Super-conductive Data Center EOS v1.0.5

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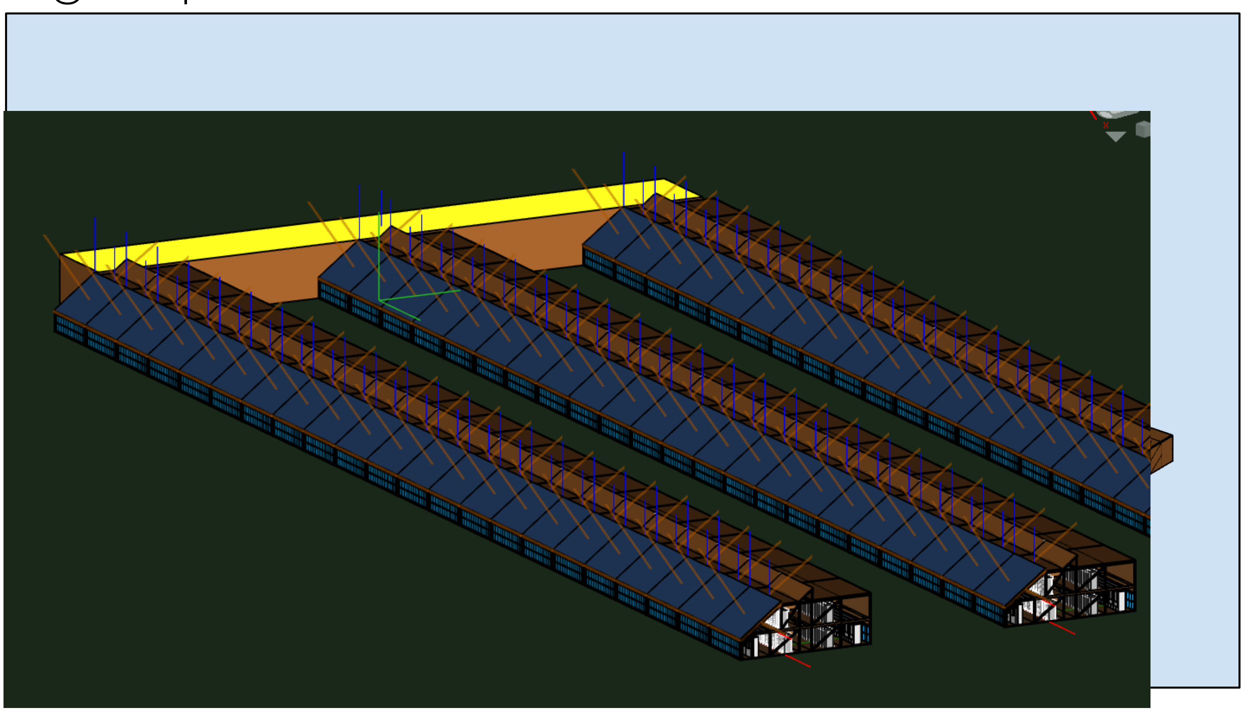


Abstract -- This paper is highlighting the overlooked area of inefficiencies in the Power Distribution chain of large scale Data Centers and proposes a new

approach on how to run Data Centers directly on super-conductive direct current (SCDC) power. On top of it, we present sustainable options for Building materials and Backup Generators. Creating the first open specification for the Hyperscale Data Center of the Future. In the spirit of the OCP, the specification and the Data Center CAD Modell are open-sourced ready to deploy.

Introduction:

Data Centers are vastly bad for the climate! They already are causing around 5 % of all GreenHouse Gases (GHG) emissions. Not only IT equipment is consuming energy but also cooling, UPS, Power Distribution are consuming a lot of energy. So Data Centers are facing a very difficult task: “How to keep my Availability high, my cost low and improve my overall impact on the climate. The Open Compute Project (OCP) was created to answer exactly this. In its 10 years of existence Data Center efficiency increased tremendously.

The Problem:

But the Data Center Efficiency improvements, mostly measured with the Power Usage Effectiveness KPI (PUE), cannot improve much further. On the one hand, this is due to the limitation of the PUE itself and on the other hand due to Data Centers already Achieving very low PUE values, e.g. the Boden DC one has an annual PUE of under 1,03. This is mostly a partial PUE (pPUE) concerning the Cooling system of that Data Center. But there is still one big area inside the Data Center where massive improvements can be made.

The power supply of servers is inefficient and wasteful.

Especially looking into Power Supply Units and UPS Systems, in both cases a majority of energy is lost, or transformed to heat, when Alternate Current (AC) electric energy is rectified to Direct Current electric energy. Furthermore, electric energy is lost when transferring energy from voltage level to another and through Ohm resistance in the Power Distribution systems.

But building a Data Center, especially a 100 MW Hyperscale DC, in 2021 is not only about Energy and Efficiencies. OCP Members like Facebook and Microsoft measure report their GHG emissions according to the GHG Protocol in the 3 emission scopes. Both report about 95 % of their total GHG emissions is contributed by the scope 3 emissions (Indirect emissions, like purchased goods & capital goods, not from their direct energy consumption (scope 1&2).

Build as lean as possible, avoid steel & concrete in construction

Concrete alone is responsible for 7% of the global CO2 emissions, even more than Data Centers or a country like Germany.

How to improve beyond this:

We embrace the OCP approach to simplify, reduce and redesign their Server Hardware and Racks already get rid of 90 of all Power supply units in a Server Rack and run the remaining 1-2 power shelves with high efficiency. But we propose to avoid rectifying of energy completely and reduce Power shelves UPS Management systems Heavy Busbar systems completely from the Data Center. Everything on the server PCB runs on DC energy, hence we will power the complete Data Center on DC energy. To avoid Ohm resistance losses we propose a super-conductive power distribution based on

high-temperature superconductors (HTS)

HTS are ceramic materials that become super-conductive at around 77 K (-196 Celsius) which is perfect to run them with liquid nitrogen, which is cheap and widely available. Introducing liquid nitrogen to a Data Center facility benefits other systems, which leads to further reduction of traditional Data Center equipment. Superconductor systems are still more expensive than traditional Busbar systems, but offer a return on investment quickly.

To improve the scope 3 emissions the complete physical infrastructure of the proposed and open-sourced Data Center is built from cross-laminated timber (CLT) a wooden engineering material with 20.5 % of the CO_2 emissions equivalent of concrete and only 15.2 % of steel. With its low embedded carbon CLT can even create climate-positive buildings if a high percentage of the material is reused. CLT is starting to replace Steel & concrete in traditional construction like multi-storey office and residential buildings. In Sweden, the first Data Centers have been build from CLT(e.g ecodatacenters & Hydro66). CLT is easy to adapt for use in DC construction via CNC machinery. Most properties like strengths, load, fire-resistants for CLT are certified. CLT does not have limitations in creating secure and available Data Centers.

Result and Findings:

To easily adapt a new technology like super-conductive busbars and CLT construction we designed a Data Center with all necessary systems for a cost-effective, high-available and sustainable DC Operation. We created an open specification, published the CAD Models and go into deep for new systems and new processes, like Cogeneration.

The Datacenter features:
- A scalable Reference Design 100 MW
- super-conductive Busbar
- Evaporative Cooling
- CLT Infrastructure
- 1 MWp solar energy production
- Direct connection to DC solar park
- Gas Backup Genset
- Nitrogen Fire protective solution

The super-conductive busbar redefines power distribution. The partial **pPUE is 1.04** of the super-conductive power distribution compared to a traditional power distribution: Transformer+MSB+Genset+UPS+Busbar+ PSU the **pPUE = 1.23-1.56** (This is mostly hidden in conventional PUE Analysis.)

The scope 3 emissions are compared to a traditional data center **80 %** lower compared to a steel and concrete-based construction.

We can eliminate **power shelves, separate fire-fighting gear, UPS management systems and outsource the backup system** via an Energy Service Agreement.

Radical new Data Center Design for net-zero Hyperscale Operations

1 Scope

This document describes the mechanical and electrical specifications used in the design of a Hyperscale innovative and energy-efficient super-conductive data center.

2 Contents

3 Overview Paper

Data Center reached a point where its Efficiency gains are very small and only can be achieved with either exponential costs or with introducing innovations in the Data Center Industry on Processes, equipment and Buildings. In this paper, we want to introduce some innovations that have either not been applied in the Industry so far or have not been applied together to create the most efficient and cost-effective Hyperscale Data Center possible to date. We choose the OCP FTI to highlight our findings because we are convinced that the OCP and its community are leading the charge and change in the Data Center industry.
To create the efficiency improvements we present, we need to introduce one major new medium to the Data Center Industry:

- **Liquid Nitrogen**

Liquid nitrogen is necessary to run the main innovation, the super-conductive busbar, of the proposed 100 MW Hyperscale OCP Data Center. In the specification, we will go into detail about how this benefits the operations and which additional benefits are enabled by liquid nitrogen into a Data Center facility. With this paper we want to show that it is more than feasible to apply super-conductive busbars in a 100 MW class Data Centers, our findings are published in an open specification, based on the OCP Facebooks Pinewood facility. But this specification is not limited to North America, rather can be deployed in most geographical regions.
This specification is specific to OCP technology, however traditionally racks can be integrated via 370 VDC PDUs and DC/DC PSUs.

Featured Highlights of Innovation:

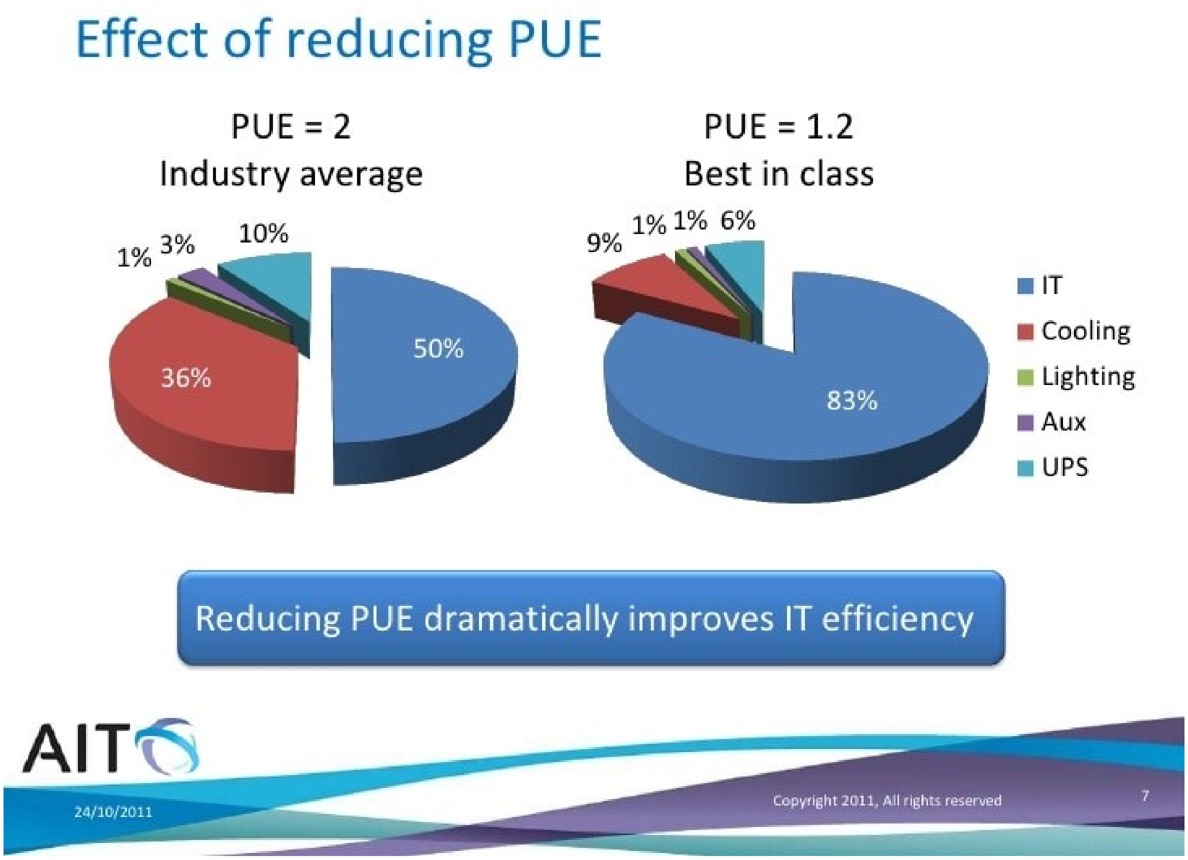
- 100 MW total IT Capacity (min. 40 MW, max. 400+ MW)
- Super-conductive DC power distribution
- DC central, scalable UPS
- ECOcooling equipment, with direct free cooling
- Heat reuse for liquid-cooled equipment
- Infrastructure build from woods in segments
- active PUE reduction with PV energy production
- Direct integration of renewables
- Natural Gas Backup generator, offering secondary energy to the utility grid
- Burst cooling, by Nitrogen (4.10)
- Burst O2 reduction, by Nitrogen
- Keymetrix: cost per kW, cost per sqm whitespace, real PUE
- Flexibility: OCP, 19" Mining equipment, Immersion and Liquid cooling

PUE considerations:

To measure the efficiency usually, the Power Usage Efficiency KPI is used (PUE). This is a Value that offers a simple definition, but to get a holistic picture the PUE is hard to measure.

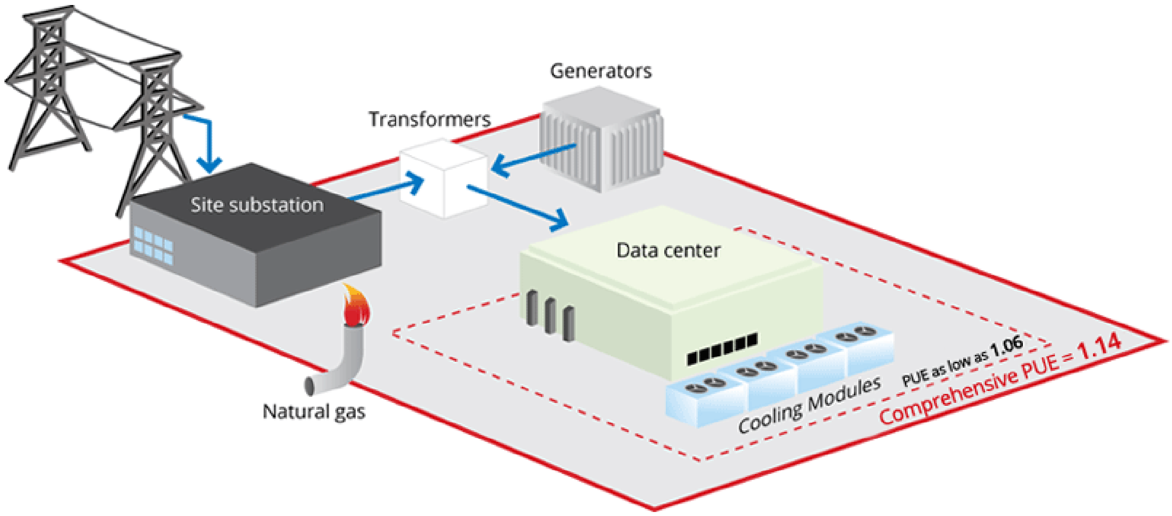
$$PUE = \frac{Total\ Data\ Center\ Energy\ used}{Server\ Energy\ used}$$

This is the traditional definition of a popular Key Performance Indicator (KPI) for a Data Center. Experimental Data Centers, e.g Boden Type One, have shown that you can achieve very efficient operations around 1.01-1.02. You cannot get better than this problem solved. But the PUE is limited in its definition of what belongs to the Server energy and what is facility energy.



PUE Examples:
If you look to Liquid cooling server solutions, like immersion cooling or Direct-to-chip liquid cooling they eliminate the necessity of Server fans inside the Server which is a very important part of the cooling chain of CPU systems. Submer, an immersion cooling company, estimates that if you add the server fans to the Cooling System of the Data Center the real PUE of the cooling for a server is close to 1.5. So we need to have a closer look at the denominator if we want to improve already efficient data centers.

$$PUE = \frac{Total\ Data\ Center\ Energy\ used}{Server\ Energy\ (Server\ Fans + \ CPU\ TDP, PSU\ losses, RAM\ losses, Storage\ losses, Led\ Lighting,}$$



PUE example from Google: There is an issue with the scope of gas-powered DC measures.

$$PUE = \frac{Total\ Data\ Center\ Energy\ (Server, cooling, UPS, Distribution, switch\ gear, Transformers, Generators)\ -\ (Energy\ created\ on\ site)}{Server\ Energy\ (Server\ Fans +\ CPU\ TDP, PSU\ losses, RAM\ losses, Storage\ losses, Led\ Lighting,}$$

So there is an area in the Data Center PUE scope that is for the most part not very well represented and often not factored in in the overall PUE accounting which are the losses in the Energy distribution from the grid to the Server.

Additionally, the PUE is not very good at recognizing renewable energy created on-site. Which would give some Data Centers a sub 1 PUE Value. We tried to acknowledge all of these factors on this specification. If we mention the PUE Value in this paper we are usually referring to this equation above. For our Findings, we will address a traditional PUE, a Comprehensive PUE and one including PUE compensation.

3.1 License

4 Electrical Design

The electrical system designed for 100 MW IT Equipment.

Basic Assumption:
100 MW IT load
25 KW per OCP Rack
4000 Racks
380 V DC means 65 Amps per Rack 263.2 kA total

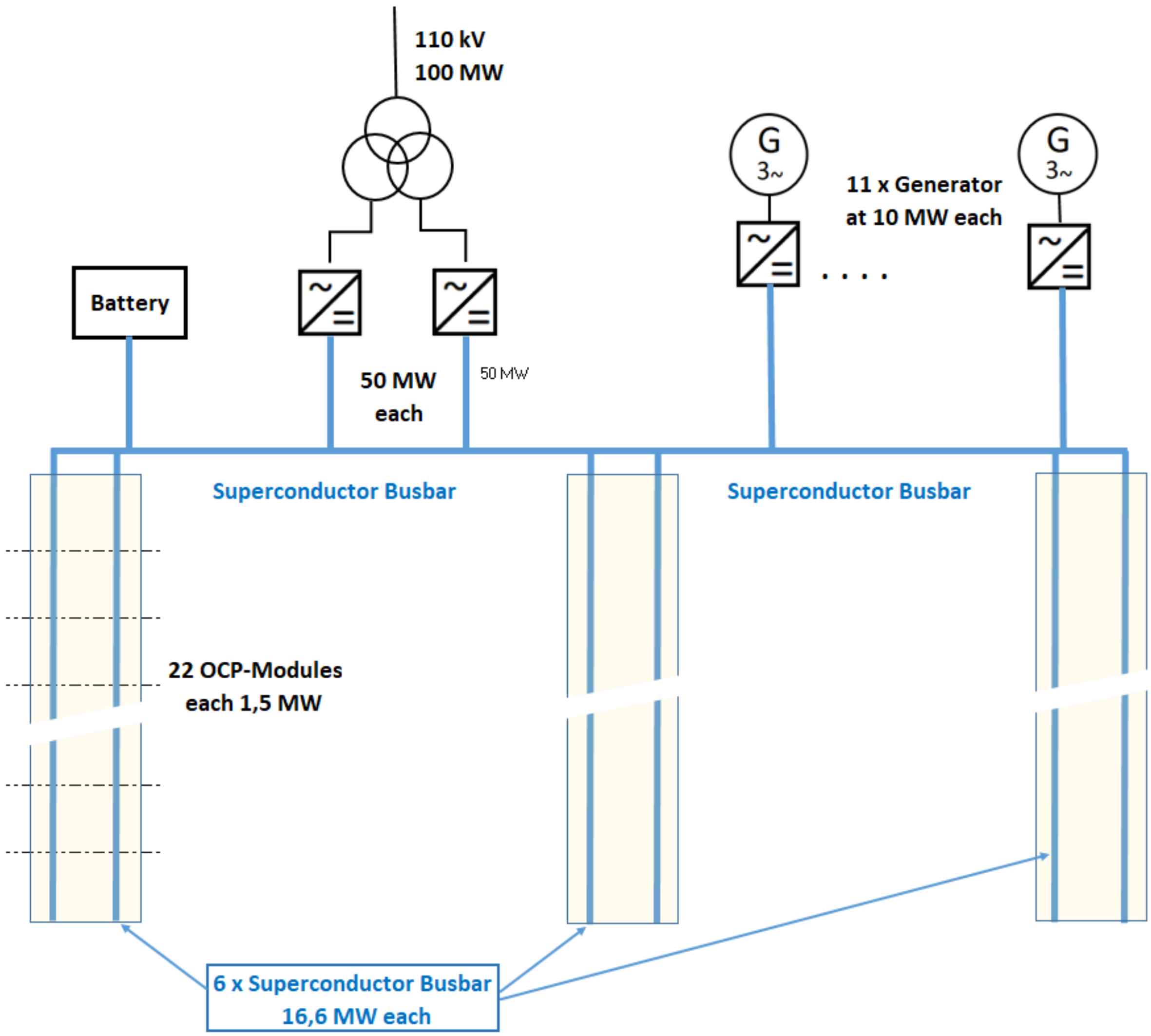
4.1 Codes, Guidelines, and Standards.

The systems are designed to meet or exceed American or European standards.

4.2 Featured Electrical Systems

In addition to standard data center electrical design elements (from grounding to transformers), the facility features these electrical and related systems:

- 115 kV / 110 kV substation and rectifier
- Gas-powered backup generators
- Main superconducting busbar
- Battery with monitoring system
- 480/277VAC distribution switchboards
- Server battery backup
- Nitrogen-based fire sprinkler system eliminates pipe corrosion
- LED lighting systems
- Cam lock connections
- Solar panels



4.3 115 kV, 60 Hz / 110 kV, 50 Hz Rectifier station

The rectifier station consists of the following main components:

• One 100 MW transformer with two secondary circuits with phase sift to reduce grid perturbation. Voltage tab changers are provided to allow for an adjustment of 5% above and below nominal voltage in steps. The transformer is provided e.g. by lightning arresters, thermal relays, liquid pressure relays and differential relays.
• Two 50MW rectifier units with 400 / 380 VDC upto 1500 VDC output.
• All controls, protection and measuring appliances are integrated in the transformer incoming switchgear.

Outgoing DC values are recorded by the rectifier units which can be electrically insulated by the circuit breaker and on-load disconnecting switch. Both rectifier units are directly feeding to the current leads of the superconducting busbar.
Incoming and outgoing measured values are recorded and transferred to a central control and operating system. Local emergency control is possible too.

The substation including the power transformers and the additional equipment is installed outdoors under a weather protection roof at a secured fenced yard. Rectifiers and the related equipment are installed in an air ventilated electrical building.

Grounding is provided to ensure the lowest practical resistance between circuit neutrals and true earth; it is also provided to ensure safe operation of the substation with low values of touch and step potential that conform to IEEE Standards.

4.4 Gas - Cogeneration Generators

• A single-engine generator is dedicated to a single main switchboard (MSB) in this block redundant scheme.
• The engine generators run on natural gas.
• The local utility can access the generators to provide flexible power to the grid. The CAPEX and OPEX for operating the generators for the flexible power are borne by the utility.
• The engine generators provide backup power to the MSBs, which distribute power to all facility loads:
o Power distribution to server load.
o HVAC equipment loads.
o Interior and exterior lighting systems.
o General purpose power.
• Generators are located in a secured exterior yard.
• Weather enclosure only; no sound attenuating enclosure.
• Generators are solidly grounded.
• 30-hour backup natural gas fuel storage belly tank.
• The engine generators are natural gas-fueled with standby rating 10.000 kW/9740 kVA, Class H insulation and 125°C rise, ready in 7,5 seconds, for flexible power to the grid. Rated for higher elevation use. For constant power to the grid alternatively, the generators have a rating of 9830 kW at 60 Hz.
Each with its own Rectifer to feed 380 VDC into the Busbar.
• Equipment monitoring interface:
o BMS Modbus interface for equipment monitoring.
o Critical operating parameters.

4.5 Main Superconducting Busbar and Switchgear

The superconducting busbar is collecting and distributing all incoming and feeding main circuits and is working as a distributed switchgear. No central switchgear is required.

The superconductor busbar itself is monitored and controlled by an independent supervisory system. For maintaining the operating temperature of the superconductors, redundancy in the cooling equipment is provided according to the data center security requirements.

Incoming and outgoing circuits are short-circuit current protected by superconducting fault current limiters and circuit breakers.

A central control unit will switch on/off emergency equipment and control the power flow on all branch power circuits. Electrical interlocking, data acquisition, data storage and evaluation is included in the control equipment of the superconducting busbar. All operational data are recorded and transferred to a central control unit.

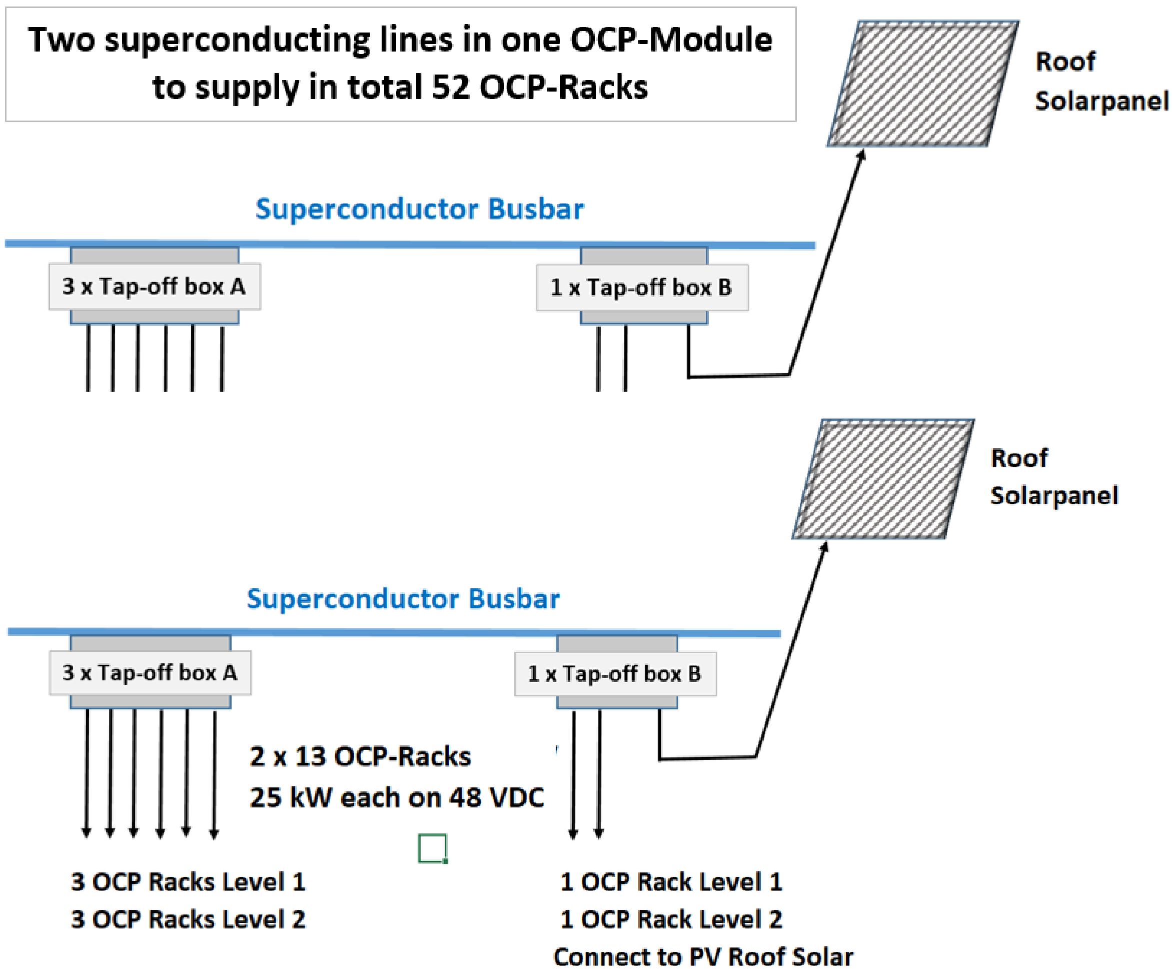
For all non-IT-related power requirements a standard low voltage switchgear will contain all equipment to supply and monitor electric power to the buildings. A relatively small transformer will be connected to the incoming feeder.

Indoor 263 kA busbar is constructed to each feeding with 6 main tap-off busbar systems 2 into each Data Hall supplying 16,6 MW each.

The generator setup out of 11 x 10 MW Gas Generators is feeding directly into the busbar system in brown- or Black-out scenario.

The bus duct uses interlocked circuit breakers.
Each Tap-off from the Busbar system feeds 3 OCP Racks. The Tap-off have integrated DC/DC conversion from 380 V to 48 V feeding directly into the busbars at the back of the Rack.

Each Module has on “Tap-In” for the direct feed of the Solarpanels mounted on top.



4.6 Battery with Monitoring system

Due to the elimination of the Rack power shelves, a decentralised approach to Battery backups is not suitable. A central Battery Pack is directly connected to the DC super-conductive busbar. NO UPS system is required. The Battery Pack consists of a High C Factor that enables for quick charging and discharging of the DC system. It buffers the Data Center for 30 seconds until the Gas Generators are taking over.

• Monitoring of the battery system is provided for status and alarm conditions.
• Battery string voltage, battery discharge current, individual voltages, configured temperature, individual resistance, inter-cell connection resistance, and inter-tier resistances are monitored.
• The battery monitoring system communicates status and alarm conditions to the BMS via TCP/IP on the facility Ethernet backbone.

4.7 Server Power

• Overhead 380 V DC super-conductive busways Tap-off with DC/DC converter from 380 V to 48 V direct supply, power shelf eliminated.
• Rack power distribution: 48VDC
• up to 45 kW per Rack

4.8 ~~DC Battery Backup~~

Integrated in point 4.6

4.9 ~~Power Busbar System~~

Integrated into point 4.5

4.10 Fire Alarm and Protection System

• Pre-action fire sprinkler system uses nitrogen gas instead of compressed air to eliminate pipe corrosion.
• Online nitrogen generator.
• A VESDA air sampling system is provided for early detection for fire/smoke Detection.

4.11 LED Lighting Systems

Energy-efficient LED lighting is used throughout the data center interior.
• Innovative power over Ethernet LED lighting system.
• Each fixture has an occupancy sensor with local manual override.
• Programmable alerts via flashing LEDs.

4.12 Cam Lock Connections

The 380 VDC distribution system is equipped with cam-lock connections that allow for maintenance bypass of key components.

4.13 Solar Panels

The Data Center Design features a Design optimal to install on the roof facing the sun.
3564 sqm of Photovoltaic with 1MWp power output are directly fed into the DC Busbar system, no inverter system necessary.

5 Mechanical Design

The goal of the mechanical design is a system combining very low operating cost and a relatively low installed cost with low GHG emissions in all 3 Scopes when compared to a conventional data center. Energy-intensive
cooling systems are replaced with far simpler and lighter technologies that
allow for a ductless overhead air distribution that can operate in an expanded
temperature and humidity range beyond 2020 ASHRAE TC9.9 guidelines (see Figure 1).
We went beyond ASHRAE guidelines because we're using our own custom servers (see other Open Compute Project specifications) that we have tested, and are confident that they will operate within our dictated lifecycle.
The Data Center Design features 3 Data halls each consisting out of 22 x 8 m OCP-Modules, these Modules are built from Cross-laminated Timber (CLT) for significant lower embedded CO_2. The Modules are designed so that they can be added as needed. Which enables high utilisation of the existing Data Center.

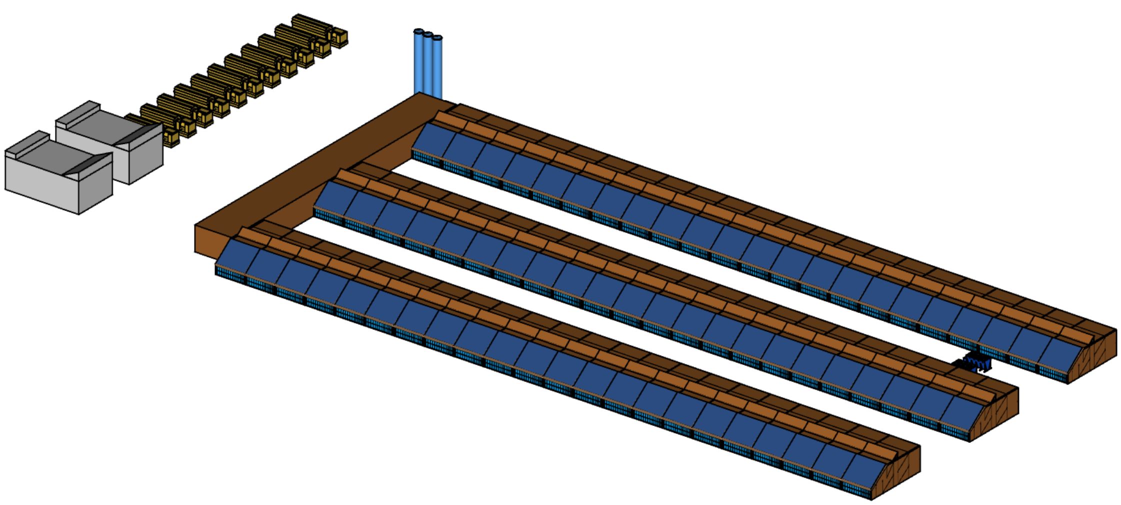


Figure: 100 MW Hyperscale Data Center

Featured mechanical systems beyond the traditional Data Center Systems:

- Wooden infrastructure built with cross-laminated timber (CLT)
- Vakuum Subcooler
- Liquid Nitrogen Cooling in Combination with Evaporative cooling

5.1 Mechanical System Design Criteria

The data center was built with the following internal and external environmental conditions as guidelines.

5.1.1 Data Center Conditions
• Cold aisle temperature controlled between 65ºF (18.3ºC) and 85ºF (29.4ºC)
• Dewpoint minimum 41.9ºF (5.5ºC)
• 65% relative humidity (RH) maximum

5.1.2 Outside Air Design Conditions
OA conditions at the north European site are ideal for using an evaporative cooling system.
• Summer: 110ºFDB (37.3ºC) (dry bulb) maximum, 70.3ºFWB (21.27ºC) (wet bulb) maximum (105.6ºF (38.8ºC) is the 50 year extreme maximum and 70.3ºF (20.27ºC) is the worst recorded WB temperature
between 1972 and 2001 in South Denmark per ASHRAE)
• Winter: -30.8ºFDB (-15.6ºC), 50%RH, 0.55 grains (50 year extreme minimum per ASHRAE)
Note: Design data is based on published data for Apenrade, Denmark, which is the closest city to the data center location that has complete information available.

5.2 Outside Air Operating Conditions

The operating conditions of the different installed systems (economizer, direct evaporative cooling, and humidification) vary based on the outside air (OA) conditions. Figure 1 is a psychrometric chart indicating where these conditions occur. To better understand the sequence of operations, see section 6.

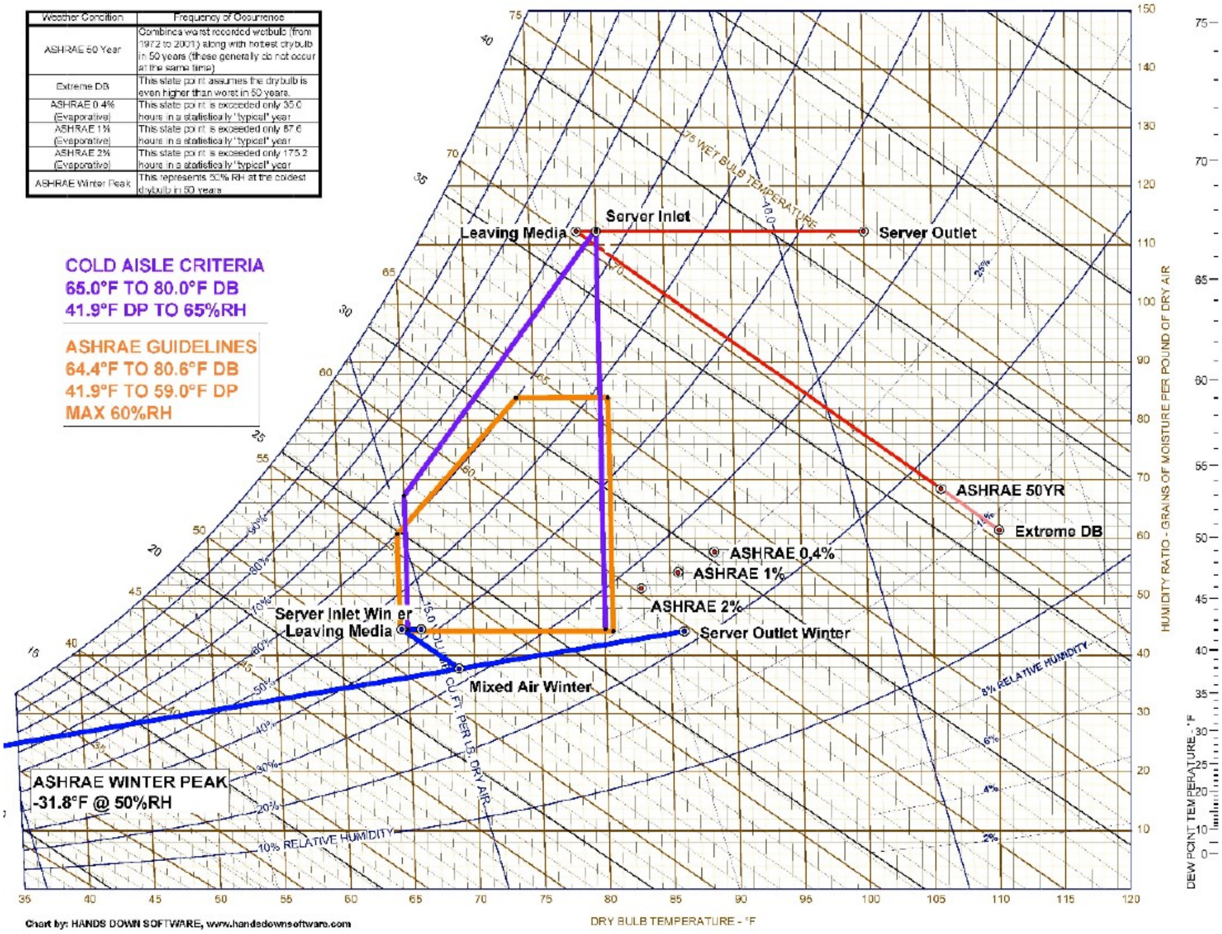
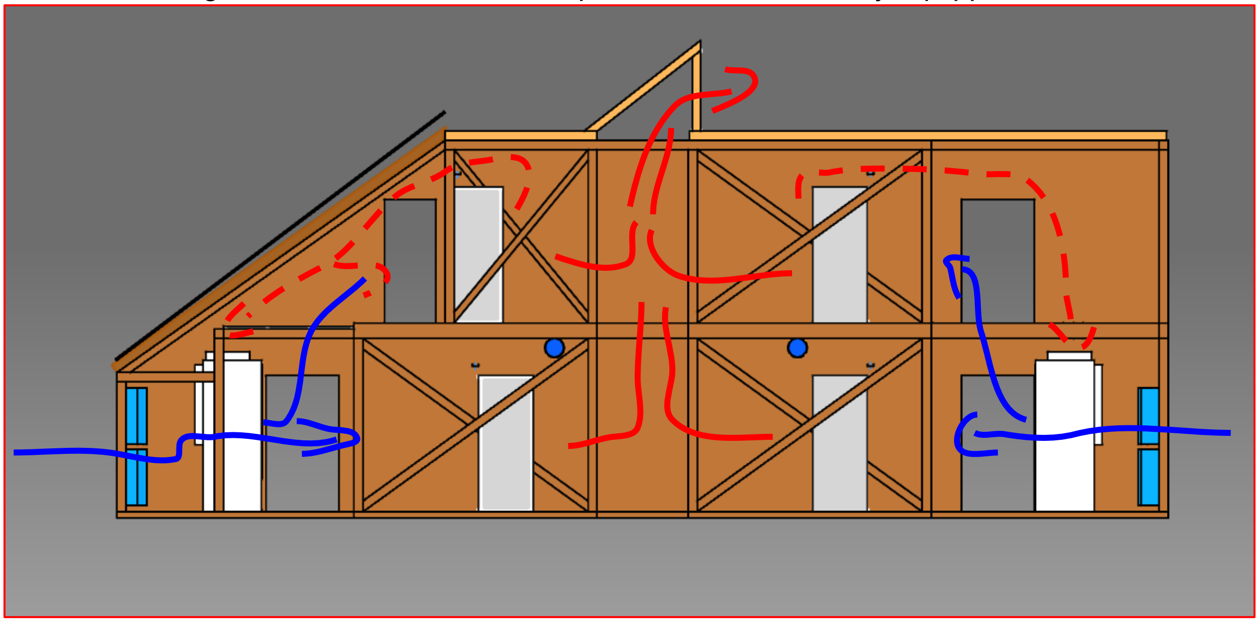


Figure 1 Design Psychrometric Chart

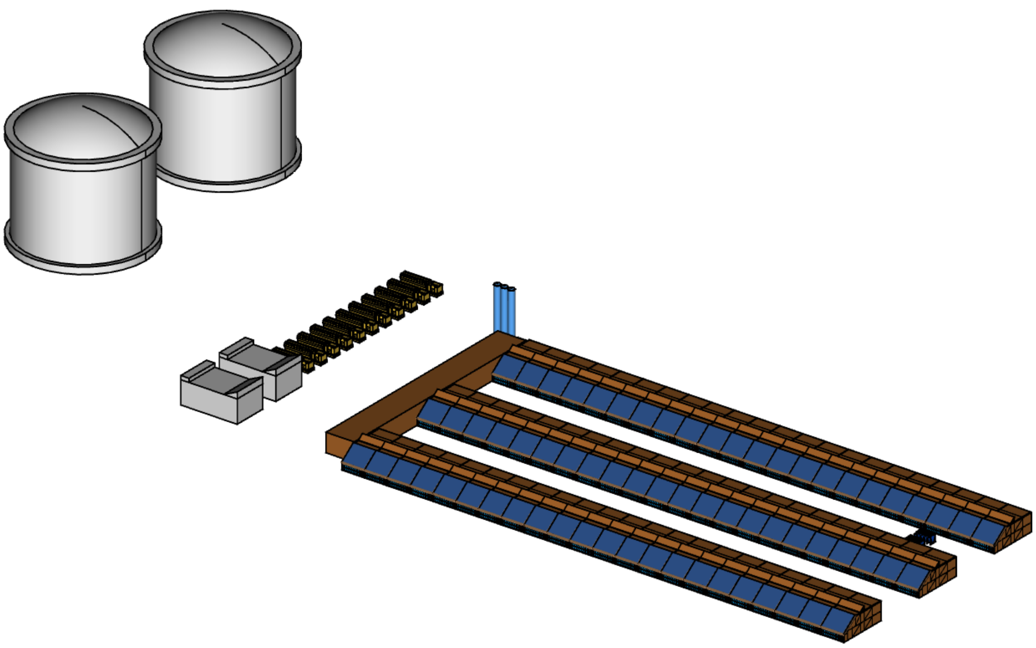
5.3 Mechanical System Concept

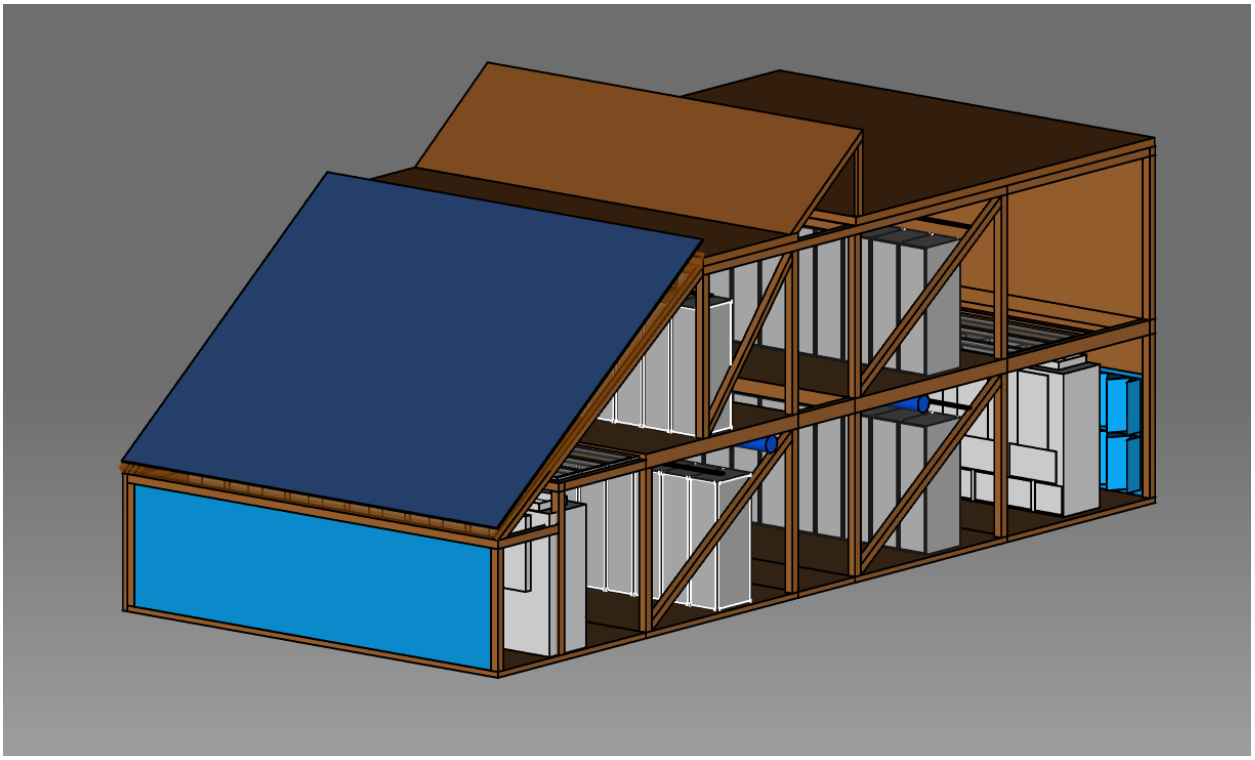
The mechanical system basis of design utilizes a direct evaporative cooling concept where no chillers or compressors are needed for cooling the IT load.
The design utilizes a built-up system where the mechanical airside functions are located in a field-constructed penthouse.

The Data Center is built in 8m Modules that are designed around a central hot aisle with OCP Racks positioned on the ground floor and the first floor. The Modules width and the thickness of the floor is designed to hold the static load up to 13 OCP Racks fully equipped



The OCP Racks are only accessed from the front. This way a very high hot isle





5.3.1 Built-Up System Advantages and Disadvantages

A built-up system (penthouse design) has advantages with construction and operational serviceability.

Construction Advantages

• Reduced footprint of mechanical room.
• No field ductwork required; air is distributed with plenums.
• Lower potential for roof leakage that can penetrate into the data center compared to roof-mounted AHUs.
• No exposed piping on the roof that can cause access, potential leaks, and reproofing issues.
• Less required equipment redundancy, which can result in a lower construction cost.

Operational and Maintenance Advantages

• Enclosed interior space makes service and maintenance better than being exposed to exterior elements (cold winters and hot summers).
• Less likelihood of mixing relief/exhaust air with outside intake air.
• Longer life expectancy than AHU casing based on the AHU's exposure to outside elements.
• Less maintenance cost (door seals, control cabinets, etc. exposed to weather).
• Easier access to service and maintenance of damper actuators, fans, starters, VFDs, humidifiers, and controls.

Built-up System Disadvantages

• More reliance on mechanical contractor capabilities to field assemble and install a

quality system.
• Drains required for direct evaporation/humidification will most likely need to be located below the roof and thus will require double containment and leak detection.
• Scaling is limited, as unit count must increase to match built-up system capacity and Redundancy.

5.3.2 Airflow Overview

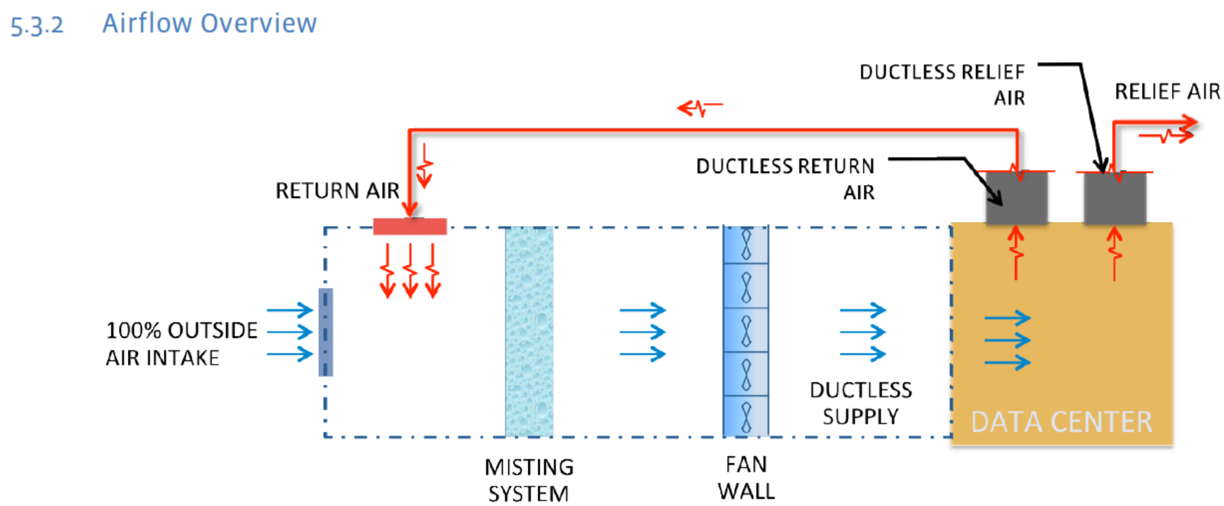


Figure 2 Airflow Overview

1. Outside air (OA) enters through vertical drainable louvers in the penthouse.
2. The air proceeds into the OA intake corridor.
3. OA mixes in with data center return air and passes through the filter bank in the filter room.
4. Air enters the evaporative cooling/humidification room and may get sprayed by the misting system.
5. The air passes through mist eliminators to prevent water carryover.
6. The air enters the supply fan room, and gets pushed down the supply air openings to the data center cold aisles.
7. The air enters the front of the server cabinets and passes through to the contained hot aisles, entering the return air plenum. The air then is returned to the filter room or exhausted out of the building by natural pressure and/or relief fans.

5.3.3 System Functions and Features

The system is designed to provide the following functions and features:
Full Airside Economizer System

• Can obtain free cooling whenever outside air conditions are favorable.
• Provides very significant operating cost savings, especially in the high desert climate.
• Dampers are situated so that there is good mixing and to avoid moisture issues when the cold outside air mixes with the relatively moist return air in the winter condition.

Filters

• MERV 13 (ASHRAE 85%) cartridge filters with low initial pressure drop and high dust loading capability will be provided. The filter system has space for 2" pleated 30% prefilters. The filters can be upgraded to MERV 14 (95% ASHRAE). However, the pressure drop increases from 0.27"SP at 500 FPM to 0.36"SP.

High Pressure Atomization

• High pressure pumps and atomizing heads provide both evaporative cooling and humidification.
• System is fully modulating.
• Redundant softener and reverse osmosis (RO) systems with distribution pumps and piping to each built-up AHU system.
• The softener and RO systems require maintenance; the atomizing heads require replacement after approximately 10 years.

Supply Fan Systems

• Low operating cost, direct-drive plug (plenum) fans.
• Fan array fed by three electrical busses at N+1 redundancy.
• Fans are controlled with VFDs to minimize the operating cost, as the load and fan pressure requirements vary.
• Fan array minimizes penthouse area.

Complete Hot Aisle Containment

• Center and end aisles are considered to be cold aisles to keep as much of the area as comfortable as possible.

Relief Fans

• Fan array fed by three electrical busses at N+1 redundancy.
• Fans are controlled with VFDs to minimize the operating cost as the load and fan pressure requirements vary.
• The fans discharge through hooded automatic dampers to minimize the possibility of moisture penetrating into the space.

Building Management System (BMS)

• Distributed system provides redundancy in case of failure.
• Direct Digital Control (DDC) based. Provides all control, data logging, monitoring, and alarming functions required for the mechanical systems.
• Interfaced to the electrical components and provides monitoring and alarming of critical points.
• Interfaced to the fuel systems, VESDA, and fire alarm to provide monitoring and alarming of critical points.
• Does not monitor data center power use at the server level.

Other Items

• Major equipment is controlled with VFDs to minimize operating cost and to allow the systems to accurately match the load.
• Redundancy is provided for major equipment so that on loss of any single electrical bus or a mechanical failure, the full design capability is still available.
• The direct evaporative system is supplied primarily by an on-site well and secondarily by the normal city water distribution system. Both sources feed into a storage tank. The storage tank provides 48 hours of water in the event well water and city water sources are unavailable. The water storage tank is not insulated, and there is no bubbler to keep it from freezing.
• Piping outdoors is insulated and heat traced to protect it from freezing. Systems that will be drained down during the winter would not require freeze protection.

7 Appendix B: Indirect Cooling

One option considered but not implemented at Facebook's Prineville site was to use indirect cooling, which uses cooling coils that are piped to open cooling towers with condenser water pumps.

An indirect system can provide sensible cooling to bring data center recirculated air from 100ºF down to 78.5ºF (80ºF cold aisle -1.5F fan heat) when the outside wet bulb temperature is 66.0ºF or lower.

Note: 66.0ºF WB was chosen as this allows the system to control to 80ºF cold aisle while supplying 72ºF water to the coil, which makes the cooling tower selection a reasonable 6ºF approach and keeps the coil air side pressure drop to approximately 0.65"SP; basically optimizing the cooling tower and coil. 66.0ºF WB is 2.7ºF above the ASHRAE 0.4% WB design of 63.3ºF WB, indicating that there is a good safety factor to allow the overall system to maintain conditions within the ASHRAE guideline envelope of better than 99.6% or 8725 hours of an average year.

This capability would therefore allow the system to operate in the non-economizer mode if there is an outside atmospheric problem such as smoke or dust.

The indirect system would allow the overall cooling system to stay within the ASHRAE data center guidelines of 60%RH and 59.0ºF DP (dew point) maximum up to the ASHRAE extreme maximum of 70.3ºF WB with a coincident of 110ºF DB (this high a DB has never been coincident with the 70.3ºF WB).

Bypass dampers could be installed at the cooling coils so that when the conditions are such that they are not required, they will open and the supply fans can then work at a lower pressure drop, thus saving significant energy during the year.

The cooling towers could have VFDs on the fan motors, sweeper piping in the basin with filtering system, and a non-chemical water treatment system. Due to the freezing climate, they would need to be drained in the winter.

The system can use an N+1 redundancy for the cooling towers and the condenser water pumps, but not for the water distribution piping systems. It seems very unlikely that the space conditions would be compromised if there were a leak with a possibility of a high RH condition for perhaps a few hours. The likelihood of a leak that could not be repaired within a reasonable time is very low. This system would only be used to avoid high humidity problems and handle unusual dust or smoke conditions, which are infrequent. There would be one tower and pump for each electrical bus.

In order to minimize piping runs, the cooling towers can be located on a roof, particularly if a built-up outside air system is selected; however, they could be located on the ground, if desired. For sites implementing rooftop air handling units, the towers would have to be located on the ground because of space limitations.

The indirect coil would be fully active in the following outside air conditions (as per section 6):

- Condition E: >80ºFDB (-fan heat) and >41.9ºFDP and >65.76ºFWB
- Condition H: Unacceptable OA conditions (smoke or dust)

In these situations, the cooling towers and pumps would be on. Condenser water temperature would be controlled (cycle on towers and control tower fan speed with VFD and stage pumps and control pump speed with VFD) to maintain 80ºF (-fan heat) cold aisle temperature.

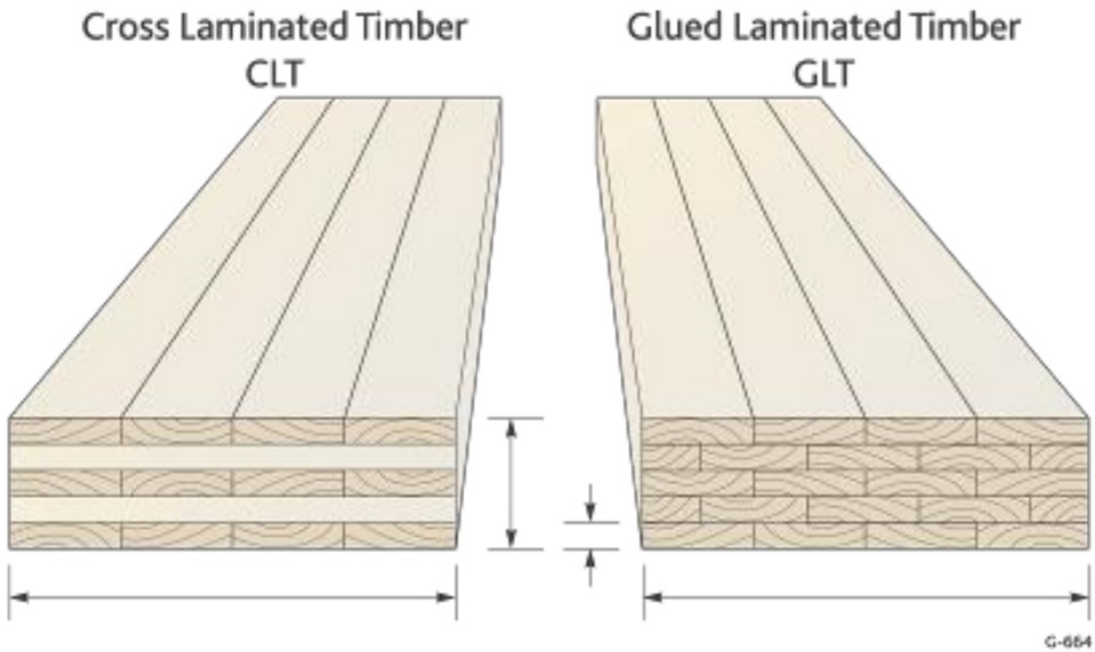
Appendix C: Cross Laminated Timber (CLT) as Construction Material for Data Center

Mass timber and hybrid systems started to play a notable role in sustainable construction of taller and larger buildings. CLT is one of several mass timber products considered to be the "game-changer" in this endeavour and the catalyst to enable other wood products to be used in the construction of Data Centers. The first wooden data center facility is run in Sweden by https://ecodatacenters.se. They chose CLT after a holistic GHE analysis.

Key Advantages of CLT

CLT used for prefabricated wall and floor assemblies offers many advantages. The cross-laminating process provides improved dimensional stability to the product, which allows for prefabrication of long, wide floor slabs, long single-storey walls, and tall plate height conditions as in multi-storey balloon-framed configurations. Additionally, cross-laminating provides relatively high in-plane and out-of-plane strength and stiffness properties, giving the panel two-way action capabilities like those of a reinforced concrete slab. The 'reinforcement' effect provided by the cross-lamination in CLT also considerably increases the splitting resistance of CLT for certain types of connection systems.

Figure X illustrates the primary difference between CLT and glulam products.



Manufacturing Process

A typical manufacturing process for CLT includes the following steps: lumber selection, lumber grouping and planing, adhesive application, panel lay-up and pressing, product cutting, surface machining, marking, and packaging. Stringent in-plant quality control tests are required to ensure that the final CLT product will be fit for the intended application.
Panel dimensions vary by manufacturer. The assembled panels are usually planed and/or sanded for a smooth surface at the end of the process. Panels are cut to size and openings are made for windows, doors, service channels, connections, and ducts, using CNC (Computer Numerical Controlled) routers, which allow for high precision.

Figure X: CLT Manufacturing:

CLT considerations

CLT structures are well suited for use in a wide variety of structural applications, from low-rise commercial and institutional buildings, to mid-and high-rise residential and non-residential buildings. Several buildings, as high as twenty-four storeys, have already been constructed around the world, which uses CLT in their structural system.

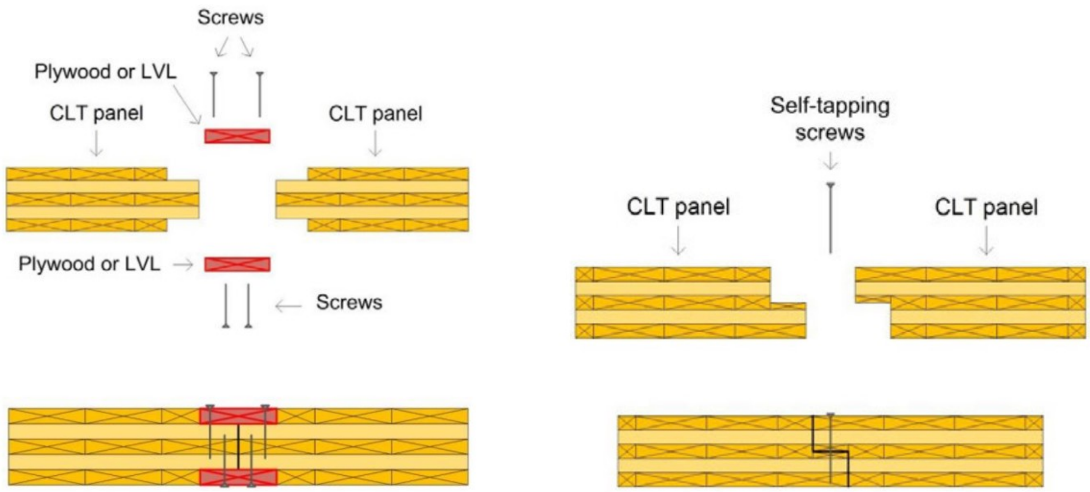
CLT panels are typically used as load-carrying plate elements in structural systems such as walls, floors, and roofs, and sometimes as beams and lintels. For floor and roof CLT elements, the key critical characteristics that must be taken into account are the following:

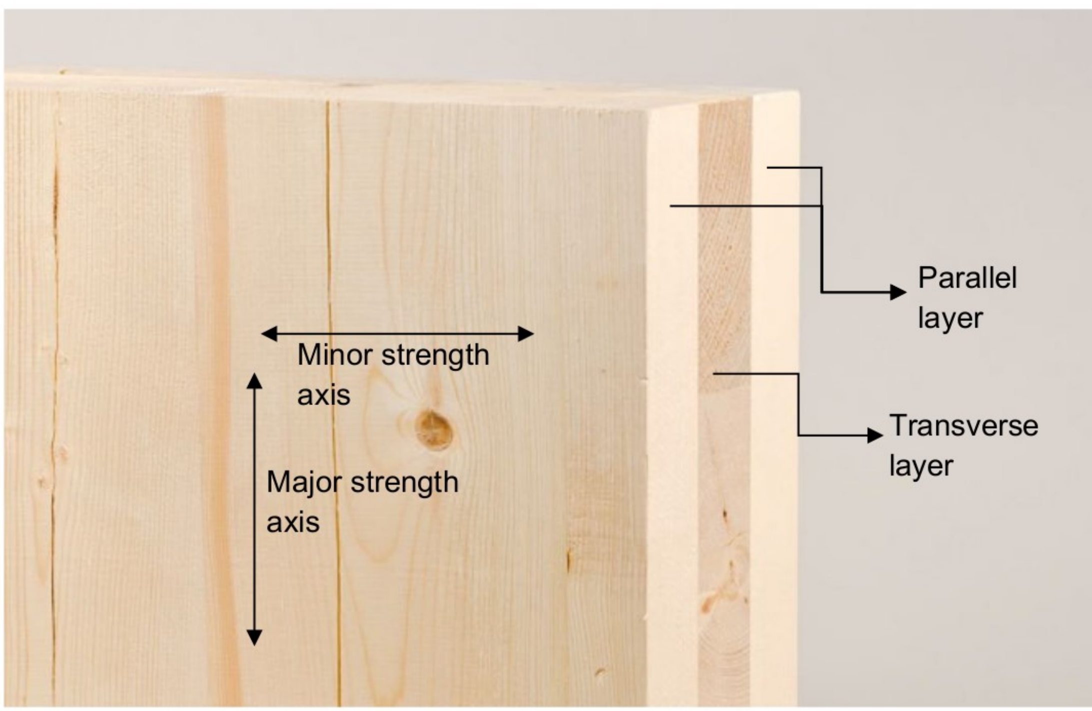
- In-plane and out-of-plane bending strength, shear strength, and stiffness
- Short-term and long-term behaviour:
    - instantaneous deflection
    - long-term deflection (creep deformation)
    - long-term strength for permanent loading
- Vibration performance of floors
- Compression perpendicular to grain (bearing) deformations
- Fire performance
- Sound insulation
- Durability
- Energy efficiency

For wall elements, the following are key characteristics that must be taken into account at the design stage:

- Load-bearing capacity (critical criterion)
- In-plane shear and out-of-plane bending strength
- Fire performance
- Sound insulation
- Durability
- Energy efficiency

Connecting of CLT panels





Fire resistance in CLT

Cross-laminated timber (CLT) has been used in numerous applications ranging from single-family dwellings to mid-rise and tall wood buildings. As more research becomes available, particularly about the fire performance of CLT, the number of larger and taller CLT projects being approved has grown, which has resulted in the construction of several high-profile CLT buildings.

Background of Fire resistance in CLT

Mass timber products are generally known to perform well under fire conditions due, to a slow rate of charring, which generates a thick layer of low-density insulating char and thereby protects the timber below from elevated heat effects. Charring is a material-specific property attributed to timber; understanding this behaviour is fundamental in estimating the reduced thickness of full-strength timber when exposed to fire, which designers can use to calculate a member's residual strength for a given fire exposure.

Several fire tests have been performed by CLT manufacturers on a proprietary basis. There is also, a range of full-scale standard fire-resistance tests performed with CLT assemblies under various structural loading that is publicly available in the literature. An adapted methodology predicting fire-resistance performance for CLT assemblies has been developed in Europe and is currently being used on a proprietary basis by many European CLT manufacturers

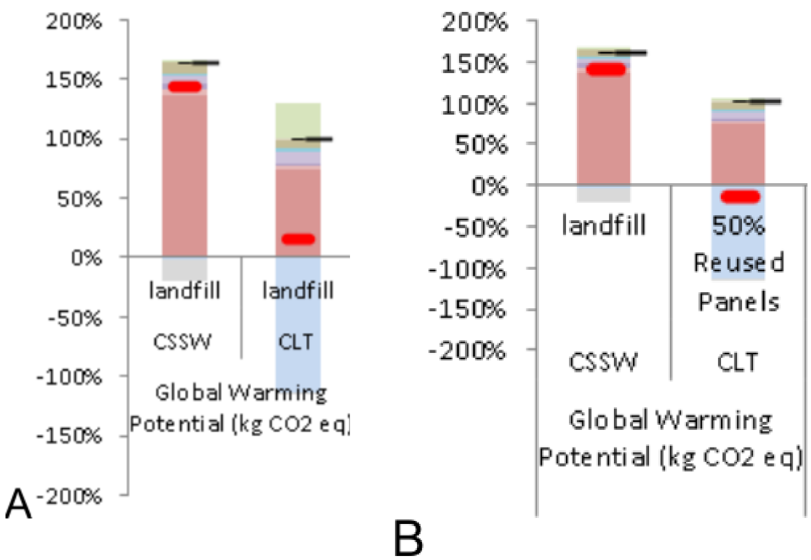
CLT has very predictable behaviour in a fire scenario, there is no doubt that char is happening of a Fire. CLT elements have the potential to provide excellent fire resistance, comparable to that of other
building materials, including non-combustible materials. This is due to the inherent nature of thick timber members to char slowly at a predictable rate, allowing mass timber systems to maintain significant structural capacity for extended durations, when exposed to fire.
As with any combustible material, CLT may contribute to the growth of a compartment fire. Frangi et al. (22) were among the first to study the impact of additional fixed fuel load from CLT panels on fire growth. They evaluated a three-storey CLT building constructed with 85-mm thick CLT wall panels and 142-mm thick CLT floor slabs exposed to a natural, full-scale fire. In this particular experiment, walls were protected with a face layer of 12.7-mm fire-rated gypsum board (directly exposed to fire) and a base layer of 12.7-mm standard gypsum board, while the ceilings were protected with 25.4-mm mineral wool insulation and a layer of 12.7-mm fire-rated gypsum board (Figure 2a). In an attempt to replicate similar fire severity, such as that encountered in typical residential dwellings, a design fire load of 790 MW/m 2 was used and burned for slightly over 1 hour. It is reported that flashover occurred after about 40 minutes, due to the initial low levels of ventilation provided. The fire severity started to decline after
55 minutes and was extinguished, as planned, after one hour. Furthermore, the measured charred depth on the gypsum-protected CLT compartment elements was very low, ranging from approximately 5 to 10 mm. No elevated temperatures were measured and no smoke was observed in the room above the fire room. From this full-scale design fire test, it may be concluded that CLT buildings can effectively be designed to limit fire spread beyond the point of fire origin.

Standard Fire Exposure	Effective Char Depth, $x_{c,eff}$ (mm)					
	Thickness of first lamination (fire-exposed lamination) (mm)					
	19 (¾")	21 (⅞")	25 (1")	32 (1¼")	35 (1⅜")	38 (1½")
30 minutes	31	27				
45 minutes	43			36		
1 hour	55					
1.5 hours	79					
2 hours	103					

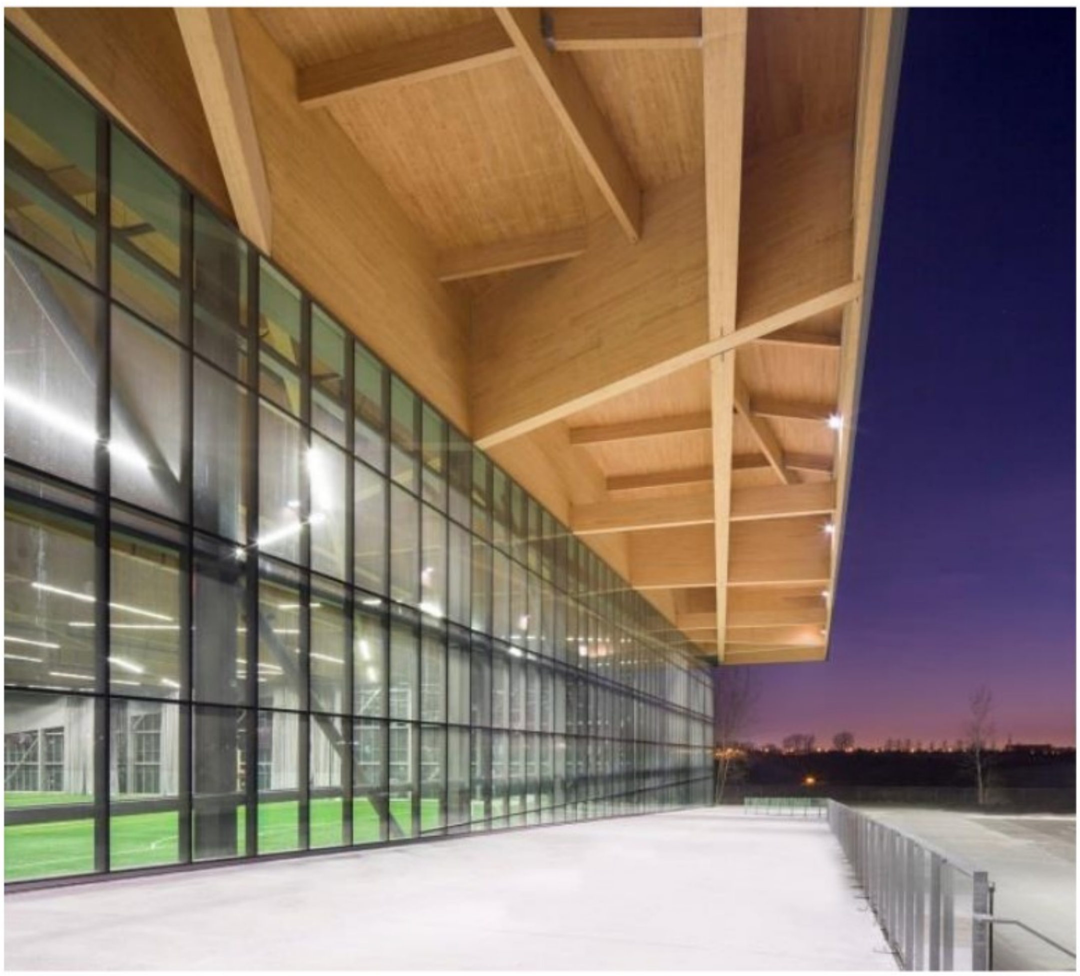
Environmental Attributes of CLT.

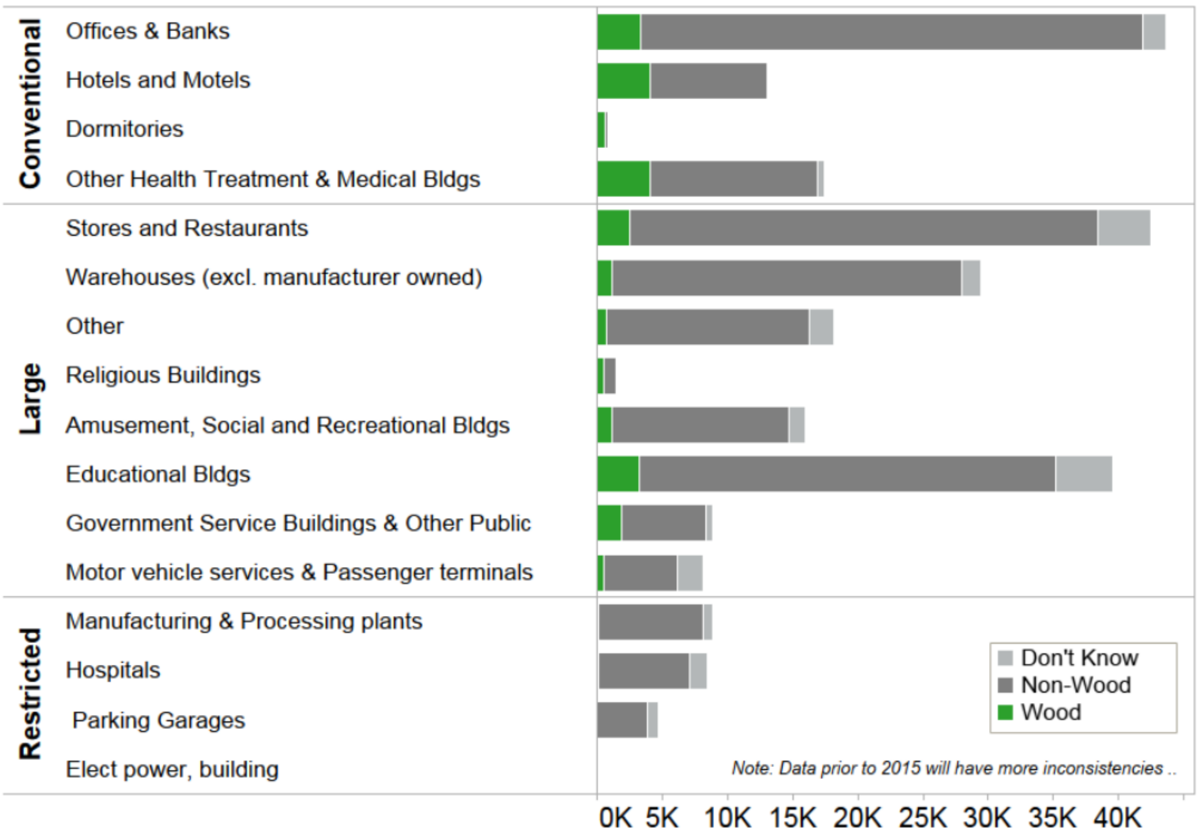
The CLT Handbook compared the Global Warming Potential of two different approaches to building buildings. They compared on the one hand buildings build from concrete, steel & Stonewool (CSSW) and Cross-laminated Timber (CLT).

They created different scenarios, which tried to show different approaches that should represent realistic Lifecycles of buildings. All findings indicate a significantly lower GWP of CLT compared to CSSW, in some cases, the CLT Buildings can be "climate-positive.



Give the low percentage of Buildings currently build from wood and CLT this is a huge potential for a change in the building industry to create sustainable housing, offices and schools, Manufacturing, Industry, basically everything. We believe that this will be especially true for Data Centers.





Appendix D: Gas-powered Genset for Dual Operations

While diesel-based backup generation may be the traditional solution for meeting resiliency regulations, natural gas-fueled cogeneration can offer facilities a more comprehensive resiliency strategy that includes cost savings, lower emissions, and other key benefits.

Utility outages can cause highly adverse effects for all types of commercial and industrial facilities, potentially resulting in severe financial losses, damaged equipment, and far-reaching community impacts, particularly in the case of hospitals. With an increasingly unreliable grid and rising weather-related outages, any comprehensive resiliency plan requires some form of on-site power generation. Traditionally, many facilities have opted for diesel-based backup generators, which can offer quick-starting power for life safety equipment like fire alarms and exit lighting or can be sized to cover additional loads during outages while pulling from the grid the rest of the time. These systems can require significant upfront capital investment and ongoing costs. Today, facilities can choose a more comprehensive energy solution that not only helps achieve the intended resiliency goals but offers cost savings and other benefits. Cogeneration, or combined heat and power (CHP) systems, can support critical or full loads for even lengthy outages. They run continuously, which means they offer benefits that conventional backup does not: they can offset thermal loads, reduce emissions, and often pay for themselves over time.

To choose the right solution for a facility, it's worth understanding the function and typical use of both technologies, as well as key factors, like cost-effectiveness, emissions, and system longevity, that may be relevant to the decision.

How the Technologies Work — and When to Use Them

Conventional diesel-fueled backup generation can be essential for life safety support and sized for temporary support of larger loads, while CHP systems run continuously to offer cost savings and can enter island mode during outages to support facility operations indefinitely.

Conventional Backup Generation

A conventional backup generator, also known as an emergency generator, typically uses diesel to produce electricity at about 30% efficiency. Backup power is required to get up and running at full output power within 10 seconds, according to NFPA 70 National Electrical Code (NEC) guidelines1 and California hospital OSHPD guidelines. Because they can typically start-up in seven seconds, backup generators are a requirement for supporting life safety devices like fire pumps, fire alarms, emergency lighting, exit lighting, smoke evacuation fans, and elevators. They can also be sized to support larger facility loads as needed. In some cases, backup generation is all that a facility may need. However, these generators are built to provide power for only relatively short durations. They require fuel deliveries if a power outage continues, which can be difficult depending on weather conditions. In addition, because they are run infrequently, they are not built to ensure efficient energy consumption or low emissions. Nonetheless, if the facility needs only life safety support, or the overall load doesn't warrant a CHP system, conventional backup may be sufficient.

Combined Heat and Power Generation

A CHP or cogeneration system typically uses natural gas generators to create electricity. But instead of wasting the heat from the exhaust or cooling circuits like backup generators, CHP can capture the waste heat and use it to offset a facility's thermal loads, such as providing hot water or steam for heating applications. CHP units operate continuously, which allows the facility to reduce its utility usage. They have an efficiency of at least 60-80%, more than twice a utility power plant.

A CHP microgrid provides resilient energy during grid outages by activating its island mode capabilities. Typically, a CHP system is interconnected with the utility and operates in parallel to it, but when the utility fails, the system moves into island mode, separating from the grid to provide power to the facility and creating a microgrid, or an independent power grid under local control, that supports either critical loads or all loads, by design. Because a CHP system runs off of natural gas, no fuel deliveries or forethought are required.

While facilities may have backup generation in place to power life safety equipment during emergencies, it is difficult to size backup generators to cover an entire facility. A CHP microgrid can be designed to provide both electric and thermal resiliency for the site as a whole. One important differentiator from diesel-fueled backups is that a CHP system is not suitable as a standby life safety generator, because it is not designed to start up within 10 seconds. By executing a pre-defined sequence of operations, a CHP-based microgrid can enter island mode instantaneously during a utility outage but initially will only power a small portion of the facility's electric loads. These will be the most critical, non-life-safety loads. Over 15-30 minutes the CHP will ramp up to full power as it incrementally adds the site's loads to its generator. Once a CHP is running in island mode it can run all equipment, including the life safety load, and stay operational for as long as natural gas is available in the pipeline.

How Cogeneration and Backup Compare Across Key Factors

Cost Saving

Using cogeneration for baseload power, and for backup power when needed, can pay for itself because purchasing natural gas for on-site generation is nearly always cheaper than purchasing energy from the grid. This is especially true for sites with large electrical or thermal loads, or those in areas with high utility costs. CHP clients tend to see 10-20% savings starting in their first year.4 In addition, with an energy services agreement (ESA), the facility is not responsible for the costs associated with purchasing and maintaining the system — they pay the provider for usage alone. Natural gas units above 150 kW typically cost 60-100% more than comparable diesel units, leading to 30-60% project cost increases, but with an ESA, these capital and operational costs are eliminated and no longer a barrier to implementation.5 Purchasing diesel-based backup generation requires a large upfront, sunk cost as well as ongoing operating costs. There are no cost savings because it doesn't run continuously. In addition, backup generation systems may be cheaper to maintain over the life of the system, as they run very few hours — but this isn't necessarily a critical point of comparison, as with an ESA the maintenance costs of a CHP system fall on the provider, not the facility. With diesel backup, service contracts for maintenance can range from $20-$100k per year. In this Concrete 100 MW Design we are talking of 50 units of the Caterpillar G3520 2000 E KW according to the Assumption in this paragraph 100 MW Diesel Backup generators would cost approx. $30 mio. while a CHP gas infrastructure could cost up to $45 mio. These costs can be offset by 100% if you manage to find an agreement with a national utility for an ESA.

Backup and CHP Attribute Comparison

	Backup Generator	Combined Heat and Power
Upfront Costs (CapEx)	**$300,000 per MW** ✓ Paid by facility ✓ Installation cost similar to CHP	**$0** ✓ All capital costs of CHP are included in an ESA and paid by Unison Energy
Operating Costs (OpEx)	**$20k-100k annually** ✓ Service contracts with a service provider ✓ Periodic fuel replacement	**$0** ✓ All O&M costs are included in an ESA ✓ Saves money over time vs local utility
Operating Profile	✓ Runs during power outages and 30 minutes per week for testing ✓ Does not supply thermal loads	✓ Runs 24/7/365 in parallel with your local utility powering all electrical and thermal loads
Fuel	✓ Diesel stored on-site	✓ Natural gas from an underground pipeline
Resiliency	✓ Starts quickly ✓ Requires frequent fuel deliveries during long outages ✓ Best for short (<24 hour) outages ✓ Life Safety Certified	✓ Best for short and long, multi-day outages ✓ Several-minute ramp up time ✓ No refueling required due to uninterruptible and infinite gas supply in the pipeline
Permitting	✓ Customer required to file and update annually	✓ Included in ESA

Fuel Costs

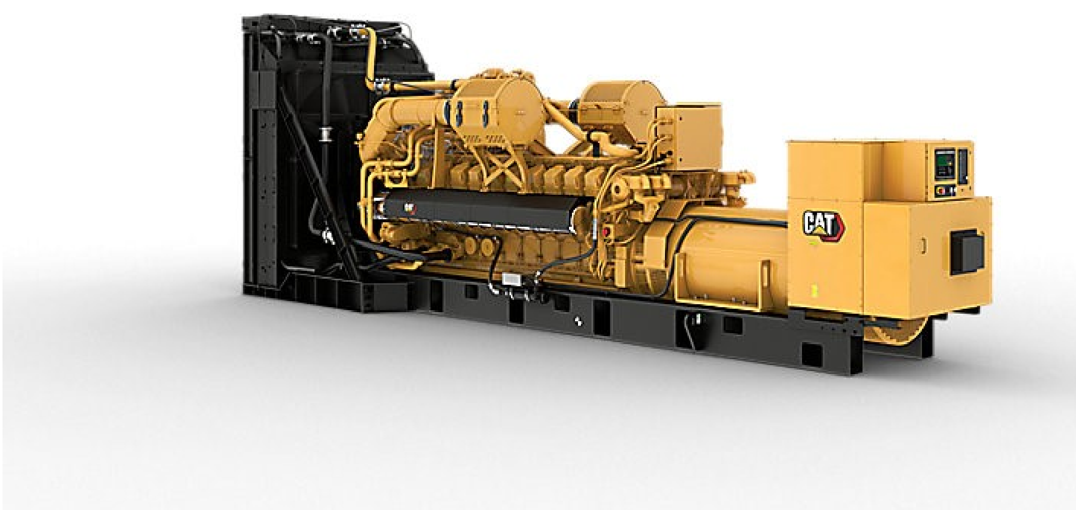
Per thermal unit, fuel costs are lower for natural gas than diesel. Diesel costs between $20-30/MMBtu, while natural gas costs just $2-4/MMBtu.6 With just 26 hours of no-load testing per year, a 1 MW unit will consume about 546 gallons of diesel and rack up a large bill.7 As an added cost, diesel fuel must sometimes be discarded, as it has to be tested annually, according to NFPA 110 8.3.8, to ensure it has not gelled from the cold or grown microorganisms that could plug up filters.

Emissions

Because cogeneration systems operate continuously, reduce grid usage, and support thermal loads, they can lead to significant carbon reductions of 30-40% for facilities, especially those with large thermal loads.9 Compared with diesel, natural gas generators release much less SOx, NOx, and carbon dioxide.10 Diesel generators can also release a pungent smell and often require a Title V Air Permit for operation. Natural Gas is the lowest CO2 emitting fossil fuel, with a big infrastructure that can mix in Biogas and Hydrogen up to 25% his means that perspective the CO2 emissions can be reduced up to 70-80 % compared to burning Diesel fuel.

Resiliency

During Outages Natural gas is supplied directly to the site's generator from a pipeline, which allows it to run indefinitely in most scenarios. The National Renewable Energy Laboratory found that in the U.S., natural gas backup generators are on average 2.6% more reliable than diesel.11 According to regulations like OSHPD, sites that use diesel backup for life safety may be required to keep a 24-72 hour supply of the fuel on-site.12 However, once the supply runs out, the site would then require diesel delivery, which may be difficult to ensure due to widespread demand or bad weather conditions. In addition to the comparison chart on page 27, the proposed Gas-powered Gensets G3520 2000 E KW from Caterpillar is ready in seconds, so even if you are using the CHP only in a flexible scenario to support a grid with high availability of renewable energy this is a very capable solution which is offering a lot of savings to a data center provider.



Picture: Caterpillar G3520 2000 E kW

Appendix E: Super-conductive Busbars

Data centers have been improved and optimized in many ways and aspects. Energy efficiency ever was and is still a key topic. Be it cooling, auxiliary components, software-defined power management, all to decrease power consumption and to maintain or leverage the performance. Considering all those efforts, it is interesting that the power transmission system is still almost the same then it was a long time ago.
There are several approaches to introduce direct current power transmission that promise fewer conversion steps, transformers, and rectifiers and thus a higher energy efficiency.
In 2007 the advantages of DC for data centers were described by Pratt and Kumar (Evaluation of Direct Current Distribution in Data Centers to Improve Energy Efficiency, A. Pratt & P. Kumar, INTEL Corporate Technology Group). In 2010, at the 3rdAnnual Green Technology Conference, Joseph V. Minervini, MIT Senior Research Engineer reported on an increasingly rising electricity demand for data centers and the benefits of a facility level 400 VDC power transmission.

“Deploying DC power distribution it the data center instead of using the traditional AC design is one way to reduce power loss, eliminate unnecessary conversions and, ultimately, lower energy costs”
James Stark, P.E., Engineering and Construction Manager at Electronic Environments Corporation in Industry Perspectives Jun 25, 2015

Efficiency and Reliability Analyses of AC and 380V DC Distribution in Data Centers

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A remarkable IEEE Paper (DOI 10.1109) from 2018, written by authors from Amazon, Microsoft, South Dakota State University and Pacific Northwest National Laboratory, concludes that DC data centers are more efficient and more reliable. Despite those advantages, DC in data centers did not establish itself on the market.

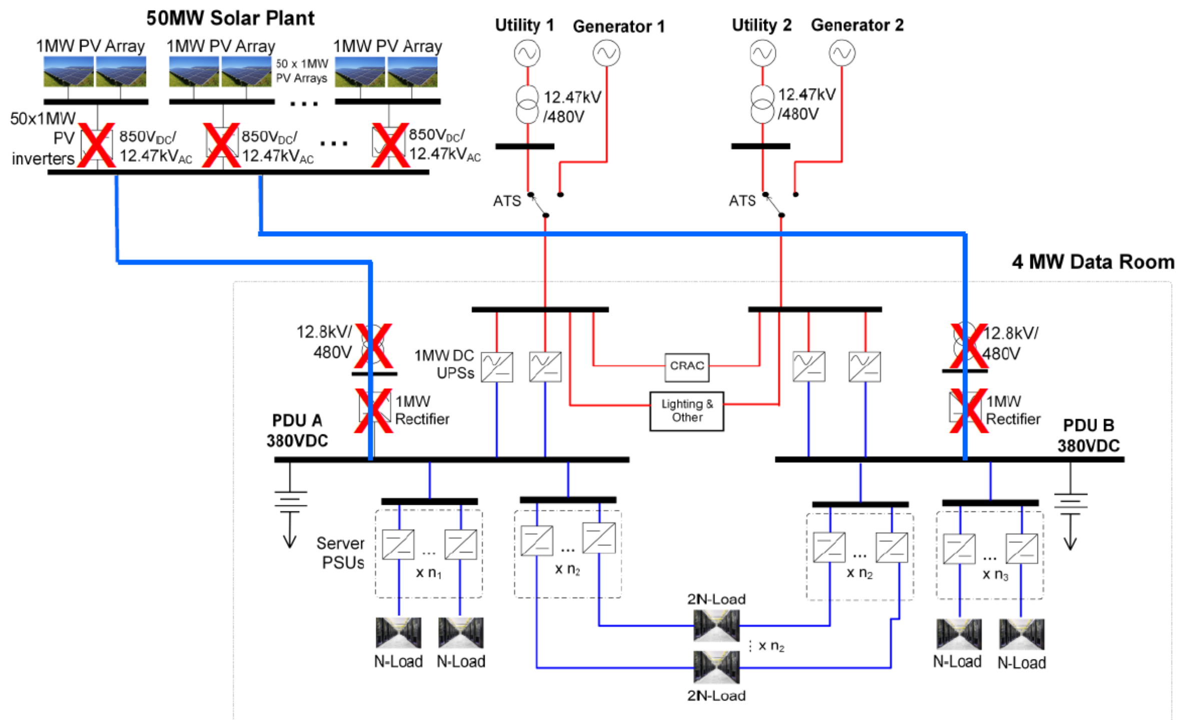


FIGURE 6. 380 DC superconductor power distribution system with 50 MW PV integration

Although there is no doubt that DC powered data centers are more efficient on total power evaluation. Evidence is given by numerous investigations and publications within the last years which show a value between 10% and 20% [6, 7]. To demonstrate this approach a few DC-data centers [8] are operating and proofing the advantage of the technology.

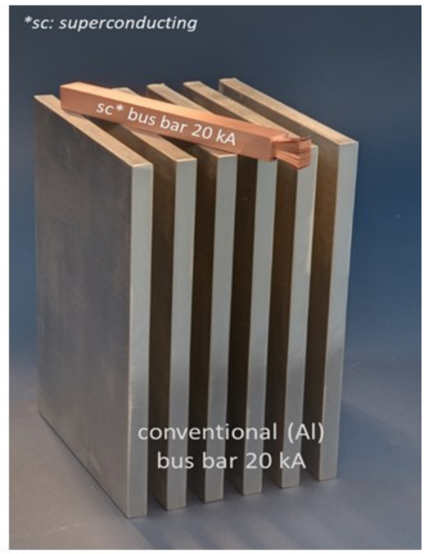
One reason for the low market traction is the electrical design standards that is given by the available components which are almost all in AC. These standards have been established by a few organizations and are adapted by the market. Additionally, significant economies of scale can be realized which is not given within the small market for DC components [5].

Another reason is the market velocity – despite for some big individual datacenters, designs, architecture and construction come out of the box – highly standardized in order to build on time with increasing shorter deadlines. This means that all the innovation within the power transmission has to fit in the AC-scope established as standard and to which the market is habituated. AC transformations and the power losses in the transformation steps as well as in line are considered as immanent to the system. The PUE, still an important KPI for energy efficiency, does not include those losses. Maybe the benefits of DC are just too little to leave the comfort zone and disrupt this well-established industry.

Today we have new drivers that encourage to think about new approaches. The focus on Scope 3 emissions and sustainability becomes more evident and the simple limitation on available electricity and cables with a simultaneous high market growth demand to think about new possibilities. There is a new technology available that could solve several problems and bring data center on a far better efficiency and sustainability level:

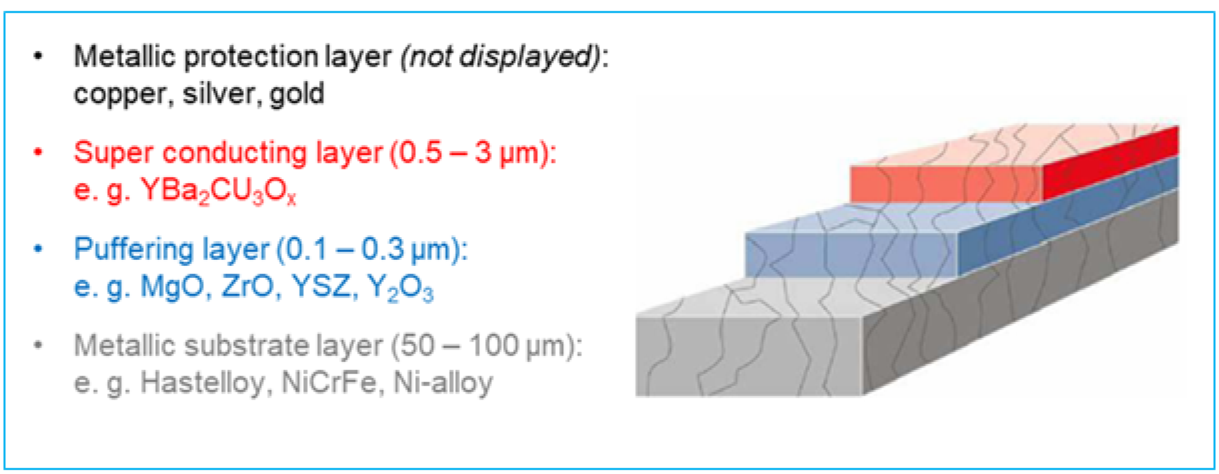
Superconductors.

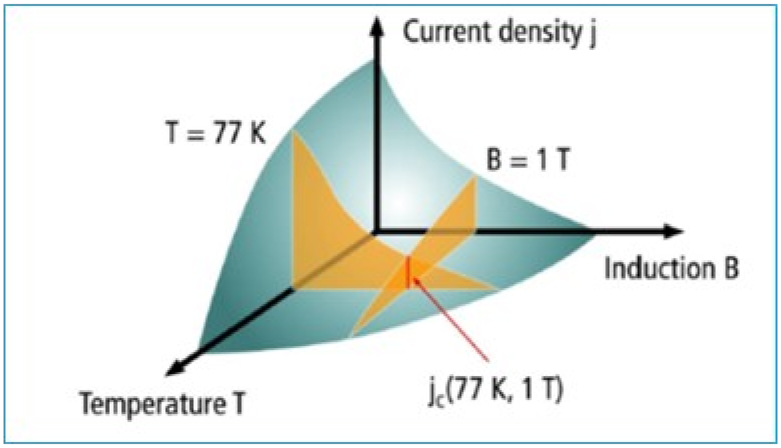
Superconductors, Solutions and technical readiness



Superconductors are metallic or ceramic materials that have among others, two major abilities: extremely high power density up to 62A per mm² (0,03937 in) and to conduct current without any resistance and over any length. Therefore the superconductor needs to be cooled down to reach a critical temperature from that these abilities apply. A further cool down results in an increased current carrying capacity, which is increasingly limited by an ascending magnetic field.

Superconductors are differentiated into low- and high-temperature superconductors. Low-temperature superconductors were discovered by Heike Kamerlingh Onnes in 1911. They are used today in MRIs and several scientific applications like colliders or fusion reactors. To reach their superconductive abilities they usually cooled with liquid helium to 4,2 K.





High-temperature superconductors (HTS) vere discovered by Müller and Bednorz 35 years ago, in 1986. They received a noble prize for that discovery in 1987. Dr. Georg Bednorz, IBM Fellow, supports Vision Electric Super Conductors in their research activities. HTS are ceramic and have their critical temperature above 77 K, which is the temperature of liquid nitrogen. LN2 is highly available at low cost and therefore HTS are suited for completely new power transmission solutions.

HTS applications are evolving, though they are still new to the world and have not reached the mind of the general population. The evolution for the applications below varies from TRL 3 to TRL 7: concepts over prototypes to proofed installations. The most developed applications are a superconducting busbar for high current industrial applications and superconducting cables for city distribution grids (see source 2,4).

<u>HTS applications:</u>

magnetic levitation trains, cable systems (see source 1,2), electrolysis (see source 3), metal smelters (see source 4), wind turbines (see source 5) data centers and generally every application that requires high electrical energy.

<u>Sources:</u>

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2. https://www.tdworld.com/overhead-distribution/article/20964180/the-ampacity-project
3. https://publikationen.bibliothek.kit.edu/1000075563
4. https://demo200.de/
5. https://iopscience.iop.org/article/10.1088/1757-899X/502/1/012004/pdf

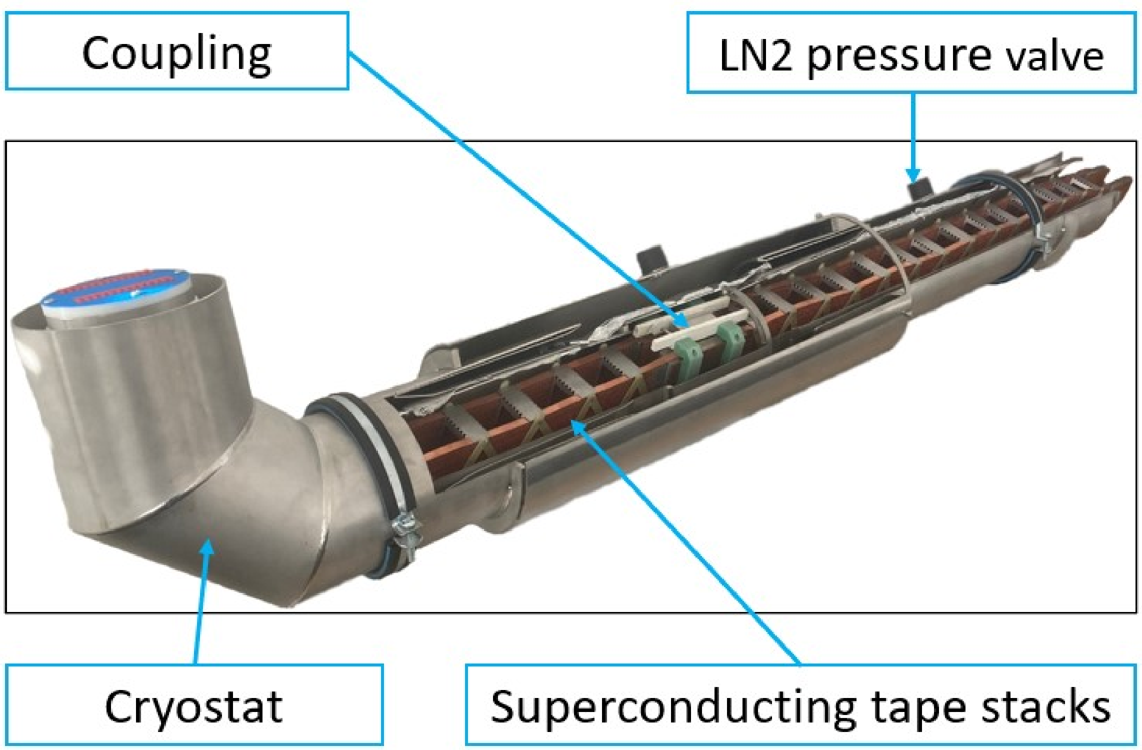
Innovative power transmission for data centers:

The concept of a high-current superconducting busbar, developed by Vision Electric Super Conductors and proofed in a chlorine plant at BASF reached TRL 7 and is easily adaptable for data centers to meet the growing power demand and environmental criterias.

To introduce superconductors to data centers it is first necessary to consider and implement a DC infrastructure like introduced above and additionally replace the normal-conducting busbars with superconducting busbars. Additionally, a liquid nitrogen fueling tank must be integrated. The modular superconducting busbar (ICE-BAR®), developed by Vision Electric Super Conductors, adds different properties to and enhances the DC data center concept to a game-changing solution that improves power consumption, energy efficiency as well as sustainability and safety. Superconducting technology is the missing part for the DC concept to outperform AC data centers. This approach allows completely new designs to meet the actual and future requirements regarding energy efficiency and sustainability.

Today's DC power supplies are working on an input voltage of up to 400 V which is in most cases the battery voltage level while the IT equipment is running on DC at much lower voltages like 48 V, 24 V or 5 V.

With the installation of superconductor systems the energy infrastructure, like switchgear, rectifiers, battery, etc. can be located at a remote place, not necessarily in the close vicinity of the data center. Thermal loads at air conditioned rooms and electromagnetic shielding are reduced. Optimized conditions for white and grey space lead to optimized space usage and reduced operation costs which is also optimizing civil building costs due to lower space and cooling requirements.

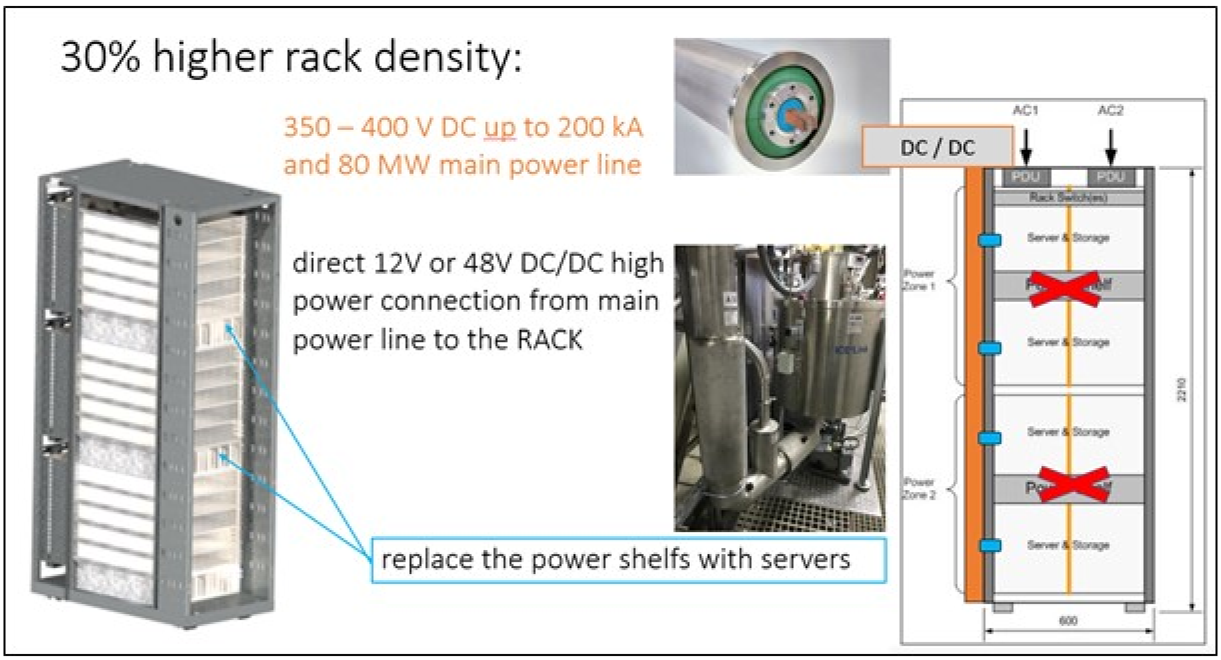


Major Improvements in detail

Increased power density: Allows the power transmission from the energy generation point to the rack with one defined voltage, e.g. battery voltage 380 V or 400 V. Compared to most current data center designs the most conversion and transformation steps are omitted.

Power efficiency: The absence of electrical resistance and several conversion and transformation in superconducting busbars and the LN2 cooling circuit safes ca. 15 % power transmission energy of the data center, including the needed energy for the cooling circuit. Accurate numbers must be obtained in a proof of concept installation.

30% higher rack density: Superconductors can be operated with very high power up to 200 kA under low voltage and thus can be connected directly to the rack. The power shelves can be replaced with additional servers.



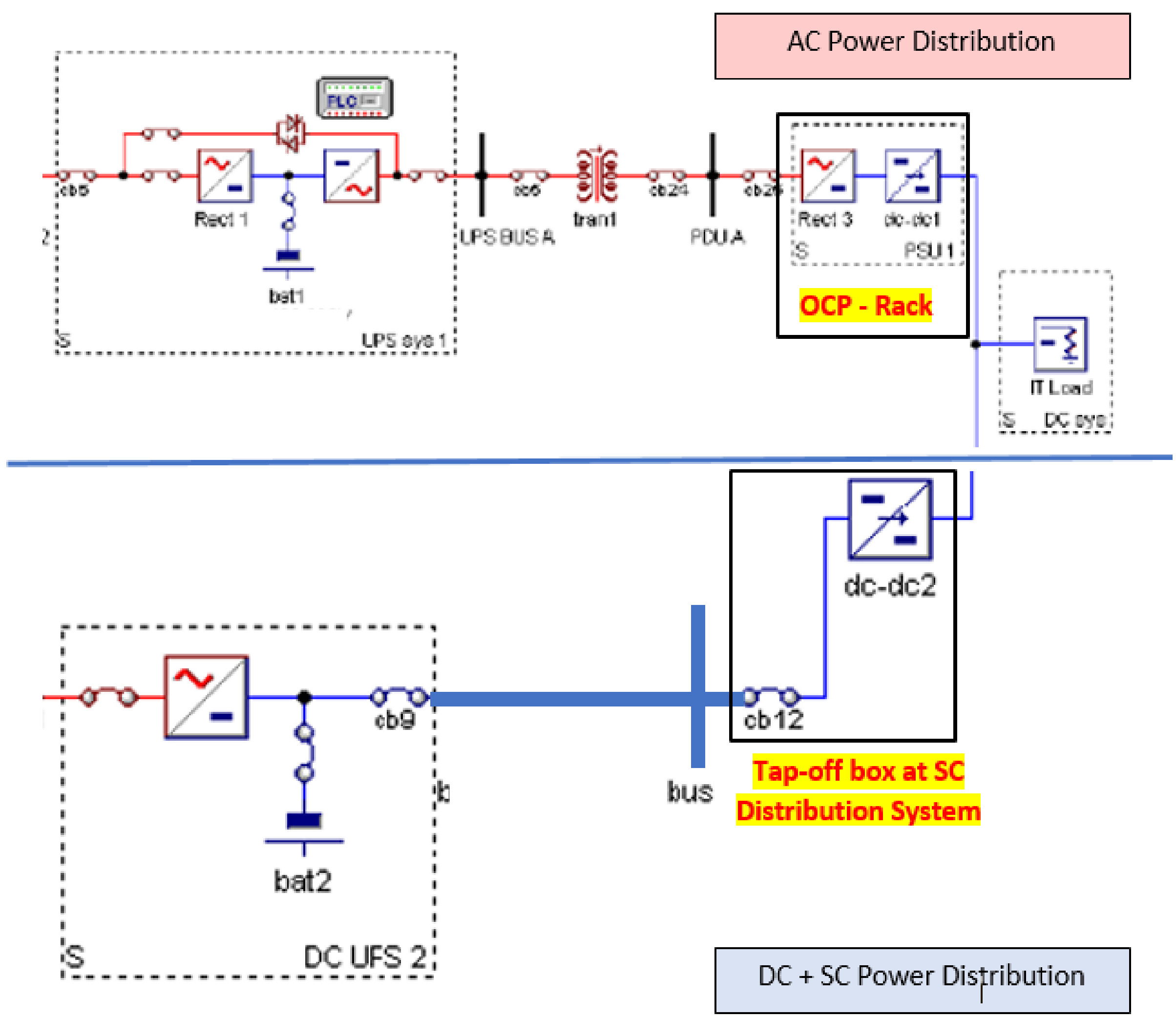
Reduced Scope 3 emissions: The modules of the superconducting busbars are reusable and do need to be recycled. Additionally, there is a reduction of the factor of 10 in material usage compared to aluminium busbars. This results in much lower material production, storage and transportation to the construction site.

Safety and fire load: HTS are cooled with liquid nitrogen and have no fire load. ICE®Bar offers an IP65 protection degree. There is no heat dissipation into the ambient. In case of a short-circuit the LN2 warms up and evaporates into the atmosphere over the provided pressure valves, which is harmless for humans and equipment. Under these conditions, the superconductor turns into a resistive component. Furthermore, the superconducting busbar is encapsulated in a double-walled stainless steel tube and has, depending on the design, a very low magnetic field.

Optimized white space and civil engineering: With the installation of superconductor systems the energy infrastructure, like switchgear, rectifiers, battery, etc. can be located at a remote place, not necessarily in the close vicinity of the data center. Thermal loads and electromagnetic shielding are reduced. Optimized conditions for white and grey space lead to better space usage.

New cooling concepts: The design with integrated valves for cold, gaseous state LN2 cooling additionally allows an active peak- and spot cooling with efficient use of energy.

Single Line Diagram comparing AC versa DC+SC Power Distribution



Costs and Return-On-Invest

There are several manufacturers for superconducting tapes worldwide. Bigger manufacturers for HTS are Theva in Germany, AMSC in the U.S.A., Super Ox in Russia and Sumitomo in South Korea.

Investment Costs

Currently, a superconducting busbar is approximately 3 times more expensive compared to a standard aluminium busbar. The biggest cost driver is the HTS tapes and it should be noticed that the high costs result in low economies of scale effect and low grade of manufacturing automation and not on the material prices. There is a lot of scale potential, a high increasing demand would lead to a price drop on the same level as aluminium today. ICE®Bar is a manufacturer-independent solution that can integrate multiple vendors into a module and is thus most cost-effective.

Operation costs

Operation costs are reduced by approx.90% through the energy savings due to the zero resistance of the superconductor. The remaining 10% of the energy and costs are needed to maintain the cooling circuit.
There is no doubt: DC technology together with superconductivity will become state of the art for data centers. DC and superconductors offer the possibility for new innovative designs saving energy and improving cost structure and performance.
Superconducting DC data centers are the future because they are much more power efficient than standard AC or DC data centers. Furthermore superconducting DC data centers are space saving and more reliable with lower costs.
Figure ?? shows the difference between the AC power distribution given in the IEEE paper [3] and superconductive DC power distribution, comparing the power distribution at the battery supply components.
It is clearly seen that the DC+SC system requires less components which increases reliability as mentioned in the IEEE paper. All power conversion units and transformer steps are no necessary any more. Especially the power supply units that are located at the OCP racks are eliminated. This function is moved to the tap-off units of the superconducting power distribution system. The total saving of power losses is between 15 and 30 % depending on size and layout of the data center. The higher efficiency is originated in the

- reduction of power conversion levels
- better performance values of DC/DC-converters compared to AC/DC-converters which shows a max. of 67,5% for AC and 73% for DC system.
- zero-loss power distribution by superconductors

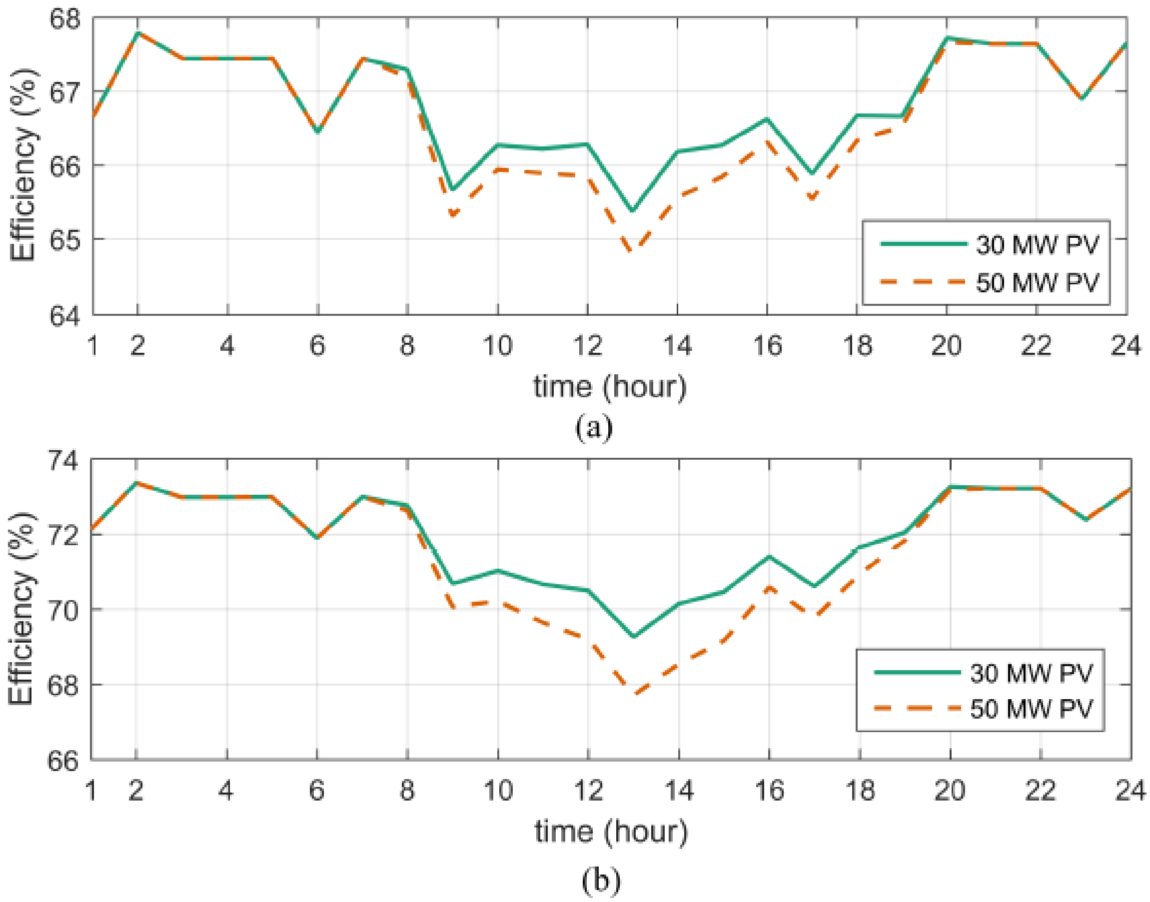
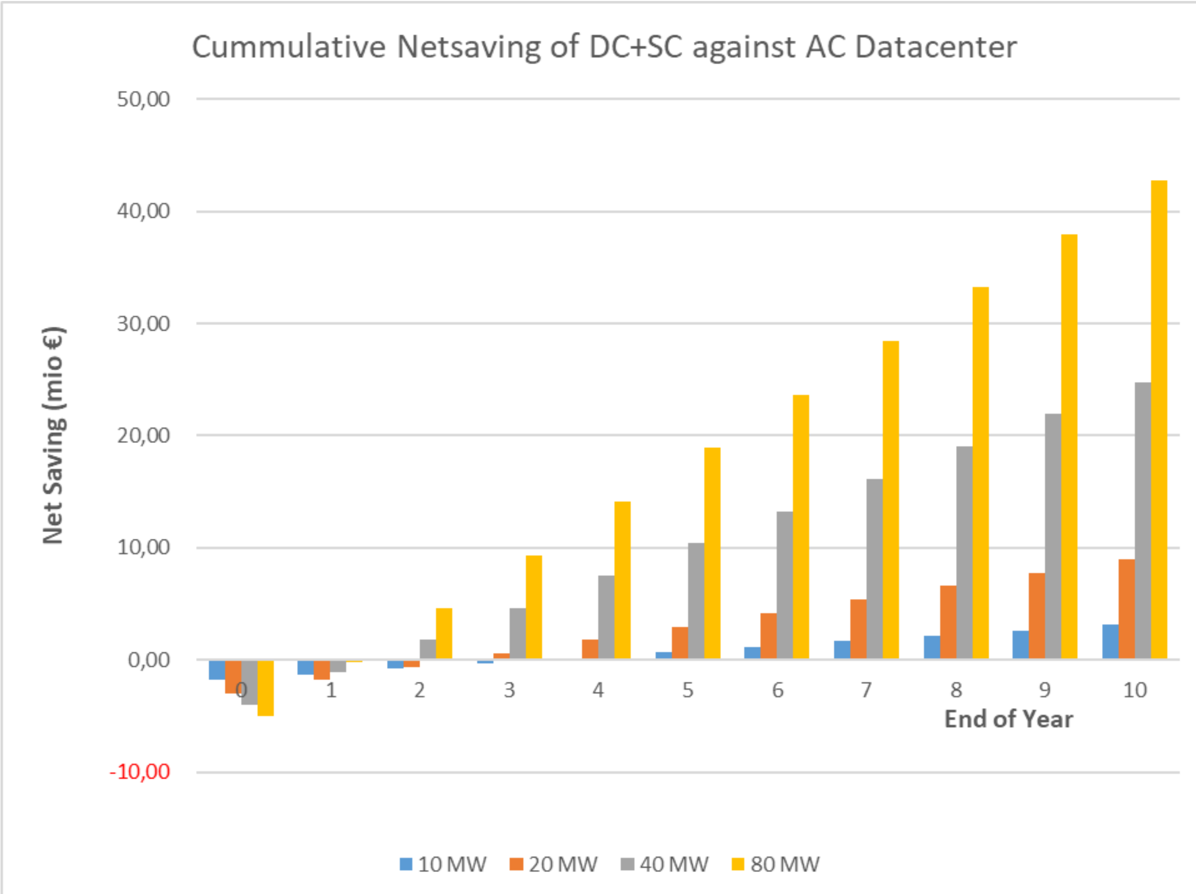


FIGURE 8. Hourly efficiency plot: AC and DC data center with PV, July 8, 2011: a) AC system and b) 380 V DC system.

Hourly efficiency plot: AC and DC data center with PV, July 8, 2011 (a) AC system and (b) 380 V DC system

Return-on-Investment

The ROI highly depends on the electricity prices and the input for the data center. Compared to a standard AC data center a positive ROI can be achieved in year 2. The figure above illustrates the relation, calculated in € and with German electricity prices. Under current prices and conditions, superconductors are best suited for a hyperscale data center.

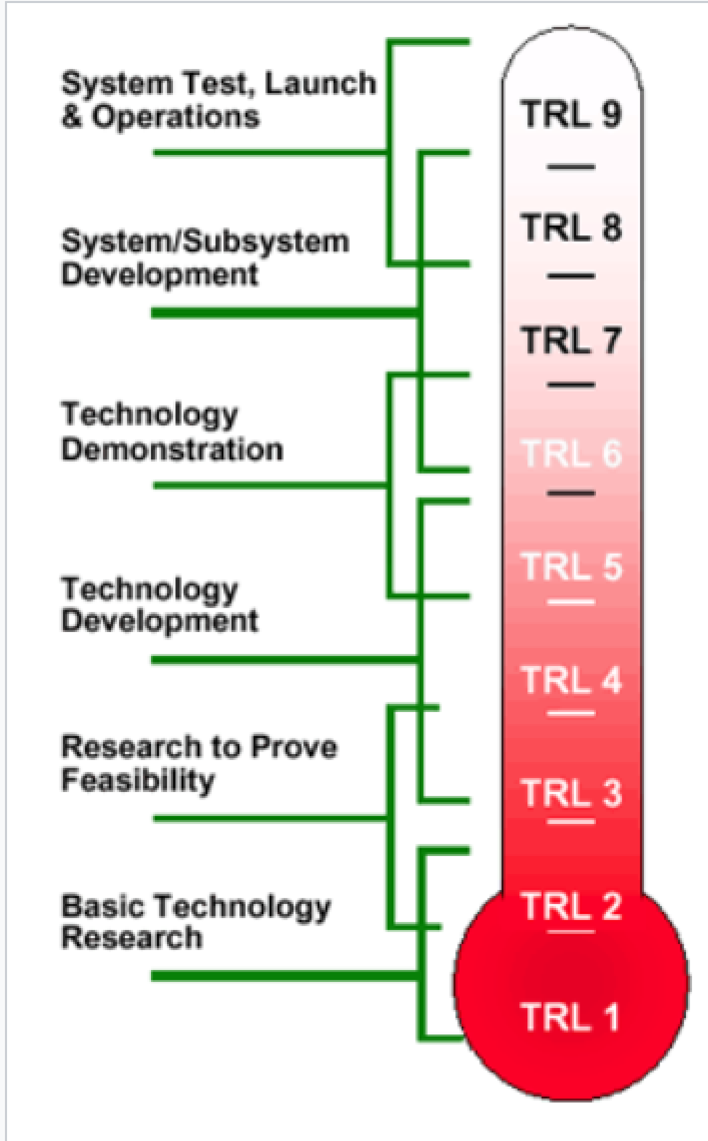

Cummulative Netsaving of DC+SC against AC Datacenter
50,00
40,00
30,00
20,00
10,00
0,00
-10,00
Net Saving (mio €)
0
1
2
3
4
5
6
7
8
9
10
End of Year
10 MW
20 MW
40 MW
80 MW

Standards and certificates

There are no standards to test and prove high-current superconducting busbars. National and local standards have to be considered, ICE®Bar has passed the strict health- safety and security standard of BASF to be operated in chlorine electrolysis and can be adapted to all needed standards.

Necessary steps for commercialisation

The solution has reached TRL 7. It has to be adapted to data center standards and conditions. A demonstration within a pilot project or proof of concept is needed to facilitate market traction and to realize the first commercial projects.



NASA Technology Readiness Levels

https://de.wikipedia.org/wiki/Technology_Readiness_Level

DC and AC Data Centers

Most data centers today are receiving AC power, even their primary equipment is using DC power. Multiple conversion from AC to DC power is required.
There is no doubt that DC powered data centers are more efficient on total power evaluation. Evidence is given by numerous investigations and publications within the last years which show

a value between 10% and 20% [6, 7]. To demonstrate this approach a few DC-data centers [8] are operating and proofing the advantage of the technology.

The Efficiency and Reliability Analyses of AC and 380 V DC Distribution in Data Centers, published in 2018, shows that a DC power distribution architecture has been utilizied to obtain improved efficiency and higher reliability in data center power distribution system
Main statements are:

- DC power distribution are more efficient than comparable AC systems
- DC distribution systems' solar integration is more efficient than typical AC distribution
- DC distribution is more reliable than a typical AC distribution system

Why are DC data center not yet state of the art?

There are different hurdles like lack of experience (where to put the AC to DC conversion), lack of standards, etc. Another hurdle is the way datacenters are build: in a hurry, without innovative technology, just taking what is available out of shelf, not system optimized. No time is given for thinking about a better system – therefore OCP is an essential platform for the innovative development of datacenter structure, in our case on power distribution.

One main challenge to overcome is pure physics: Transferring electric power by standard copper and aluminium cables produces losses which heat up cables and surroundings. The more power distributed on server voltage level the more heat losses. The more heat losses the more HVAC with more operating costs. This leads to higher installation costs to reduce the losses. The copper institute advices to increase the cross section of copper conductors by factor 3 for most economical use which of course need more costly space which is better utilized fpr servers, storages and other IT equipment. The space requirements for aluminium cables are even higher. DC power distribution gives advantages to small, medium, large and hyper scale datacenters.

Why Superconductor systems in addition to DC?

Especially hyper scale data centers can benefit from the use of superconductors in addition to the advantages of DC distribution.
Superconductors systems have outstanding advantages compared to conventional copper or aluminium distribution systems.

- electrical advantages
    - no electrical power losses
    - low electromagnetic fields
    - magnetic field suppression available
    - best 0V ground earth stability - no voltage difference between different power supply paths

- facility advantages
  - reduced space requirement, even on rack level
  - easy to design power distribution
  - easy to modify at changed usage requirements
  - lower investment & reduced space for cooling equipment
  - easy integration of renewable power like PV and wind
  - higher efficiency on equipment running with DC like LEDs, pumps, etc.

- operating advantages
  - lower electricity bill
  - zero additional heat
  - zero fireload on main distribution power
  - integrated possibility for reduced oxygen atmosphere and spot fire fighting by emitting cold nitrogen.
  - low carbon and environmental footprint is much lower than that of any other power distribution system.

Overall we believe that **superconductors are the missing link** for the breakthrough of DC in data centers.

Superconductors do not emit any heat to the work environment of a data center because they are not producing any electrical losses. They are ultracompact due to their enormous power density which is up to 1000 times higher compared to copper or aluminium. Besides the high energy efficiency superconductors are also most material efficient. The environmental footprint for production and operation is lower than of any other electric conductor.
Superconductors are not commodity materials like copper and aluminium and due to the production processes of today more expensive. Superconductors require an operating temperature of liquid nitrogen, of about 70K/-200°C/-330°F. They are placed in a thermal insulation pipe.
It is obvious that superconductor systems require a base inventory for providing liquid nitrogen. Therefore the use of superconductor systems is preferable for large and hyperscale datacenters.

What are the technical advantages of superconductors in DC data centers?
IT equipment, servers, storages, switches, monitors etc. are electronic devices that require low voltage DC power. Instead of converting AC to each of the devices it is much more efficient to supply DC power directly. Therefore the massive use of converters on different voltage levels is dispensable.
Today's DC power supplies are working on an input voltage of up to 400 V which is in most cases the battery voltage level while the IT equipment is running on DC at much lower voltages like 48 V, 24 V or 5 V.
With the installation of superconductor systems the energy infrastructure, like switchgear, rectifiers, battery, etc. can be located at a remote place, not necessarily in the close vicinity of

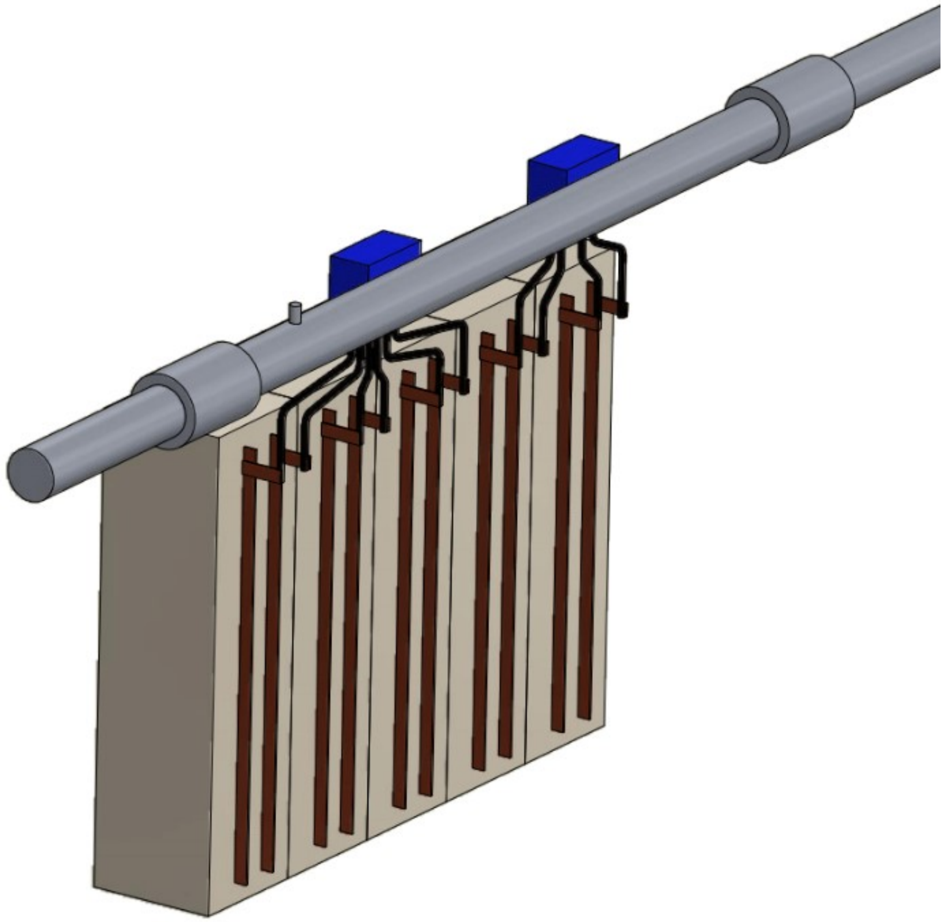
the datacenter. Thermals loads at air conditioned rooms and electromagnetic shielding are reduced. Optimized conditions for white and grey space lead to optimized space usage and reduced operation costs which is also optimizing civil building costs due to lower space and cooling requirements.
Placing the data center energy supply at a remote place offers the potential to optimize the total electric power system together with the grid supply, DC power from solar plants and wind farms, power regulation systems like flywheels, batteries and emergency generator sets in an easy way. The distance between the power area and servers is not critical – superconductors enable loss-free power transmission.
Auxiliary devices are in most cases already running on DC. Lighting has changed to LED, most drives use frequency controls which run efficiently on DC input.
Fire load is a concern in data centers. Big energy cables add a lot of thermal load to the fire load calculation. Superconducting systems of Vision Electric Super Conductors are without any outer plastic material and thus reducing the total caloric value of the installation in case of fire.

Superconducting power distribution system (SCDS)

The superconducting power distribution system is taking the DC power from the battery at a battery voltage level which is in most cases between 240 and 500 VDC. The SCDC can accept all DC voltages up to 1500 VDC.
The SCDC is designed on elements with a nominal length up to 12 m, container shipped to site and which are easily installed just by wall or construction mounted pipe clamps. The elements are locally connected by an easy to install, patent-protected coupling.
Distributing branches will take over part of the power for supply to the OCP racks. In this area, elements carry tap-off units for connection to OCP racks. The factory-installed tap-off units are housing conversion and protection equipment and are the interface between SCDS and OCP rack cables. The tap-off boxes contain the following functional devices:

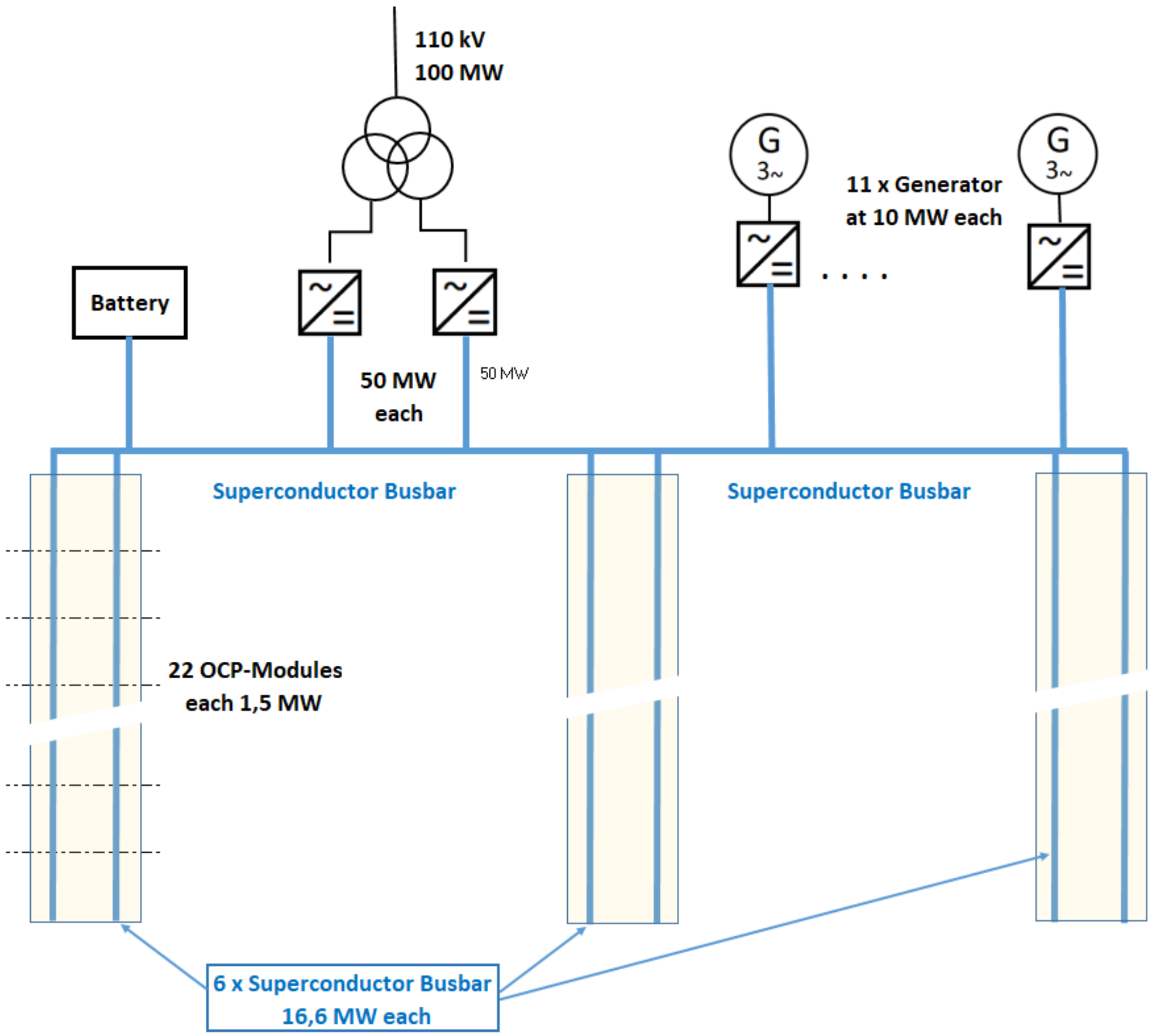
- The current lead between liquid nitrogen (LN2) and ambient temperature
- DC-DC converter to convert power from battery voltage level to server & storage level, 48 V, 12 V or 5 V, whatever is required
- Protection and monitoring of electrical circuits, interface to main data center control
- Terminals for connection of standardized power cables to the racks

For surge cooling or fire-fighting by O2-reduction nitrogen-nozzles are installed optionally.



Connection arrangement of SCDS with tap-off units to OCP racks

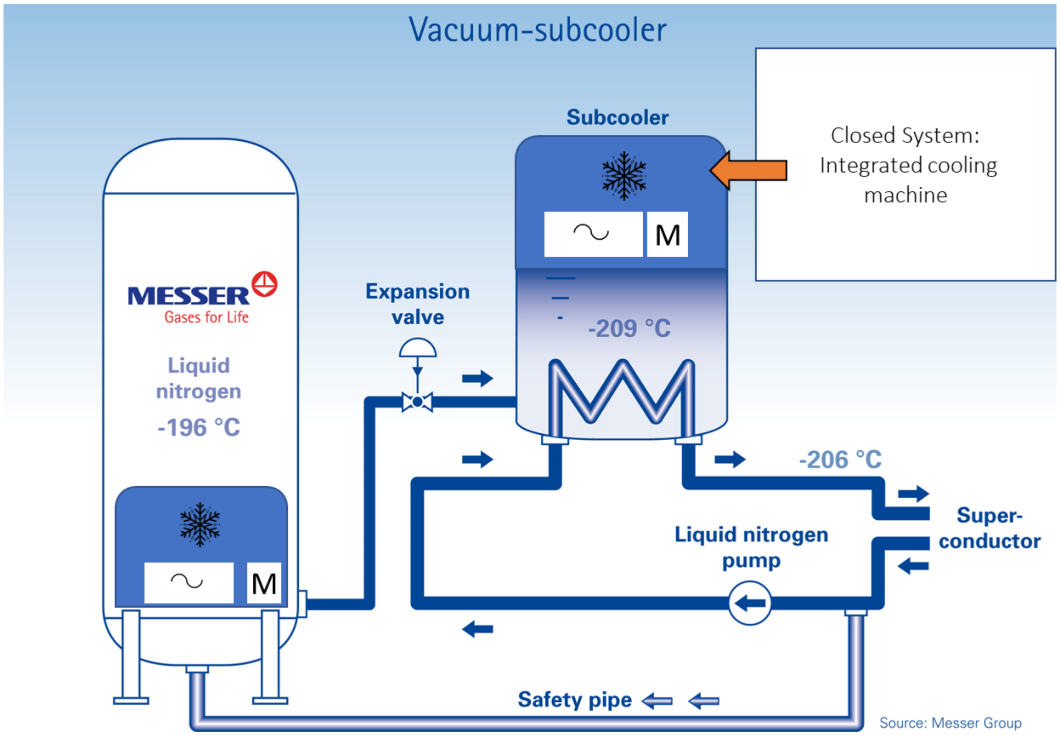
The single line diagram of the superconductor power distribution system is shown in fig. ??? below. Monitored system and operation data are collected at the central control room of the data center. AI integrated systems analyze operational data to optimize cooling power and prepare information for predictive maintenance. Status reports are generated with exceptions and alarm levels on system conditions. The SCDS allows insights of the power distribution down to each tap-off unit optimizing the power consumption of the data center.



Single-line Diagram of the SC Busbar System of the Data Center

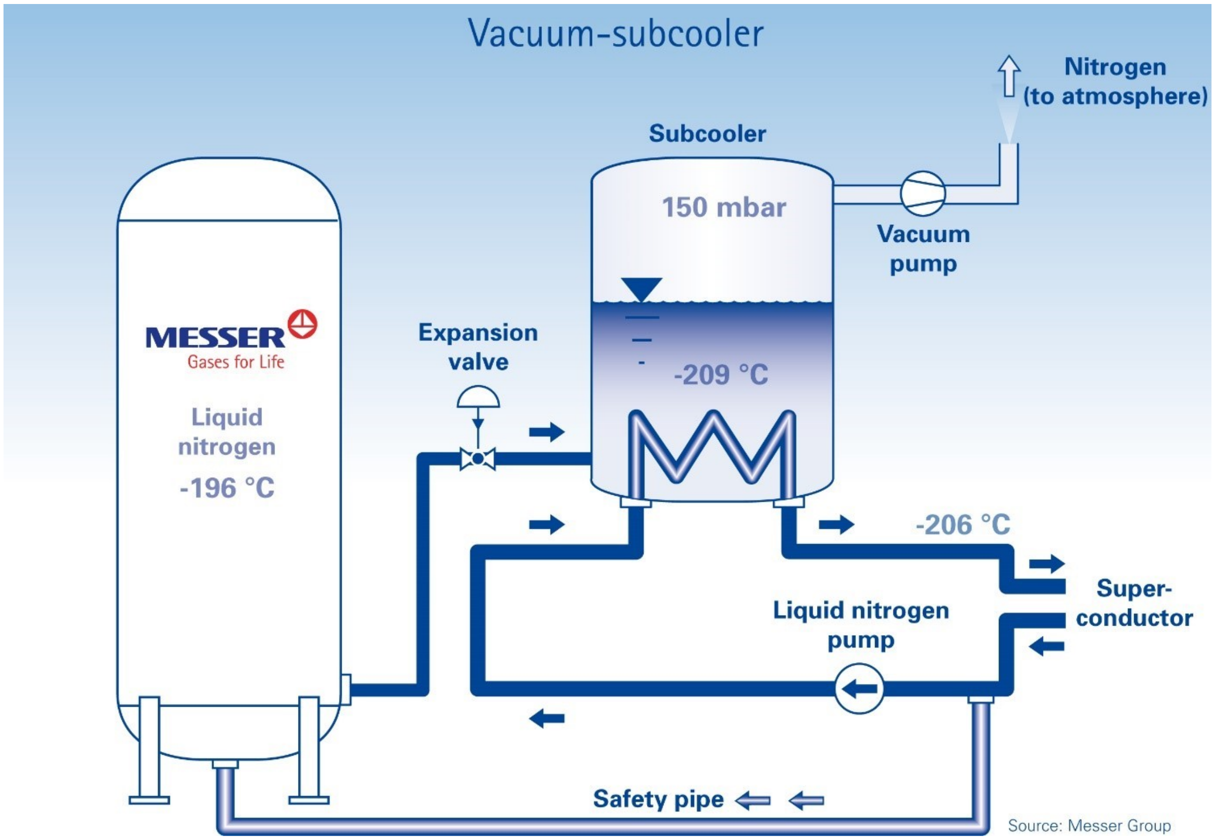
Choose depends on the availability of LN2 and concept. Closed concept: Almost o LN2 losses. LN2 only needs to be refilled after use for peak cooling or firefighting. The cooling machines and tanks can both be placed in an outside container. For redundancy two cooling machines connected to the busbar system are needed.

Closed system



The cooling machine is connected to the busbar system and a small cooling machine in the LN2 Tank to keep the LN2 in the tank liquid to avoid evaporation.

Open system



No cooling machines are needed.
LN2 evaporates into the atmosphere.
Constant supply of LN2 needed for refill

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