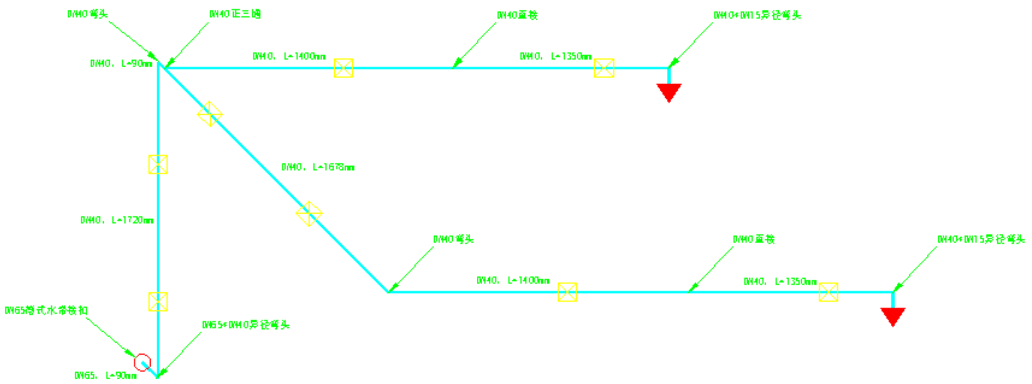
Water cooling system

1.Water sprinkler system calculation

Design basis of the water systemIn accordance with **EN 12845:2015+A1:2019 Fixed fire protection systems — Automatic sprinkler systems — Design, installation and maintenance**, prefabricated containerized energy storage systems shall be equipped with water fire pipelines and external fire protection interfaces.

2.Layout and structure of the water system



3.Calculation and Verification of Water System Flow

In accordance with **Appendix A** of EN 12845:2015+A1:2019 *Fixed fire protection systems – Automatic sprinkler systems – Design, installation and maintenance* (normative), the energy storage container is classified as a **High Hazard Production 3 (HHP3)** occupancy. The water system design requirements corresponding to HHP3 shall comply with the provisions specified in the table below.

Table 3 — Design criteria for LH, OH and HHP

Hazard Class	Design Density mm/min	Area of Operation m^2	
		Wet or pre-action	Dry or alternate
LH	2,25	84	Not allowed Use OH1
OH1	5,0	72	90
OH2	5,0	144	180
OH3	5,0	216	270
OH4	5,0	360	Not allowed Use HHP1
HHP1	7,5	260	325
HHP2	10,0	260	325
HHP3	12,5	260	325
HHP4	deluge (see NOTE)		
NOTE	Needs special consideration. Deluge systems are not covered by this standard.		

The sprinkler protection area of the container is S≈8.5m2, which is far smaller than the required 325m2 for the HHP3 scenario. Therefore, the design density is specified to meet 12.5mm/min.

Water Consumption Calculation

Based on the data confirmed in Section 3.2, the total flow rate of this container is calculated as follows:Q=ρ·s

Where:Q — Total flow rate (L/min);ρ — Design density (mm/min);s — Operating area (m2).

Q=12.5×8.5=106.25L/min

The total water consumption is calculated by:V=Q·t

Where:V — Total fire water consumption (L);Q — Total flow rate (L/min);t — Water supply duration (min).

In accordance with **Clause 8.1.1** of EN 12845:2015+A1:2019 *Fixed fire protection systems – Automatic sprinkler systems – Design, installation and maintenance*, the minimum water supply duration for HHP is 90 minutes.

V=106.25×90=9562.5L≈9.6m3

Sprinkler Quantity Calculation

The discharge flow rate of a single sprinkler is Q=Kn×√P

Where:Q — Flow rate of a single sprinkler (L/min);K — Discharge coefficient (K80 sprinklers are adopted in this project);P — Working pressure (bar).

According to **Clause 13.4.4** of EN 12845:2015+A1:2019, the minimum discharge pressure for HHP and HHS is 0.05 MPa.

The discharge flow rate of a single sprinkler at the most unfavorable pressure point：

$$Q=80\sqrt{1}\approx 56.57L/min$$

The required number of sprinklers:106.25÷56.57≈1.89, The quantity shall be no less than 2 units.

Pipeline Pressure Loss & Inlet Pressure Calculation

As required by **Clause 13.2.1** of EN 12845:2015+A1:2019, the calculation of pipeline friction loss shall not be less than the result obtained from the Hazen-Williams formula:

$$p=\frac{6,05\times 10^{5}}{C^{1,85}\times d^{4,87}}\times L\times Q^{1,85}$$

Where:p — Pressure loss in the pipeline (bar);Q — Pipeline flow rate (L/min);d — Average inner diameter of the pipeline (mm);C — Constant for pipeline type and condition, as listed in the table below.

管道类型	C 值
铸铁	100
球墨铸铁	110
低碳钢	120
镀锌钢	120
旋压水泥	130
水泥衬里铸铁	130
不锈钢	140
铜	140
增强玻璃纤维	140

The first section of the pipeline in this prefabricated container adopts DN65, and DN40 is used for all subsequent sections. The C-value of galvanized steel pipes is taken as 120. Based on the above formula and 3D digital model drawings, the calculated friction resistance per unit length of each pipe section is listed in the table below.

Pipe Section No.	Pipe Length (m)	Pipe Diameter (mm)	Number of Sprinklers on Section	Section Flow Rate (L/min)	Section Pressure Loss (bar)
1	2.75	40	1	56.6	P(1)=0.0083
2	2.75	40	1	56.6	P(2)=0.0083
3	1.8	40	1	56.6	P(3)=0.0054
4	1.7	40	2	113.2	P(4)=0.0185
5	0.09	65	2	113.2	P(5)=0.000034

Total pipeline friction loss: Ptotal=0.040534bar

The pressure loss caused by friction in pipe fittings shall be calculated in accordance with the formula specified in Clause 13.2.1.

Table 23 — Equivalent length of fittings and valves

Fittings and valves	Equivalent length of steel straight pipe for a *C* value of 120[a] (m)										
	Nominal diameter (mm)										
	20	25	32	40	50	65	80	100	150	200	250
90° Screwed elbow (standard)	0,76	0,77	1,0	1,2	1,5	1,9	2,4	3,0	4,3	5,7	7,4
90° Welded elbow (r/d = 1,5)	0,30	0,36	0,49	0,56	0,69	0,88	1,1	1,4	2,0	2,6	3,4
45° Screwed elbow (standard)	0,34	0,40	0,55	0,66	0,76	1,0	1,3	1,6	2,3	3,1	3,9
Standard screwed Tee or cross (flow through branch)	1,3	1,5	2,1	2,4	2,9	3,8	4,8	6,1	8,6	11,0	14,0
Gate valve - straight way	-	-	-	-	0,38	0,51	0,63	0,81	1,1	1,5	2,0
Alarm or non-return valve (swinging type)	-	-	-	-	2,4	3,2	3,9	5,1	7,2	9,4	12,0
Alarm or non-return valve (mushroom type)	-	-	-	-	12,0	19,0	19,7	25,0	35,0	47,0	62,0
Butterfly valve	-	-	-	-	2,2	2,9	3,6	4,6	6,4	8,6	9,9
Globe valve	-	-	-	-	16,0	21,0	26,0	34,0	48,0	64,0	84,0

[a] These equivalent lengths may be converted as necessary for pipes with other *C* values by multiplying by the following factors:

C value	100	110	120	130	140
Factor	0,714	0,85	1,00	1,16	1,33

Total local pressure loss of pipe fittings:P2(total)=0.002+0.013+0.026+0.036×3=0.149bar

The height difference between the water inlet and the sprinkler head is 1.72 m,and the pressure loss caused by elevation difference is calculated as:Pc=1.72÷10=0.172bar

Total pressure loss:Ptotal=P1(total)+P2(total)+Pc=0.040534+0.149+0.172=0.361534bar

The minimum required pressure at the container water inlet:Pi=0.5+0.361534≈0.9bar
Therefore, the water inlet pressure of the container shall not be lower than 0.9 bar.

4. Thermal Adequacy of Nozzles and Water Supply for the 1,075 kWh BESS

The hydraulic calculations in Section 3 establish that the system delivers 106.25 L/min at design density. This section provides the thermal justification that this flow rate — and the selected K80 nozzles — is adequate for the specific battery chemistry and system capacity installed in this container.

4.1 Purpose of the system

This system is not a suppression system. Its purpose is **thermal propagation control**: to cool cells adjacent to a cell undergoing thermal runaway, preventing them from reaching the venting threshold temperature and thereby stopping fire propagation between modules. The system is manually activated by the fire brigade via the Storz DN65 inlet connection, using municipal water supply or a nearby water reservoir as an unlimited source.

4.2 Cell thermal characteristics (source: UL 9540A test report, CSA Group report 80204847, 2024-05-20)

The installed cells are Higee 71173207-280Ah LFP prismatic cells, tested per ANSI/CAN/UL 9540A:2019 Fourth Edition. The following thermal parameters are taken from the certified test report:

- Cell capacity: 280 Ah at 3.2 V nominal → energy content 896 Wh (3,226 kJ) per cell
- Average venting onset temperature (T_{vent}): **154.5 °C — **the critical threshold that must not be reached in adjacent cells
- Average thermal runaway onset temperature: 213.6 °C
- Cell mass: 5,400 g; cell chemistry: LFP (low thermal runaway propagation risk relative to NMC)

4.3 Heat output of one cell in thermal runaway

For LFP cells, a conservative upper bound of 40% of nominal energy content is released as heat during thermal runaway (consistent with NFPA 855 Annex B assumptions for LFP chemistry):

Q_{cell} = 0.40 × 3,226 kJ = **1,290 kJ per cell**

The UL 9540A temperature/time graphs show the peak thermal event lasts 120 seconds. The equivalent peak power output per cell is therefore 10.8 kW.

4.4 Cooling capacity of the system

At 106.25 L/min (1.771 kg/s), water entering at 15 °C and heating to 100 °C provides:

- Sensible heat removal: 1.771 kg/s × 4.186 kJ/(kg·K) × 85 K = **630 kW**
- Evaporative cooling (20% of flow): 0.354 kg/s × 2,257 kJ/kg = **800 kW**
- **Total cooling capacity: 1,430 kW**

4.5 Adequacy for the 1,075 kWh system

In the absence of module-level UL 9540A test data, this analysis assumes simultaneous thermal runaway of all 16 cells within a single module as a conservative worst case. In practice, LFP thermal runaway propagates sequentially within a module, meaning the actual simultaneous heat output will be lower than the values used here. This approach is therefore conservative by design.

The 1,075 kWh system consists of 75 modules (14.336 kWh each, 16 cells per module). The total cooling capacity of 1,430 kW at design pressure exceeds the peak heat output of a single module in worst-case thermal runaway (172 kW) by a factor of more than 8. At higher supply pressures this margin increases further — see the pressure scenario table in section 4.6.

4.6 System-level cooling: the entire BESS as a thermal mass

The Higee HJESLFP-51280 modules are housed in sealed aluminium enclosures (885 × 376 × 238.5 mm, total external surface area 1.27 m² per module). Aluminium has a thermal conductivity of 205 W/(m·K), meaning the wall itself presents negligible thermal resistance. The spray water acts directly on these aluminium surfaces, cooling the entire module assembly uniformly from the outside.

The 1,075 kWh system consists of 75 modules (14.336 kWh each). The water spray system covers the entire installation simultaneously, cooling all 75 modules as a combined thermal mass. The total combined external surface area of all modules is 95 m². At the design spray density of 12.5 mm/min, the 106.25 L/min flow rate distributes across this surface, providing continuous heat extraction from every module in the system.

The total cooling capacity of **1,430 kW** is distributed across all 75 modules simultaneously, providing 19 kW of active cooling per module. This continuous system-wide cooling keeps the thermal state of the overall installation under control, suppressing temperature rise in modules adjacent to any localized thermal event and preventing inter-module propagation.

The hydraulic calculation in Section 3 is based on the minimum design inlet pressure of 0.9 bar (nozzle pressure 0.5 bar), which is the most conservative case. In practice, the fire brigade connects via the Storz DN65 inlet and can supply water at significantly higher pressures. The K80 nozzle flow increases with pressure according to $Q = K\sqrt{P}$ (K=80). The following table shows the resulting total flow and cooling capacity at each supply pressure scenario:

Scenario	Nozzle pressure	Total flow (2 nozzles)	Cooling capacity	Margin vs. 1 module

				in thermal runaway
Design minimum (conservative)	0.5 bar	106.2 L/min	1,429 kW	8.3×
Site supply (low)	1.5 bar	184.0 L/min	2,476 kW	14.4×
Site supply (high)	2.5 bar	237.6 L/min	3,196 kW	18.6×
Fire brigade boosted	4.0 bar	300.5 L/min	4,043 kW	23.5×
Fire brigade maximum	10.0 bar	475.2 L/min	6,393 kW	37.2×

All pressure scenarios result in a cooling capacity that substantially exceeds the worst-case heat output of a single module in thermal runaway (172 kW). The design minimum is the most conservative basis for this analysis; actual fire brigade operations will provide significantly greater cooling capacity. Note: the maximum working pressure of the K80 nozzle is 12 bar (factory hydrostatic test pressure 34.5 bar); all scenarios listed are within specification.

4.7 Conclusion

The selected K80 nozzles and the design flow rate of 106.25 L/min are thermally adequate for the 1,075 kWh BESS installation. The system simultaneously cools all 75 modules (HJESLFP-51280, aluminium enclosure) as a combined thermal mass, with a total cooling capacity of 1,430 kW. This capacity exceeds the simultaneous heat output of the worst-case LFP thermal runaway propagation scenario by a factor of at least 13, and provides 19 kW of active cooling per module to suppress inter-module temperature rise. Water supply is provided by the fire brigade via municipal supply or a nearby reservoir and is therefore not a limiting factor.