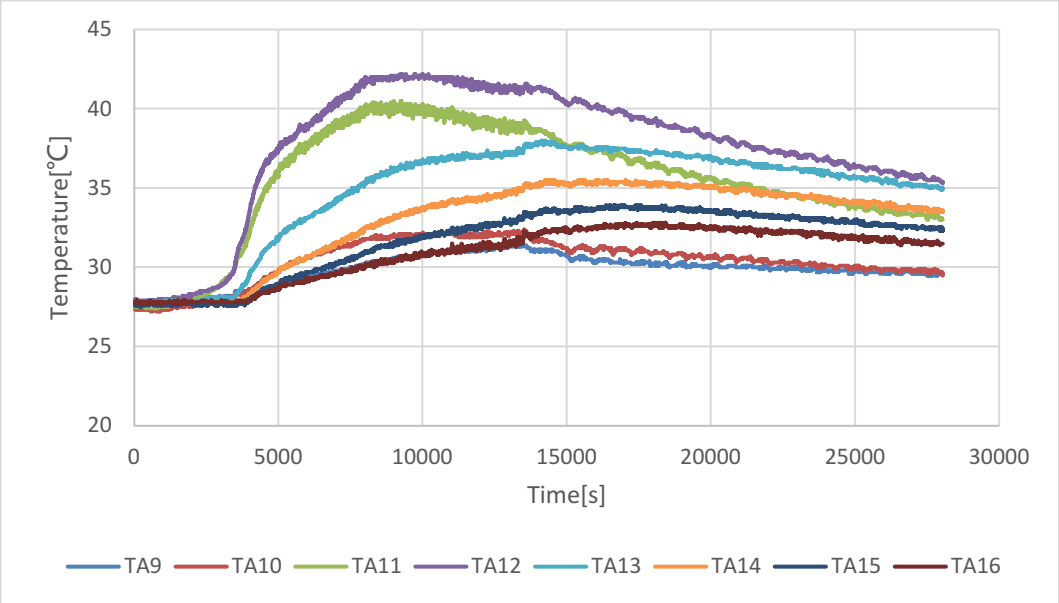
Thermocouple array location (view side: top view)

The first thermocouple starts from 152 mm from the ground. A total of 23 thermocouples were used for array A, array B and array C. The thermocouples were numbered from low to high as TA1 to TA8 for thermocouple array A. TA9 to TA16 for thermocouple array B. TA17 to TA24 for thermocouple array C. TA25 to TA32 for thermocouple array D.

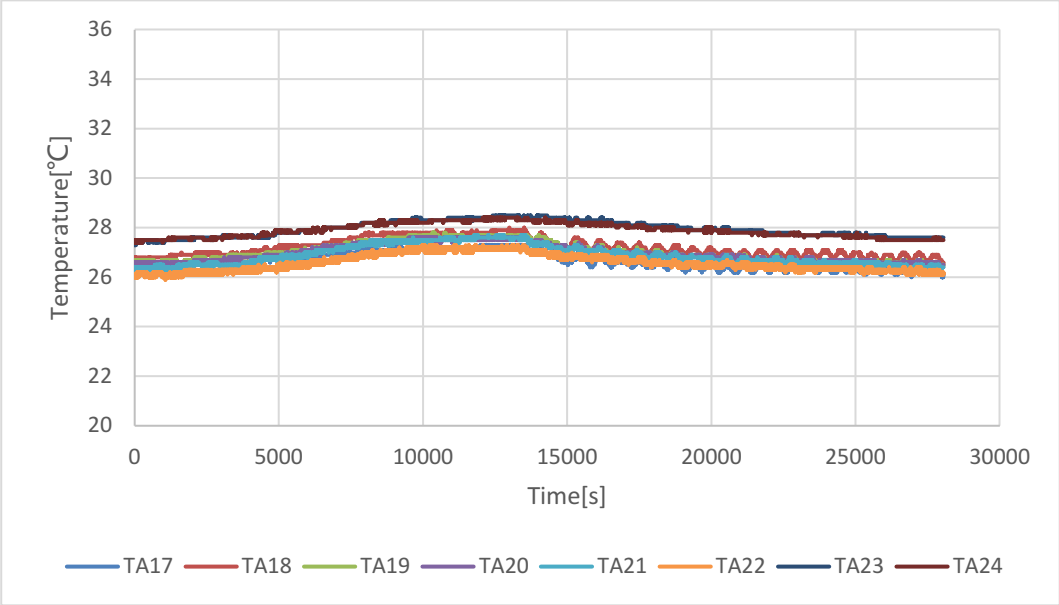
The measured surface temperature of the right surface of target unit 1 during test is shown in below figure.



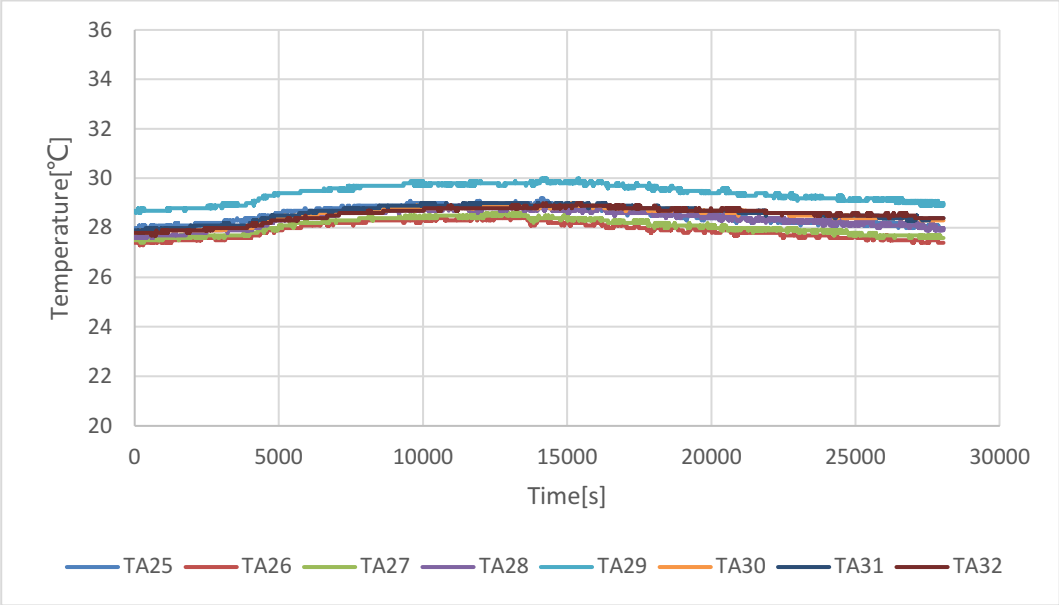
The measured surface temperature of instrumental wall B during test is shown in below figure.



The measured surface temperature of the left surface of target unit 2 during test is shown in the figure below.



The measured surface temperature of the back surface of target unit 3 during test is shown in the figure below.

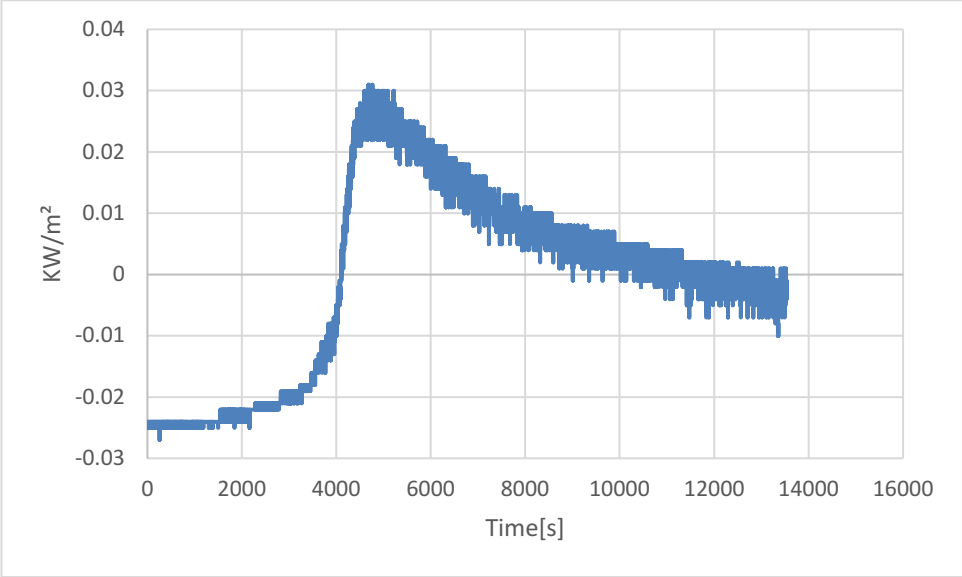


The maximum measured surface temperature of each location on the right surface of target module 1, instrumental wall B and the left surface of initiating module 3 is shown in the below table.

Thermocouple No.	Maximum temperature (°C)
Surface temperature on the right surface of target unit 1	
TA1	26.2
TA2	26.3
TA3	26.4
TA4	26.5
TA5	26.9
TA6	27.2
TA7	27.0
TA8	27.3
Surface temperature on wall B	
TA9	31.4
TA10	32.4
TA11	40.5
TA12	42.2
TA13	38.0
TA14	35.5
TA15	33.9
TA16	32.8
Surface temperature on the left surface of target unit 2	
TA17	27.3
TA18	28.0
TA19	27.8
TA20	27.7
TA21	27.7
TA22	27.3
TA23	28.5
TA24	28.4
Surface temperature on the back surface of target unit 3	
TA25	29.2
TA26	28.5
TA27	28.6
TA28	28.9
TA29	30.0
TA30	29.0
TA31	29.0
TA32	29.0

Attachment 7 Heat flux measurements

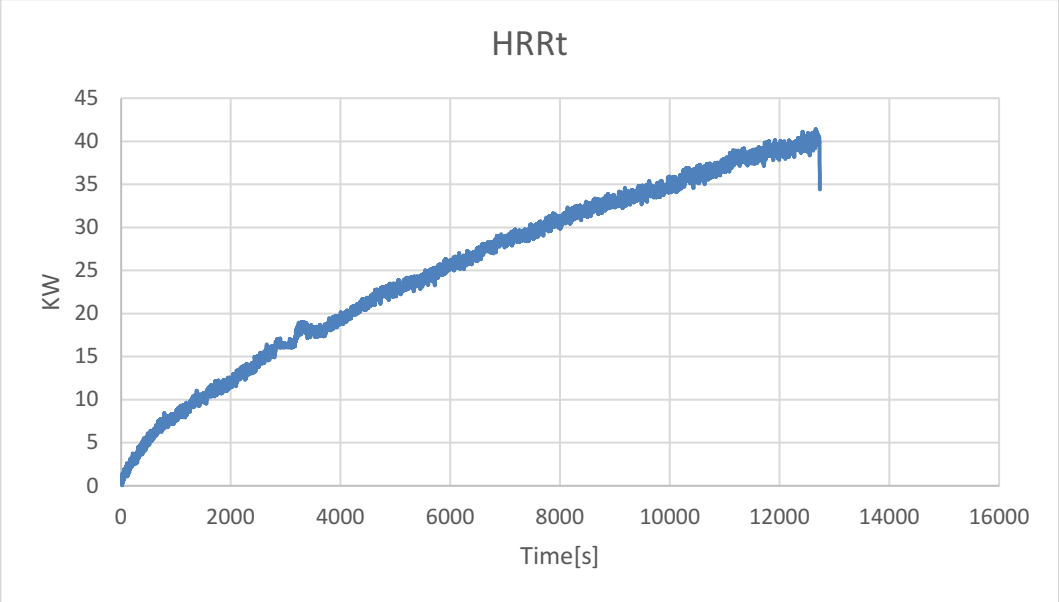
Measure Heat flux in the center of the accessible means of egress: 0.031KW/m²



Attachment 8 Chemical heat release rate measurement

The chemical heat release rate was measured by a measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, 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 HRRt: 41.41kW.



Chemical heat release rate (HRRt) versus time data curve

Attachment 9 Convective heat release rate measurement

The convective heat release rate was 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:

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

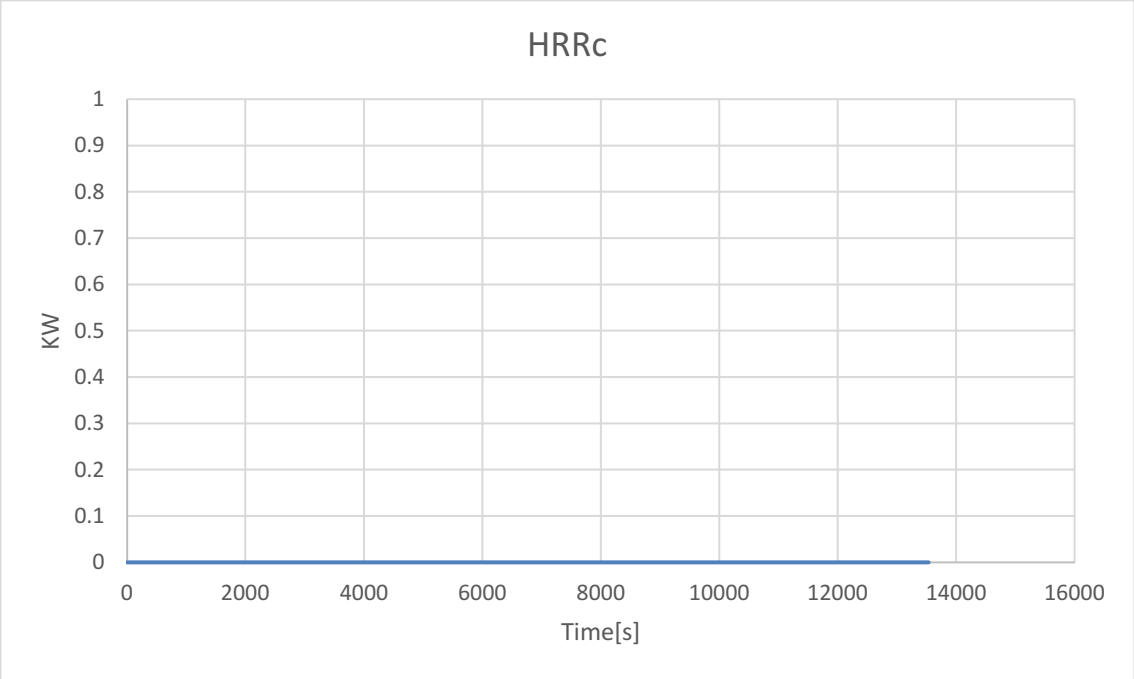
Where:

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/m^3)
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.



Convective heat release rate (HRRc) versus time data 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, a heat conduction sensor and an electrochemistry sensor.

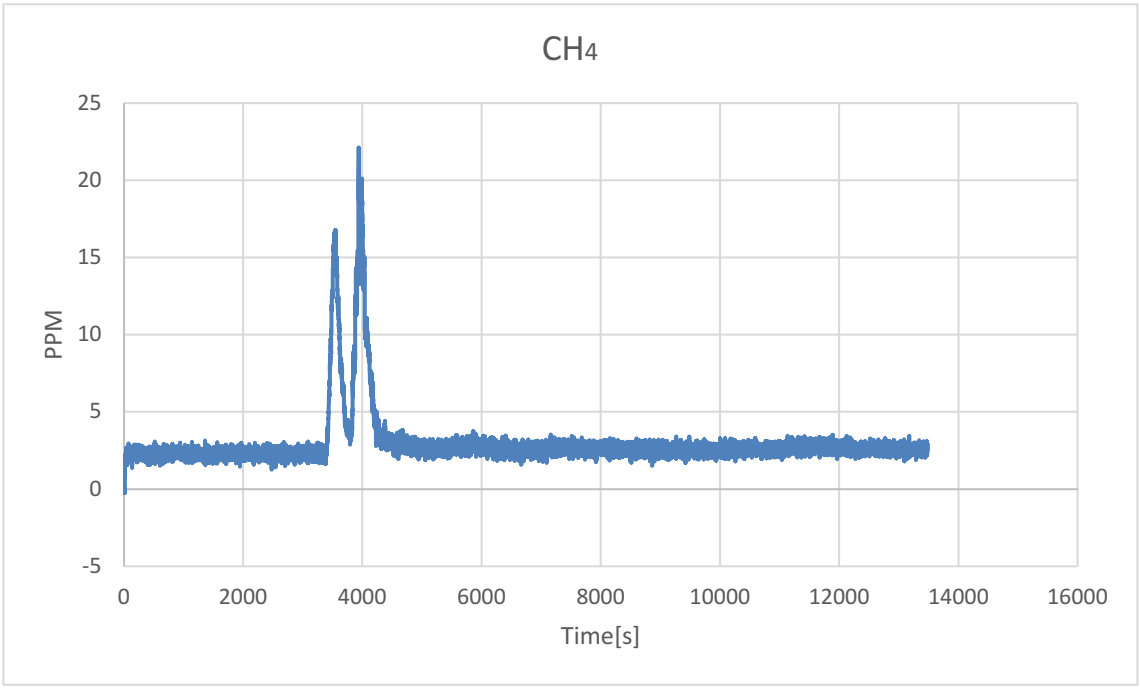
The Hydrogen was not detected by the palladium-nickel thin-film solid state sensor and heat conduction sensor. The Hydrogen content value in the below table was measured by electrochemistry sensor.

The gas composition and volume are shown in the below table.

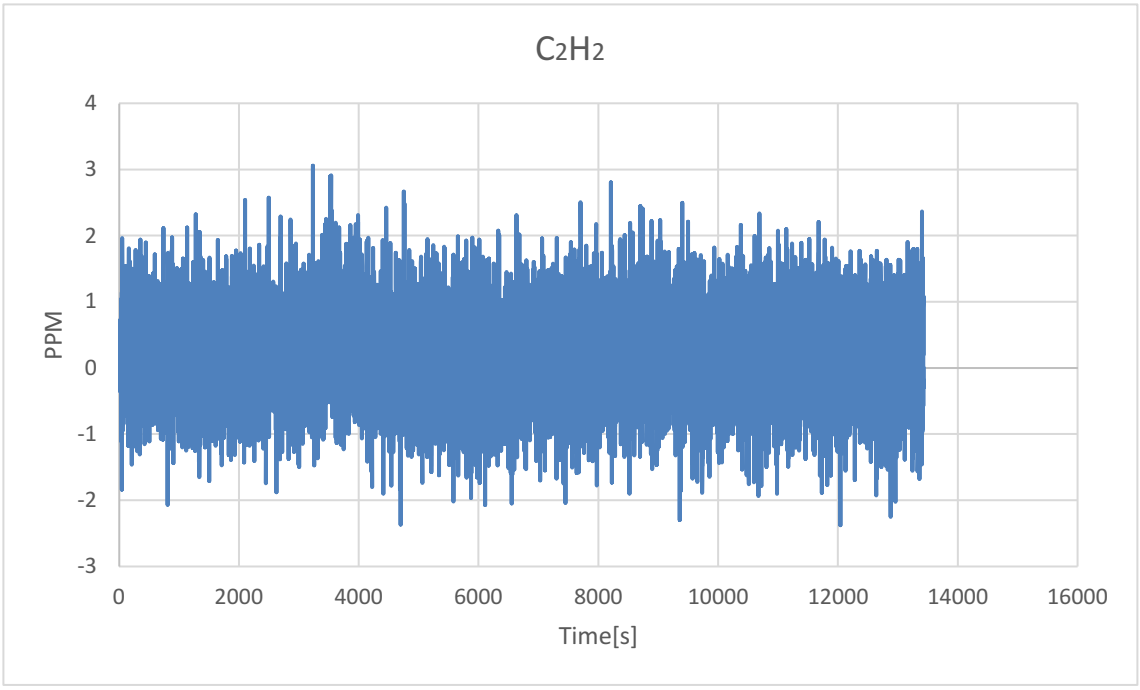
Gas type	Gas components		Total volume of gas (L)
Hydrocarbon species	Methane	CH_4	18.10
	Acetylene	C_2H_2	1.03
	Ethylene	C_2H_4	10.53
	Ethane	C_2H_6	2.09
	Propylene	C_3H_6	10.42
	Propane	C_3H_8	0.11
Hydrogen halide species	Hydrogen Fluoride	HF	1.28
Nitrogen containing species	Nitrogen Monoxide	NO	0.10
Other species	Carbon Monoxide	CO	17.40
	Carbon Dioxide	CO_2	59.51
	Ethylmethyl carbonate	C_4H_8O	14.00
	Oil as octane	--	1.24
	Hydrogen	H_2	45.54
Total Hydrocarbons (equivalent to CH_4, measured by FID)			9.21

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

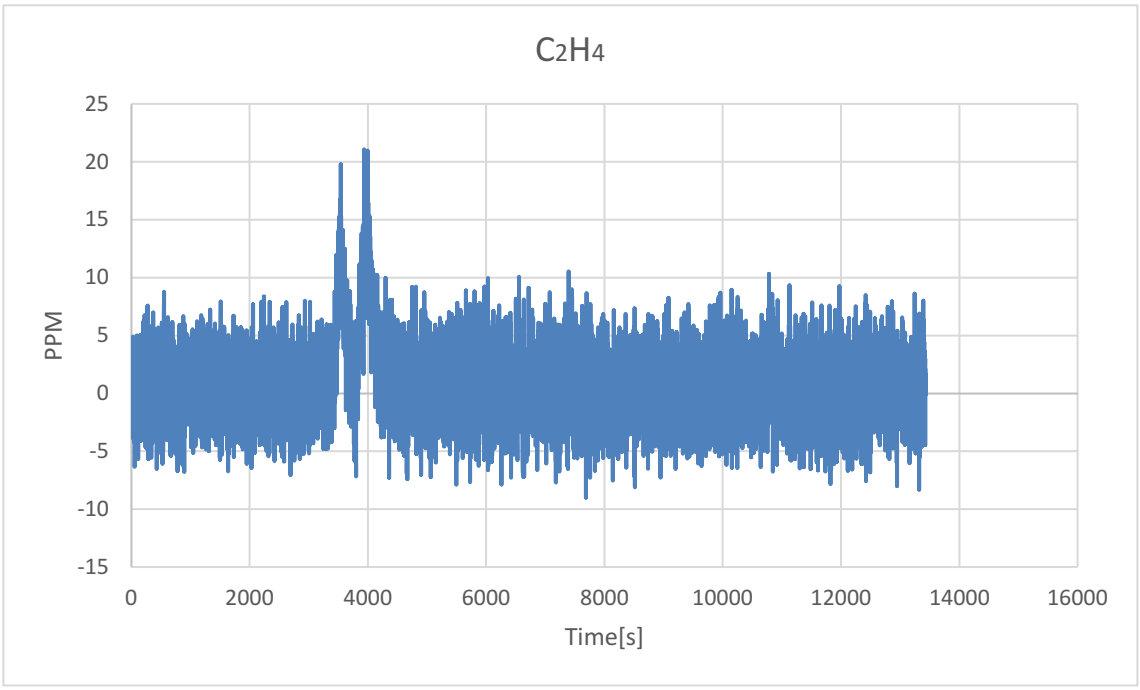
Hydrocarbon species



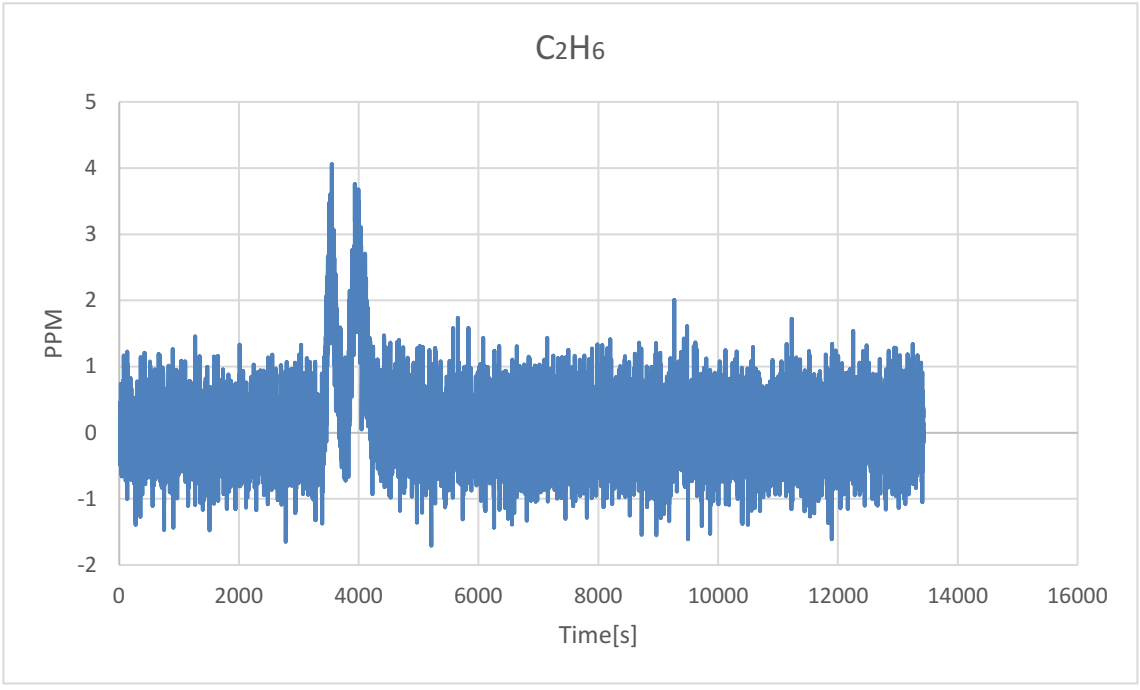
Concentration of Methane (CH_4)



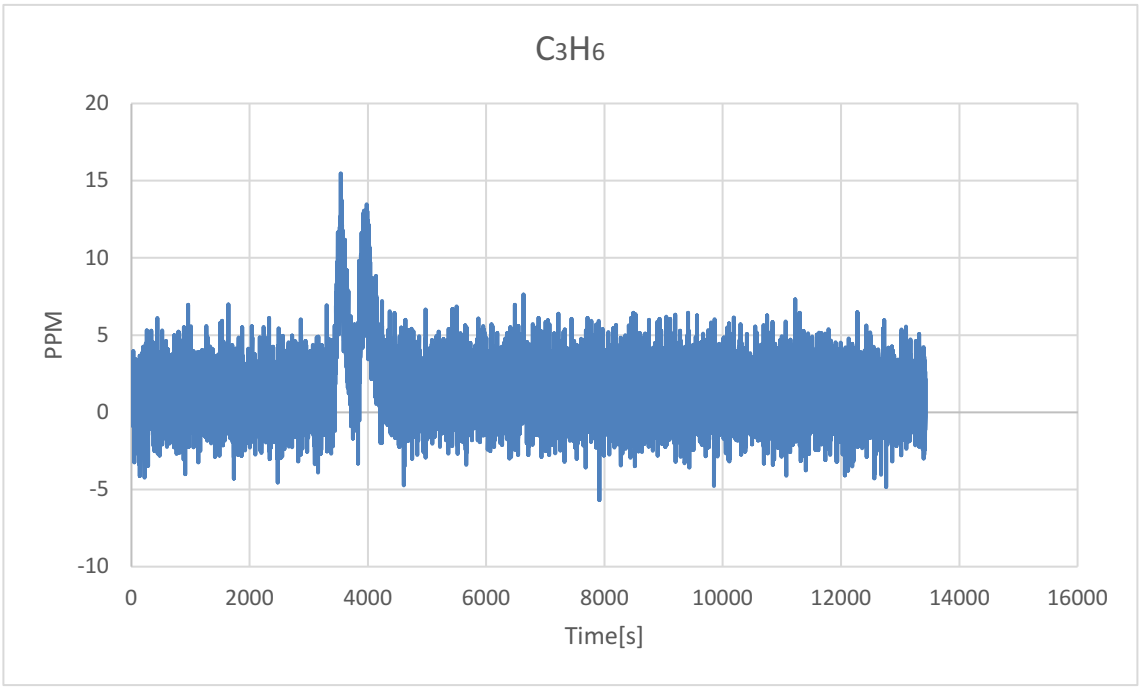
Concentration of Acetylene (C_2H_2)



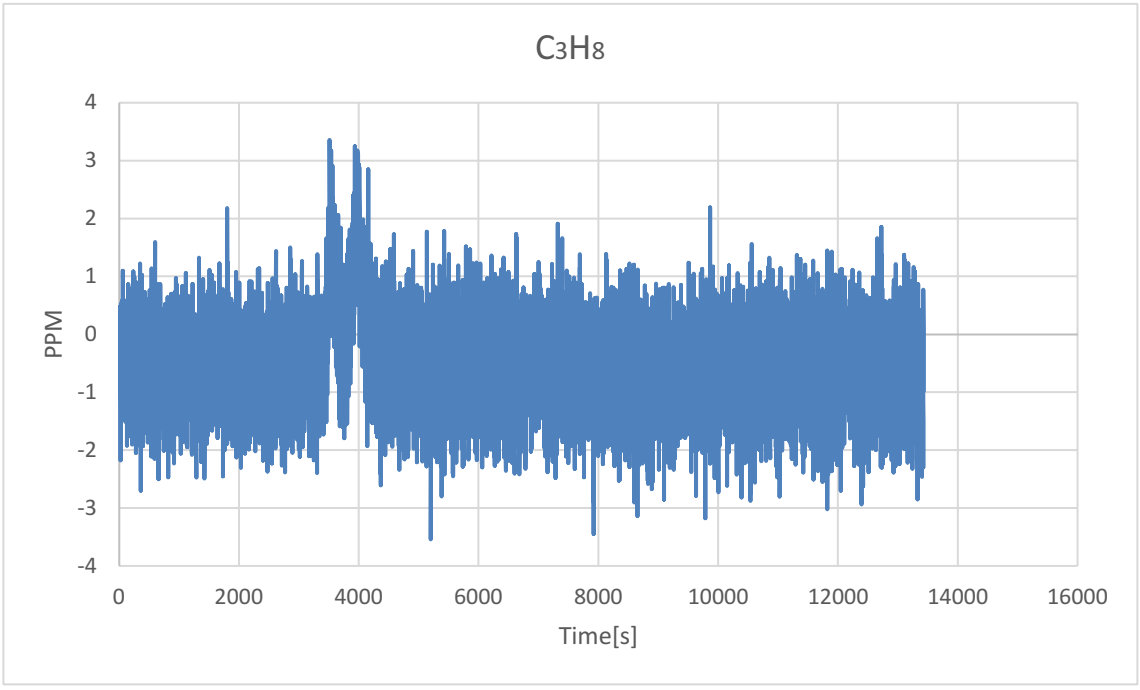
Concentration of Ethylene (C_2H_4)



Concentration of Ethane (C_2H_6)

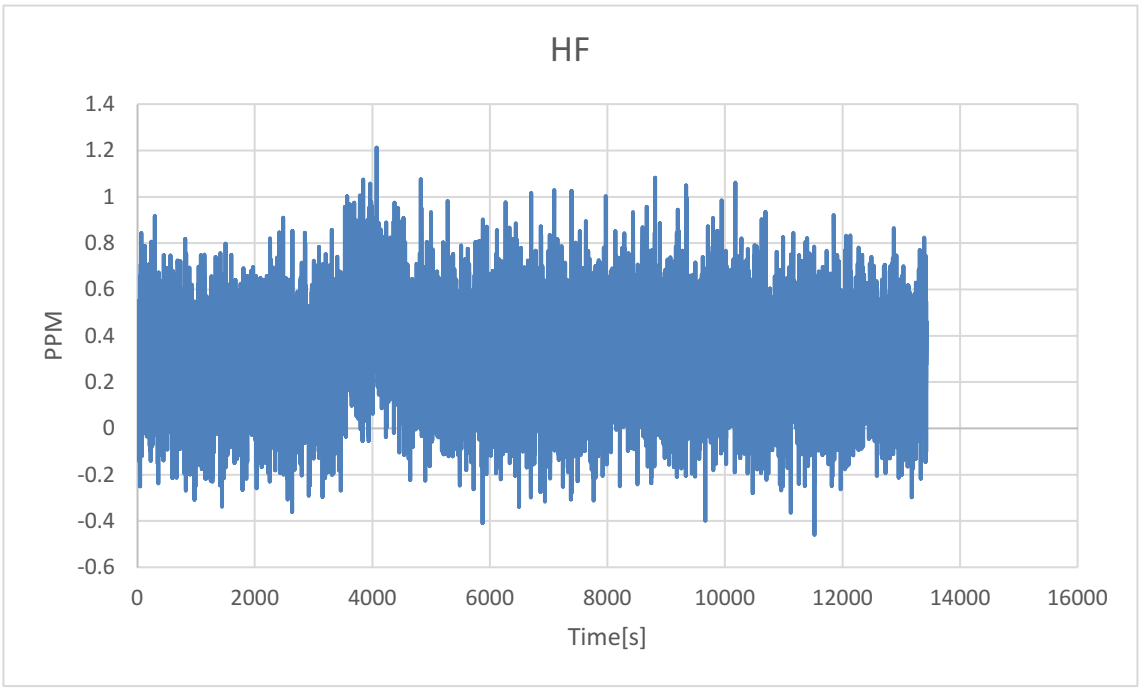


Concentration of Propylene (C_3H_6)



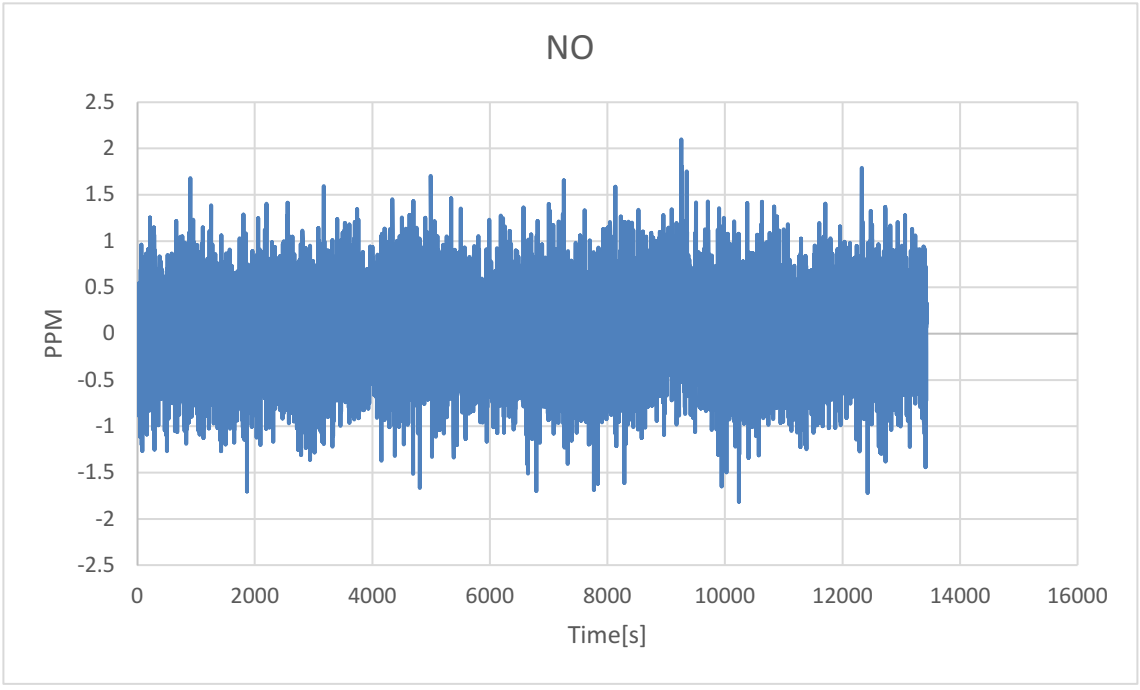
Concentration of Propane (C_3H_8)

Hydrogen halide species



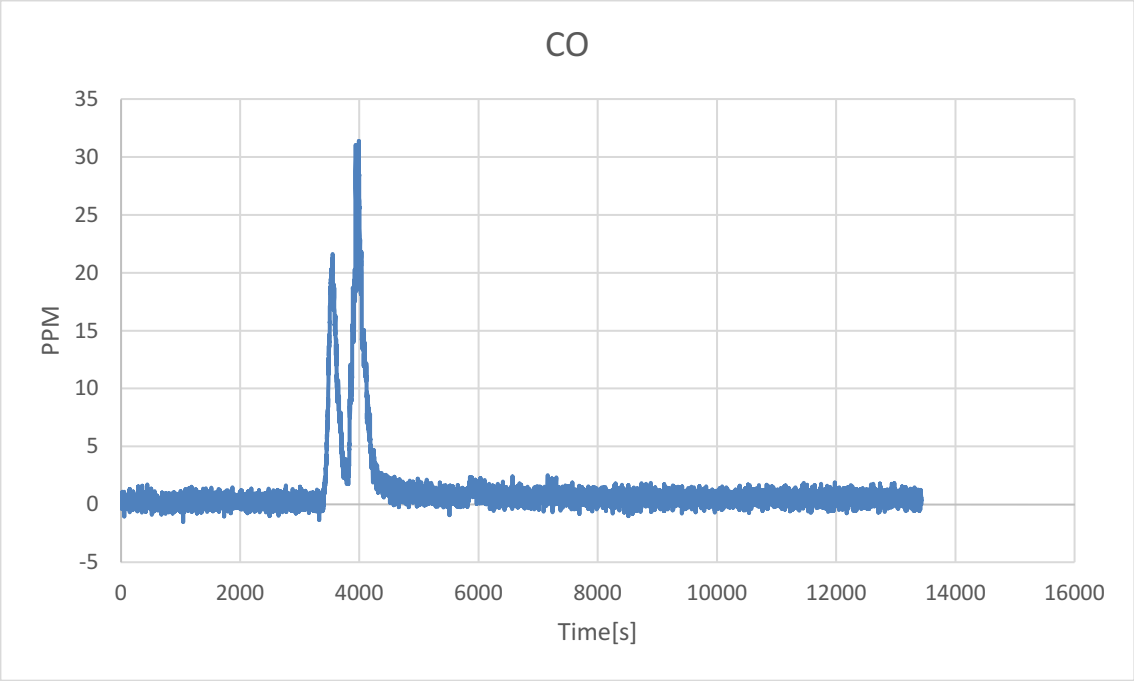
Concentration of Hydrogen Fluoride (HF)

Nitrogen containing species

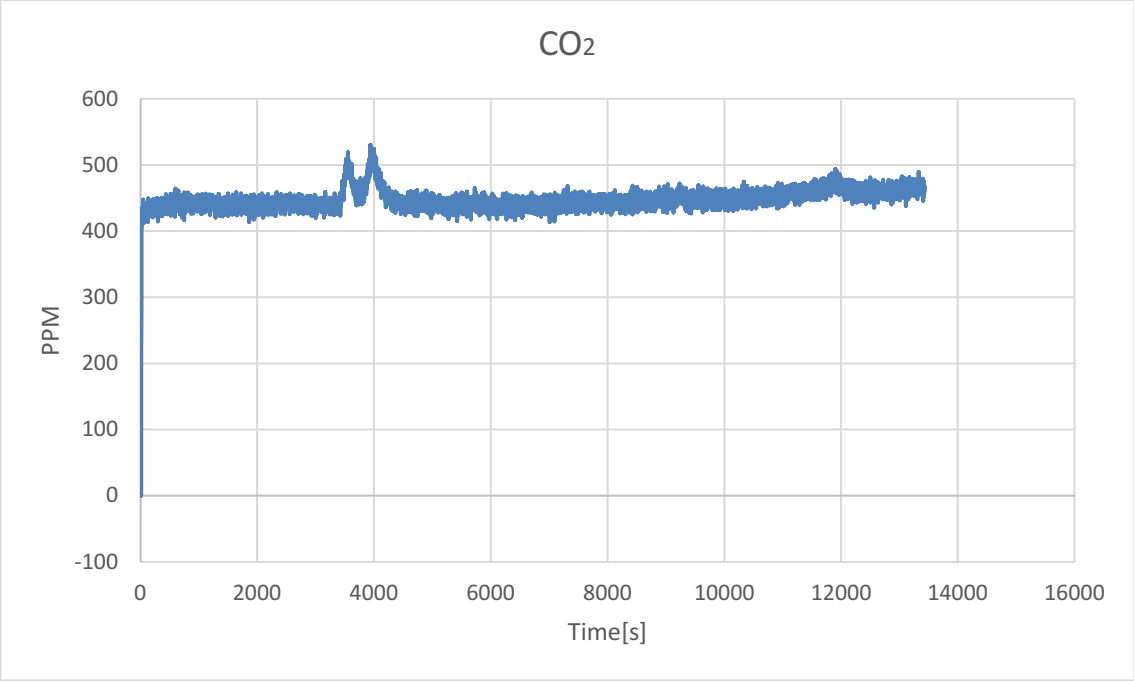


Concentration of Nitrogen Monoxide (NO)

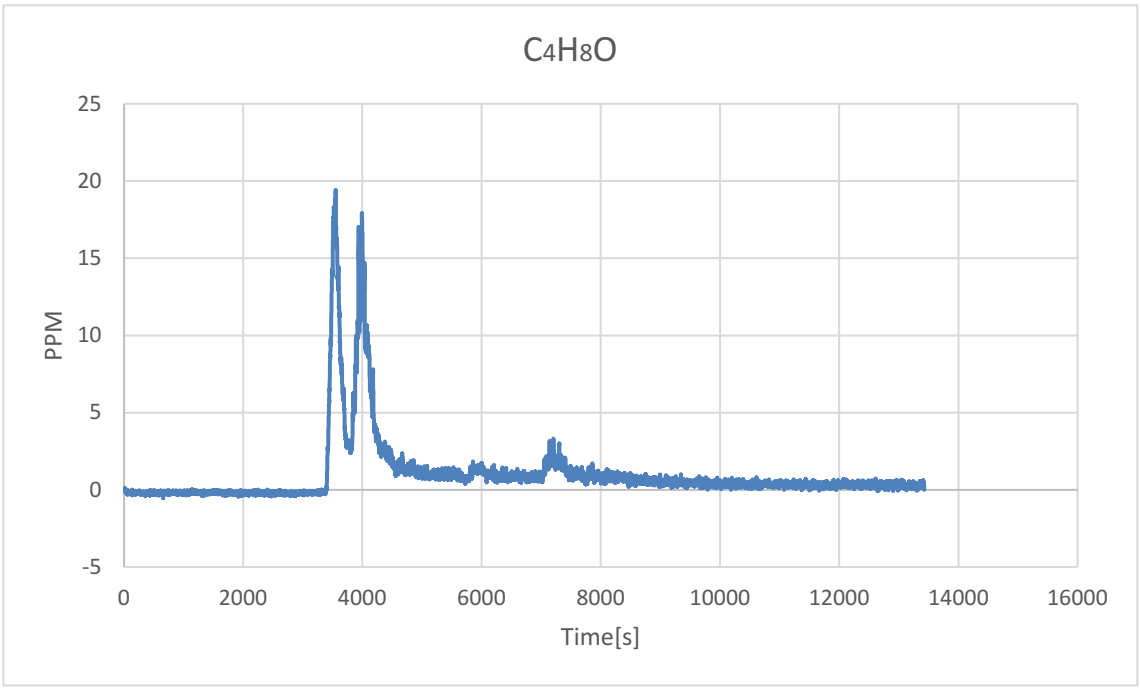
Other species



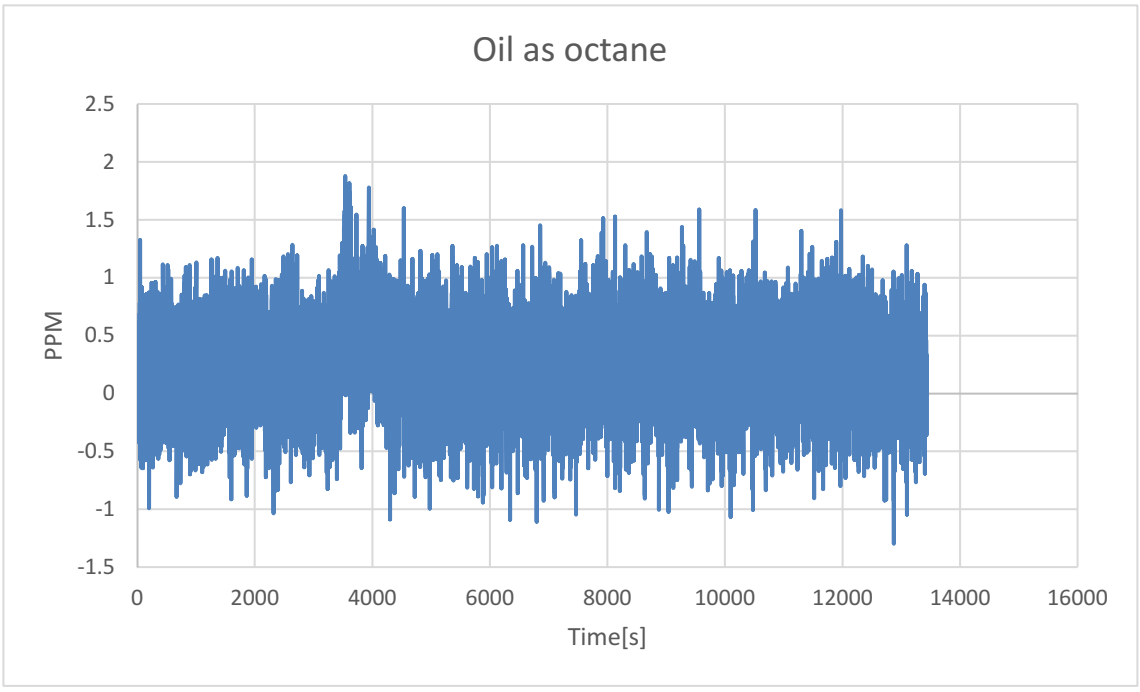
Concentration of Carbon Monoxide (CO)



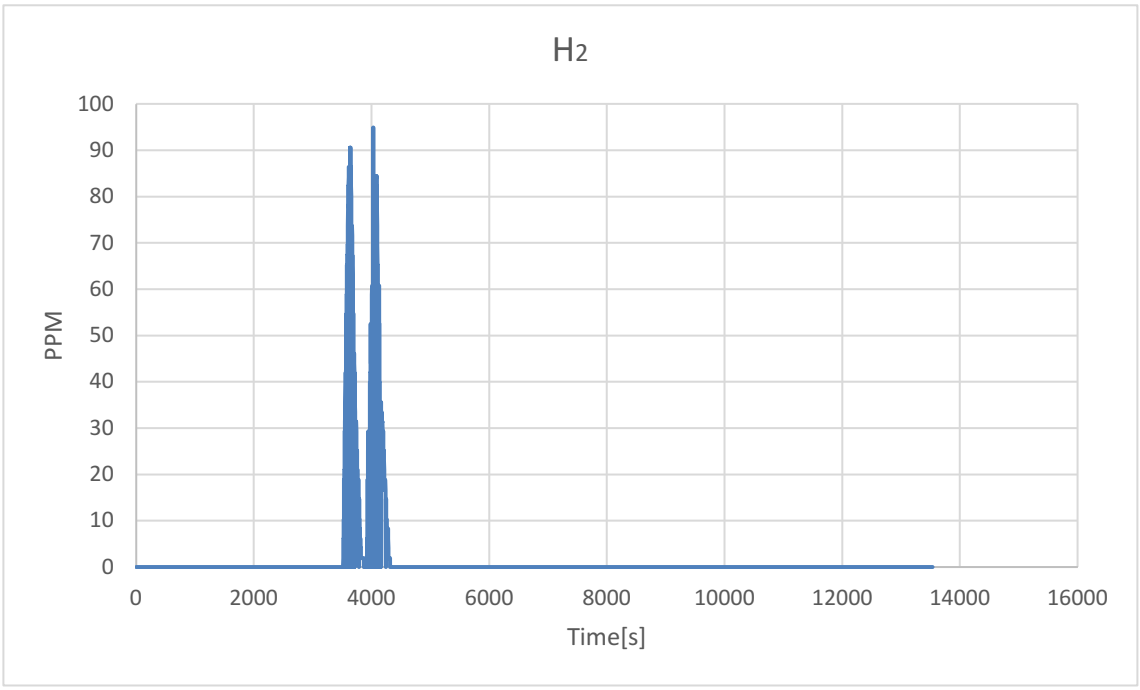
Concentration of Carbon Dioxide (CO_2)



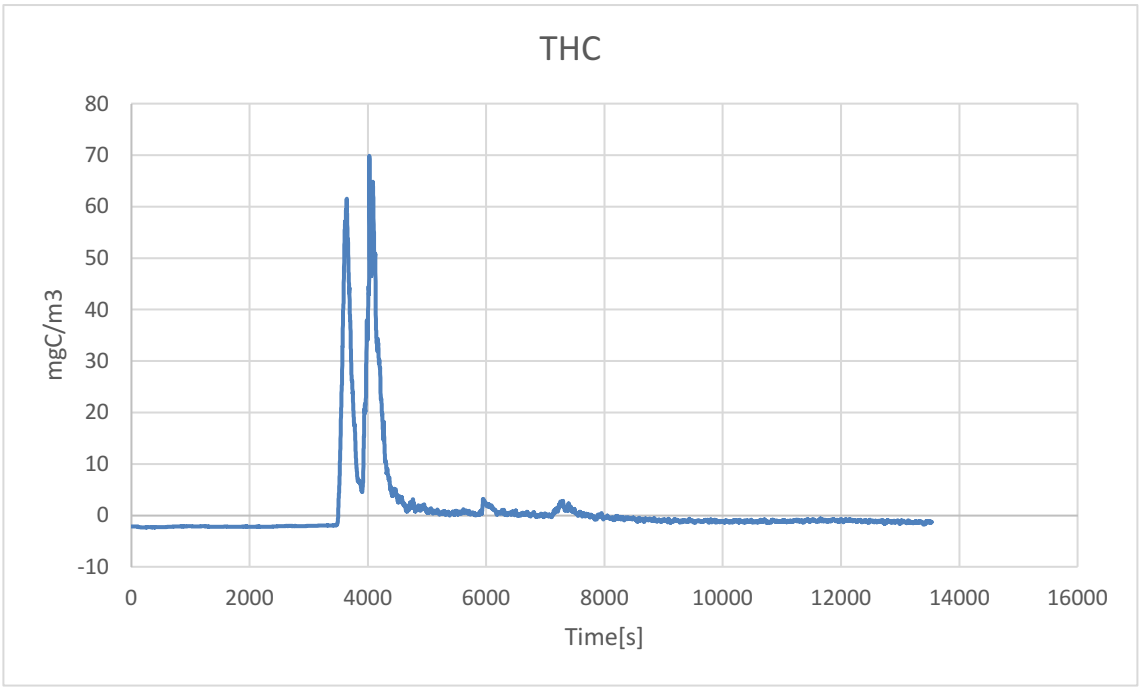
Concentration of Ethylmethyl carbonate(C_4H_8O)



Concentration of Oil as octane



Concentration of Hydrogen (H_2)
Electrochemical sensor



Concentration of total hydrocarbons (measured by FID)

Attachment 11 Smoke release rate measurement

Smoke release rate shall be calculated as follows:

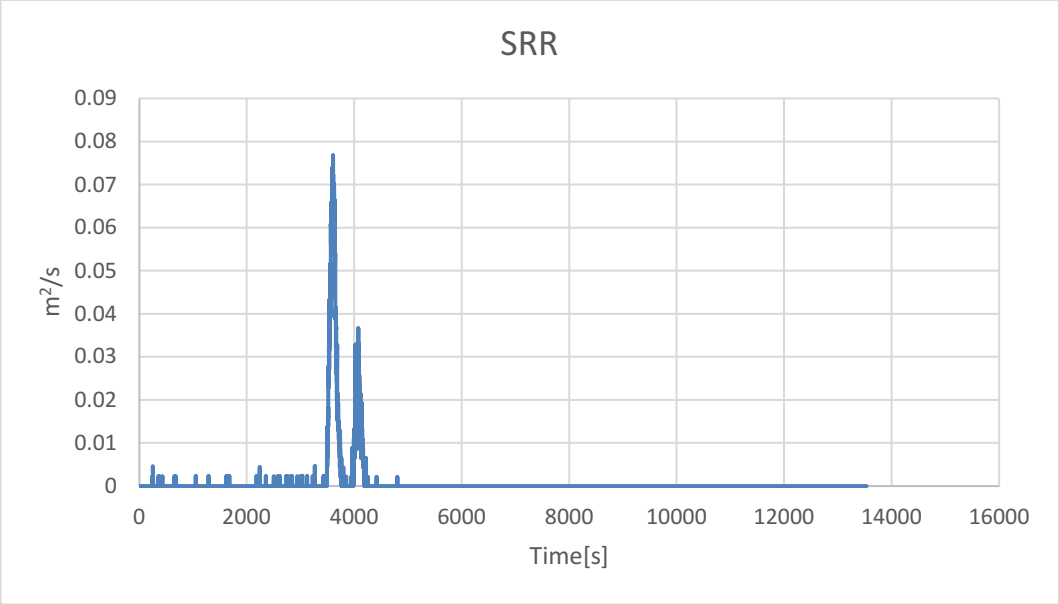
$$SRR = 2.303\left(\frac{V}{D}\right) Log_{10}\left(\frac{I_o}{I}\right)$$

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)

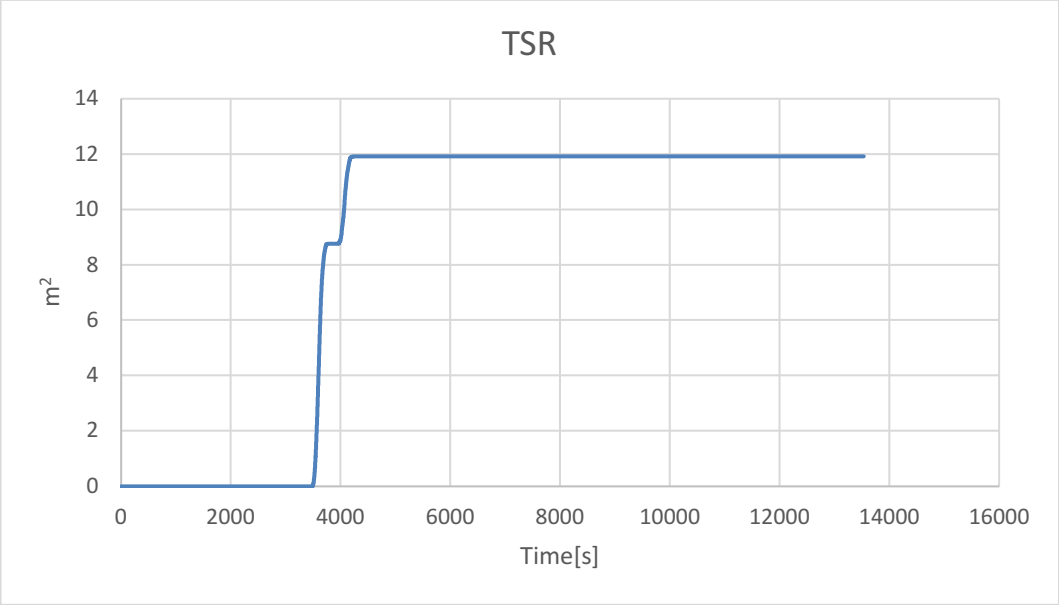
The smoke release rate measurement system was self-checked using calibrated light filter before test.

Measured peak smoke release rate SRR: 0.0768m^2/s
Measured total smoke release TSR: 11.92m^2

Smoke release rate (SRR) versus time data curve



Total smoke release (TSR) versus time data curve



Attachment 12 Equipment list

No.	Equipment	Model	Rating	Inventory no.	Initial cal. date
1	Digital Temperature-Humidity Recorder	RS210	0%~ 100%RH, -20~70°C	SA047-106	2024-09-11
2	Digital multi-meter	175C	0~1000Vdc, 0~1000Vac	SA012-194	2024-07-24
3	Charge /discharge equipment	BAT-NE-250-V001	Max 900V, 400A	SA064-40	2024-07-23
4	3MW lithium battery heat release calorimeter	RHR	0-1100°C, 0~0.4Mpa	SA200-69	2024-09-27
5	Gas analyzer	AO2020	O_2: 0-25%, CO_2: 0-10%, CO: 0-1%	SA200-69-01	2024-08-27
6	Gas mass flowmeter	HZ020-LK2-S-L-C13-R4-DI2-DB9M-050-500-101	0-500SLPM	SA200-69-02	2024-04-28
7	The total hydrocarbon gas analyzer	EL3020	TCH: 0-10000ppm, CH_4: 0-10000ppm, C_3H_8: 0-3300ppm	SA200-70	2024-08-27
8	Palladium-nickel hydrogen analyzer	H2SCAN710B	H_2:0.1%-10%	SA200-71	2024-08-23
9	On-line Fourier infrared analyzer	MKS 6030	500cm-1~4200cm-1, 0.01ppm-100%	SA200-76	2024-01-10
10	Temperature and voltage acquisition device	79 channels	0-1100°C, 0-500V, 0-10V,	SA200-73	2024-08-23
11	Electrochemical hydrogen analyzer	JXB5-J001-H2-Y05	0-1000ppm	SA200-74	2024-01-10
12	Electronic weighing scale	SCS	10~3000kg	SA028-59	2023-12-07

End of test report

Legenda toegepaste uitzonderingsgrondslagen

In dit document zijn gegevens definitief geanonimiseerd op grond van:

Wet	Artikel	Omschrijving	Pagina's
Wet open overheid	Art. 5.1 lid 2 sub e	De eerbiediging van de persoonlijke levenssfeer	1