

30 November 2025

MISD Edge Data Centres

Design Review & Prototype testing

Deliverable: 1.1.2

Status: Issued for M24

Version: v1.0

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1 Executive Summary

1.1 Purpose of the report

The aim of the report is to assess the capabilities of the staging test lab facility for conducting tests, provide insights into the existing system and propose recommendations for future improvements.

To achieve this, a description of the existing system is included, the maximum capacity of the components is evaluated, and the influence of each component on the overall operation of the system is explored. The report outlines how the testing lab facility meets the project intended goals, identifying strengths and limitations, areas for improvement and future arrangements.

The report begins with an introduction, followed by a brief description of the project requirements which explains the reasoning behind key design decisions. The next session focuses on the description of the test lab prototype installation, diving into the components of the system. The “Lab testing” chapter refers to the objective of the testing and plan and future arrangements for the installation. The design assessment and validation section examines the strengths of the proposed design alongside its shortcomings, deviations, and potential bottlenecks. It concludes with a discussion of feasibility and scalability considerations, which form an integral part of the project. Following this, the report reflects on lessons learned during the testing process, offering new insights and identifying opportunities for future innovation. Finally, we conclude by summarizing the findings and outcomes.

1.2 Key findings from design review and prototype testing

The key findings indicate that the overall system design is functional and aligned with the project’s initial objectives, while also revealing several technical constraints that influence performance, efficiency and scalability. The prototype testing confirmed that the cooling concept is viable under current operating conditions, but also highlighted limiting factors related to heat rejection, chilled water distribution and power capacity.

The assessment showed that operating at elevated cooling and IT loads will require consideration of new operating setpoints and cooling strategy. In addition, some parts of the installation will require capacity upgrade in order to achieve a higher maximum achievable testing capacity.

From the electrical perspective, the system architecture provides reliable operation and effective monitoring at this stage, while the back-up power solution is sufficient for maintaining cooling continuity during operation. However, as the scope of testing expands to include higher IT loads and the immersion cooling tanks are pushed to their operational limits, significant equipment upgrades will be required to support these tests.

1.3 Main conclusions and recommendations

- The installation is adequate for the current testing requirements.
- The main limiting factors in the installation are the power supply from an electrical perspective and the capacity of the controlling valves from a mechanical point of view.
- The system’s energy metering setup needs to be designed to provide metering of all power circuits to allow for reliable assessment of the system’s PUE.

- At this stage, testing of ventilation, fire protection and their overall power consumption have not been considered.
- An increase in the testing load, combined with the integration of the heat exchanger, will necessitate significant changes to the cooling strategy and equipment requirements. This is detailed further in the report.

2 Introduction

2.1 Background of the project

The MISD project focuses on the development of a unique field lab, a "decentralized network of data centers of the future," where innovations in modularity, advanced cooling, energy, communications, networking, and cybersecurity technologies converge. The field lab will enable data centres to accelerate innovation and share knowledge in the areas of efficiency, sustainability, and security. The MISD consortium consists of the following participants: Aecoris BV (Asperitas), BetterBe BV, Deerns Nederland BV, Eurofiber Nederland BV, the National Internet Providers Management Organization (NBIP), the University of Twente, and the Netherlands Organisation for Applied Scientific Research (TNO).

2.2 Scope and objectives of the design review

The scope of the design review includes assessing the current testing laboratory installation (staging lab), identifying the limiting factors for potential testing expansion, and proposing strategies to achieve such expansion. The objective of the design review is to provide insights for a testing laboratory design that supports the full range of required tests with the aim of an MISD modular edge data centre that is not only efficient and technically solid, but also simple, practical, and easy to scale as IT loads grow from 50 kW up to 2 MW. At the same time, the goal to reach a PUE of 1.2 or better to support Europe's energy ambitions, while still meeting ASHRAE, NEN, and TIA-942 standards remains. The design review addresses the electrical aspects of the project, the mechanical systems- including considerations for fire protection and ventilation- and the energy management systems.

2.3 Overview of the prototype developed

The staging lab consists of two Aperitas immersion tanks- a PNC immersion tank and a DFCX1 immersion tank- and a chilled water loop that includes a dry cooler, a circulation pump, and two regulation valves dedicated to the respective immersion tank loops. The system also includes an expansion tank, additional control valves to regulate chilled water flow, and sensors that enable continuous system monitoring.



From an electrical power perspective, the testing laboratory is supplied with power from the adjacent data centre. Power is distributed through a control/electrical panel with energy meters collecting information for the power consumption of the respective loops. A battery array, installed in an adjacent room, provides backup to ensure uninterrupted operation of the cooling system.

The laboratory is also equipped with an Ixora Hypotherm rack unit and separate heat recovery equipment, which are prepared for future integration into the system. System operation and performance are continuously monitored. A more detailed description of each subsystem is provided in the corresponding chapters.

Figure 1: The staging lab environment, equipped with immersion tanks, control equipment, and the cooling cycle components.

In order to assess the design and the key design decisions, it is necessary to consider the project requirements and the regulations with which the project must comply. This section outlines the primary standards and regulations applied in the design, as well as key performance targets and functional requirements. In addition, it addresses the project's modularity and redundancy needs, along with its sustainability goals.

Regulatory and compliance requirements

- European energy targets: PUE ≤ 1.2
- ASHRAE TC 9.9 (thermal guidelines for datacom equipment)
- NEN standards applicable to mechanical and safety systems
- TIA-942 / Uptime Institute Tier II structural requirements
- Local Dutch legislation:
 - EML 2023 (PH1: free cooling requirement)
 - PGS-37-2 for battery ventilation (if applicable)

Performance targets

The system must meet the following performance indicators:

Category	Target
PUE	≤ 1.2
Cooling continuity	100% uptime for immersion tanks
Internal environmental stability	Maintain ASHRAE A1 range at all times
Free cooling utilization	Maximize annual free cooling hours
Hydraulics	Support 22°C / 32°C supply and return temperatures
Modularity	Expandable from 50 kW → 2 MW with minimal redesign

Table 1: Design targets and performance requirements.

External and internal climatic conditions

Climatic boundaries are based on ASHRAE.

Condition	Value
Summer dry bulb	$\approx 39.1^{\circ}\text{C}$
Summer wet bulb	$\approx 25.6^{\circ}\text{C}$
Winter dry bulb	$\approx -14.7^{\circ}\text{C}$
Winter wet bulb	$\approx -15.0^{\circ}\text{C}$

Table 2: ambient design conditions.

Internal climatic conditions

To ensure safe and stable operation of IT hardware, the internal environmental conditions must comply with **ASHRAE TC 9.9** recommendations:

Parameter	Requirement
Temperature range	20°C – 32°C, with a setpoint of 27°C
Relative Humidity	20% – 80%

Table 3: Temperature and humidity requirements.

Glycol mixture for freeze protection

The external cooling loop must be protected against freezing using an ethylene glycol–water mixture, selected based on the ambient winter conditions:

Glycol %	Freezing Point
10%	-3°C to -4°C
15%	-6°C to -7°C
20%	-9°C to -10°C

30%	–15°C to –16°C
40%	–24°C to –25°C
50%	≈ –36°C

Table 4: Glycol concentration versus freezing point.

Modularity

The cooling system must support incremental expansion without redesigning the entire infrastructure. Requirements include:

- Modular IT tanks (Asperitas immersion units)
- Modular cooling skids (CDU + pumps + sensors)
- Standardized piping and connections for rapid deployment
- Scalable plant from 50 kW to 2 MW

Redundancy

To ensure continuous operation and meet MISD reliability expectations, the system must follow Tier II / Uptime Institute principles:

- Internal cooling equipment: N+1 redundancy
- External cooling equipment (dry coolers): N + 20% capacity margin
- CDU battery backup for safe emergency operation
- No single point of failure in the critically cooled loop

All cooling loops (Facility Water System and Immersion Loop) must be concurrently maintainable.

Cooling Concepts for the MISD Edge Datacenter

Cooling method	Explanation	Efficiency	Water usage	Temperature suitability	Advantages	Disadvantages
Dry Cooler	Air-cooled finned heat exchanger using fans.	High	None	Yes (weaker near +38.9°C)	Low operating cost; simple; no water consumption	Large footprint; weaker in heat waves
Hybrid dry cooler	Dry cooler with optional evaporative pre-cooling.	Very High	Low	Excellent in heat	Great hot-weather performance; efficient	Needs water & pad replacement

Table 5: Comparison of cooling methods for the staging laboratory.

Ventilation

The data center is a non-occupied space, so only minimum ventilation is required:

Room	Requirement
Computer/Plant room	0.5–1 air change per hour
Battery room	Follow IEEE 1635-2018, ASHRAE Guideline 21-2018, PGS-37-2, NPR 3229:2019, ARBO

Table 6: Ventilation rates and standards for data center rooms.

Sustainability goals

MISD emphasizes sustainable deployment of modular datacenters. The cooling design must support:

- Maximized free cooling through dry or hybrid dry-adiabatic coolers
- Minimized water usage (no cooling towers allowed)
- Low refrigerant impact, fully compliant with EU environmental legislation
- Heat reuse readiness for district heating connections
- Energy-efficient pump and fan control strategies

These measures directly contribute to achieving $PUE \leq 1.2$ and reducing total CO₂ footprint.

3 Prototype description

3.1 Overall design

This section provides a description of the staging lab installation. Testing is conducted using two Asperitas immersion cooling tanks (a PNC and a DFCX1), each equipped with MB 3000 OWR 1 heaters that simulate the heat load generated by IT servers. The immersion tanks operate on separate chilled water loops (DN40), each controlled by a dedicated IMI TA control valve. Both chilled water loops are connected to a DN65 header, which directs the water to a Guntner GFVC dry cooler. Circulation of the chilled water is maintained by a Grundfos TPE3 pump. An expansion tank is included, along with sensors and actuators, to enable comprehensive monitoring and management of the system.

From electrical perspective, the installation is powered via an LV panel, reflecting the laboratory's integration within an operating data centre. A battery array provides back up power for the cooling production and distribution system, supported by the necessary electrical distribution and control panels.

Additionally, a rack installed in an adjacent room houses networking servers and a test server. This test server is used to compare immersion cooling performance with a traditional air-cooled system, with conditioned air supplied by a split A/C unit. This air-cooled equipment is currently outside the energy metering scope of the testing installation.

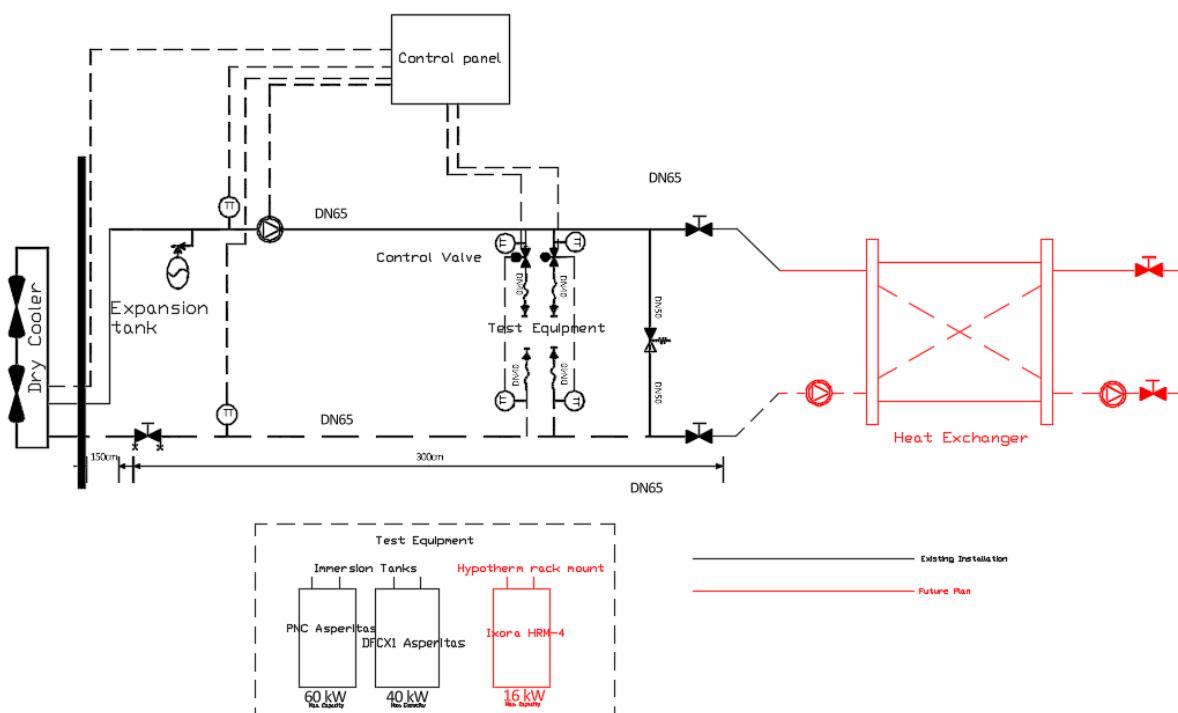


Figure 2: Schematic diagram of the staging laboratory cooling cycle.

3.2 Electrical Design

The test laboratory is located adjacent to an operational data centre, which supplies electrical power to the installation. A single incoming feed line is routed to the main electrical panel of the test laboratory. In addition to the main supply, the electrical panel is connected to a battery array that serves as a back-up source.

Due to the relatively long switchover time required between these two parallel power sources, redundancy for the IT loads cannot be provided. Instead, the backup system is intended to maintain operation of the cooling installation in the event of a power interruption. Unlike to the conventional current practice, no generator backup is installed in the facility.

From the main feed and electrical panel, power is distributed to a temporary electrical panel. This panel provides separate outlets for each immersion cooling system as well as dedicated feed for the cooling equipment associated with the chilled water loop. All electrical branches are equipped with individual energy meters, enabling precise measurement of power consumption for each cooling loop during test activities.

The following section provides a brief description of the main components of the electrical system.

LV panel



Since the staging laboratory is located within an operational data centre, the system has no direct connection to the power grid. The first point of electrical connection is the low voltage (LV) panel. The maximum electrical power available to the staging laboratory is approximately 52.65 kW, supplied through a three-phase connection rated at 3×80 A, supplying the testing IT facility, along with the chilled water production and distribution loop.

Figure 3: LV panel.

The Main Switchboard

The main switchboard is the central electrical interface between the external power supply, the staging laboratory, and the battery backup system.

- 1- Incoming connection from the main electrical source - This connection brings the three-phase utility power into the switchboard.
- 2- Outgoing connection to the staging laboratory loads, from the switchboard - Power is distributed to the staging laboratory, supplying IT equipment, cooling systems, and auxiliary loads.
- 3- Connection to the battery backup system the switchboard is also electrically connected to the battery energy storage system (BESS). In normal operation, this connection allows coordination between the grid supply and the battery system. In the event of a power outage or grid disturbance, the switchboard enables the battery system to supply power to the staging laboratory, ensuring continuity of critical loads.

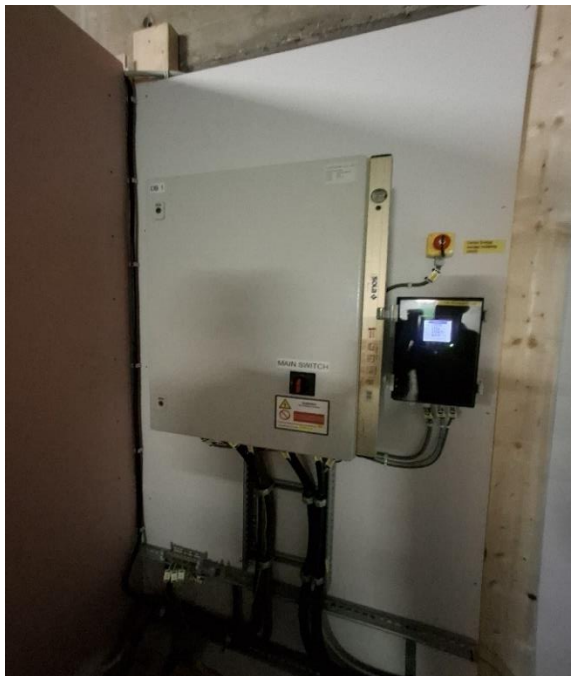


Figure 4: The Main Switchboard.

Back-up Battery

The staging laboratory is equipped with a battery array connected to the LV panel. The 130kWh battery system is used as a backup power source to supply the cooling system of the staging laboratory. Due to the relatively slow switching response, this backup solution is suitable only for the cooling infrastructure and not for potential IT server loads.

Parameter	Specification
Battery capacity	130 kWh
Battery chemistry	Lithium Iron Phosphate (LiFePO ₄)
Rated effective power	45 kW
Rated apparent power	45 kVA
Max. charge / discharge power	45 kVA
Battery efficiency	> 98%
Battery management	Integrated Cactus BMS
DC operating voltage	468 – 648 V DC
AC operating voltage	400 V
Grid frequency	50 Hz
Operating temperature	+5 °C to +35 °C
Humidity	0 – 85 % (non-condensing)
Degree of protection	IP20
Dimensions (H × W × D)	1870 × 1560 × 1010 mm
Total weight	1800 kg

Figure 5: Battery energy storage.



Table 7: Battery system parameters and operating conditions.

The mobile power distribution unit

The mobile power distribution unit is designed to receive a single three-phase electrical supply and distribute it to multiple three-phase and single-phase loads. A high-capacity three-phase inlet supplies the unit, which then distributes power through protected output circuits. Three-phase outputs are intended for high-power equipment, while single-phase outputs provide power for auxiliary and low-power devices.

For the current phase of the staging laboratory, the electrical outputs supply the PNC immersion tank, the DFCX1 immersion tank and the compact power distribution unit that feeds the chilled water production and distribution loop. In parallel, metering sensors are installed on each electrical line to measure power consumption, providing detailed information on the energy use of the IT loads and the respective immersion tanks and the chilled water loop.



Figure 6: Battery energy storage.

Compact Power Distribution Unit

The compact power distribution unit is used to distribute electrical power to different components. It is compact and designed for industrial use. It is connected directly with the mobile power distribution unit, and in specific, the line of the chilled water production and distribution loop. It feeds the circulation pump and the controlling valves.



Figure 7: Compact Power Distribution Unit.

3.3 Mechanical Design

In this section a brief description of the main components of the cooling system of the testing laboratory is provided.

Güntner GFVC FD 063 – Dry Cooler

The Güntner GFVC FD 063 is an air-cooled dry cooler designed for high-efficiency heat rejection without the use of water. The unit has a maximum capacity of 198.4 kW under the specified design ambient conditions, with chilled water flow rate of 18.25 m³/h and an inlet/outlet temperature regime of 10°/20°. The corresponding air volumetric flow is 31.780 m³/h.



Figure 8: Air-cooled dry cooler.

Grundfos TPE3 40-200 S-A-F-A-BQQE

The Grundfos TPE3 40-200 S-A-F-A-BQQE pump is a single-stage pump, close-coupled. The maximum capacity of the pump is 20.5 m³/h. Considering a chilled water regime of 10°C /20°C ($\Delta T=10$), the maximum cooling capacity provided by the pump is 238.3 kW at a fluid velocity of 2.46 m/s, ensuring sufficient performance for the system requirements.



Figure 9: Single-stage pump.

TTM Shuntopac 20-200 UX

TTM Shuntopac is a system divider for a heating or cooling system used where different media, pressures and temperatures in primary and secondary circuits are desired to be hydraulically separated. It is within the future plans to integrate the heat exchanger into the current system configuration in order to utilise the heat rejection of the system. This will be used for testing the UT thermal heat ammonia adsorption/desorption reactor and connecting it directly to the data centres heating system.



Figure 10: Heat exchanger.

IMI TA Control Valve

The valve continuously measures the energy flowing through the pipework and regulates the flow rate in the cooling branch. The size of the control valve used is DN40 and there is one control valve for each cooling loop that services each immersion tank.



Figure 11: Control Valve.

Heater – MB 3000 OWR1

The MB 3000 OWR1 heater is used in the prototype to simulate IT thermal loads during testing. It is one of the future plans to use heat load banks of higher capacity in order to replicate better real-world applications.



Figure 12: Heat bank.

3.4 Immersion Cooling Systems

Perpetual Natural Convection (PNC) – Asperitas

The PNC system represents Asperitas' established immersion cooling solution, based entirely on natural convection. The fluid circulates without pumps, driven solely by the thermal gradient inside the tank. This results in a silent, highly reliable system with minimal moving parts.

Key Characteristics

- Operates on perpetual natural convection with no active pumping
- Capable of warm-water cooling and independent of ambient climate

- Offers strong heat-reuse potential, ideal for sustainable data-centre concepts



Figure 13: heat circulation within the immersion tank.



Figure 14: Asperitas PNC immersion tank.

Parameter	Value
IT Capacity	24×1U (21") or 22×10U (21")
ASHRAE Classification	W3 compliant
Footprint thermal density	~18 kW/m ² at 32°C
Electrical capacity	Up to 44 kW (fully redundant)
Cooling capacity	Technical max: 60 kW; typical operation: ~32 kW

Table 8: PNC immersion tank parameters and operating conditions.

Direct Forced Convection (DFCX1) – Asperitas

A forced-convection circulation method that pushes the dielectric fluid through the IT stack with controlled flow. This approach significantly increases heat transport efficiency compared to traditional passive immersion systems.

Key Characteristics

- Uses direct forced convection, enabling fast and uniform fluid movement around heat-generating components
- Focused on delivering high thermal load performance, even at elevated supply temperatures.



Figure 15: heat circulation.



Figure 16: : Asperitas DFCX1 immersion tank.

Parameter	Value
IT Capacity	12U, 19"/21", up to 1050 mm height
ASHRAE Classification	W3 compliant
Footprint thermal density	~29 kW/m ² at 32°C
Electrical capacity	44 kW (2N redundancy)
Cooling capacity	Up to 60 kW (≈5 kW per U)

Table 9: DFCX1 immersion tank parameters and operating conditions.

3.5 Sensors

The test laboratory installation is equipped with a comprehensive set of sensors and control signals to ensure an insight into the operation of both the chilled water loop and the cooling loop with the immersion tanks in order to have an efficient and robust testing installation. These sensors provide continuous monitoring, fault detection, and control feedback to the control system.

Temperature

The dry cooler serving the chilled water loop is monitored using multiple temperature sensors to ensure thermal controllability for testing purposes. There are inlet and outlet dry cooler temperature sensors that allow the calculation of the temperature differential and the evaluation of the cooling efficiency. A redundant inlet temperature sensor is installed to provide reliable operation in case of failure of the primary one. Thermometers are also installed on the inlet and outlet pipes of the heat exchanger in order to have an insight into the heat exchanger performance and calculate the heat recuperation. The ambient temperature is also monitored by a temperature sensor installed outside.

Pressure

The immersion cooling system is equipped with a pressure system sensor that monitors the operation pressure of the immersion cooling loop. This sensor ensures that the system operates within defined pressure limits and supports early detection of leaks, blockages or pump malfunctions. The chilled water loop pressure is also monitored through pressure sensors

Fault Monitoring and alarms

The system includes multiple fault signals to detect abnormal operating conditions and to initiate alarms or proactive actions. A dry cooler fault signal indicates malfunction or failure of the dry cooler (fan failure, control error, thermal performance issues). The circulation pump fault sensor monitors the operational status of the circulation pump in the chilled water loop. A fault signal is generated in the event of pump failure, overload, or electrical malfunction. A low-pressure early warning alarm when system drops below a predefined threshold, allows preventive maintenance before a critical fault occurs.

Energy Metering

The energy meter control valve fault signal indicates a malfunction of the control valve associated with the energy metering system, such as actuator failure or loss of control signal. There is also a control valve feedback sensor that provides position feedback from the control valve, confirming correct actuation and enabling accurate energy measurement.

General Faults signals

Urgent fault and fault reset signals allow monitoring critical faults and resetting the alarms when the fault condition has been resolved.



Figure 17: Control panel for the sensors in the cooling loop.



Figure 18: Sensor readings within the cooling loop..

3.6 Fire Protection Design

The battery room is equipped with an AF-X Fireblocker n-BL fire suppression system, suitable for enclosed technical spaces and lithium-ion battery installations. The system is electrically activated and uses aerosol-based fire suppression technology, which interrupts the combustion process without displacing oxygen, thereby limiting damage to electrical equipment and avoiding the use of water.



Figure 19: Fireblocker.

In addition, the battery system is continuously monitored by Cactus, the battery supplier. Any abnormal changes in battery temperature are detected and monitored to ensure safe operation and early risk identification.

4 Design assessment and validation

4.1 Maximum Capacity

In this section, the system is broken down into its individual components, and the maximum thermal capacity that can be delivered by each is evaluated. The analysis covers the piping system, pump, control valve, and dry cooler. For each component, the system performance under the current operating conditions and setpoints is examined, supported by relevant calculations. These calculations also address the system requirements and provide a basis for evaluating potential future tests.

a) Pipe Size

The first component examined is the pipe sizing. The two immersion tank loops are connected to a common manifold (with a third loop to be connected in the same manner in the future). The supply and return headers are connected to the dry cooler and, in a future phase, to a heat exchanger.

In the current installation, the header is DN65, while the branches supplying the immersion tank cooling loops are DN40. This section evaluates the maximum thermal capacity achievable for DN40, DN65, DN80 pipes, using cooling medium velocities of 1.5 m/s, 2 m/s, and 2.5 m/s which are typical for chilled water systems. Calculations for DN100 under the same conditions are included in the appendix; however, this pipe size exceeds the scope of the testing laboratory.

The cooling media considered in the calculations are water and a 30% glycol-water mixture. The latter is selected because it represents the fluid used under the environmental design conditions of the site. The tables below present the maximum cooling capacities for each medium as a function of ΔT and flow velocity.

For the calculation of the pipe internal diameters, schedule 40 wall thickness is considered, as the piping system is specified as PN10/16. The appendix provides the complete set of calculations for both media, all three velocities, and a range of temperature differences. This approach reflects the wide range of testing requirements, from the current low-capacity tests to higher capacities anticipated in future testing scenarios.

Pipe Size (Water, $\Delta T=10$, velocity=2,5 m/s)	Max. Capacity
DN 40	138 kW
DN 65	323 kW
DN 80	499 kW

Table 11: Pipe sizing and corresponding cooling capacity.

Pipe Size (Water, $\Delta T=2$, velocity=1,5 m/s)	Max. Capacity
DN 40	16.6 kW
DN 65	38.8 kW
DN 80	59.8 kW

Table 12: Pipe sizing and corresponding cooling capacity.

Pipe Size (Glykol mix (30%), $\Delta T=10$, velocity=2,5 m/s)	Max. Capacity
DN 40	131 kW
DN 65	307 kW
DN 80	473 kW

Table 13: Pipe sizing and corresponding cooling capacity.

Pipe Size (Glykol mix (30%), $\Delta T=2$, velocity=1,5 m/s)	Max. Capacity
DN 40	15.8 kW
DN 65	36.8 kW
DN 80	56.7 kW

Table 14: Pipe sizing and corresponding cooling capacity.

b) Circulation Pump

Another limiting factor of the system is the circulation pump, which feeds both immersion tanks. Table 15 below presents some of the pump's technical characteristics. The pump has a nominal flow rate of 20.5 m³/h.

Circulation Pump	Parameter	Value
Hydraulic Performance	Nominal flow rate	20.5 m ³ /h
	Nominal head	14.9 m
	Maximum head	20 m
	Rated speed	5000 rpm
Operating Limits	Maximum operating pressure	16 bar
	Max. pressure at temperature	16 bar @ 120 °C
	Liquid temperature range	-25 to 120 °C
	Ambient temperature range	-20 to 50 °C
Pumped Fluid	Design medium	Water / Water-Glycol
	Fluid density (20 °C)	998.2 kg/m ³
Electrical Data	Nominal motor power (P2)	1.1 kW
	Supply voltage	3 × 380–500 V

	Frequency	50 / 60 Hz
	Nominal current	2.05–2.3 A
	Efficiency class	IE5

Table 15: Hydraulic, electrical, and operating parameters of the circulation pump.

Table 16 summarizes the cooling capacity that can be provided by this flow rate for different ΔT ranges of the chilled water and for both water and water-glycol (30%) mixture media.

Water Cooling medium	Max. Capacity facilitated by the pump
$\Delta T=2$	47.7 kW
$\Delta T=4$	95.3 kW
$\Delta T=6$	143 kW
$\Delta T=8$	190.7 kW
$\Delta T=10$	238.4 kW

Table 16: Temperatures and corresponding maximum cooling capacity.

Water-glycol (30%) Cooling medium	Max. Capacity facilitated by the pump
$\Delta T=2$	44.9 kW
$\Delta T=4$	89.8 kW
$\Delta T=6$	134.7 kW
$\Delta T=8$	179.6 kW
$\Delta T=10$	229.4 kW

Table 17 Temperatures and corresponding maximum cooling capacity.

However, considering that the maximum capacity of the dry cooler under design conditions with a ΔT of 10°C corresponds to a flow rate of 18.25 m³/h, we calculated the maximum cooling capacity that the pump can facilitate at this reduced flow rate.

Water (18.25 m ³ /h)	Max. Capacity facilitated by the pump
$\Delta T=2$	42.4 kW
$\Delta T=4$	84.9 kW
$\Delta T=6$	127.3 kW
$\Delta T=8$	169.8 kW
$\Delta T=10$	212.2 kW

Table 18: Temperatures and corresponding maximum cooling capacity.

Water-glycol (30%) (18.25 m ³ /h)	Max. Capacity facilitated by the pump
$\Delta T=2$	40.3 kW
$\Delta T=4$	80.5 kW
$\Delta T=6$	120.8 kW
$\Delta T=8$	161 kW
$\Delta T=10$	201.3 kW

Table 19: Temperatures and corresponding maximum cooling capacity.

Water (13 m ³ /h)	Max. Capacity facilitated by the pump
$\Delta T=2$	30.2 kW
$\Delta T=4$	60.5 kW
$\Delta T=6$	90.7 kW
$\Delta T=8$	120.9 kW
$\Delta T=10$	151.2 kW

Table 20 Temperatures and corresponding maximum cooling capacity.

Water-glycol (30%) (13 m ³ /h)	Max. Capacity facilitated by the pump
$\Delta T=2$	28.7 kW
$\Delta T=4$	57.4 kW
$\Delta T=6$	86 kW
$\Delta T=8$	114.7 kW
$\Delta T=10$	143.4 kW

Table 21: Temperatures and corresponding maximum cooling capacity.

c) Controlling Valves

Another potential limiting factor of the system is the controlling valves. These valves are used to regulate the chilled water flow in the system according to the cooling requirements of the immersion tanks. There are two controlling valves, one for each immersion tank loop, with a nominal size of DN40. Table 22. presents the minimum and maximum flow rates that the control valves can accommodate.

Controlling Valve	Min. Flow rate (m ³ /h)	Max. Flow rate (m ³ /h)
DN32	0.72	3.6
DN40	1.0	6.5
DN50	2.15	11.2
DN65	4.15	24.1

Table 22: Pipe sizing and corresponding min and max flowrate.

Given that the installed control valves are DN40, the maximum achievable chilled water flow is approximately 6.5 m³/h per loop, resulting in a total system flow of 13 m³/h. For this reason, the cooling capacity corresponding to a maximum chilled water flow of 13 m³/h has already been calculated and presented in the circulation pump section.

d) Dry Cooler

The system dissipates heat to the environment through a dry cooler. Several variables influence the operation and performance of the dry cooler, including ambient temperature and system heat load, which at this stage relatively low (approximately 3.5 kW). In addition, the chilled water operating regime plays a significant role, as it directly affects the efficiency of heat rejection from the dry cooler, the immersion tanks operation efficiency and the heat recovery potential of the heat exchanger.

A comprehensive analysis of the operation and efficiency of the dry cooler requires the definition and application of specific temperatures setpoints and energy demands. This level of analysis is beyond the scope of the present work and may form the basis of future research and reporting. However, to understand the capabilities of the existing equipment and to assess the potential to become a bottleneck in the current installation, several system configurations are discussed.

First, the current setpoints and operating conditions are described. At present, the system heat loads are very low (approximately 3.5 kW in total), which makes a meaningful evaluation of the dry cooler's efficiency impractical. The typical chilled water operating regime used for testing is 41° C at the outlet and 47° C at the inlet of the dry cooler, which is sufficient to cover the heat load with a chilled water flow rate of 10.1 m³/h.

An advantage of operating the system in elevated temperatures is that the outlet water temperature at 47° C can be efficiently utilised for heat recovery purposes. However, this operating regime negatively impacts the efficiency of the dry cooler. The figure below presents technical performance data for the dry cooler operating at ambient temperature of 35° C with a water temperature regime of 47° outlet and 41° inlet, resulting in a cooling capacity of 65.4 kW, which is significantly higher than the cooling load currently required.

Drycooler

GFVC FD 063.1/21-65-0076139M

Capacity:	65,40 kW ⁽¹⁾	Medium:	Ethylene glycol 30 Vol. % ⁽²⁾
Surface reserve:	0,00 %	Inlet temp.:	47,00 °C
Air flow:	30 967,00 m³/h	Outlet temp.:	41,00 °C
Air velocity:	3,50 m/s		
Air inlet:	35,00 °C 40 %	Pressure drop:	0.27 bar
Air pressure:	1 013,00 mbar	Volume flow:	10.01 m³/h
Air outlet:	41,70 °C 28 %		
Heat transf. coeff.:	36.47 W/(m²·K)	Mass flow:	10412 kg/h
Fans (EC):	2 Aantal 3~400V 50-60Hz	Noise pressure level:	65,00 dB(A) in 10,00 m ⁽⁴⁾
Data per motor (nominal data):		Noise power level:	97,00 dB(A)
Speed:	1510 min⁻¹	ErP:	Compliant ⁽⁶⁾
Capacity(el.):	3.20 kW		
Current:	5,00 A ⁽³⁾		

Figure 20: illustration and the power consumption and noise levels of the equipment under these operating conditions.

Since electrical power consumption, and noise level production of the unit which is installed outdoors, can be limiting factors, both parameters are important considerations in the evaluation and testing of the system.

To gain a better understanding of the equipment's operation, additional calculations were performed. The first analysis involved measuring the dry cooler's capacity under the design ambient conditions of 38,2 °C using a chilled water regime with a ΔT of 10 degrees (10°C inlet/ 20° C outlet) at both full and partial load. This configuration employs the typical $\Delta T=10$, but with lower chilled water temperature regime, which increases the efficiency of the dry cooler.

This approach provides an indication of the maximum capacity under design ambient conditions, while also allowing assessment of capacity, power consumption, and noise levels at a more moderate (partial load) heat demand. The main limitation of this configuration is that the chosen chilled water regime limits the use of the system for heat recovery.

Air cooler coil		GFVC FD 063.1/21- 65 GCO F/6/40/2.10/1200/ECS/ /015030 (FT09)	
Capacity:	198.4 kW ⁽¹⁾⁽²⁾	Construction for:	Casing
Surface:	319.7 m ²	Connections:	right side
Rqrd. surface:	319.7 m ²	Tube pattern:	staggered
Surface reserve:	0.0 %	Frost thickness:	0.0 mm
Air	Inlet	Outlet	Medium: Ethylene glycol 30 Vol. % ⁽³⁾ 
Volume flow:		31780 m ³ /h ⁽⁴⁾	Inlet: 10.0 °C
Temperature:	38.2 °C	24.3 °C	Outlet: 20.0 °C
			Volume flow: 18.25 m ³ /h
Air pressure:	1013 mbar		
Pressure drop:	199 Pa	Pressure drop:	0.52 bar

Air cooler coil		GFVC FD 063.1/21- 65 GCO F/6/40/2.10/1200/ECS/ /015030 (FT09)	
Capacity:	152.9 kW ⁽¹⁾⁽²⁾	Construction for:	Casing
Surface:	319.7 m ²	Connections:	right side
Rqrd. surface:	319.7 m ²	Tube pattern:	staggered
Surface reserve:	-0.0 %	Frost thickness:	0.0 mm
Air	Inlet	Outlet	Medium: Ethylene glycol 30 Vol. % ⁽³⁾ 
Volume flow:		21676 m ³ /h ⁽⁴⁾	Inlet: 10.0 °C
Temperature:	38.2 °C	22.6 °C	Outlet: 20.0 °C
			Volume flow: 14.07 m ³ /h
Air pressure:	1013 mbar		
Pressure drop:	105 Pa	Pressure drop:	0.33 bar

Figure 21: Technical specs for the dry cooler.

In conclusion, to assess the dry cooler, we assume a target PUE of 1.2 as it is the design requirements. For the next testing stage, where the two Asperitas immersion tanks will operate at full load (40kW and 60kW, respectively), a heat dissipation capacity of 120kW is required. Considering the future integration of the Ixora system, which would add an additional 64kW of heat load from the test servers, the dry cooler's ability to meet the total cooling demand becomes marginal. It is important to emphasize that this assessment is based on the design outdoor conditions (38,2°C) and a $\Delta T=10$ (10°C/20°C) chilled

water regime. Any alternative setpoint configuration would require a fresh assessment from the ground up.

Test system configuration	Total Thermal requirement
Current	3.5 kW
2 Asperitas immersion tanks (PNC-typical+DFCX1 full load)	92 kW
2 Asperitas immersion tanks (full load)	120 kW
2 Asperitas immersion tanks (PNC-typical+DFCX1 full load)+Ixora	108 kW
2 Asperitas immersion tanks (full load)+Ixora	136 kW

Table 23 Power requirements for different immersion tank configurations.

Last but not least, it is important to note that the chilled water flow rate at the maximum load capacity of the dry cooler is 18.25 m³/h. This represents a limiting factor for the circulation pump, as the maximum flow rate through the dry cooler is lower than the pump's maximum rated capacity, which must be considered during the pump validation.

e) Power Capacity

Parameter	Value
Electrical supply type	Three-phase AC
Nominal frequency	50 Hz
Connection rating	3 × 80 A
Maximum available power	~52.65 kW
Supply voltage	400 V
Application	Staging laboratory loads (IT, cooling, auxiliaries)

Table 24: Electrical supply specifications for the staging lab.

4.2 Strengths of the design

Scalability: The design demonstrates high level of scalability as additional loads can be used in order to achieve the testing purposes. Scalability is also one of the key design requirements for the MISD project

Flexibility-adaptability: The design demonstrates a high level of flexibility and adaptability, allowing the testing laboratory to support multiple cooling strategies and operating conditions.

Operational control: The separation of cooling loops and the use of independent control elements enhance operational control and system reliability. This allows targeted testing, improved fault isolation and more precise performance evaluation.

Cooling Capacity: The cooling capacity is adequate for the level of the heating loads of the current tests and for the next steps as well.

Heat recovery potential: Heat recovery is also a key design requirement, since it will enable a more sustainable and efficient operation.

4.3 Shortcomings, deviations, bottlenecks

Low power supply: Power supply is adequate for the current level of testing, but it requires upgrade for the next stages.

No fire protection considerations: To develop the staging lab, proper fire protection with detection and suppression should be implemented. UTs adsorption/desorption reactor may require specific fire protection systems.

No ventilation considerations: Ventilation is required, since the staging lab has occupancy for carryout out testing. A requirement for fresh air typical to an electrical room would suffice. Implementation of UTs adsorption/desorption reactor may increase ventilation requirements further.

No comprehensive PUE measurement strategy: Up to this point, there is no comprehensive metering of IT and the cooling loads. Therefore, there is currently no reliable method in place to measure the PUE.

Control valves: Control valves are the limiting factor of the design of the chilled water loop. In order to test higher IT loads, control valves should be replaced, or more cooling loops should be integrated in the system. These are described further in chapter 5.2.

5 Laboratory testing expansion

5.1 Objective

The goal of the testing laboratory facility is to simulate and evaluate different cooling strategies with the aim of improving efficiency and assessing the scalability and modularity of the MISD edge data centre project. To achieve this objective, the testing laboratory must increase the IT loads used during testing and explore a range of installation configurations and design concepts.

Under the current installation, the laboratory conducts tests focused on the performance of the immersion cooling tanks and on comparing immersion cooling with traditional air-cooled server solutions. For this purpose, an air-cooled server is installed in an adjacent room.

To expand the range of IT loads tested and to integrate additional equipment and alternative cooling strategies, several future testing scenarios are planned. This section outlines these future plans and configurations and discusses the limitations and assumptions that must be considered before proceeding with their implementation.

5.2 Plan and future arrangements

- **Future cooling concept with pumps replacing control valves.**

One of the planned future configurations of the testing laboratory involves replacing the control valves with pumps operating under variable frequency drive (VFD) control. In the fully developed testing laboratory, where the Ixora unit and the heat exchanger are connected, the system configuration will be as illustrated in the figure below.

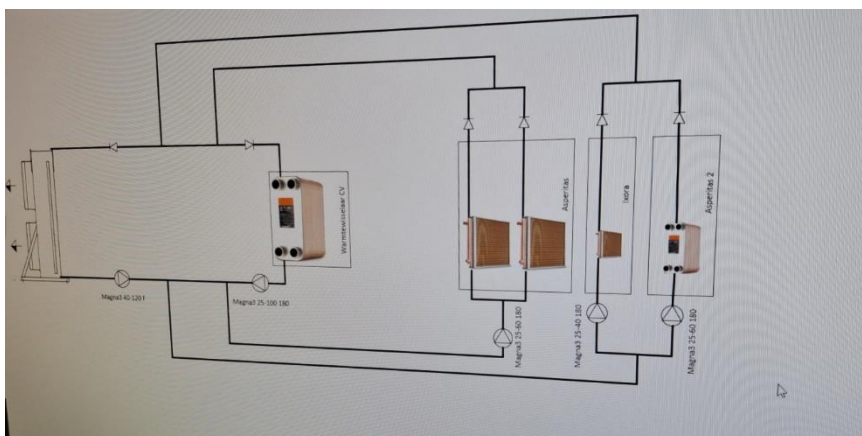


Figure 22: Future cooling concept.

In this arrangement, the cooling load from the immersion testing tanks will be regulated by VFD-controlled pumps, while the distribution of heat between the heat exchanger (heat recovery) and the equipment that rejects heat to the ambient will also be controlled by VFD-driven pumps.

The operating status of each pump will be monitored to indicate which parts of the system are active at any given time. This monitoring will also allow verification of whether the available heat recovery capacity

is sufficient to absorb the system loads, or whether operation of the heat rejection equipment is required to dissipate excess heat to ambient.

Regulating the system using pumps equipped with VFDs is preferred over the use of control valves, as it offers significant advantages in terms of energy efficiency, controllability, and operational flexibility. By modulating pump speed to match the required flow, the system delivers only the hydraulic energy needed to meet the thermal demand, avoiding pressure losses induced by control valves. In addition, VFD-controlled pumps provide improved performance under variable load conditions, which is particularly important for a testing laboratory. Moreover, this approach enhances system monitoring and diagnostics, while improving flexibility and scalability, as the system can easily adapt to future expansions and new testing modes, which is particularly valuable for the MISD project.

- **Fire Protection**

Fire protection should be improved. Proper fire detection should be implemented in each of the rooms and connected to a suitable fire suppression system. The highest risk is foreseen in the main MISD testing lab. Should this room always be occupied during testing, a fire situation will be earlier detected and therefore the fire protection systems could be reduced. If testing is carried out with no occupancy in the room, proper fire protection systems should be implemented. The fire protections should be connected to the main building addressable alarm system.

- **Load banks and heat banks to check the chilled water system.**

To improve testing accuracy, load banks are planned to be added to the laboratory setup. This component will allow the chilled water system to be tested under controlled and realistic thermal loads, simulating the actual heat output of immersion tanks and enabling accurate measurement of temperature differences and cooling power consumption.

- **Installation of solar panels**

The use of a green energy source aims to reduce emissions and lower the overall operational costs of the laboratory. In addition, it allows the testing of a secondary energy source and provides valuable insights into its performance and feasibility for future implementation in a real data centre environment.

- **Ixora HRM-4 Implementation**

The plan is to integrate the Ixora HRM-4 (Hypotherm Rack Mount) system in the staging lab to test and evaluate its performance under real conditions. This closed immersion cooling solution supports E-ATX boards, provides 16 kW per chassis, and can reduce power usage by up to 50% compared to air cooling. Each chassis has four individual cassettes, and the cooling liquid, Compuzol IM2020, operates via natural convection with a lifetime of ~10 years. The system is easy to install in existing 19" racks and connects to the existing heat grid.



Figure 23: Ixora HRM-4 immersion cooling solution.



Figure 24: Ixora setup.

Feature	Details
Model	HRM-4 (Hypotherm Rack Mount)
Cooling Type	Closed immersion per server
Cooling Capacity	4 kW per cassette, 16 kW per chassis
Number of Cassettes	4 per chassis
Compute Format	E-ATX boards
Temperature Range	Inlet up to 40°C / Outlet up to 60°C
PUE	1.04 – 1.10
Power Savings	Up to 50%
Cooling Liquid	Compuzol IM2020, natural convection, ~10 years
Rack Requirements	Min. 1200mm × 600mm, max weight 510kg for 3 chassis
Testing Plan	Integration in staging lab for performance evaluation
Features	Easy install, individual cassettes, no liquid spills

Table 25: HRM-4 immersion solution parameters and operating conditions.

Integration of Solar Panels and multidirectional converters

Due to the current battery switchover time of approximately 200 ms, which is relatively high, the laboratory plans to further develop the electrical backup architecture. The existing system operates in a parallel AC configuration between the grid and the battery system, resulting in a noticeable transition delay during grid disturbances.

As a future upgrade, the lab plans to implement multidirectional power converters within a DC-coupled architecture. This configuration is expected to significantly reduce switching times, improve conversion efficiency, and enhance system controllability. An additional benefit of this approach is the ability to

export surplus electrical power, for example generated by on-site solar panels, back to the grid, thereby increasing overall system flexibility and supporting sustainable energy integration. Figure 25. Shows the current and future configuration.

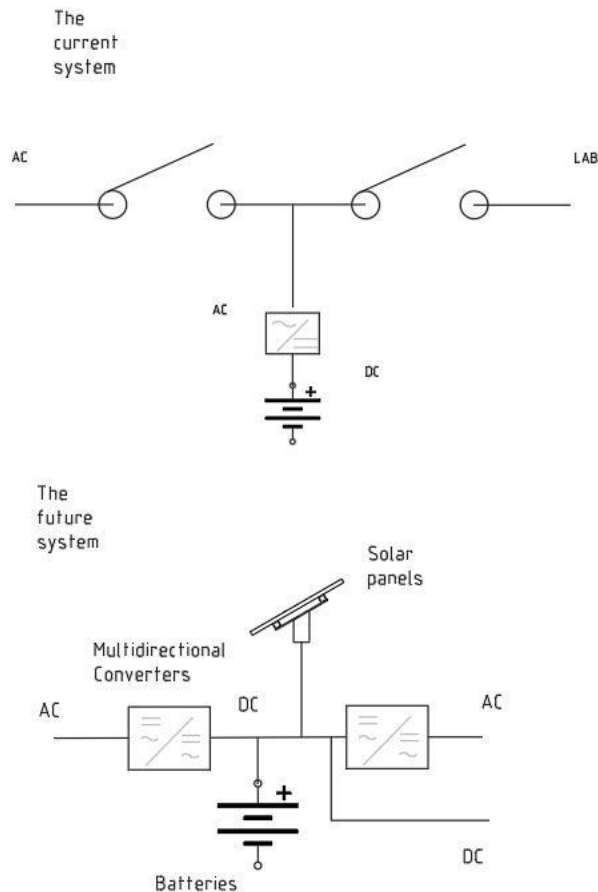


Figure 25: the current and the future electrical layout.

Implementing the heat exchanger for heating purposes

The heat exchanger unit allows the laboratory to recover heat and at the same time provides cooling to the chilled water loop. The primary and secondary flows are hydraulically separated. This configuration will be used for heating-related testing scenarios, supporting future laboratory expansion and heat reuse applications.

Item	Specification
Application	Heating / laboratory testing expansion
Function	Hydraulic separation of primary and secondary circuits
Working fluid	Water
Primary flow rate	0.72 l/s (53 / 39 °C)
Secondary flow rate	1.33 l/s (55 / 45 °C)
Primary / secondary pressure drop	3.33 kPa / 2.54 kPa

Connected system pressure drop (secondary)	60 kPa
Primary pump power (P1)	183.7 W, speed controlled
Secondary pump power (P1)	153.4 W, speed controlled

Table 26: Technical specifications of the shunt unit.

5.3 Limitations and Assumptions

In order to implement the aforementioned future plans, several limitations must be addressed. The primary constraint is the available electrical power supply. Increasing the power capacity can be achieved either by upgrading the existing electrical configuration or by introducing a dedicated transformer path specifically serving the testing laboratory.

Additionally, the implementation of the Ixora Hypotherm rack or the use of heat banks to enable higher thermal testing loads will require upgrades to the chilled water production and distribution system, as discussed in another chapter of this report. Replacing control valves with circulation pumps would necessitate a fundamentally different approach to system monitoring and control.

Furthermore, the installation of solar panels and their integration into the system would require the use of converters and rectifiers, as well as a dedicated immersion tank for cooling, as planned. The integration of a heat exchanger would also impose tighter constraints on the chilled water temperature range to ensure the availability of an efficient and usable heat source.

Finally, the addition of a fire protection system would allow the testing laboratory to more closely replicate real-world operating conditions; however, it would also require modifications to the monitoring and managing of the system and potentially to systems setpoints.

6 Conclusions

6.1 Technical

The main goal of this report is to assess the capabilities of the testing laboratory facility. Throughout the report, we have reviewed the performance of the various components of the installation to identify potential limiting factors- specifically, the components that would need to be upgraded first to enable an expanded spectrum of load testing. This focus is critical, as achieving valuable future results will require testing at higher capacities and pushing the immersion tanks and dry cooler to their operational limits.

The following table provides an overview of the maximum capacity of the equipment. Apart from the obvious limitation of power supply, the table highlights that, from a mechanical perspective, the control valves would need to be upgraded to support higher cooling loads. The DN40 pipes serving each cooling loop are sufficient for the immersion tanks, while the dry cooler- at least under the selected conditions and chilled water regime- is more than adequate.

Overall, the table demonstrates that the current testing loads (approximately 3,5 kW) can be significantly increased before a major redesign or equipment upgrade becomes necessary. Additional details on the capabilities of each component are provided in the relevant chapters earlier in the report.

Current testing Configuration	Max. Capacity
Power Supply	52.65 kW
DN40 (2,5 chilled water velocity)	138 kW
DN65 (2,5 chilled water velocity)	323 kW
Circulation pump (20 m ³ /h)	238.4 kW (151,2 kW at 13 m³/h)
Control valve (13 m ³ /h)- Limiting factor**	150.8 kW
Dry Cooler (18.5 m ³ /h)	198.4 kW (152,9 kW at 13 m³/h)

Table 27: Maximum cooling capacity of the current test configuration components.

6.2 Recommendations and improvements

Based on the findings of this project, several recommendations have been identified to enhance the performance, flexibility, and future readiness of the MISD staging laboratory.

- The main limiting factors in the current installation are the power supply from an electrical perspective and the capacity of the controlling valves from a mechanical point of view. Allocation of a higher power supply provision and the upgrade of control valves (or the introduction of more cooling loops) will allow the testing lab to expand the scope of testing.
- The system's energy metering setup needs to be redesigned and provide metering of more power consumption sectors to allow for reliable assessment of the system's PUE.

- An increase in the testing load, combined with the integration of the heat exchanger, will necessitate significant changes to the cooling strategy and equipment requirements. The proposal of different cooling methods and the investigation of different setpoint strategies, taking into consideration efficiency and sustainability, may be the scope of a future report.
- Extending the laboratory setup with load banks and heat banks would enable more realistic testing of the chilled water system. This allows immersion tank operation to be simulated under control and higher thermal loads, resulting in more accurate assessment of temperature differences and cooling power demand.
- Implementing a proper fire detection and suppression system linked to the main building fire control panel will improve safety on site.
- Testing different firefighting strategies would improve understanding of their interaction with cooling and electrical systems.

6.3 Lessons Learned

The testing and assessment of the laboratory provided several valuable lessons. It highlighted the importance of carefully matching equipment capacity to expected loads, ensuring that critical components such as cooling systems, pumps, and controlling valves are not limiting factors. The evaluation also demonstrated the need for comprehensive monitoring to accurately track performance metrics and energy efficiency. Additionally, planning for future expansion from the outset reduces the need for major upgrades, while integrating modular and scalable solutions enhances flexibility and long-term sustainability.

Last but not least, the project also highlighted the value of combining theoretical design with hands-on testing. Practical constraints, operational behavior, and system integration challenges became clearer through real implementation, reinforcing the role of staging laboratories as an essential bridge between conceptual design and real-world data center deployment.

6.4 Next Steps

Further investigation is required to fully characterize the performance of the dry cooler supplied by Güntner. More detailed vendor-specific data is needed to accurately evaluate the system behaviour under different operating conditions, including varying outdoor temperatures, seasonal weather scenarios, and different temperature differences across the cooling loop.

Following the completion of the current design and prototype testing phase, the next deliverables within the MISD project will focus on Sustainability design and energy efficiency, integration with WP3 and Collaboration and support for future use.

Annex

1. Piping Max. Load Charts

Water Medium

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	10					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,00132	0,00198	0,0020	82,9
DN 65	62,7	0,0627	0,00309	0,00463	0,0046	193,8
DN 80	77,9	0,0779	0,00476	0,00715	0,0071	299,1
DN 100	102,4	0,1024	0,00823	0,01235	0,0123	516,8

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	8					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,00	66,3
DN 65	62,7	0,0627	0,0031	0,0046	0,00	155,0
DN 80	77,9	0,0779	0,0048	0,0071	0,01	239,3
DN 100	102,4	0,1024	0,0082	0,0123	0,01	413,5

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	10					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,00132	0,00264	0,0026	110,5
DN 65	62,7	0,0627	0,00309	0,00617	0,0062	258,4
DN 80	77,9	0,0779	0,00476	0,00953	0,0095	398,8
DN 100	102,4	0,1024	0,00823	0,01646	0,0165	689,1

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	8					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,00	88,4
DN 65	62,7	0,0627	0,0031	0,0062	0,01	206,7
DN 80	77,9	0,0779	0,0048	0,0095	0,01	319,1
DN 100	102,4	0,1024	0,0082	0,0165	0,02	551,3

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	10					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,00132	0,0033	0,003299	138,1
DN 65	62,7	0,0627	0,00309	0,00772	0,0077152	323,0
DN 80	77,9	0,0779	0,00476	0,01191	0,0119093	498,5
DN 100	102,4	0,1024	0,00823	0,02058	0,0205783	861,4

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	8					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0033	0,00	110,5
DN 65	62,7	0,0627	0,0031	0,0077	0,01	258,4
DN 80	77,9	0,0779	0,0048	0,0119	0,01	398,8
DN 100	102,4	0,1024	0,0082	0,0206	0,02	689,1

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	6					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,00	49,7
DN 65	62,7	0,0627	0,0031	0,0046	0,00	116,3
DN 80	77,9	0,0779	0,0048	0,0071	0,01	179,5
DN 100	102,4	0,1024	0,0082	0,0123	0,01	310,1

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	6					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,00	66,3
DN 65	62,7	0,0627	0,0031	0,0062	0,01	155,0
DN 80	77,9	0,0779	0,0048	0,0095	0,01	239,3
DN 100	102,4	0,1024	0,0082	0,0165	0,02	413,5

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	6					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,00	82,9
DN 65	62,7	0,0627	0,0031	0,0046	0,00	193,8
DN 80	77,9	0,0779	0,0048	0,0071	0,01	299,1
DN 100	102,4	0,1024	0,0082	0,0123	0,01	516,8

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	4					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,00	33,1
DN 65	62,7	0,0627	0,0031	0,0046	0,00	77,5
DN 80	77,9	0,0779	0,0048	0,0071	0,01	119,6
DN 100	102,4	0,1024	0,0082	0,0123	0,01	206,7

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	4					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,00	44,2
DN 65	62,7	0,0627	0,0031	0,0062	0,01	103,3
DN 80	77,9	0,0779	0,0048	0,0095	0,01	159,5
DN 100	102,4	0,1024	0,0082	0,0165	0,02	275,7

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Water					
ρ (kg/m ³)	1					
Cp	4186					
ΔT	4					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0053	0,01	88,4
DN 65	62,7	0,0627	0,0031	0,0123	0,01	206,7
DN 80	77,9	0,0779	0,0048	0,0191	0,02	319,1
DN 100	102,4	0,1024	0,0082	0,0329	0,03	551,3

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Water					
ρ (kg/m ³)	1					
C _p	4186					
ΔT	2					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,00	16,6
DN 65	62,7	0,0627	0,0031	0,0046	0,00	38,8
DN 80	77,9	0,0779	0,0048	0,0071	0,01	59,8
DN 100	102,4	0,1024	0,0082	0,0123	0,01	103,4
Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Water					
ρ (kg/m ³)	1					
C _p	4186					
ΔT	2					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,00	22,1
DN 65	62,7	0,0627	0,0031	0,0062	0,01	51,7
DN 80	77,9	0,0779	0,0048	0,0095	0,01	79,8
DN 100	102,4	0,1024	0,0082	0,0165	0,02	137,8
Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Water					
ρ (kg/m ³)	1					
C _p	4186					
ΔT	2					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0033	0,00	27,6
DN 65	62,7	0,0627	0,0031	0,0077	0,01	64,6
DN 80	77,9	0,0779	0,0048	0,0119	0,01	99,7
DN 100	102,4	0,1024	0,0082	0,0206	0,02	172,3

Water- Glycol 30% mixture

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	10					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,00132	0,00198	0,0021	78,6
DN 65	62,7	0,0627	0,00309	0,00463	0,0048	183,8
DN 80	77,9	0,0779	0,00476	0,00715	0,0075	283,7
DN 100	102,4	0,1024	0,00823	0,01235	0,0129	490,3

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	10					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,00132	0,00264	0,0027579	104,8
DN 65	62,7	0,0627	0,00309	0,00617	0,0064499	245,1
DN 80	77,9	0,0779	0,00476	0,00953	0,0099561	378,3
DN 100	102,4	0,1024	0,00823	0,01646	0,0172035	653,7

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	10					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,00132	0,0033	0,0034474	131,0
DN 65	62,7	0,0627	0,00309	0,00772	0,0080623	306,4
DN 80	77,9	0,0779	0,00476	0,01191	0,0124452	472,9
DN 100	102,4	0,1024	0,00823	0,02058	0,0215043	817,2

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Glycol/Water	.				
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	8					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,0021	62,9
DN 65	62,7	0,0627	0,0031	0,0046	0,0048	147,1
DN 80	77,9	0,0779	0,0048	0,0071	0,0075	227,0
DN 100	102,4	0,1024	0,0082	0,0123	0,0129	392,2

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	8					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,0028	83,8
DN 65	62,7	0,0627	0,0031	0,0062	0,0064	196,1
DN 80	77,9	0,0779	0,0048	0,0095	0,0100	302,7
DN 100	102,4	0,1024	0,0082	0,0165	0,0172	523,0

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	8					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0033	0,0034	104,8
DN 65	62,7	0,0627	0,0031	0,0077	0,0081	245,1
DN 80	77,9	0,0779	0,0048	0,0119	0,0124	378,3
DN 100	102,4	0,1024	0,0082	0,0206	0,0215	653,7

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	6					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,0021	47,16
DN 65	62,7	0,0627	0,0031	0,0046	0,0048	110,29
DN 80	77,9	0,0779	0,0048	0,0071	0,0075	170,25
DN 100	102,4	0,1024	0,0082	0,0123	0,0129	294,18

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	6					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,0028	62,9
DN 65	62,7	0,0627	0,0031	0,0062	0,0064	147,1
DN 80	77,9	0,0779	0,0048	0,0095	0,0100	227,0
DN 100	102,4	0,1024	0,0082	0,0165	0,0172	392,2

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	6					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,0021	78,6
DN 65	62,7	0,0627	0,0031	0,0046	0,0048	183,8
DN 80	77,9	0,0779	0,0048	0,0071	0,0075	283,7
DN 100	102,4	0,1024	0,0082	0,0123	0,0129	490,3

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	4					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0020	0,0021	31,4
DN 65	62,7	0,0627	0,0031	0,0046	0,0048	73,5
DN 80	77,9	0,0779	0,0048	0,0071	0,0075	113,5
DN 100	102,4	0,1024	0,0082	0,0123	0,0129	196,1

Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	4					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	41	0,041	0,0013	0,0026	0,0028	41,9
DN 65	62,7	0,0627	0,0031	0,0062	0,0064	98,0
DN 80	77,9	0,0779	0,0048	0,0095	0,0100	151,3
DN 100	102,4	0,1024	0,0082	0,0165	0,0172	261,5

Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Glycol/Water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	4					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity kW
DN 40	40	0,04	0,0013	0,0050	0,0053	79,8
DN 65	62,7	0,0627	0,0031	0,0123	0,0129	196,1
DN 80	77,9	0,0779	0,0048	0,0191	0,0199	302,7
DN 100	102,4	0,1024	0,0082	0,0329	0,0344	523,0

Carbon/ Stainless Steel						
Velocity (m/s)	1,5					
Medium	Glycol/water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	2					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity k/w
DN 40	41	0,041	0,0013	0,0020	0,0021	15,7
DN 65	62,7	0,0627	0,0031	0,0046	0,0048	36,8
DN 80	77,9	0,0779	0,0048	0,0071	0,0075	56,7
DN 100	102,4	0,1024	0,0082	0,0123	0,0129	98,1
Carbon/ Stainless Steel						
Velocity (m/s)	2					
Medium	Glycol/water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	2					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity k/w
DN 40	41	0,041	0,0013	0,0026	0,0028	21,0
DN 65	62,7	0,0627	0,0031	0,0062	0,0064	49,0
DN 80	77,9	0,0779	0,0048	0,0095	0,0100	75,7
DN 100	102,4	0,1024	0,0082	0,0165	0,0172	130,7
Carbon/ Stainless Steel						
Velocity (m/s)	2,5					
Medium	Glycol/water					
ρ (kg/m ³)	1,045					
Cp	3800					
ΔT	2					
	Inner Dia (mm)		Area (m ²)	Q (m ³ /s)	Mass Flow (kg/s)	Capacity k/w
DN 40	41	0,041	0,0013	0,0033	0,0034	26,2
DN 65	62,7	0,0627	0,0031	0,0077	0,0081	61,3
DN 80	77,9	0,0779	0,0048	0,0119	0,0124	94,6
DN 100	102,4	0,1024	0,0082	0,0206	0,0215	163,4

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