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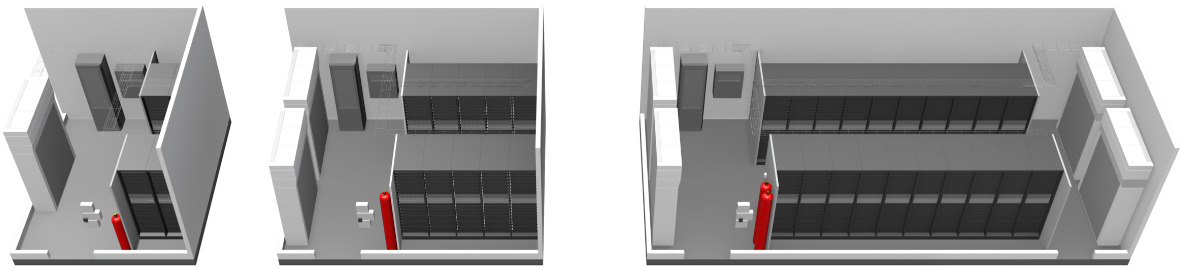

Design of a prefabricated data center optimised for Edge Computing

Concept development focusing on user needs

Master of Science Thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Department of Industrial and Materials Science
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Master of Science Thesis at the Master Degree Program Industrial Design Engineering
In collaboration with Swedish Modules and First to Know

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Abstract

With the emergent implementation of new technology, like autonomous vehicles and Internet of Things (IoT), the strain on the Cloud increases as more data need to be processed and stored. To reduce the load on the Cloud and lower the latency, data processing and storage needs to be closer to the users. This can be done by building an Edge Computing Network, which is a middle layer between users and the Cloud, with data center nodes geographically distributed closer to where data is generated. This allows data to be processed closer to the source, resulting in a reduction of data traffic.

This report concerns the development of a concept for this type of data center, with modern IT hardware developed by the Open Compute Project (OCP), focusing on user friendly maintenance. The project was performed on behalf of the consultancy firm First to Know for Swedish Modules, who produces prefabricated modular buildings.

The project process consisted of three main phases, namely an initial exploration phase, a development phase as well as a finalisation phase. Firstly, the result showed it is difficult to predict the need and usage of data centers for an Edge Computing network, thus a flexible solution has been developed to support different types of future uses. Another key finding is that redundancy may be built into an Edge Computing network, meaning backup power will not be needed in all data centers.

The final concept is a scalable design for a prefabricated data center, with a coherent layout across different sizes. It is suitable for different types of cooling methods to be used for different climates and local assets. The concept also allows backup power to be added as a separate module to the MDC to suit different needs for redundancy.

Solutions to assist service technicians have also been included in the final concept to support safe and ergonomic work. This through aids for reaching and offloading as well as comfortable thermal climate during maintenance. To further support a safe and ergonomic work the concept layout and aids supports service technicians to work in pairs, to be able to assist each other.

Acknowledgements

This report is the result of a master thesis, conducted during the spring semester 2018, by two students at the department of Industrial Design Engineering at Chalmers University of Technology. The project was performed in collaboration with the modular facility manufacturer Swedish Modules through the consultancy company First to Know.

We want to acknowledge all the helpful people sharing their knowledge, expertise and opinions. First, we want to thank First to Know and Swedish Modules for trusting us and for all valuable input and support throughout the thesis. Special thanks to Roberto Söderhäll and Sven Lans for all your valuable input and for discussing ideas with us during the development process.

Without input from all service technicians and other experts the design would not have been as thoughtful and considerable as it is. We therefore want to direct a thanks to everyone who participated in interviews and shared their knowledge and ideas with us.

Also, a special thanks to our examiner and supervisor Lars-Ola Bligård who have supported us in many ways throughout the project. He has not only provided us with valuable tips and feedback, but also enhanced our self-confidence which have made us perform even better.

Finally, we want to thank our fellow master thesis students and other friends at Industrial Design Engineering for volunteering to test our survey, discussing our problems and findings and for just making this final semester at Chalmers joyful. We have really enjoyed spending our breaks with you and sharing a large amount of coffee together.

Gothenburg, 7 June 2018

Olivia Bång and Sam Edvardsson Ceder

Glossary

BBU	Battery backup unit
Cloud computing	Computing resources available on-demand over the internet.
Colocation	Data center where customers rent space for IT equipment, and power, cooling and safety is provided for them.
DCIM	Data Center Infrastructure Management
IT	Information Technology
MDC	Modular Data Center
PDU	Power Distribution Unit
Rack	Houses IT hardware such as servers and storage solutions
UPS	Uninterruptible Power Supply

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01
Introduction

This chapter gives the background to the project and describes the project aim and objectives. It provides the reader with an understanding of why the development of a prefabricated data center for Edge Computing is desired.

1.1. Background

As technology progresses, in fields such as automotive automation, a demand for improvements within data communication has risen. Edge Computing is a method that aims to improve data communication by bringing the data processing closer to the source of the data, thereby reducing the latency as well as the data traffic (Luan et al., 2016). Apart from enabling automotive automation, Edge Computing will also help expand the Internet of Things by optimizing the flow of data. For Edge Computing to be possible there needs to be a decentralization of data services. The way to proceed with this is to create a middle ground between the end user and the Cloud, with an infrastructure of geographically distributed data centers. To accomplish this, a very large amount of smaller new data centers needs to be produced, this is the area that First to Know and Swedish Modules are currently looking into.

First to Know is a consultancy firm that focuses on sustainable business development and growth management. Currently they are working together with Swedish Modules to find new avenues for their business.

Figure 1.1. Existing data center module from Swedish Modules (Swedish Modules, 2018)

Figure 1.2 Inside of Swedish Modules data center module (Swedish Modules, 2018)

Swedish Modules develops and manufactures modular environments for customers in fields such as medicine, industry, IT and more. The modules, including functional and technical solutions, are manufactured in Swedish Modules factory in Emtunga, Sweden, before they are transported and installed at the desired location. It makes the production effective and well controlled, since the modules can be tested before being mounted on location.

Right now, Swedish Modules together with First to Know are exploring options for their modular data center (MDC) to be used for Edge Computing. They have recently joined the Open Compute Project (OCP), a large community that promotes innovation through information sharing, described by Open Compute Project (2017). OCP is a collaborative project that aims to efficiently develop technology and improve the standards by sharing knowledge and information. The efficient development is needed because more and more applications and services are moved to the cloud and connectivity of products is increasing, which means the Cloud needs to handle more data.

The core principles for the project are:

- Efficiency - contributions need to, for instance, be power, thermal or cost efficient
- Scalability - contributions need to support maintenance in large scale data centers
- Openness - contributions must be open source and compatible with existing OCP technology
- Impact - contributions need to create positive impact within the OCP

(Open Compute Project, 2018a)

Swedish Modules aims to develop a design for prefabricated MDCs in cooperation with this community, and for this purpose they initiated several project groups working in parallel with different aspects of MDCs for Edge Computing, such as value and market, servitization, energy reuse and service.

Swedish Modules sees integration of results from the OCP as a valuable way of developing MDCs in terms of cost effectiveness (Open Compute Project, 2017). Implementing these products will require a new design of prefabricated modular data centers as they differ from the conventional hardware that is used today. Aside from reducing costs for the module itself Swedish Modules are looking for innovative solutions relating to both installation and service of the modules, a vital aspect due to the sheer number of units that will be needed and the different types of locations they will be installed at.

1.2. Aim

The aim of the project is to develop a concept for a prefabricated MDC, with OCP technology, optimised for Edge Computing and maintenance.

1.3. Objectives

The objective of the project is to deliver a visualisation, floor plan and written description for a concept of an MDC, optimised for Edge Computing, maintenance and OCP Open Rack V2 together with OCP hardware. Focus should be on including solutions to facilitate maintenance and upgrading of hardware and other systems in the data center. The final concept should be scalable, and the design focus should be on the interior of the MDC.

02
Theory

This chapter describes theories included in the context studied and methods used for the project. The theory regarding the context includes Edge Computing, Data Centers and OCP technology. It is recommended to read this chapter to fully understand the process and the result.

2.1. The studied context

To understand the studied context requires knowledge of three main areas, Edge computing, data centers and OCP. A summary of these areas is presented in this part of the chapter, along with a short description of Predictive maintenance.

2.1.1. Edge computing

As the amount of data generated in the world increases each year, bandwidth and latency are becoming bottlenecks, particularly for the IoT. According to Di Francesco et al. (2018). Edge Computing is a method for bringing the data-processing closer to the source of the data, thereby lowering latencies for applications whilst at the same time reducing the size of the data sent to the Cloud. Whilst the computational power of our everyday electronics increases, allowing for more data to be processed in the edge devices themselves, there is still need for new infrastructure to support this (Traver, 2018). One way of doing this is through geographically distributed small-scale data centers, bringing servergrade processing power as well as data storage closer to the users. These data centers can function as nodes for communication between devices at the edge, the Cloud and other small-scale data centers, acting as a layer between devices and the Cloud (figure 2.1).

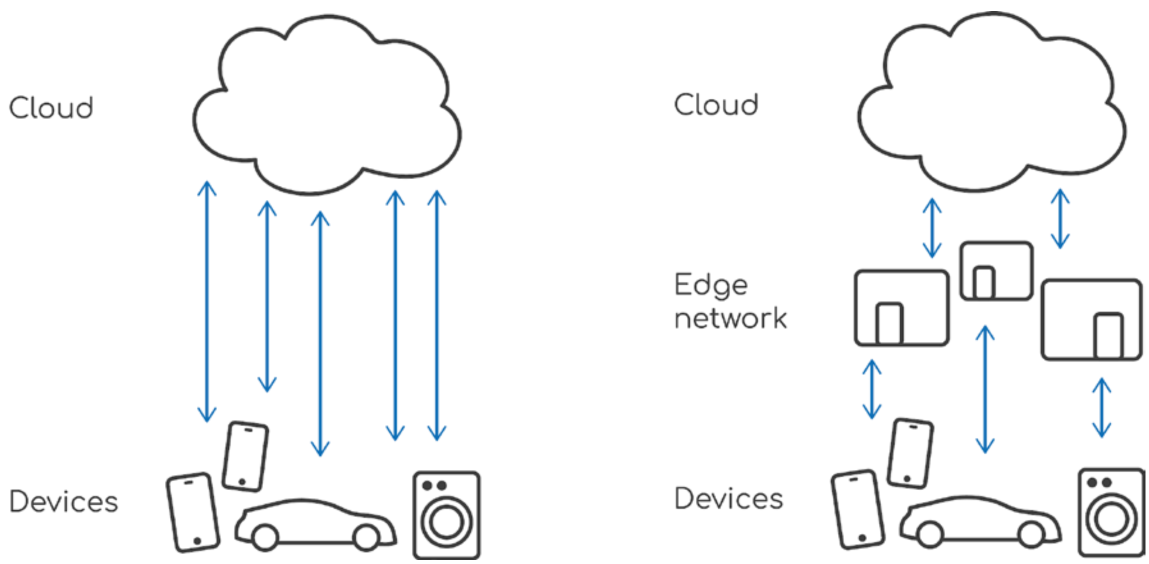


Figure 2.1. Comparison without and with an Edge network. Traditional Cloud computing to the left and Edge Computing to the right.

The increased data processing capabilities of these data centers can assist Edge devices as well as provide data processing on a larger scale, reducing the load on the Cloud, further decreasing the amount of data going to and from it. Another way that data traffic can be reduced is by caching data that is high in demand, known as a Content Delivery Network (Held, 2010). For example, as a new episode of a popular show is released, the smaller data centers can help reduce the data traffic required to allow users to stream it. There is also the possibility for applications to be run from these data centers, which brings many advantages.

With the ability to process large amounts of data at low latencies many opportunities open up, and these factors can be key for critical areas such as healthcare or finance, according to Rubin (2018). And as the IoT expands these factors will become more desirable and more necessary.

Though there are several ways of accomplishing the goal of Edge Computing, the benefits remain the same. Users and applications will be able to utilize low latency communication and near real-time data processing, and providers will reduce the amount of data being transferred. In the future Edge Computing also has the potential to be used for critical applications such as autonomous vehicles, according to Traver (2018) and Rubin (2018), but to what extent and for what purposes is still rather unknown. What is known is that there will be a need for an Edge Computing infrastructure.

2.1.2. Data centers

Data centers are facilities that hold equipment for storing and processing data (figure 1.1-1.2). They can have different designs and layouts but includes the same type of technical components. The main technical components of a data center is IT-hardware, Data Center Infrastructure Management (DCIM), cooling system, switchboard, UPS, fire suppression system, security system and backup power (Fortlax, 2016).

IT hardware and cooling

IT-hardware provides data processing and storage (Fortlax, 2016), often stored in racks which are commonly placed beside each other (figure 1.2). The power density of the racks can differ between different models and manufacturers up to over 20 kW (Avelar et al., 2014). Almost all energy used by the IT-hardware is converted into heat and therefore the facility requires a cooling system that allows the IT-hardware to be cooled from front to back, meaning heated air will rise up behind the racks and needs to be transported away (Evans, 2012). Data centers also need to be kept at an acceptable humidity level to avoid electrostatic discharges, caused by low humidity levels, or having moisture form on the equipment, caused by high levels of humidity (Fortlax, 2016).

Power

Power to the data center is fed through the main input of a switchboard which then distributes the power to the different components in the data center.
In traditional data centers power to the IT-hardware passes through an Uninterruptible Power Supply (UPS), which ensures that the equipment is provided with optimal power flow at all times, described by Clark (2012). If the main power goes out there is a battery backup connected to the UPS, which supplies the IT-hardware with power temporarily until the backup power, a generator, has been started and can supply the equipment for a longer period of time.

Safety

A fire suppression system, including a detection system, connected to an alarm and extinguishing system, is required to detect and put out fires (Siemens, 2015). The security system also serves to protect the equipment and the data center, usually by using security cameras and a key system for accessing the facility (Scalet, 2015). Its purpose is to prevent unauthorised people to enter the facility and to alarm in case of burglary or sabotage.

Usage

The data center facility can be anything from a big building, like Facebook's 27 000 m^2 data center in Luleå, Sweden (Data center Knowledge, 2018), to a small 7 m^2 node (Coromatic, n.d.). According to Fortlax (2016) data centers can be owned, operated and used by a single company or user, but this is not always the case. Another common solution is Colocation, providing users with a place for their IT-hardware in a shared facility, where all the vital systems such as cooling and power are managed by one of the companies or a separate company entirely. Depending on the needs of the user or users the data center could be a complete building, a room in a building or a separate data center node. A common node solution is Containerised Data Centers (CDC), where the data center is built based on standard container dimensions (Delta, 2018).

2.1.3. Open Compute technology

The hardware and server racks developed in the OCP differs from traditional hardware and racks in several ways. One of the main differences, described by Open Compute Project (2016), is that all installation and service of the IT hardware is performed from the cold side of the rack, due to the hardware having all input and output placed at the front. No tools are needed for routine service and the interaction surfaces for removing or opening IT components, the power is distributed by a busbar at the back of the rack and the servers are connected to it by simply sliding them into the rack. According to the OCP their solutions are more energy and material efficient compared to traditional hardware, the amount of parts is kept as low as possible. By only keeping essential elements they are able to eliminate nearly 2.7 kg of material per server. For the 21" Open rack V2 it is possible to use 3 node servers (figure 2.2-2.3), these are split up into three separate nodes, the nodes can be removed individually and are housed on a sled that provide power distribution from the racks busbar.

Figure 2.2. OCP Server Sled
(Wiwynn, 2017c)

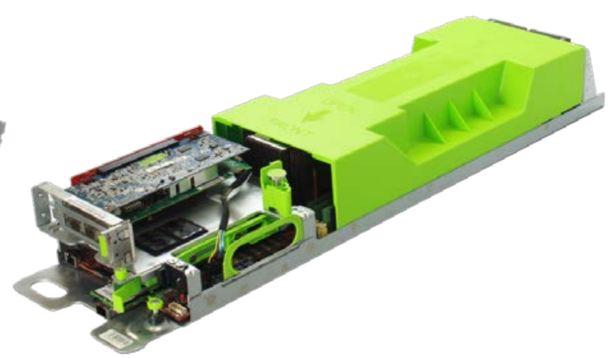


Figure 2.3. OCP Server Node
(Wiwynn, 2017d)

With OCP Open Rack V2 the function of a UPS and battery backup is integrated into each rack and therefore there is no need for a standalone UPS. The Battery Backup Units (BBU) are slid into the rack like the IT hardware. The racks are provided directly with AC power, which requires lighter cords than data center power cords.

For the Open Rack V2, described by OCP (2016), all IT equipment is provided with power through a vertical bus bar in the back of the rack. The equipment is connected to the busbar simply by sliding the component into the rack. The rack houses equipment that is either 660 or 800 mm deep (Open Compute Project, 2017), in total the rack is about 1050 mm deep depending on the manufacturer. The depth of the rack used in the study is 1067 mm, however the depth of the rack is not part of the specification for the Open Rack V2, as long as it can hold the IT hardware. Outer dimensions of OCP Open Rack v2 are 600 mm in width and about 2200 mm tall, depending on manufacturer, with four wheels underneath.

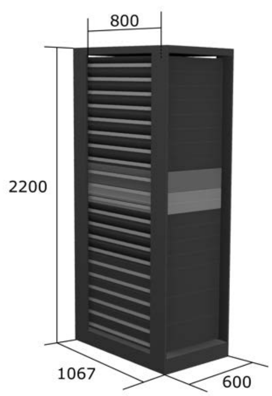


Figure 2.4. OCP Open Rack V2

Figure 2.5. OCP Open Rack V2 with OCP IT hardware (Shi, 2014)

2.1.4. Predictive maintenance

Downtime for data centers is often a costly ordeal, according to Lachance (2016), and something that most want to avoid. Usually the frequency of downtime is lowered by scheduling maintenance to ensure that the systems in the data center are running smoothly. This reduces the amount of reactive maintenance that has to be performed. Predictive maintenance is taking it a step further, by digitally monitoring several aspects of the data center and its machines. A Computerised Maintenance Management System (CMMS) is then able to predict issues before they occur, without requiring any human interaction.

2.2. Methods

This part of the theory chapter describes the methods used in the project to give an understanding for the process described in the next chapter and the result presented in following chapters. The chapter serves as support for understanding the project execution described in chapter 3.2.

2.2.1. Data collection

The methods for data collection fulfils the purpose of gathering information within the studied context for further analysis.

Literature study

Performing a literature study means, according to Wikberg Nilsson et al. (2015), existing knowledge is studied by reading different types of literature. The literature can preferably be found through searches on internet with relevant keywords for the studied context. It is important to review the literature critically to be able to determine what information is relevant for the specific project.

Benchmarking

Wikberg Nilsson et al. (2015) describes benchmarking as studying the market and existing solutions. The method can be used to find inspiration in how others have solved similar problems, but it is also important to not let the existing solutions limit the creative process.

Interview

An interview is a method for gathering information from users, stakeholders or experts within the studied field. A semi structured interview, described by Wilson (2014), means questions are prepared with the possibility to add or change questions during the interview depending on the interviewees answers. It is a combination between a structured interview, which is fully prepared with an interview guide, and the explorative unstructured interview. This type of interview is flexible and ensures the interview topics are covered, however, there is a risk that the interviewer can affect the interviewees answers. An interview guide is prepared before the interview including an introduction to the project, subject and interview as well as topics or questions.

Survey

A survey is a method for gathering quantitative data from a larger amount of people, according to Wikberg Nilsson et al. (2015). It is a way of measuring or comparing and the data is used to increase understanding. How the questions are formulated is important because it can affect its interpretation and in turn the answers, and there is no possibility for the survey-taker to receive clarification by asking questions to the creator of the survey.

2.2.2. Data analysis

Collected data needs to be analysed to support drawing conclusions and structuring the data to be used in the development.

KJ

The KJ-analysis method, described by Martin and Hanington (2012), is used for sorting qualitative data to get an overview of the data collected. It is performed by writing data on notes and grouping them together in different categories. The groups are then named to describe the theme of each group.

System diagram

A system diagram, described by Bligård (2015), defines the boundaries of the system or subsystems. Systems are defined by the creator and consists of communicating elements. Each element can in turn be a system and the communication between the elements can consist of material, information or energy. The purpose of a system diagram is to get an overview of the studied system and define the boundaries.

Use profile

Described by Janhager (2005) there are different types of users for a product listed below:

Primary user:	Uses the product for its intended purpose.
Secondary user:	Uses the product in some way, however, not for the primary purpose.
Side user:	Have not decided to use the product but is affected by it.
Co-user:	Cooperates with primary or secondary user with their own product.

After defining the users for the studied context, a use profile can be defined for the different users. It is a description of the users' relation to the product through the following categories:

- Use experience
- Influence on and responsibility
- Emotional relationship
- Degree of interaction

Persona

Wikberg Nilsson et al. (2015) describes a persona to be a fictive character representing a user group in a specific situation. The persona is described objectively from information gathered about the users and the scenario for the context studied. It is used as visual communication of the users of the specific project.

2.2.3. Ideation

Ideation methods are used to generate ideas for solutions for the project with the purpose to solve different problems or fulfil goals. After ideas have been developed they should be further evaluated.

Brainstorming

Brainstorming is an ideation method for generating a large amount of ideas, according to Wikberg Nilsson et al. (2015). In a group, ideas are created around a specified theme for each brainstorming session. The ideas are written or sketched on a paper, sticky notes or a whiteboard and it is important not to be critical to any ideas, because the goal is to produce a high quantity of ideas rather than strictly qualitative ideas.

Gallery method

With the gallery method each participant sketches ideas individually on a specific theme and then presents their ideas to each other, writes Technische Universität Braunschweig (2015). When presenting an idea, the participants can contribute with suggestions for the presented idea. The presentation is then followed by another round of individual ideation with inspiration from the ideas presented.

SCAMPER

This method is used on solutions developed in, for instance, a brainstorming session where the participants questions the ideas to further develop them, says Wikberg Nilsson et al. (2015). The name SCAMPER stands for:

- Substitute
- Combine
- Adapt
- Modify
- Put to other use
- Eliminate
- Reverse

These points describe the questions asked, like “What would happen if we combined this solution with another to create something new?”.

2.2.4. Evaluation

To choose between and further develop ideas they need to be evaluated. The methods described in this part of the chapter are used to evaluate and compare ideas created with the ideation methods.

Pros and cons method

This evaluation method is performed by listing all pros and cons for each idea within a theme to facilitate choosing or improving concepts.

Kesselring matrix

The Kesselring matrix is, described by Bligård (2015), a weighted evaluation method where criteria for a dream solution are listed on the y-axis and given a weight depending on its importance. Concepts are listed on the x-axis and graded by how well it fulfils the criteria. Finally, the weight and grade are multiplied which results in the final score.

Prototyping

According to Wikberg Nilsson et al. (2015) prototyping is a way to explore the design problem. It can be done in many different ways such as sketching, physical models or digital models. It is meant to be a method for exploring and evaluating different variations, combinations, possibilities and formations for a solution.

Rapid Entire Body Assessment (REBA)

REBA is an ergonomic analysis of body positions, described by Osvalder et al. (2010), preferably performed on the most critical positions in a scenario. Positions of the different body parts are analysed, together with loads and other affecting factors, which results in a score for how important it is to improve the product or task. The scores are:

1	Negligible risk, no action required
2-3	Low risk, change may be needed
4-7	Medium risk, further investigation, change soon
8-10	High risk, investigate and implement change
11+	Very high risk, implement change

(Hignett & McAtamney, 2018)

03
Project process & execution

This chapter initially describes the overall process of the project followed by a more detailed description of the methods used in the different phases of the project. It gives the reader an understanding for how the concept was developed and where the result comes from.

3.1. Overall process

The project started with a project planning where the scope, aim and limitations where defined, as well as a schedule for the project made (appendix 1). Following questions were formulated to describe what needed to be answered in the project to reach the aim of the project:

- How should an MDC for Edge Computing with OCP components be designed to be optimised for maintenance?
  - What will be the frequency at which the hardware will need to be maintained or upgraded, both from the perspective of the hardware itself as well as its utilisation in the Edge Computing infrastructure?
  - What is the best way to maintain an MDC with OCP Open Rack V2 and OCP hardware?
  - What sizes of MDCs will the Edge Computing infrastructure require?

The planning was followed by an exploration phase where the focus was on understanding the technology and context of the MDC (figure 3.1). It was followed by the main part of the project which was an iterative development phase. The development process for the project is mainly built on the ACD^3 design process method, described by Bligård (2015). Four of the five iterative levels presented in the literature were used for the development in the project, where the development got more and more detailed for each level. The four levels were;

- Effect - the intended effect the solution should have on the context
- Usage - the type of usage that gives the intended effect
- Architecture - overall design of the MDC
- Interaction - detailed design of interaction between user and MDC

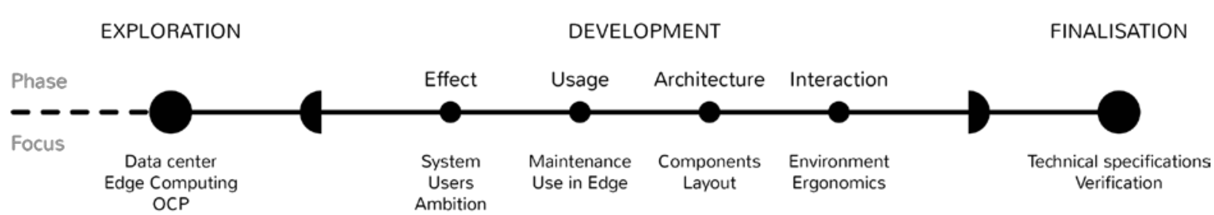


Figure 3.1. Project process.

Each level of this part of the process included data collection, data analysis, ideation, synthesis and evaluation (figure 3.2), and the result from each level was used as a base for the following level. After the interaction level the finalisation phase of the project was performed, the aim of which was to evaluate and refine the final concept.

This process was mainly used because of the complexity of the product developed, which required many design decisions on different levels of detail. It was also a valuable method for including both the complex technical aspect as well as the user focus.

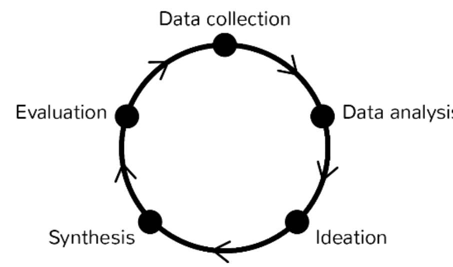


Figure 3.2. Iterations in the development phase.

3.2. Project execution

This chapter describes the execution and how the methods were used throughout the different phases of the process. The synthesis step is not described as this was done continuously throughout the process, mainly through defining requirements.

3.2.1. Exploration phase

The initial exploration phase served the purpose of mapping out the relevant areas of knowledge needed in order to better understand the scope and context of the project.

Data collection

Data was gathered from reading literature found through web searches, including articles, blog posts and reports, as well as videos relevant for the subjects studied. The main subjects for this phase were Edge Computing, data center facility and Open Compute. Through literature, benchmarking was also performed to gather information to be able to find similarities and differences in different designs. The purpose of which was to examine what experts on data center and edge computing predicted the future need of data centers to be.

Additionally, a semi structured open interview with an expert on data centers was held to further explore and understand the area of data center facilities. Questions were prepared (appendix 2) but some questions where added, changed or skipped during the interview depending on the interviewees answers. Since the questions were mainly open the interviewee could elaborate the answers, resulting in qualitative responses.

The two project members held the interviews together, where one was the interviewer and the other mainly a secretary, who also added questions during the interview. Notes were taken during the whole interview, and it was also recorded to allow the project members to go back and listen again if something was unclear. However, a full transcription was not considered to be required because of the notetaking.

Data analysis

The findings from literature studies and benchmarking was sorted into categories in a matrix so that conclusions could be drawn for each category, by combining the result from different sources. Data from the interview was analysed in a similar way, but separate from the other data, using the KJ-method (figure 3.3) (appendix 3). From the analysis of all the collected data, in the exploration phase, the first requirements for the prefabricated MDC were listed and sorted into categories.

Figure 3.3. KJ analysis.

3.2.2. Development phase

In the main part of the project process the concept was developed through the four iterative development levels, concerning desired effect, design of use, overall design and detailed design respectively.

Data collection

As in the exploration phase data was collected through literature studies and interviews. In addition, benchmarking of two large data center facilities was done, in order to gain a better understanding of data center architecture and the technical components included. The benchmarking was done through visiting the facilities which also provided a better understanding of the environment from a technician's perspective, in terms of perceived space and climate. Later in the project a containerised data center was also visited with the same purpose. Whilst visiting the data centers, photography was not allowed. The data collection was therefore based on notetaking.

At the initial development level of the project focus was on expectations on the future Edge Network. Therefore, one expert in the area of edge computing and one in the area of autonomous vehicles were interviewed. As input for both the usage and the interaction level, five service technicians were interviewed. Two of which IT hardware technicians, one power technician, one cooling technician and one with experience in power, cooling and facility maintenance. The purpose of the interviews was to gather information about how data centers are used and maintained today and discuss what it could look like in the future. Each interview differed in the prepared interview guide to fit the interviewee's specific knowledge, however, an example is presented in appendix 4. Since none of the technicians interviewed had experience with maintenance of OCP components or facilities, consultation through phone interviews with two OCP experts were also performed. For the architecture level a cooling system supplier was interviewed, and further benchmarking was done, where focus was on the layout of the existing containerised data centers (Chapter 6.2).

For the interaction level a benchmarking was done to find tools and aids that could be of use in a data center (Chapter 7.2). This benchmarking was primarily done through web searches based on needs identified through previous data analysis. At a later stage of the development process a survey (appendix 5) was sent out to service technicians within different areas of expertise, the purpose of the survey was to assist in the evaluation of the layout, cooling system and aids. The survey was built on questions were one out of two to three ideas should be chosen as the preferable solution, followed by a written motivation. All questions were mandatory to get a more qualitative result.

All of the interviews were semi structured to be able to gather qualitative data from each expert. Both project members were present for all of the interviews, with one member primarily focusing on taking notes and the other on performing the interview. Based on the preference of the interviewee the majority of the interviews were recorded in case some note required clarification, however the interviews were not transcribed. All interviewees are listed in table 3.1.

Table 3.1. List of interviewees for the project.

Name	Knowledge area	Date
Technician 1	Power, cooling and facility	2018-02-07
Expert 1	Autonomous vehicles	2018-03-08
Technician 2	IT-hardware	2018-03-16
Technician 3	IT-hardware	2018-03-16
Expert 2	Edge Computing	2018-03-26
Technician 4	Power	2018-03-29
Expert 3	OCP hardware	2018-04-11
Expert 4	OCP	2018-04-13
Technician 5	Cooling	2018-04-19
Expert 5	Cooling supplier	2018-04-26

Data analysis

Relevant results from the literature studies where implemented into the requirement list along with results from the different interviews. From the data collected on the effect level system diagrams were developed to define the main parts of the system and how they are connected. It also resulted in a user profile describing the users that mainly affects the design of the prefabricated MDC. The different types of users in the context and their needs were also further analysed and developed into personas.

The interaction between subsystems was described further with a detailed system diagram of the interaction between different users and the MDC.

The results from the survey included both quantitative and qualitative answers, the qualitative answers were in the form of motivations to the quantitative answers. The quantitative results were made into diagrams (appendix 6) and the qualitative answers were grouped and compared using the KJ-method (appendix 7). The motivations were considered when looking at the quantitative answers and some conclusions were drawn from this (Chapter 6.3 and 7.2).

Ideation

Early on, a concept ambition (Chapter 4.3) based on user needs, was defined in order to create a shared ambition for the concept. The ideation in the project has included two main methods; brainstorming and the gallery method. Brainstorming was, with a defined theme for the specific session, performed together in pair by writing and drawing ideas on sticky notes. Examples of themes for the ideation sessions are; scalability, overall layout and physical ergonomics (Chapter 5.1).

Sketching is a tool that was used for the ideation to explain and develop ideas for different types of solutions throughout the whole development phase. On the architecture and interaction level physical modelling was also used to facilitate the ideation. The models used for the ideation were models in the scale 1:20 and represented the technical components and the primary users, they were made in Kapaboard and paper (figure 3.3). 2D layout drawings (figure 3.4) were also used for developing layout ideas on the architecture level, where required clear distances from technical components as well as working space was also included. After evaluating the ideas, they were further developed with the SCAMPER method.

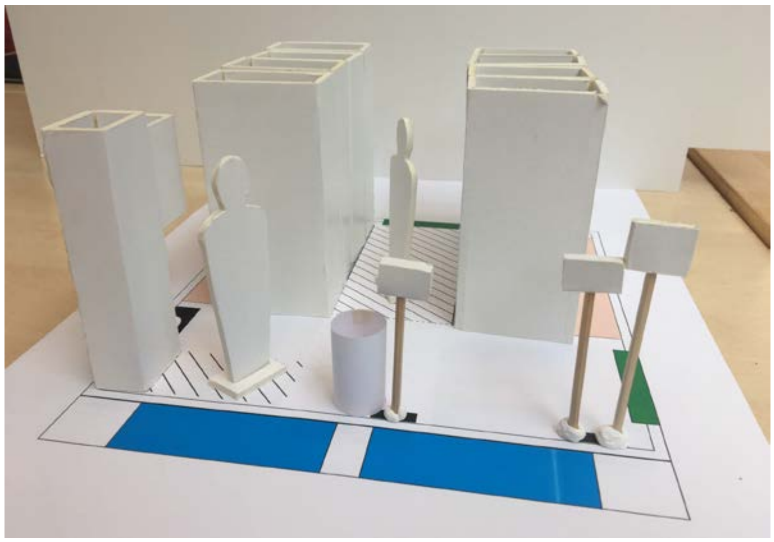


Figure 3.4. Combination of 2D and physical 3D prototyping

Evaluation

After each ideation session the ideas were sorted and discussed. The most promising ideas were then further evaluated with the pros and cons method. The evaluation aimed to facilitate improvements for the concepts and to sort out less promising ideas. For the remaining concepts developed on the usage level a Kesselring evaluation was performed to facilitate the choice of concept (Chapter 5.1). Physical 3D and digital 2D modelling also worked as tools for evaluating concepts, by visually evaluating the space and measuring distances.

The personas (Chapter 4.2.2) were used for evaluation as well, by discussing how different solutions would affect different users. To include the actual users' expertise and ideas in the product development, a few concepts were shown to three of the service technicians interviewed to get their opinions on them (Chapter 5.1.2). Their opinions helped to choose and improve concepts on the different design levels of the project.

Different iterations of the concept were created as 3D models throughout the architecture and interaction levels, the program used to create the 3D models was Autodesk Alias AutoStudio, the models served as a good way to more precisely evaluate the measurements of the concepts. The 3D models were also a good way to present the concepts in an easily understandable way.

3.2.3. Finalisation phase

The finalisation phase is where the final concept was refined and the result analysed, with the purpose to further improve concept details and confirm the result. More literature was studied to define certain aspects of the concept. To both evaluate and improve upon the cooling of the concept, a consultation was held with the same cooling system supplier that was interviewed during the development phase. Existing 3D models were also updated to reflect the changes that were made. To ensure that the layout of the final concept allowed for the type of maintenance intended, a 3D model of the concept was tested using 3D manikins to verify that the space was sufficient. The manikins where placed in various positions to ensure that there was enough space for simultaneous work as well as manoeuvring. The program used for this was Jack (appendix 8). Lastly, the final concept was also discussed with Swedish Modules.

04

Effect – Defining the desired effect

The first level for developing the final concept is the Effect level where the system boundaries as well as the subsystems are defined, including the users and stakeholders that affect the design of the MDC. Initially the defined system is presented including interaction between the different subsystems. It is followed by a description of the users in the system that affect the design of the data center. The users are then further described with personas before the ambition of the concept is presented. Finally, the requirements defined on this initial level of development are listed and the design decisions for the effect level summarised.

4.1. The system

Through knowledge gained through literature, videos and initial interviews a system diagram was developed to visually describe the context and the system. It was updated during the project as new information was gathered.

The MDC is the main sub system in the Cloud system which, in turn, includes several subsystems serviced by technicians with different competences. In figure 4.1 the system studied is illustrated together with the interaction between the different parts of the system. The MDC is a part of the edge network and cooperates with other MDCs, meaning they share information needed to provide the users with Edge services. In turn, the Edge network receives information from and provides information to the cloud to offload the Cloud and provide users with faster response time.

Physical human-machine interaction is between the MDC and the installers and service technicians respectively. However, the service company, the users of the edge infrastructure and the owner of the MDC or the infrastructure are also part of the system since they remotely can check and control the technical systems. The locals are users that does not interact with the data center directly but are affected by the function of the MDC as well as its physical presence.

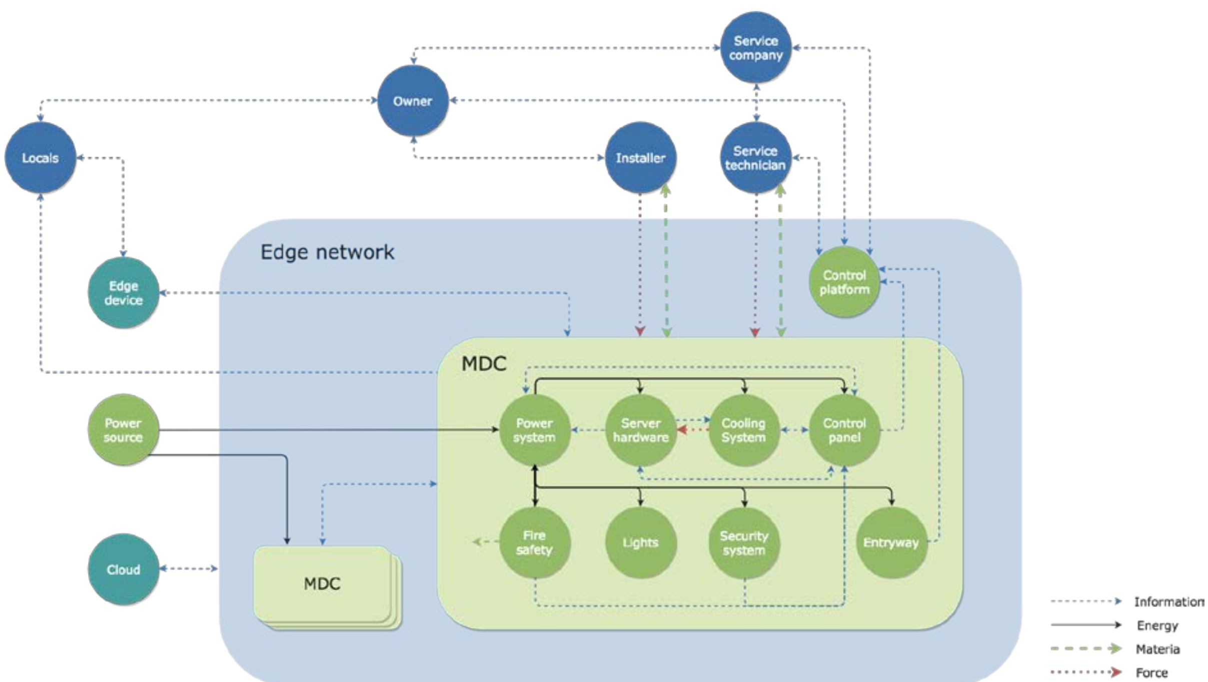


Figure 4.1. System diagram of the Edge infrastructure.

Since service technicians with different competences services the different subsystems in the MDC, the system is actually even more complex than shown in figure 4.1. A more detailed description of the interaction between service technicians and the MDC is illustrated in figure 4.2, which shows the individual interaction for each of the technicians as well as the interactions common for all technicians. Common interactions for most visits are with the control panel and with lights, key card and entryway for all visits. There is also interaction with the fire suppression system in case of fire for all technicians, besides that each technician interacts with their respective subsystem during service.

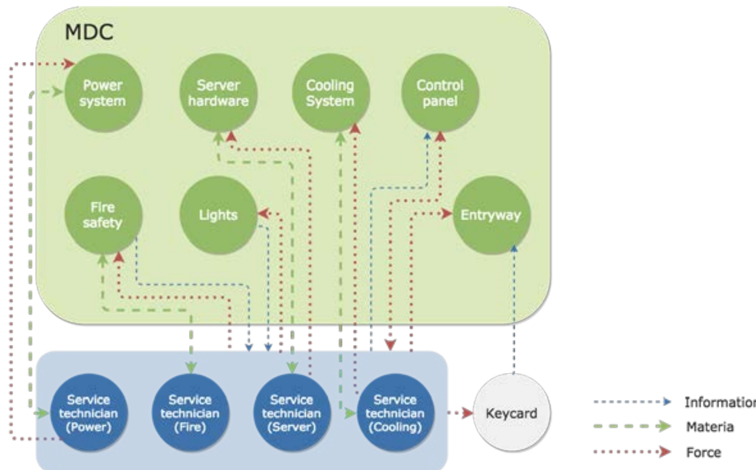


Figure 4.2. Detailed system diagram of interaction between service technicians and MDC.

4.2. Users in the system

When focusing on maintenance of the MDC, the primary users in the system are service technicians. There are, however, different types of users within the category mainly divided into their areas of expertise. The different areas for service technicians interacting with the data center are; cooling, power, IT, fire suppression, and security. It could, however, be possible to combine some of the competences to reduce the number of service technicians required to completely service an MDC. There will also be co-users in the system who cooperates with the primary user. It is colleagues on phone support within either the same competence area or most likely another area. This is because when the primary user is on a call assignment regarding a part of the system, which is outside their competence area, they probably need to be guided.

The secondary users are, in the case of this project installers, cleaners and purchasers or planners of the Edge infrastructure. Since the service technicians do not have any, or only a low level of influence on which data center solution they are going to use, the purchasers or planner are important users to consider in the development. The users of the fog infrastructure are side users in the system because they are affected by the MDCs and the fog network it provides them with, but they do not interact with the MDC.

4.2.1. Use profile

To further understand the use of a prefabricated data center, the following use profile for the primary user was developed.

Use experience

The primary users, service technicians, are experts in the domain of the system they are working with. However, their experience of working in a data center or working in a specific data center differs from between complete novice to being experts. Therefore, the data center need to be easy to understand and use without disturbing experienced users. Despite different levels of experience, service technicians frequently work and interacts with data centers. Good physical and cognitive ergonomics are therefore of high importance.

Influence

Service technicians are the only users who interacts with the data center frequently, but they have very low or no influence on what solution to use or how their work situation looks like. A solution therefore needs to be designed for and adaptable for the different user needs.

Responsibility

Technicians have a high degree of responsibility for the data center, mainly the specific part of the data center that is within their expertise, as they are responsible for keeping the systems running. Thus, it is important for the technicians to be able to feel confident in performing maintenance work.

Emotional relationship

The technicians are not the owners of the data center and do not have an emotional relationship to the facility, this makes aesthetics of the interior less important than ergonomics, usability and adaptability, for instance.

Degree of interaction

Interaction with the data center is on a high level of physical interaction for service technicians, meaning physical ergonomics is an important aspect to consider in data center design.

4.2.2. Personas

The four personas presented in this part of the chapter represents the main users to consider for the development of the concept, and what they value and stand for. They have been evolved from studying data center contexts in literature and through expert consultations and have worked as a tool for developing and evaluating concepts.

Two personas, Stefan (figure 4.3) and Anton (figure 4.4), are service technicians where their confidence level, differences in area of expertise, experience and interests, as well as ways of working are described. They represent two different types of possible technicians working with maintenance of MDCs.

Veronica (figure 4.5) represents purchasers or edge network planners, as the secondary users. Her profile describes what they value and what trade-offs they might encounter. She is a main user for the project since she is the one who decides what solution should be used and therefore affects the service technicians job.

Simone (figure 4.6) represents the side users and their demands on the edge network which in turn affects the demand on data centers. She might not ever be in physical contact with a data center or even know how they work or what they do so her needs differ much from the other personas needs.

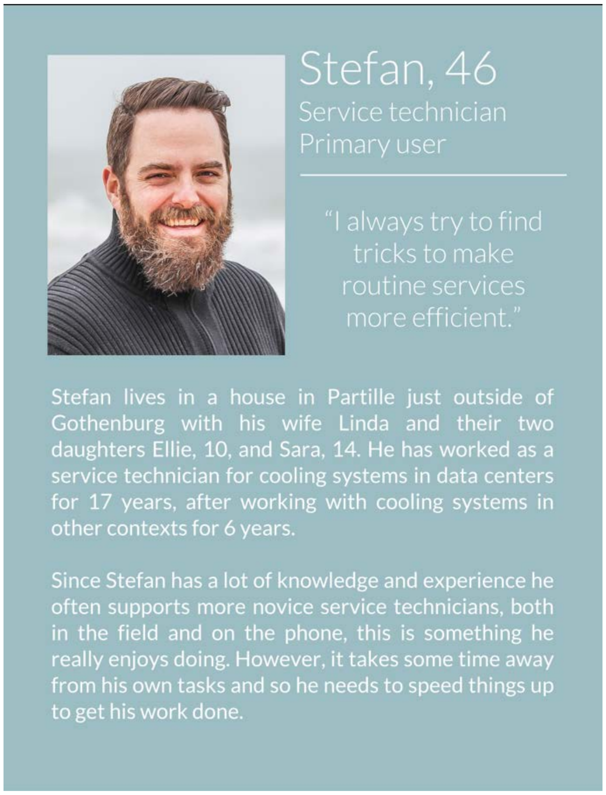


Figure 4.3. Persona representing the more experienced service technician.

Figure 4.4. Persona representing the inexperienced and curious service technician.

Figure 4.5. Persona representing the customers and Edge Network planners.

Figure 4.6. Persona representing the people using Edge Network applications.

4.3. Concept ambition

During the development the ambition of the concept was defined (figure 4.7) based on the user needs identified. The concept overall should be sustainable, since it is a power consuming product, and in particular since a large number of MDCs will be geographically distributed. Because of the scattered distribution, the concept also need to be customisable, so that it can be used in different locations and for different applications. The MDC also needs to express that it is a secure solution for users to trust that it works and will not be susceptible to sabotage.

It is important that the concept is perceived as organised, logical and structured for the users to trust the product, be able to feel confident and not be confused by it. This can make the primary users feel more confident, like the experts they are or want to become. Because of the advanced technology in the data center, and that the edge network supports, the concept should also express that it is advanced and futuristic, which can contribute to all users understanding of the product and its value.

Figure 4.7. Concept ambition.

4.4. Conclusion

Studying the overall system, its users and interactions, and developing ideas for the intended effect of the concept have resulted in many insights regarding the context and system, leading to requirements and and concept decision. The result is the desired effect of a data center for Edge Computing.

Edge Computing
The concept should:
- Provide processing power and data storage for an Edge Computing network
- Cater to different needs
- Function as a layer between devices and the Cloud
    - Relieve the Cloud through assisting with data processing and storage
    - Provide users with applications

The concept is a prefabricated MDC optimised for Edge Computing. It is a part of a complex system with many subsystems included, both technical and human, with many interactions to consider. MDCs that are connected to each other can create an Edge Network, which in turn interacts with both the Cloud and with the users of the network applications. The concept therefore needs to provide side users with applications and functions as well as relieving the amount of data the Cloud need to handle.

It is Important to also consider the customers or Edge Network planners that have the most influence in the purchase of solutions. They value customisation possibilities to be able to find a suitable solution for every site. Thus, the concept should cater to different types of needs through a flexible design.

OCP The concept should: - Accommodate 21” OCP Open Racks v2 - Be adapted for OCP hardware

Through designing the concept based on the requirements and possibilities of the racks and hardware, the concept should fulfil these requirements.

Service
The concept should:
- Allow service to be performed on each subsystem
    - Be efficient to maintain
    - Be safe to maintain

The primary users are service technicians, who physically interacts with MDCs on a daily basis. Within the user group there are technicians with different competences and work tasks for each technical subsystem within the MDC; IT hardware, cooling, power, fire suppression and security. Their main needs are to be able to perform their job efficiently and safely. Therefore, the concept need to be designed to allow efficient and safe work by user friendly design.

05

Usage – Designing the use

The next level of the development process is the Usage level, where different concepts for how the prefabricated data center can be used in the future has been developed and evaluated. First the development focusing on flexibility is presented followed by development of the overall layout. Then the result from studying different future usage scenarios for service technicians is presented. Finally, the customers' needs and how they are fulfilled with the concept are described.

5.1. Developing the overall use

The development of ideas for the overall use focused on two main themes; flexibility and service layout. After an initial ideation session, followed by an evaluation, the results were used to determine what areas were necessary to gather more information on. Here follows a short description of the concepts together with pros and cons for each idea.

5.1.1. Flexibility

The flexibility of a modular data center determines how well it can suit a customer's specific needs, it also has an effect on the production, generally a more flexible solution will require more resources to produce. The most promising ideas for a flexible concept are presented below together with the result from the evaluation with the pros and cons method.

Concept: Standard wall sizes

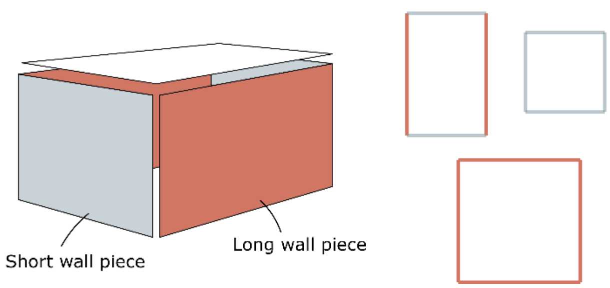


Figure 5.1. Flexibility concept with standard wall sizes.

Using a small set of different wall lengths (Figure 5.1), the MDC can be easily produced in different sizes, having premade walls will also allow for quick assembly based on specific requests. This concept gives the customer more options in terms of MDC size, in a way that is not detrimental to the company's production capabilities. Depending on the available wall dimensions, different sizes for the data center could end up having varying form factors. This would affect the layout coherence of the designs.

Concept: Modules

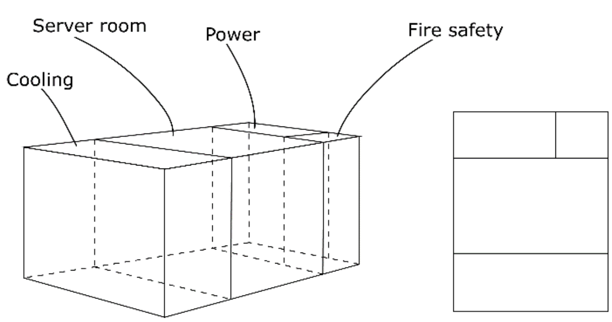


Figure 5.2. Flexibility concept based on modular assembly.

This concept houses each system in its own module (Figure 5.2), allowing for each module to be pre-produced and the MDC to be assembled to the customers' demands upon order. This concept allows for very great flexibility for the customer, supporting a sort of "build your own MDC"-system. The producer is also able to pre-manufacture parts to speed up order delivery. The space efficiency of this concept is rather poor, and it also might entail difficulties for maintenance and user adaptation.

Concept: Utilities Stem

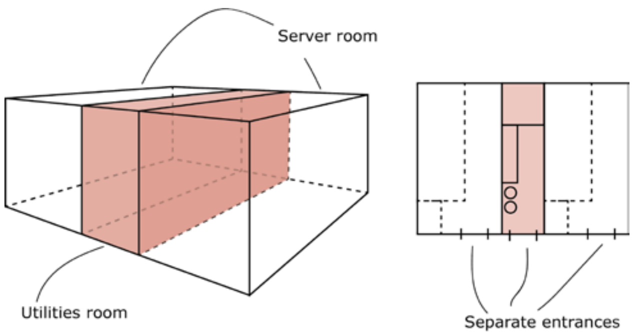


Figure 5.3. Flexibility concept with utilities collected in a separate module.

Splitting the MDC into two different parts (Figure 5.3), separating the utilities from the IT-hardware, this allows the capacity of the MDC to be expanded to suit the customers' needs as they change over time. The negative aspect of the concept is that the stem is likely to be oversized for small data centers.

Concept: One Size

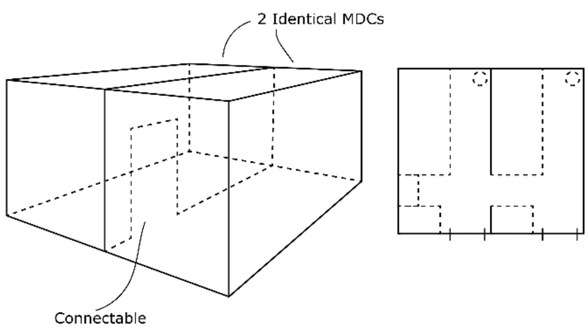


Figure 5.4. Flexibility concept based on repeatability of modules of the same size.

Focusing production on a single size MDC allows for a reduction in cost for the manufacturer and in turn the customer (Figure 5.4), the flexibility for this concept comes from the ability to physically connect the MDCs to each other to create a larger MDC. The flexibility is likely to be limited however, and the space efficiency of a single module will suffer if adapted to be joined with other modules.

Flexibility evaluation

The concepts were evaluated through the pros and cons method as well as through the use of a Kesselring matrix, where they were evaluated based on certain factors that were deemed important. The weighting of the matrix was also decided based on the knowledge gained through the project up until this point.

The result of the Kesselring matrix (table 5.1) showed that the Standard wall sizes concept along with the One-size concept were the best concepts. Compared to the other concepts these two exceeded or equalled the results for the majority of the factors, the standard wall sizes concept received the most total points both with and without weighting, the distribution of points was also fairly even across all the factors. The One-size concept received a few less points albeit almost equal to the standard wall sizes, the distribution of points was less even for this concept with a few more 5:s and 2:s. All in all, the Standard wall sizes concept and the One size concept were considered the most reasonable concepts to look into further.

Table 5.1. Kesselring evaluation of flexibility ideas.

Kesselring	Weight	1. Walls	2. Modules	3. Stem	4. One-size
Cost	2.5	4	2	3	5
Space	1.5	3	2	2	3
Service efficiency	2.5	4	2	2	3
Customisation	2	4	5	3	2
Ergonomics	1.5	3	2	3	3
Accessibility	1	3	3	2	2
Fire safety	1	4	4	4	4
Sanitation	0.5	4	2	3	3
Manufacturing	2	4	3	4	5
Transportation	1	3	3	3	4
Installation	1	4	2	3	4
Expansion	1.5	2	5	3	2
Total:		42	35	35	40
Total (weighted):		64	52.5	52	61.5
Rank:		1	3	4	2

5.1.2. Service layout

This category addresses the service layout of the data center, this is heavily affected by how the data center will be serviced, but the fact that it will be unmanned the majority of the time is also an important aspect to consider.

Concept: Overview

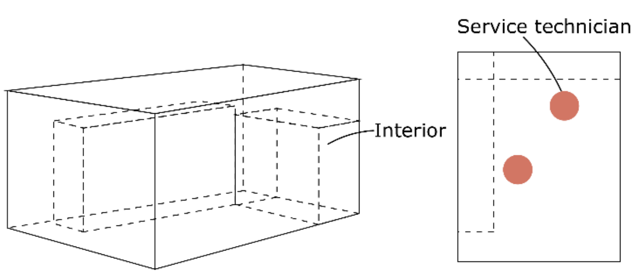
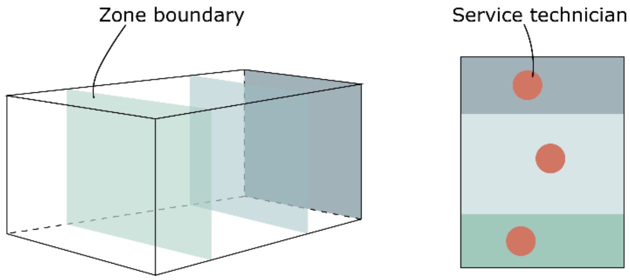


Figure 5.5. Service layout concept to allow technicians to get an overview of the entire data center.

Placing the systems in a single room in a way that allows all systems to be easily observed (Figure 5.5), will give technicians a good overview of the MDC. In addition, it also allows the technicians to easily communicate with and assist each other in the case that several technicians are on location at the same time. Possible drawbacks of this is that the shared space can increase the risk of technicians being in the way of each other.

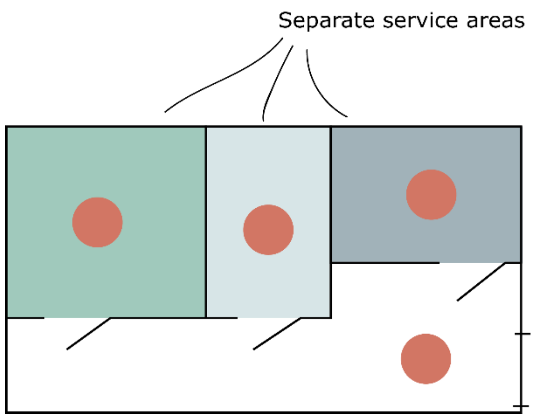
Concept: Zones



Splitting the MDC into separate zones for the service technicians will make sure that each technician has ample space to perform the service necessary for the equipment (Figure 5.6), without the risk of physically interfering with another technician. This concept retains the benefits of the Overview concept while sacrificing some space efficiency.

Figure 5.6. Service layout concept dividing the data center into zones for the different systems.

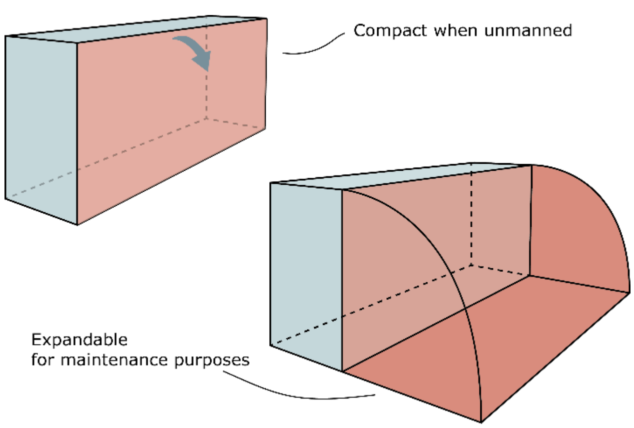
Concept: Separate rooms



Having each system in its own room will allow the technicians to be isolated from each other (Figure 5.7), eliminating the risk of interfering with each other's work. The systems being separated by walls will also provide extra protection against intrusion as well as spreading of fire. Another benefit would be the ability to control what systems can be accessed by visitors, making it especially beneficial for colocation purposes. The main drawbacks of this concept are less efficient space usage and the fact that it may hinder the ability for technicians to assist each other.

Figure 5.7. Service layout concept that houses each system in a separate room.

Concept: Expandable



This concept aims at utilizing the fact that the MDC will be unmanned the majority of the time (Figure 5.8). By allowing the MDC to be expanded for service purposes it will have a minimal physical footprint when not serviced. This will also mean that the cooling for the MDC can be more efficient due to the reduced volume. This concept does come with some fairly major drawbacks however, expanding the MDC will add another step to the service process, it is also likely that there would be a reduction in security when expanded.

Figure 5.8. Service layout concept that can be expanded to provide room for maintenance work.

Service layout evaluation

The concepts were evaluated through the pros and cons method as well as through the use of a Kesselring matrix, where they were evaluated based on certain factors that were deemed important. The weighting of the matrix was also decided based on the knowledge gained through the project up until this point. For this category different service scenarios were also included in the matrix, taking into account the different possibilities for how service of the MDC might be performed. The different scenarios were:

- Group all - All the systems are serviced simultaneously, meaning all the different competences need to be represented among the technicians.
- Group small - Not all systems are serviced simultaneously, the group consists of 2-3 technicians.
- Solo - A single technician is on location.
- Call assignment - A single technician arrives on location, responding to an emergency, this technician might not have competence related to the failing system.
- Colocation - Should the MDC be used for colocation, and the tenants choose to perform IT-hardware related work on their own, the number of visits to the MDC will increase. In addition, being able to restrict access to certain systems and areas could be beneficial for increased security.

In the Kesselring matrix (table 5.2) three of the four concepts received fairly similar scores with no major differences between weighted and non-weighted scores. There were also no major differences in terms of point distribution between the concepts. The fourth concept Expandable received the least amount of points both weighted and non-weighted, it also had the most uneven point distribution out of all the concepts.

Upon factoring in the scenarios, the fourth concept was discarded as it received the least amount of points in this section as well. The top three concepts once again, received similar scores, and the Zones concept did come out on top in both sections of the evaluation. However, the other concepts were very close score wise.

Table 5.2. Kesselring evaluation of service layout ideas.

Kesselring	Weight	1. Overview	2. Zones	3. Separate	4. Expand
Cost	2.5	4	3	3	4
Energy	2	4	4	4	5
Space	1.5	4	3	2	5
Service efficiency	2.5	3	4	4	2
Customisation	2	2	3	3	1
Security	1.5	3	3	4	2
Ergonomics	1.5	3	4	4	2
Accessibility	1	4	4	3	2
Fire safety	1	4	4	5	3
Sanitation	0.5	4	4	3	2
Manufacturing	2	4	4	3	3
Transportation	1	3	3	2	5
Installation	1	3	3	3	3
Comfort	0.5	3	3	3	1
Total:		48	49	46	40
Total (weighted):		70	72	68.5	61
Rank:		2	1	3	4

Scenarios				
Group all	3	5	4	1
Group small	5	5	4	3
Solo	4	4	5	3
Call assignment	4	4	4	4
Co-allocation	3	4	5	1
Total:	19	22	22	12

TOTAL:	89	94	90.5	73
Total rank:	3	1	2	4

Through the evaluation the three concepts Overview, Zones and Separate were deemed the most reasonable concepts to look into further. The viability of the concept Separate was discussed however, as it sacrifices space efficiency and the ability for technicians to assist each other. For the concept to be efficient, the usage of the data center needs to have a focus on co-location.

The evaluation process highlighted several aspects were more knowledge was needed in order to properly evaluate the MDC design, how the MDC should be maintained and what the customer needs for an MDC are. For this purpose, these areas where then further explored in this phase.

5.2. Defining optimal maintenance scenario

Through the initial ideation session of the usage phase, the question of how the MDC should be maintained was deemed an important factor for the design. This area was thus explored further to determine what service scenario or scenarios to design for. The question then was how many technicians will be on location at the same time, and what different expertise's they will possess.

This part of the chapter describes the results from literature studies, interviews and benchmarking as well as development of future maintenance scenarios.

5.2.1. Environmental aspects

Looking at routine service the number of technicians that are able to be on location at once will directly affect the amount of times a specific MDC will be visited, given that the technicians are able to service more than one system. A low number of visits is beneficial to keep the MDC as clean as possible, as the majority of all dust in a data center is brought in by visitors (Dycem, 2018a). More technicians on location opens up possibility for the technicians to travel to the MDC together, reducing the environmental impact of their transportation. On the other hand, having more technicians on location would likely require the MDC to be larger in size in order to accommodate them, meaning a larger cost of manufacturing as well as a larger footprint, both physical and ecological.

5.2.2. Safety aspects

There are several risks associated with performing maintenance in a data center; some tasks include heavy lifting, several tasks require the technicians to work at height, and with certain systems the technicians deal with high voltage. Maintenance of MDCs in particular could also mean that the location is remote, and that the technician or technicians working there could be the only one or ones around. According to Technician 1 it is better to be at least two technicians when servicing a remote data center. This is true not only for service technicians in a data center, but any work that is performed at remote locations, as one of the most common causes of injury in the workplace is falling (Arbetsmiljöverket, 2017). Having more than one person on location means that in the event of one person suffering an accident the other can assist as well as alert emergency services.

Man-Down systems is a solution that is used today in situations where people work in more isolated conditions, a device is worn that sends an alert in case the bearer suffers a fall (Peoplesafe, 2018). This type of system is used in some MDCs today, and it is even used in larger data centers that are manned at all hours (Datacenter.it, 2018). This shows that quickly receiving help in the event of an accident is of great value, and that working alone increases the potential consequences of accidents.

5.2.3. Ergonomic factors

According to Arbetsmiljöverket (2012) lifting load over 25 kg is unsuitable for a single person, and anything over 7 kg could potentially be harmful depending on frequency and duration. Maintenance of a data center includes a low frequency of lifting, however, there is equipment that is too heavy for a single person to safely lift on their own, this storage solution from Wiwynn (2017a) for example can weigh from 38 kg up to as much as 120 kg. Equipment that weighs below 50 kg can be lifted by two people, but with more people even heavier equipment can theoretically be lifted but the coordination difficulties will increase the more people that are involved. For Open Rack V2 it is possible to use 3 node servers, which are split up into three separate nodes that each weigh around 7 kg (Wiwynn, 2017b). These server nodes are light enough for one technician to lift in and out of the rack alone.

Other heavy equipment technicians might need to interact with during maintenance are the racks, which can weigh 1400 kg (Bailey et al., 2017), and the tube with fire extinguishing agent.

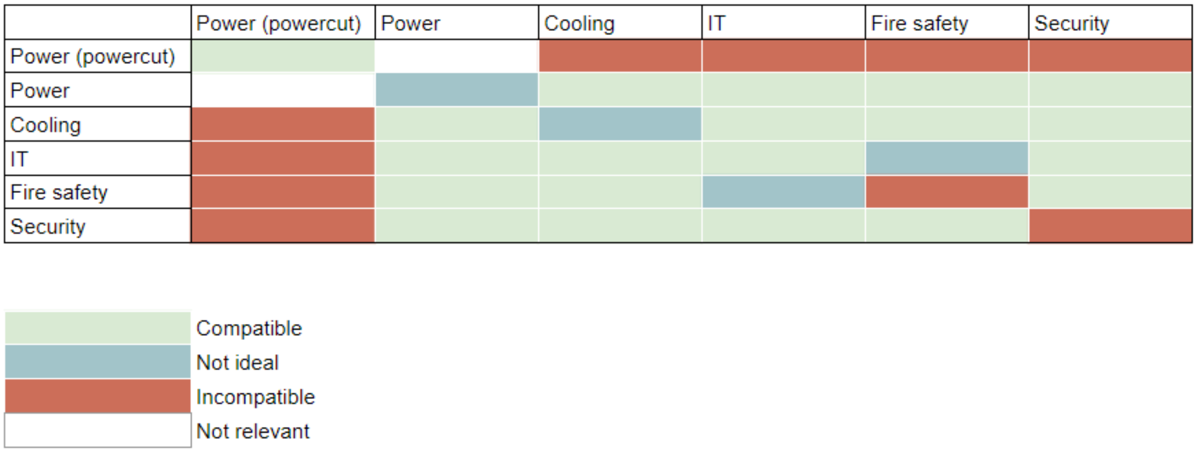
Having more technicians on location at the same time means it is possible for them to help each other out with these types of tasks. This is good from an ergonomic point of view as it is safer to lift parts, and it is also possible to lift parts heavier than 25 kg.

5.2.4. Difference in service requirements

The systems in a data center all vary in their service requirements, fire suppression systems require examination at least once per year according to Technician 4. Other systems such as cooling require service based on the degradation rate of its filters and mechanical components. As such it might be difficult to coordinate the service of multiple systems for a single visit. Another aspect that adds to this is what areas that a technician needs to access in order to perform the maintenance work. If two technicians work in the same area there is a risk this could interfere with their work. Advancements within predictive maintenance is another factor that will have a large influence on when, and how frequently, maintenance is performed for certain systems. This is particularly useful in an Edge Computing scenario as the geographical distribution of data centers will increase the transportation requirements for technicians. With predictive maintenance the visits can be planned to avoid downtime as well as any unneeded visits.

To give an overview of what combination of technicians are suitable to service the MDC simultaneously, a diagram was created. The compatibility of different technicians is based on results from interviews and observations as well as input from Technician 4 (table 5.3). From this diagram we can see what technicians are suitable for simultaneous maintenance work, as indicated by the green colour, and what technicians are not suitable for simultaneous maintenance work, as indicated by the red colour. The yellow colour indicates that the technicians may or may not be compatible depending on the layout of the data center.

Table 5.3. Technician compatibility diagram.



Certain maintenance of power systems requires the power to the data center to be cut, this type of maintenance is not compatible with Cooling and IT service as many of the tasks related to their service requires the systems to be running. For inspection purposes of power systems or service that does not require the power to be cut, IT and Cooling should be compatible.

Depending on the layout of the data center, having several technicians with the same expertise might be problematic or unnecessary, mainly due to spatial restrictions and difficulty in division of tasks. Fire safety as well as security has been deemed not compatible for these reasons, having two technicians on location purely for the sake of the security system would not be efficient, nor beneficial aside from the safety aspect. The exception to this is the area of IT-equipment, this is because it is more common for tasks to include heavy lifting in this field.

5.2.5. Number of technicians on location

Based on the gathered information the decision was to design a data center that allows two technicians to be on location at the same time. This enables taking advantage of the increased safety that follows with being able to assist each other with tasks as well as in the case of an accident. Compared to designing a data center for a larger group the size of the data center can be kept smaller, which will provide a better space efficiency when unmanned. Planning the routine maintenance visits is also simpler with fewer technicians, as it is easier to select a compatible combination of areas of expertise. Due to this decision the Separate concept was discarded as the ability for technicians to assist and communicate with each other would be hindered with such a layout.

5.3. Development for use in the Edge Network

Data centers can be outfitted in many different ways, the size, level of redundancy and cooling efficiency will all depend on the intended use and what the customer values. Whereas many data centers are built according to the demands of customer, a prefabricated data center will have to appeal to several customers with less adaptability than something built from order. The reasoning for the design decisions taken, related to the customer needs, are described in this section.

5.3.1. Capacity and expansion

As edge computing is still rather undefined it is not entirely clear what the customer needs for a prefabricated edge computing data center will be. Depending on its intended application edge computing can require a wide variety of capacity, according to Sverdlik (2017) it ranges from 20 kW to 200 kW, even going as low as 3-6 kW in an office environment. The article also mentions that the rack density ranges from 3-10 kW depending on the application. This capacity range is somewhat in accordance to what was found through the benchmarking of existing solutions, the capacity range of which were 16 kW to 120 kW.

The way in which the customer wishes to use the data center can also vary, some might prefer having several data centers with a lower capacity, able to be located as close to the sources as possible. And some might prefer having a single data center with a higher capacity, perhaps even in the form of colocation.

Expansion is another factor that should be considered, being able to keep up with increasing demands is very important, but due to the uncertainties that surrounds edge computing it is difficult to predict what the expansion rate will be. Fortunately ease of expansion is an innate trait of the prefabricated data center, as it is easy to transport there is always the option to simply replace the data center with a larger one, or to add another one.

The conclusion is that there is still great uncertainty regarding edge computing, and because of this the MDC needs to be scalable in terms of its size to suit as many different purposes as possible. With a size range of 4-20 racks the maximum capacity for each module would be 40-200 kW using a density of 10 kW per rack. Fewer than four racks would likely be an inefficient solution from a spatial point of view, and a maximum capacity of 200 kW most needs for edge computing should be satisfied.

5.3.2. Backup power

Due to data centers high demand for redundancy backup power is needed at most data centers, it is commonly provided by diesel generators that start in the event of a loss of power. For the purpose of edge computing some believe that the need for backup power will decrease, as the redundancy could be built into the network and the software (Donoghue, 2017). But that is more of a future scenario (Traver, 2018), until such a network is established it is likely that backup power will continue to be desirable. As such the decision was made to adapt the MDC to include backup power as a separate module, allowing the MDC to be purchased without backup power should the customer not require it.

5.3.3. Cooling

Data centers can be cooled in a variety of ways, the different methods of doing so all have different advantages and disadvantages. Some systems have a high capital cost and a low operational cost associated with them, and other systems are the other way around. Environmental factors also affect what the ideal method of cooling is, factors such as high or low mean temperature or access to cold water (Evans, 2012). So, depending on the customer's needs the ideal cooling method may vary, because of this the decision was made not to design for a specific method of cooling. The design of the data center should allow different methods to be used.

5.3.4. Upgrading hardware

Server hardware in a data center is generally replaced every two to three years, according to Howell (2013), this is due to used hardware being less reliable than new hardware. New hardware also has the benefits of three more years of technological advancements which will make it easier to keep up with growing demands in the industry.

The Open Compute Project aims at making it easier to replace individual components of the server, allowing it to be adapted to new standards (Circle B, 2018). Whether or not this will be used to its fullest extent in practice is difficult to say. With traditional hardware it is often preferred to replace the entire server if it's an older model, partly due to spare parts being less accessible (Technician 3). But it is possible that this could change with the use of OCP hardware.

Replacing server hardware can be a time-consuming process that includes lifting a lot of servers, so it is beneficial to be able to bring the racks to a location better adapted for upgrade or replacement of hardware. Several ideas, including mounting all the racks onto a movable frame, was discussed. The two methods that were deemed the best could also be considered the simplest. Here follows a quick description of those methods.

Concept: Rolling racks in/out

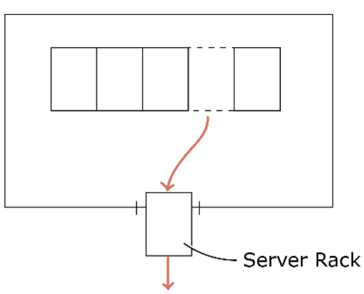
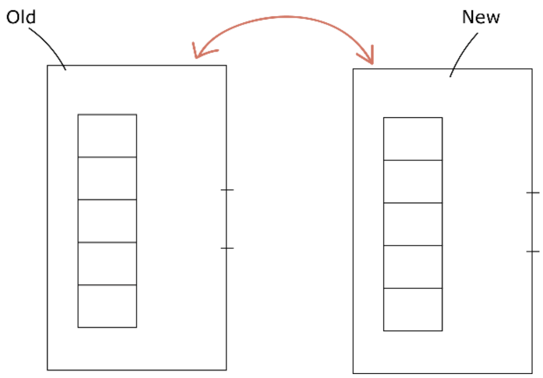


Figure 5.9. Concept for rolling racks in and out of the data center.

By rolling the racks out of the data center they can be transferred to a truck or similar and then taken to another facility (Figure 5.9). And in the same way new racks can be brought to the data center. In this way, a regular truck will be able to both bring new racks and remove old ones in a single go.

Concept: Replacing the entire module



Replacing the entire data center with a new and updated version requires more equipment but can possibly be a faster and more efficient way for certain installations (Figure 5.10). For instance, in high traffic areas or if placed by the railroad.

Figure 5.10. Concept for replacing the entire module.

To allow the entire module to be replaced the data center does not need to be designed any differently, as a core principle of the data center is that it should be transportable. So, designing the data center to allow racks to be rolled in and out of the data center will mean that both methods will work.

5.3.5. Manufacturing and delivery

The benchmark found that the most common way of building prefabricated data centers is by using shipping containers, which has the benefit of already being adapted to transportation. The disadvantage with using shipping containers is the limiting width of 2438 mm and height of 2896 mm (Container Solutions, 2015), and that it entails essentially retrofitting the container. Swedish Modules builds their modules from scratch, this means that they are not limited by the same sizing restrictions as containerised data centers, instead the restricting factor is based on ease of transportation which according to Swedish Modules allows the module to be 4450 mm wide, 4100 mm tall and over 20 meters long. Another benefit of building the module from scratch is that it allows for the size to be adapted to its content and not the other way around.

5.4. Conclusion

The development of the MDC usage resulted in requirements and design decisions regarding how the concept should be used. It consists of design of a use scenario describing the overall use of MDCs for Edge Computing.

> Edge Computing
> The concept should:
> - Be possible to scale between 40-200 kW maximum data capacity
>   - Have a scalable design
> - Allow backup power as an option
> - Be optimised for being unmanned the majority of the time

Since the concept is designed for the purpose of being used for Edge Computing it is scalable in size, to cater different needs for different sites and applications. The concept accommodates 4-20 racks with a total data capacity of 40-200 kW, fulfilling the predicted future needs. However, the size of the MDC is affected by the fact that it will be unmanned most of the time, which means the concept needs to be small to be energy and space efficient. It is developed to be built with standard parts allowing different sized MDCs to be constructed.

The need for backup power in the MDC will be decreased in an Edge Network because redundancy is likely to be built into the network and software. Thus, the concept is designed so that backup power is not included in the MDC design, but as a separate module that can be added to the MDC.

> Technical
> The concept should:
> - Be adaptable to different cooling methods
> - Not exceed the transportation limitations
> - Allow expansion
> - Allow comprehensive hardware upgrade

The cooling system is, like backup power, also a separate part which can be applied to the MDC, to allow different types of cooling methods suitable for different sites and needs.

Maximum dimensions for effective transportation of an MDC are; 4450 mm wide and 4100 mm tall. The dimensions of the concept are therefore kept within these limitations. The design does not focus on allowing physical expansion of MDCs, instead expansion can be done through replacing the MDC with a larger one or by adding another module. This because it is more controlled and probably not as expensive as performing expansion work on site. The design also needs to allow full racks and equipment to be rolled in and out of the data center for comprehensive upgrades.

Service

The concept should:

- Support service of each subsystem
- Support safe and efficient maintenance
- Provide service technicians with sufficient space to perform service on each subsystem
- Allow for service technicians to support each other
- Allow for service technicians to work in the data center without disturbing each other
- Allow for service technicians to support each other with work tasks

The MDC should be designed to allow two technicians to work in the MDC at the same time, this way they are able to support each other, which can make the work more efficient and safe. The combination of technicians working together are defined to not hinder each other's work, but also to be cost efficient. More than two technicians on site at the same time could require the MDC to be bigger to give each technician sufficient working space, which is why a pair of technicians is recommended. To further facilitate safe work the MDC has an open plan, without walls between different subsystem. It makes it easier for technicians to keep track of each other, allowing them to respond quicker in case of an accident. However, each system should have its own zone in the MDC to allow technicians to work without risk of interfering with others.

06
Architecture – Developing the overall design

In this chapter the result from the third development level, the architecture, is presented. This chapter should be read to understand the design decisions taken regarding the layout of the design concept and the choice of technical subsystems used. In the conclusion of this chapter the requirements defined, and the design decisions taken on the architecture level are summarised.

First the technological subsystems included in the data center concept are described as well as why the specific systems were chosen. It is followed by a summary of the benchmark of existing small data centers, describing the main aspects of different existing containerised data centers. The development of the layout for the concept is then presented, including the technological subsystems described in the beginning of this chapter. Finally, the main conclusions from this third part of the development process is presented.

6.1. Technological systems

From literature study within the area of cooling, power, fire suppression and security systems for data centers as well as interviews with experts the design of these systems for the concept have been developed. The result from the literature studies, interviews and development process are presented in this part of the chapter.

6.1.1. Cooling system

The benefit with the modern OCP hardware is that it can operate in higher temperatures compared to traditional hardware, which means energy can be saved by increasing the inlet temperature. Optimal operating temperature for traditional hardware is between 18°-27°C, with maximum allowable temperature at 32°C (ASHRAE, 2011). OCP hardware, however, should operate in 18,3°-29,4° (Park, 2011), with maximum acceptable temperature at 40°C for some hardware (QCT, 2017). This means higher data center temperatures are acceptable with OCP hardware. Since the MDC will be unmanned most of the time it is possible to keep a higher temperature in order to save energy and lower operational costs. The capacity of the cooling increases when the difference between the hot return air and the inlet temperature, referred to as deltaT, increases (Avelar et al., 2014)). According to Zhang et al. (2014) some systems are also able to utilize free cooling, which is a way of using the outside air as a cooling medium, for this to work the temperature inside the data center needs to be higher than the temperature of the outside air. Using free cooling can save a lot of energy, and the running a higher temperature inside the data center can increase the viability of this method.

The humidity around the hardware needs to be kept between 20%-80% according to (ASHRAE, 2011), and Open Compute (2016) recommend the relative humidity to be kept at 65%. This to avoid static discharges which could short-circuit the hardware when a technician interacts with rack or hardware, because of dry air, or equipment being damaged by moisture (ASHRAE, 2011). Depending on the location of the MDC different types of equipment for keeping the desired humidity is required. In very humid areas the air inside the MDC need to be dehydrated, and in very dry areas it need to be humidified. In some locations a system including both a dehydrator and a hydrator might be needed. These systems are preferably integrated into the cooling system.

Cooling method

Defined in chapter 5.3.3 the type of cooling system used for the concept also need to be customisable to be as energy efficient as possible for different locations, depending on the climate and local assets. Several different cooling systems have been studied and compared, but there is no perfect system to use for all possible locations and usages. How the different systems work and what advantages and disadvantages they have is shown in table 6.1. This table can be used as a guide to choose the system to use for a specific use case. However, Direct Fresh Air have been eliminated because of its disadvantages with being used in the type of data center developed. Since the data centers will be unmanned most of the time and data centers will be distributed in remote locations, it is not beneficial to use since it requires frequent maintenance due to the filtration required for bringing outside air into the data center. For an MDC that is placed in a remote location it is more suitable to use a system that uses a closed loop for the air inside the data center. The other systems presented in table 6.1 uses closed air loops and can all be applied to the concept depending on the assets and requirements.

Table 6.1. Cooling systems evaluated. Grey = eliminated

Cooling system	Description	Advantages	Disadvantages
Direct Expansion (DX)	A refrigerant is used to cool down the air, the heat is commonly dissipated through a condenser.	- Low overall cost - Easy to maintain	- Piping need to be installed on site - Refrigerant piping cannot be run long distance
Indirect air	Outside air is blown through heat exchanger and cools the hot inside air which is isolated from the outside.	- Energy efficient - Contamination protected	- Only works when outside temperature is lower than maximum hardware inlet temperature
Chilled water	Cold water (8-15°C) is pumped into a cooling distribution system and heated water returns to be cooled, by a condenser removing the heat with water or air.	- Facilitates reuse of heat - Water pipes can run long distances	- Highest capital cost for data centers under 100 kW
Direct fresh air	Uses outside air to cool the inside and transports heat directly out.	- Energy efficient	- Requires frequent maintenance due to filtration requirements. - Contamination risk - Only works when outside temperature is lower than maximum hardware inlet temperature

(Evans, 2012)

Cooling distribution units

The cooling distribution system, distributing cold air in the MDC, needs to be consistent through the produced MDCs to facilitate service. This so the layout can be coherent through all MDCs with the most ergonomic solution. The studied systems are shown in table 6.2 together with the result from evaluation of how the systems affects the data center concept.

Table 6.2. Cooling distribution systems evaluated, Grey = eliminated

Cooling distribution system	Description	Advantages	Disadvantages
Row cooling	Placed between racks in the rack row, it takes hot air directly from the hot aisle and distributes the cooled air directly into the cold aisle.	- Energy efficient	- Requires back and/or side access - Not possible to roll out if refrigerant is used because of fixed pipes
Raised floor cooling	Cold air is transported under floor and up through perforated tiling in the cold aisle	- Aerially space efficient	- Difficult to make strong enough to be able to roll racks - Tight for air flow required
Above rack cooling	Placed above racks, it takes hot air directly from the hot aisle and distributes the cooled air directly into the cold aisle.	- Space efficient - Energy efficient	- Unergonomic service - Unsafe service - Risk of leaking into racks
Cooling placed against the wall	Integrated or placed against wall, blowing cold air towards cold aisle	- Ergonomic service	- Space inefficient, requiring service space

Since the power density of the concept is quite high, the air flow needs to be high to cool down the hardware. With a raised floor solution, the airflow depends much on the area of all holes in the floor, distributing cold air in the cold aisle. To allow enough airflow, to cool the high-density racks, the floor needs to have more holes, which makes it difficult to get enough strength in the floor for the heavy racks. It also leads to poor working positions for technicians working with parts located under the floor. Thus, a raised floor solution is not optimal for the data center and this cooling solution was eliminated first. However, row cooling and cooling placed above the racks or against the wall are all technically possible to use in the data center. The solution service technicians prefer, according to the survey result (figure 6.1) (appendix 6-7), is cooling placed against the wall since it is the easiest and safest to service. Ten service technicians answered the survey, whereof seven were or had worked as cooling technicians. Since the cooling technicians interacts with the cooling distribution systems frequently it is important that the job can be performed in an ergonomic way, to prevent human injury and fatigue, and to keep the performance and efficiency high (Bohgard, 2010). Therefore, the cooling distribution system used for the concept is a wall mounted cooling system.

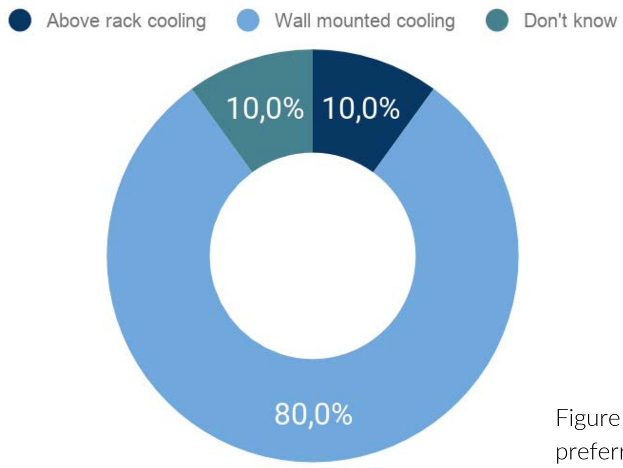


Figure 6.1. Distribution of preferred cooling distribution

Redundancy

To ensure an acceptable climate for the IT hardware there need to be redundancy built into the cooling system. A common way to ensure redundancy in the cooling system is to implement an N+1 level of redundancy. It means one extra unit, than required for the load, is used as a backup (Gonyea, 2014). So, a data center that requires four units for keeping the optimal temperature has five units instead, which allows one unit to fail without the IT hardware being affected. It also allows extensive service of cooling units, without affecting the cooling effect and the inside temperature.

Cooling unit example

A cooling distribution unit, found through benchmarking, which can be placed against a wall and also is energy efficient is a unit from SEE cooling, shown in figure 6.2 (SEE Cooling, n.d.). It is a suitable solution for the size of the concept according to Expert 5. The units allow free cooling with outside air temperatures of up to 15°C and can be used together with different types of cooling systems, allowing the use of the systems described earlier in this chapter. Because of the benefits and the suitability of the cooling units for the data center concept this cooling distribution system have been included in the concept design.

Figure 6.2. SEE cooling unit with three units combined in one housing. (SEE Cooling, n.d.)

The units require a 250 mm distance from walls on the sides and 35 mm from the back of the unit, according to AIA (2018). The distance on the sides is required to make it possible to remove the side parts during service. Service area in front of the unit is also required, however the required distance is not defined by SEE cooling.

Based on discussion with Expert 5, the number of cooling distribution units from SEE cooling required for different data center sizes have been defined. It has, however, not been carefully calculated but assumed built on tests performed with the units by SEE cooling. The number of units recommended for the concept is:

Table 6.3. Amount of cooling distribution units depending on MDC size.

Data center size (racks)	Amount of cooling units
4	3
6	4
8	5
10	6
12	7
14	8
16	9
18	10
20	12

6.1.2. Power

In a small data center the power system consists of a switchboard which provides and controls power to the equipment in the data center. There needs to be at least a 1200 mm safety distance from the front of the switchboard, meaning clear space right out in front of it. This so the power technician can recoil without bumping into anything.

The switchboard and the other systems in the data center are also connected to a Data Center Infrastructure Management (DCIM) (Rouse, 2018), which provides users with information about the performance of the systems in the data center. It can help service technicians to locate problems and analyse status for the systems to perform service or make adjustments. In an MDC it can be a wall mounted device with a display, which also can be connected to a digital platform that can be accessed remotely.

As the Open Rack V2's includes battery backup in the racks, there is no need for a UPS in this data center. An important aspect to keep in mind is that a standard configuration of such a rack will supply only a few minutes of backup power (Lite-On, 2017), which might not be enough time for the servers to perform a graceful shutdown, which can take over 10 minutes in some cases (Cheetham, 2015). This is something that needs to be considered if the data center does not have backup power.

6.1.3. Fire suppression system

The fire suppression system consists of a fire detection system, using a sniffer system, including wall mounted units with batteries and filters, as well as a pipe system in the ceiling of the MDC. The sniffer system pipes need to be spread out across the inside of the MDC, both in the cold and hot aisles, to be able to detect smoke as early as possible. The detection is in turn connected to an alarm system and a fire extinguishing system. The alarm system can release the extinguishing agent as well as alert the fire department and the ones responsible for the MDC.

In data centers it is recommended to use gas as extinguishing agent. This because it does not harm the sensitive and expensive equipment, like other agents would. Usually argon gas is used in data centers, which decreases the oxygen level from 21% to around 12%, enough to put the fire out but still allowing users being present to exit. The gas is not harmful for humans in this low concentration. When a potential fire is detected gas is released through one or more nozzles close to the ceiling connected to a gas canister. The system can be controlled with a wall mounted control panel preferably placed near the entrance. The data center needs to be sealed in order to keep the gas inside during extinguishing so that fire can be put out with certainty.

6.1.4. Security

The equipment stored in a data center is sensitive and expensive and therefore needs to be protected from burglary, theft and sabotage. It is therefore important to have a good level of security, which can be implemented through intrusion protection and monitoring. Constructions fulfilling protection grade and a secure entrance system are common ways for protecting the equipment. The entrance system needs to be designed to not only let authorised people in, but also to register who is entering. This so it can be ensured the correct person is there and to be able to track possible theft or sabotage. It is usually done with an entrance system requiring a personal key card and tag together with a personal code, which also is an applicable solution for the Swedish Modules MDC.

6.2. Existing solutions

Here the result of the benchmarking of existing prefabricated data centers is presented, as the layouts have been analysed to find advantages and disadvantages with different layouts. The data centers studied are all containerised data centers, based on ISO container dimensions, and with traditional IT hardware. This because there were no solutions based on other dimensions or with OCP Open Rack V2 and OCP hardware on the market. Each data center is described below with a 2D plan drawing and a short description of the concept. The plan drawings are based on pictures of the solutions and are thus estimations, the measurements are not exact nor the layouts fully accurate.

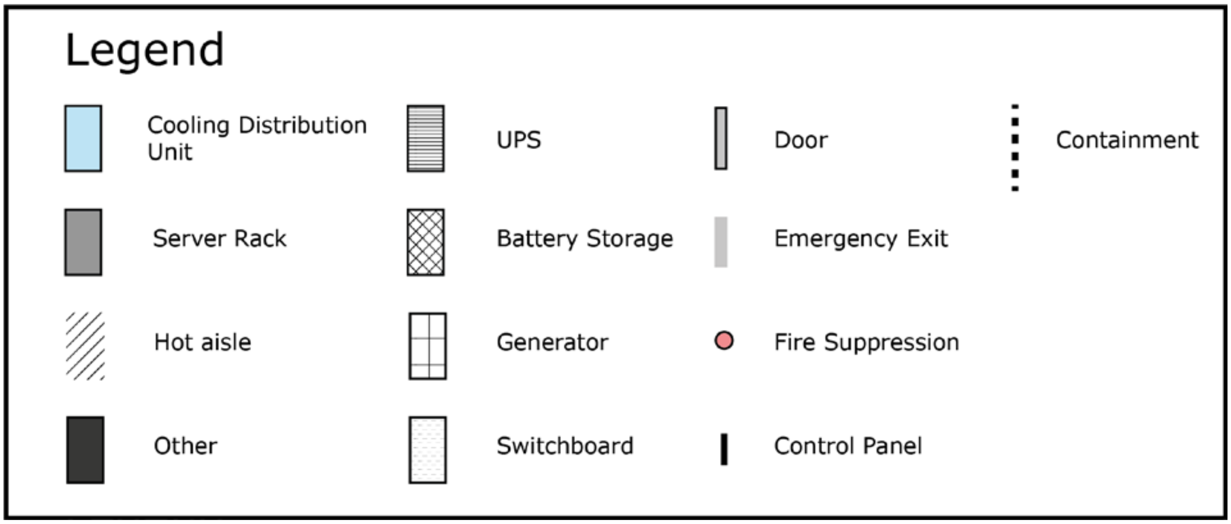


Figure 6.3. Legend for components in figures in this section.

Company 1

This data center contains six racks and has a maximum capacity of 48 kW. It also contains security cameras, fire suppression, hot aisle containment, redundant (N+1) cooling as well as partially redundant power. It does not come equipped with a system for backup power. As for its layout the data center has three different service areas, all accessed through separate doors from the outside. The mid-section of the data center consists of the cold aisle and is also where the distribution panel is accessed. The right and left sections are both hot aisles as well as access points for cooling units and UPSs. In addition to this the right section is also where the fire suppression system is located, along with the extinguishing agent. It also houses the controls for the entire cooling system and the access system.

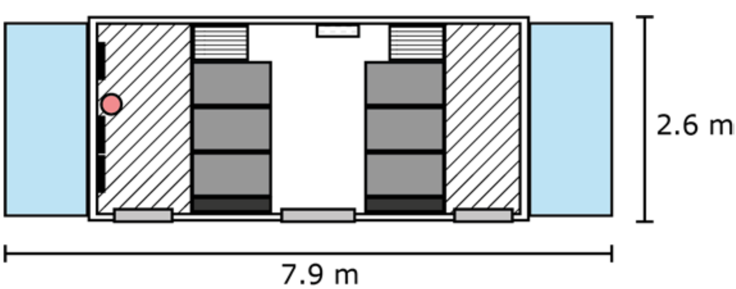


Figure 6.4. Plan of containerised data center from Company 1.

Company 2

This data center contains eight racks and has a maximum capacity of 64kW. It contains security cameras, fire suppression and hot aisle containment. The cooling used is Direct Expansion distributed by in-row cooling. There are two systems each with a 35kW capacity, this means N+1 redundancy is only possible when the cooling is at half capacity or lower, above 35kW the redundancy is lost. The data center comes equipped with a generator, with access to the generator room from inside the data center. The generator means that the data center can survive a power loss for at least 8 hours. The data center has only one entrance, its layout makes it possible to circle the racks through the hot aisle. The data center is designed to be transported as a trailer, and so its dimensions are fairly limited, as a result the hot aisle is quite narrow.

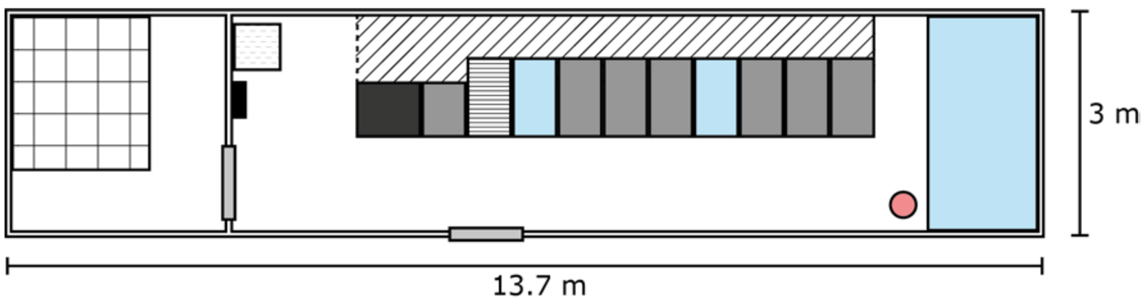


Figure 6.5. Plan of containerised data center from Company 2.

Company 3

This data center contains eight racks and has a maximum capacity of 48 kW. It contains security cameras, fire suppression and hot aisle containment. The cooling used is Direct Expansion distributed by air conditioner units next to the rack rows. There are four DX systems at 20 kW capacity each, giving the data center 3+1 redundancy. The data center does not come equipped with a generator, and it is able to run on batteries for a minimum of seven minutes. The layout of this data center has the racks ordered in such a way that there are multiple cold-aisles as well as hot-aisles, these are accessed through a hallway which also includes two emergency exits. This data center has an antechamber before entering the hallway, the antechamber contains the distribution panel as well as a battery room.

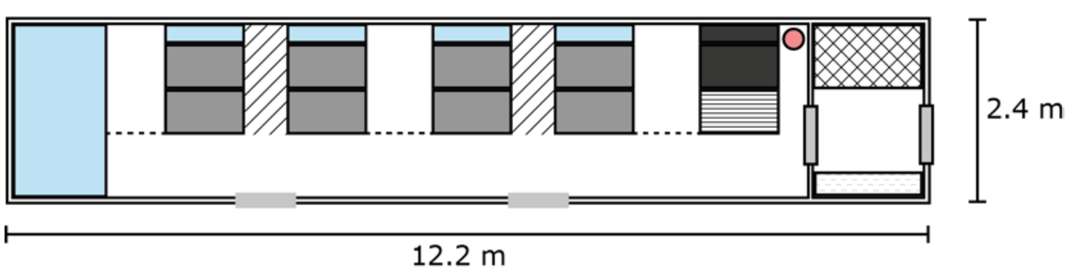


Figure 6.6. Plan of containerised data center from Company 3.

Company 4

This data center is available in four different sizes, ranging from 16 kW to 96 kW, they contain security cameras, fire suppression and hot aisle containment. They use Direct Expansion cooling that is distributed by fan coil units above the racks, the different sizes all have different amounts of distribution units, but all module size have N+1 redundancy. The data centers does not come equipped with a generator. The layout of the data centers vary between the different sizes. Due to limited space availability the two smallest sizes have the fire suppression system inside of the hot aisle containment. The size and location of the UPS system also varies. The two smaller sizes have only one entrance, the larger sizes also have emergency exits. Common for all sizes is the distribution panel and the control panel being placed along the short side of the data center. Another common aspect is the IT-racks being mounted on rails, this allows the rack to be moved to either increase the available space in front of the rack or at the back of the rack.

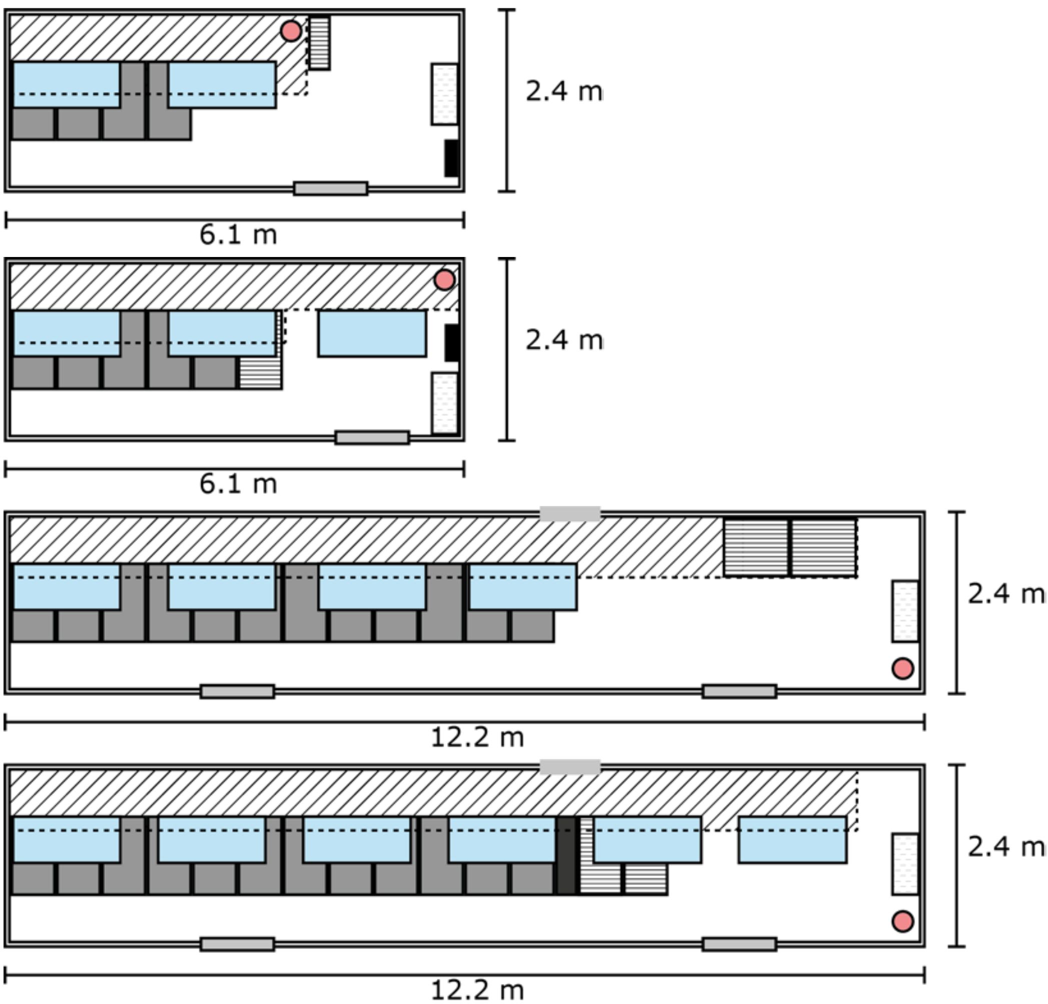


Figure 6.7. Plan of containerised data center variations from Company 4.

The data center layout in figure 6.8 is a variation of the containerised data center from Company 4, it has a maximum capacity of 120 kW and is similar to the two larger sizes of the previously described data center.

The difference between them is that this data center uses in-row cooling instead of fan coil units mounted above the racks. This data center also does not include a UPS, instead it relies on the external power source being UPS protected.

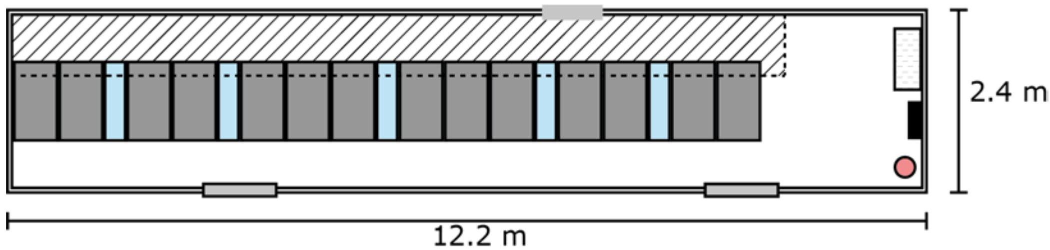


Figure 6.8. Plan of a variation on a containerised data center from Company 4.

6.3. Concept layout

This part of the chapter presents the findings from interviews, benchmarking, ideation and evaluation. It further describes the design decisions made regarding the layout of the concept.

6.3.1. Transportation limitations

To be able to transport an MDC with a truck on the roads in EU without escort, which is costly, the outer measurements of the module need to be maximum 4450 mm wide, 4100 mm tall and 25000 mm long. So, the solution needs to be kept within that frame for practical and economic reasons. The maximum width is a benefit for Swedish Modules compared to existing solutions based on ISO containers, which are 2438 mm wide and 2896 mm tall, since it can allow two rack rows to fit inside the MDC instead of only one. It means twice the amount of racks can fit into the same row length, which is space efficient since the two rows can share a common cold aisle. This is inconvenient with traditional IT hardware since it requires service from both the cold and hot aisle, but with OCP hardware hot aisle access is not needed.

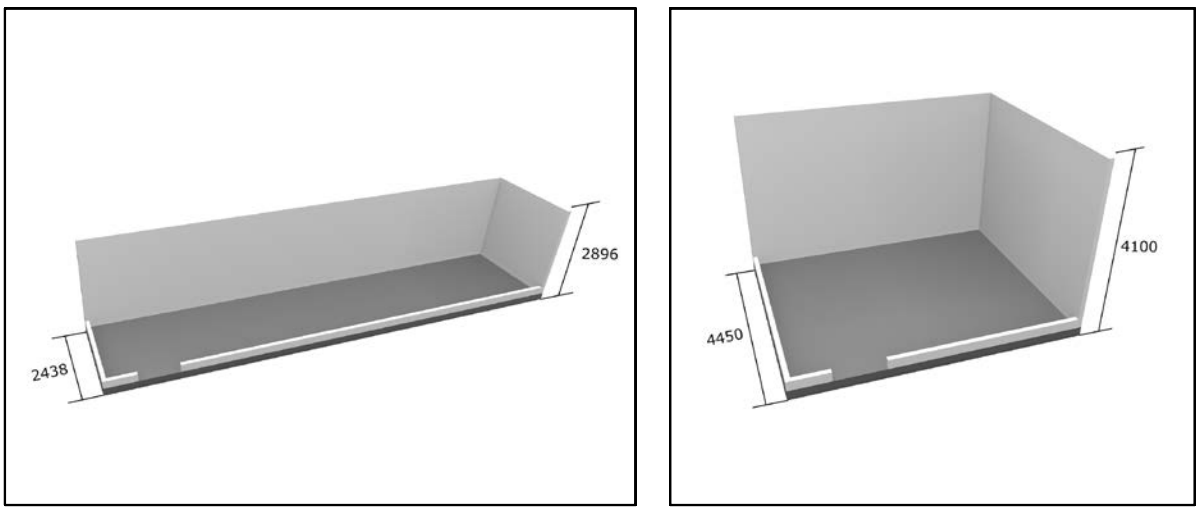


Figure 6.9. Comparison between standard container and Swedish Modules width and height limitations. Container to the left and module to the right.

6.3.2. Rack and overall layout

With two rack rows the solution can simply scale with two server racks at a time, making the rows longer (figure 6.10). By keeping the overall layout the same through different sizes, by only extending the rack rows, the concept facilitates recognition which can decrease the mental load. The layout therefore needs to be kept as constant as possible to make it easy for technicians to find the subsystems through recognition. Thus, in the concept the layout has been designed to have the power, fire suppression and security system on the same side beside the rack rows. The systems are constant in size through different sized data centers apart from the fire extinguishing container which needs to be scaled up for bigger data centers. The coherence also facilitates manufacturing and phone support during service, since it is easier to guide a technician when the layout is the same for all data centers.

How the overall layout of the data center is designed depends a lot on how the server racks are placed. The hot and cold side of the IT hardware need to be separated for efficient cooling. It also needs to be easy for the IT technicians to access everything necessary for maintenance, which means they need to have full access to the front of the racks from the cold aisle. There needs to be sufficient space in the cold aisle to be able to swap up to 800 mm deep hardware components, to suit hardware maintenance. It also needs to be possible to roll out IT racks, which are 1067 mm deep using racks from Delta as an example, from the rows for comprehensive upgrades. Therefore, the shared cold aisle has been given a width of 1200 mm to allow racks being rolled in and out, with margin for manoeuvring without bumping into the rack rows. Preferably the racks used in the data center are shallower than the example racks from Delta, to further support the manoeuvring.

The hot aisles only need to be deep enough to allow the air exhausted from the IT hardware to flow, without being reflected back onto the hardware. With 100 mm thick walls, which is the thickness on Swedish Modules walls with protection grade 2, the hot aisles can be maximum 450 mm without exceeding the maximum transportation width. According to Expert 4 a 500 mm deep hot aisle is acceptable and from consultation with Expert 5 it should also be possible to have 450 mm deep hot aisles as suggested. Assuming that this depth is feasible, by allowing the hot air to expand between an inner and outer ceiling, the concept needs to have two contained hot aisles connected to the return air plenum between the ceilings. This return air plenum need to be 500-700 mm deep, according to Expert 5, however, it is something that needs to be calculated or tested for confirmation.

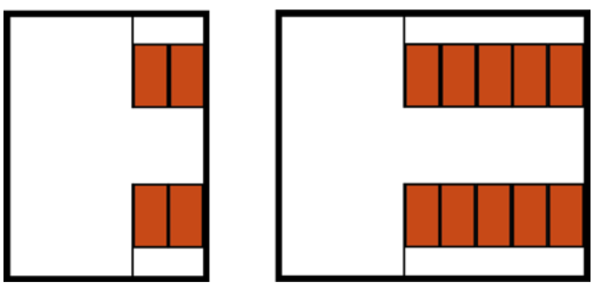


Figure 6.10. Rack placement exemplified in two MDC sizes.

6.3.3. Main entrance

The placement of the main entrance affects the layout of all subsystems to a great extent. Two different ideas of door placement were developed and evaluated, one with the main entrance on the short side of the data center and one on the long side beside the rack row.

Concept: Short side

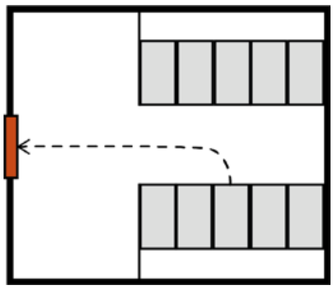


Figure 6.11. Door on the short side of the data center.

Having the entrance door on the short side of the data center facilitates rolling in and out racks as the door is in line with the cold aisle (Figure 6.11). The disadvantage with this layout is that it is not possible to use the wall on the short end for placing systems like cooling units.

Concept: Long side

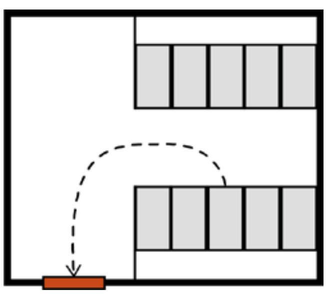


Figure 6.12. Door on the long side of the data center.

Placing the door by the racks instead gives the possibility to have cooling units or other systems placed by the wall on the short side of the data center (Figure 6.12). However, it is not as simple to roll racks in and out of the data center since it requires one turn.

To allow cooling distribution units to be placed on both sides of the rack rows, which is required for bigger data centers, the door needs to be on the long side, beside the racks. This placement is also supported by that racks are rarely being rolled in and out, since it only is required for comprehensive upgrades. Thus, the layout should not be based on that only benefit.

The door needs to be wide and tall enough to allow tools and other equipment to be moved in and out of the data center. Racks are the bulkiest equipment that is moved in and out. Since they are minimum of 2200 mm tall with castors, the door opening needs to be 2400 mm tall to allow for any variation, according to guidelines from the Open Compute Project (2018b). The same guidelines recommend pathways and lift doors to be at least 1200 mm wide for the same purpose, this width is based on the standard width of commonly used access floor tiles, which are 600x600 mm. The racks themselves are just 600 mm wide however, and so for the width of the door opening it was decided that 1200 mm was not required, and that 1000 mm should likely be sufficient.

6.3.4. Cooling unit placement

When using cooling distribution units from SEE cooling placed against a wall (cooling), the cooling units need to be positioned so that cold air can be blown into the cold aisle, with at least 250 mm free space on each short side and 35 mm distance to the wall AIA (2018). With two rows of racks there are only two directions the cooling distribution units can blow the cold air; from either of the short sides. To keep service of the cooling units efficient they need to be placed so they are easy to reach and with sufficient working space. Thus, a 1200 mm working space in front of the units are desirable and used for the concept layout. To the extent possible the units are therefore also placed on one side of the cold aisle. This was evaluated in two iterations with the layouts described below.

Concept: Opposite side

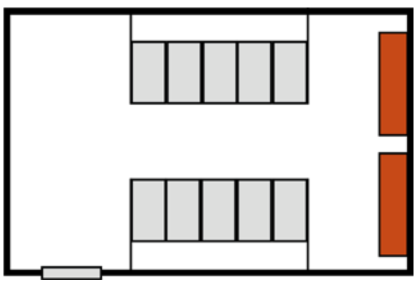


Figure 6.13. Cooling units on the opposite side of the data center. In relation to the other systems.

The first idea tested was having cooling units on the opposite side of the rack rows from the other systems for the data centers (Figure 6.13). This makes it possible to keep the units close to the cold aisle and not interfering with the other systems in the data center. The main drawback, however, is that it requires additional working space in front of the cooling distribution units which makes the data center longer.

Concept: Same side

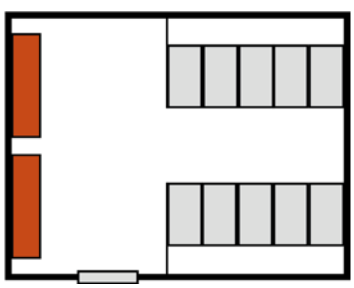


Figure 6.14. Cooling units on the same side as the other systems in the data center.

Placing the cooling units on the same side as the other systems only requires additional space for the units which are 470mm deep (Figure 6.14), because there already is working space in front of the units on this side. Though, the distance to the cold aisle is bigger for this solution which might be less energy efficient.

After discussing the first idea, with the cooling units on the opposite side from the other systems with Expert 5, it could be concluded that there will not be any significant difference in energy efficiency if the units are placed further away from the cold aisle. Thus, the second idea was developed and evaluated against the first idea through the pros and cons method. Since this idea is much more space efficient, which mainly is important for smaller data centers and for the secondary users (Chapter 4.2), it was chosen for the final concept.

For bigger data centers, with 12-20 racks (Figure 6.15), there needs to be more cooling units than can fit on one wall, and therefore it also should be units on the other side of the cold aisle. The front of the cooling needs to be accessible for service, and therefore a working space between the rack rows and the cooling distribution system is required. This space also should be deep enough to support the airflow from cooling units into the cold aisle, which according to Expert 5 is 1200 mm. Therefore, the working space is 1200 mm in the concept layout for data centers with 12-20 racks.

In the service space an emergency exit can also be incorporated, which is important for the technicians' safety as, otherwise, the cold aisle would be the only way out. As an emergency exit should be at least 800 mm wide and the emergency route at least 900 mm wide (Boverket, 2006), the layout does not need to change to incorporate the door.

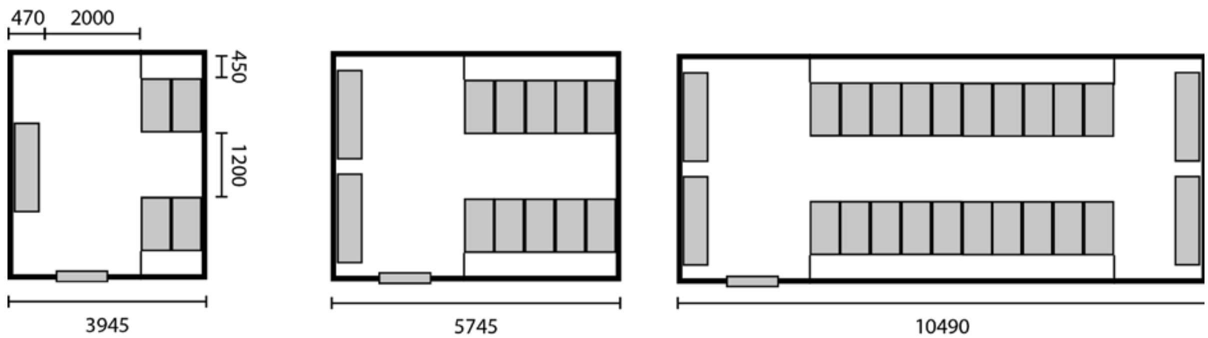
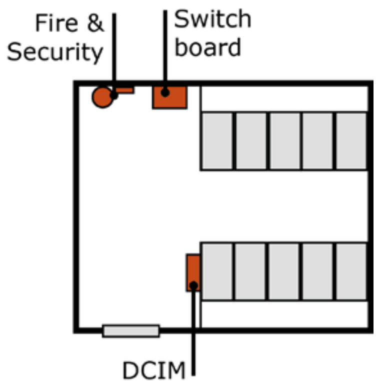


Figure 6.15. Three sizes of MDCs with the concept design; 4, 10 and 20 racks.

6.3.5. Placement of other systems

With the placement of the door beside the racks, two ideas on placement of the rest of the system was formed and evaluated with support from the survey and discussion with Swedish Modules. The sizes of the systems are assumed in order to specify their placement, the sizes are based on benchmarking however no exact systems is specified for the concept. The measurements used for the switchboard are 400, 600, 2100 mm (D, W, H), and the measurements used for the DCIM are 250, 650, 850 mm (D, W, H), this measurement is likely larger than necessary. The measurements for the extinguishing agent is based on a tube diameter of 230 mm and the different panels use varying measurements based on rough estimations from benchmarking.

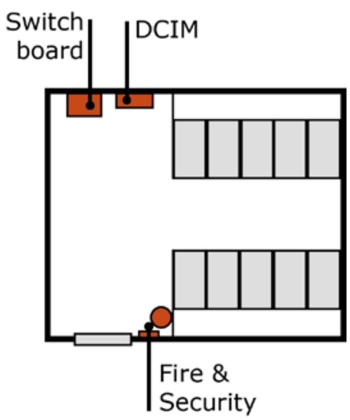
Concept: Alternative 1



The first alternative of system placement was to have the DCIM by the entrance (Figure 6.16), to make it easy to access by any technician. The switchboard, fire and security system are placed together against the opposite wall from the entrance.

Figure 6.16. Alternative 1 for placement of systems.

Concept: Alternative 2



The second idea was to have fire and security placed by the entrance instead (Figure 6.17), making these systems easy to access in case of an alarm. Switchboard and DCIM are placed together on the opposite side.

Figure 6.17. Alternative 2 for placement of systems.

Both service technicians and Swedish Modules preferred the second alternative, because it is perceived as more logical to have the switchboard and DCIM grouped and to have the fire suppression and security system close to the entrance. Thus, for the concept the systems are placed like this to facilitate the maintenance.

6.3.6. Cabling

All cables connected to IT hardware runs from the front of the racks, along the inner sides and usually up in cable ladders (figure 6.18) above the racks. Copper cables need to be separated from power cords because the power cords generate electromagnetic fields, which affects the performance of the cables (FS blog, 2014). In that case two cable ladders can be placed above each other. Having two cable ladders requires at least 500 mm, and preferably 700 mm, space between the top of the racks to the inner ceiling, according to Expert 5. This is to support cable service and installation and to ensure the different cables will not interfere. However, Swedish Modules believes using one cable ladder is sufficient in this type of data center module, as it is likely to use fiber rather than copper cables. The performance of fiber is not affected by the electromagnetic field and can therefore be placed on the same cable ladder as the power cords. Assuming only fiber cables are used in the MDC, only one cable ladder is in the concept.

Since OCP Open Rack V2 is fed by AC power the power cords are light enough to be placed on the same cable ladder as the fiber cables, without damaging the ladder or the cables. It also supports having only one cable ladder in the MDC. With one cable ladder instead of two the total height of the MDC can be lower. The ladder runs from the switchboard and DCIM to the racks and cooling distribution units. In the cold aisle it is placed above the rack rows near the front of the rack, making it easy for service technicians to access.

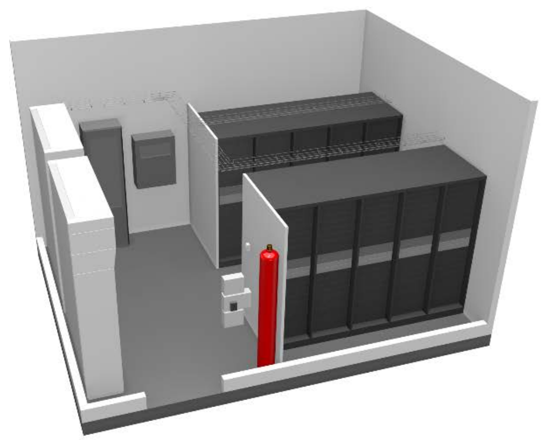


Figure 6.18. Cable ladders in the MDC.

6.3.7. Hot air containment

The hot outlet air from the IT hardware needs to be separated from the cold inlet air. This to keep the cooling energy efficient and to shield the technicians from the heat. The containment for the concept has been based on these factors as well as how the cooling distribution units works. Thus, the containment separates the hot aisles from the rest of the MDC, keeping the entire work area at the inlet temperature. The containment leads the hot air to a plenum that allows the air to expand and be transported to the cooling units. The hot air plenum needs to have a 700 mm height according to Expert 5, and the inner ceiling needs to have a 500 mm distance from the top of the racks to support cabling as well as to provide sufficient airflow to the cold aisle.

To support the required airflow from cooling distribution units into the cold aisle the inner walls need to have as large opening as possible. The containment walls to the cold aisle in the concept are therefore T-shaped, allowing air to flow between and above the rack rows (figure 6.19).

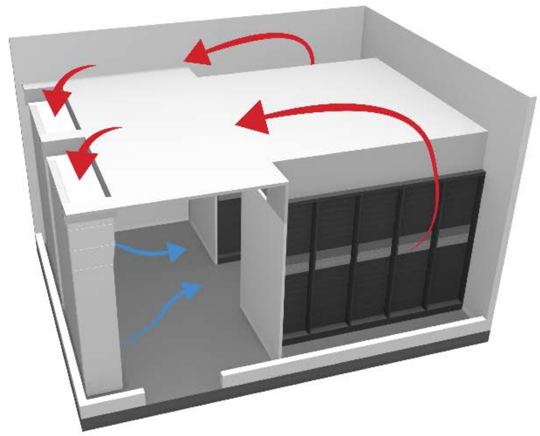


Figure 6.19. Hot air containment.

6.3.8. Backup power module

The generator needs to be in a separate module that can be connected to the MDCs, which is described in chapter 5.3.2. It is connected to the switchboard and therefore preferably placed close to it without requiring the overall layout to change. Different ideas for placing a generator room were evaluated. The most space efficient, transportable and logical solution was placing the backup power on the short end of the MDC (figure 6.20.). It is placed on the side closest to the main entrance to be close to the switchboard which the generator is connected to, but also to be close to the main entrance. The module has its own entrance to avoid oil and glycol needed for the generator to contaminating other parts of the MDC. Since the door to the generator room is still close to the MDC entrance the distance the service technicians need to go between the two rooms is short, and thus the work can still be done efficiently.

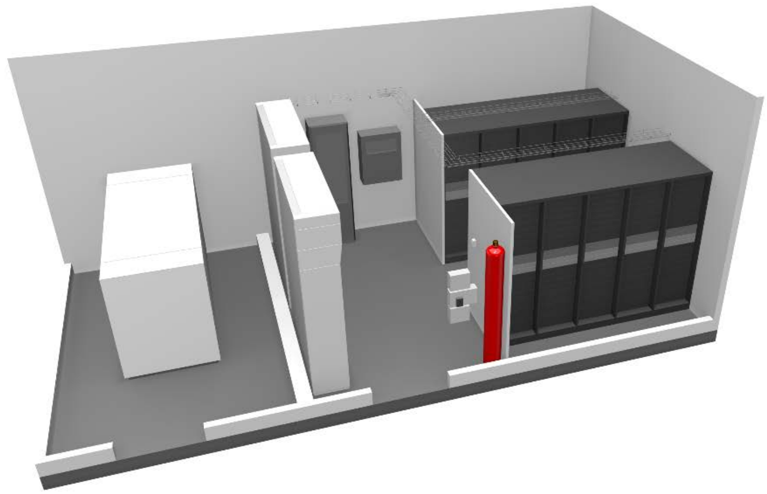


Figure 6.20. Generator room applied to the MDC.

6.4. Conclusion

From the architecture level of the development process technical requirements for the data center and its layout have been defined and fulfilled with design decisions. The result is an overall design describing the layout and functionality of the technical components of the concept.

Overall layout
The concept should:
- Include;
    - IT racks with IT hardware
    - Cooling system
    - Switchboard
    - DCIM
    - Fire suppression system
    - Security system
- Be maximum 4450 mm wide and 4100 mm tall
- Be space efficient

The requirements are fulfilled by the concept including all required subsystems with a layout with two rack rows and a shared cold aisle. It has a coherent layout through different sizes of the data center. The data center scales in length by adding racks and cooling units as well as fire extinguishing container, but with persistent placement and more or less constant sizes of the other systems.

Since OCP hardware only requires service access from the cold aisle, the contained hot aisles in the concept are 450 mm wide, which allows the width of the whole data center to be 4450 mm. This makes the concept space efficient together with a well thought out overall layout.

- Prevent contamination of interior
    - Have backup power separated from IT hardware

To prevent contamination of the data center the backup power module is a separate generator room that can be placed on the short side of the data center. It has a separate entrance to reduce the risk of contaminating the data center.

- Allow users to enter and move around with required equipment
    - Have a 1200 mm wide cold aisle to allow rolling out racks
    - Have an open plan
    - Allow authorised people to enter hassle-free
    - Have a minimum 910 mm wide and 2400 mm tall door opening
- Support safe service
    - Have at least 1200 mm clear distance in front of switchboard
    - Have sufficient space for service tasks
- Support efficient service
    - Have coherent layout for different sized solutions
    - Provide users with a logical workflow
- Support ergonomic service
    - Have easy to reach interaction areas

With placement of the main entrance on the long side of the MDC, having the rack rows to the right when entering, gives a logical overall workflow. Switchboard and DCIM are placed together at the wall facing the main entrance and the fire safety system is placed by the door. This to provide technicians with sufficient space to perform their work tasks, without interfering with each other.

Power

The concept should:

- Provide each OCP Open Rack V2 server rack with sufficient power
- Support graceful shutdown if not connected to backup power

Through the switchboard the racks are provided with sufficient power. All systems are also connected to, monitored and managed with a DCIM. No UPS is needed since its function is built into the racks, providing the hardware with uninterruptible power and a few minutes battery backup. The battery backup should be dimensioned for graceful shutdown if the MDC is not connected to a generator. This to prevent loss of data.

Cooling

The concept should:

- Keep acceptable operating climate for the hardware
  - Keep the IT-hardware cooled from the front
  - Have contained hot aisles allowing hot air to be transported away from racks
  - Keep the inlet temperature at a maximum of 40°C
    - Keep the inlet temperature between 18,3°-29,4°C
  - Keep the humidity between 20%-80%
    - Keep the humidity at 65%
  - Have N+1 cooling redundancy
  - Have cooling distribution units blowing cold air into the cold aisle

The concept allows different types of cooling systems to be incorporated in order to fit the climate and assets of different locations; DX cooling, indirect air cooling and water cooling. However, the cooling distribution system inside of the MDC is the same in all solutions to keep the layout coherent through different sizes and ensure safe and efficient service. The system used in the concept is cooling units from SEE cooling placed against the walls, which are simple and ergonomic to service. For sizes up to 10 racks cooling units are required on one side of the cold aisle, but bigger MDCs has units at both ends.

Fire suppression

The concept should:

- Be protected and safe in case of emergency
  - Have a fire detection system covering the whole data center
  - Alarm both locally and externally in case of fire
  - Have a fire extinguishing system dimensioned for the volume of the data center
  - Use extinguishing agent that does not damage technological equipment or technicians
  - Be sealed to keep required concentration of extinguishing gas in case of fire
- Include an emergency exit in data centers larger than 10 racks
  - Have a minimum 900 mm wide emergency path
  - Have a minimum 800 mm wide emergency exit

The fire suppression system in the data center consists of a detection system, connected to alarms and an extinguishing system with argon gas as extinguishing agent. In the concept design data centers with more than six racks has an emergency exit on the opposite side of the cold aisle from the main entrance, to support safe exit in case of fire.

Security system

The concept should:

- Prevent unauthorised people to enter
    - Include security cameras
    - Include a secure entrance system with individual control

The concept is equipped with a security system including security cameras and an entrance system requiring an individual code together with a personal key card. This to ensure the correct people are entering the facility.

07
Interaction – Design for the user interaction

In this chapter the results of the final phase of the development, the interaction level, is presented. To learn what design decisions have been taken regarding the detailed design of the MDC this chapter should be read. Solutions to improve and support interaction between technician and MDC were developed and are presented in this chapter, first with focus on working environment. It is followed by ergonomic solutions before the conclusion, where requirements defined on the interaction level are presented and the details of the concept described.

7.1. Work environment

Aside from the layout of the data center there are several other factors that will have an impact on the performance of the people working there. Based on literature findings and discussion with Swedish Modules the result of this section will serve as recommendations for the data center to facilitate the interactions.

7.1.1. Lighting

According to (CCOHS, 2013) Having good lighting in the workplace is important for the quality of work as well as the health of the user. Poor lighting can cause misjudgement of an object's shape or position which could be a potential safety hazard, poor lighting also negatively influences precision tasks. Too much or too little light will also cause eye-strain which can lead to headaches.

The correct amount of light needed depends on the type of work performed. The work performed in a data center varies depending on the field of the technician, but there are no major differences in lighting requirements as few if any precision tasks are performed in the data center itself. Available recommendations for similar work environments falls in the 300-500 lux range (Gianniris, 2011; Standards Informant, n.d.; Bångens, 2008), similar to office environments. 500 Lux is also what MSB (2013) recommends as the average illumination level for data centers. Based on this data the decision was made that the final concept should have an illumination level of 500 Lux.

7.1.2. Emergency lighting

In facilities that lack access to natural light it is very important to have emergency lighting if the ordinary lighting fails (Boverket, 2006). The emergency lighting should fulfil the appropriate standards of the country, such as SS-EN 1838 standard for Sweden.

It is also a good idea to include an emergency torch in the data center, emergency torches light up if power to the data center is lost, the torch gives anyone in the data center a greater flexibility in terms of lighting both inside and outside of the data center. This type of system was recommended by Technician 5 to be included in an MDC.

7.1.3. Service outlets

A data center needs to have a service outlet that makes it possible to use electric equipment like for example vacuum cleaners (MSB, 2013). Service outlets should be easily accessible by technicians and should be placed in such a way that the cord of the equipment does not risk interfering with another technician or system. Two variations of possible placement have been developed which could be implemented to the MDCs.

Concept: Containment wall

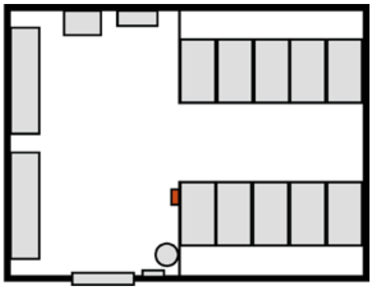


Figure 7.1. Service outlet placement on the containment wall.

Having the service outlets on the containment wall on the side of the rack row (Figure 7.1), makes it easy to find and reach by any technician. It is placed so that cords will not interfere with any equipment in the MDC. The roll able and foldable table can also with advantage be placed by the outtake, giving the technician a working space for their laptop. However, it is important to place the outlet so it does not interfere with the table and work trestle which could be placed against the same wall.

Concept: Beside entrance

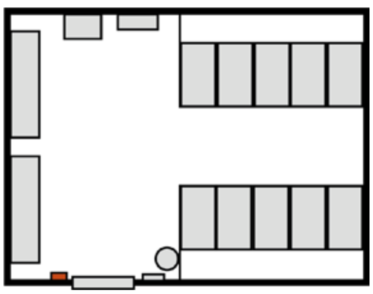


Figure 7.2. Service outlet placement to the side of the entrance

Outlets can also be placed beside the main entrance door (Figure 7.2), where it is accessible for all technicians and easy to find. With this placement, cords could, however be in the way for technicians entering and exiting the MDC.

7.1.4. Contamination prevention

To reduce the amount of dust that enters the data center there are several different methods that are commonly used. Perhaps the most common method is the contamination control mat which is a sticky mat that removes dirt from the soles of shoes, they are usually placed just inside the door. Contamination control mats are available in many different sizes and are easily "cleaned" by peeling of sheets, each mat usually consists of 30-60 sheets. A contamination control mat will last for 3-5 years (Dycem, 2018b).

To prevent airborne contamination, it is common to have an overpressure in the data center, this prevents dust from getting in through any openings and reduces contamination caused by opening doors.

For an edge computing MDC there are two main things that sets it apart from a regular data center, the possibility of the entrance going directly between the data center and outside, and that the number of visits will be lower. Due to the lower number of visits, the limited amount of space available and the fact that the majority of dust is brought in on the soles of feet (Dycem, 2018b), the use of a contamination control mat was deemed to be sufficient.

To reduce the amount of contamination related to opening the door of the data center using a segmented door could be viable solution. The door opening has to be 2400 mm high to allow for racks to fit through, but it is not necessary this height is not necessary for when no large equipment is transported in or out. Separating the top 300 mm of the door from the bottom part would reduce the size of the door opening for regular use (Figure 7.3).

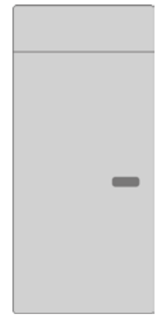


Figure 7.3. Segmented door.

7.1.5. Climate

The temperature in a data center is typically adjusted to be as energy efficient as possible whilst still staying within a range specified for the hardware. The allowable temperature range for server hardware has increased over the years, in 2004 ASHRAE's recommended interval was 20-25°C, their current recommended interval is 18-27°C, and their allowable interval is 15-32°C (ASHRAE, 2011). According to specifications of OCP servers on the solution providers websites, the servers should be okay to run at 35°C (Penguin Computing, 2018) or even 40°C (QCT, 2017). There appears to be a trend of servers being able to handle higher and higher temperatures, which is very good from an energy efficiency point of view. Increasing the temperature difference between inside the data center and outside allows for a higher percentage of free cooling or fresh air cooling. The negative aspect of having higher temperatures inside the data center is that it reduces the thermal comfort of any person in the data center. Working in warm conditions will affect performance as the pace and alertness will decrease, it also negatively affects physical and mental capacity which increases the likelihood of errors and accidents (Bohgard et al., 2010).

As the MDC will be unmanned for the majority of the time it would be wasteful not to take advantage of the higher heat tolerance of the OCP hardware, however even though the maintenance visits from service technicians are temporary for each data center, the technician will likely visit several identical data centers and collectively spend a lot of time in that environment. For this reason, being able to adjust the temperature in preparation for maintenance visits seems like a viable solution, according to ASHRAE (2011) the allowable temperature rate of change for server hardware is 20°C/h, and given that the majority of visitations will be planned it should be possible to adjust the temperature in the data center to a degree comfortable for the technicians. The optimal temperature for the work performed in the data center will need further investigation to determine, but based on recommendations from Arbetsmiljöverket (2013) and Bohgard et al. (2010) the temperature should be somewhere in the range of 20-26°C.

The negative aspect of reducing the temperature for the sake of maintenance is that the cooling system will need to be dimensioned to allow for lower than operating temperatures. This could potentially be combined with a higher redundancy for cooling during the time the data center is unmanned.

7.2. Ergonomic support

Work tasks in a data center can be both physically and mentally demanding. Therefore, it is important that the concept supports the service technicians ergonomically. Ergonomic support prevents errors from occurring and can make the system perform better. The findings presented in this part of the chapter comes from benchmarking on existing solutions, literature, ideation and evaluation, based on results from interviews with technicians and a survey.

7.2.1. Reaching

Some of the service tasks performed in a data center requires the technicians to reach components placed high up. For instance, IT hardware, which is placed in the 2200 mm tall racks and cables that usually are placed above the racks. Work performed with arms above the shoulders is unergonomic and unsafe. Therefore, technicians need support to be able to perform these tasks in a safe and comfortable way. Different aids for supporting the tasks was identified through benchmarking and evaluated through the survey answered by 10 service technicians with different competences and areas of work.

The aids evaluated were a ladder, a work trestle and a kick-step (table 7.1). The ladder described in the survey has a few steps on one side and a handle at the top, unlike the work trestle which has steps on both sides and no handle. A work trestle also has a wide and deep platform at the top step. Results shows that benefits with the ladder are that it is possible to reach higher up with it and it allows the user to support themselves by holding onto it. However, it is not as stable as a work trestle, which also allows two technicians to use the aid at the same time to support each other for certain tasks. The work trestle is also easier to carry than a ladder, since it is often shorter. A kick-step is also easy to move, by kicking or pushing it, and it takes up little space when used, however, it requires more floor space than a ladder and a work trestle when not used. That is because both a ladder and a work trestle can be folded to take up less space and be placed or mounted against a wall.

Table 7.1. Aids to support reaching.

Aid	Description	Advantages	Disadvantages
Ladder	Foldable aid with a few steps and a handle 	- Safe - Stable - Allows reaching high	- Takes up much floor space when used
Work trestle	Foldable aid with a few steps on both sides and a top platform 	- Stable - Easy to carry - Can be used by to technicians simultaneously - Can reach from both sides	- Does not allow reaching very high
Kick-step	Roll able cone shaped aid with two steps 	- Does not take up much floor space when used - Easy to move - Allows sitting	- Takes up much floor space when not used

According to the survey results five out of ten technicians prefer the work trestle, three prefers the ladder and two the kick-step (figure 7.4). This because it is perceived as the most portable and flexible aid and it allows two technicians to support each other. The survey result also indicated that the trestle should be sufficient for most work tasks in the data center (appendix 7). The maximum height of a work trestle is 1250 mm according to Arbetsmiljöverket (2014), which should be enough to reach both cable ladders and IT hardware.

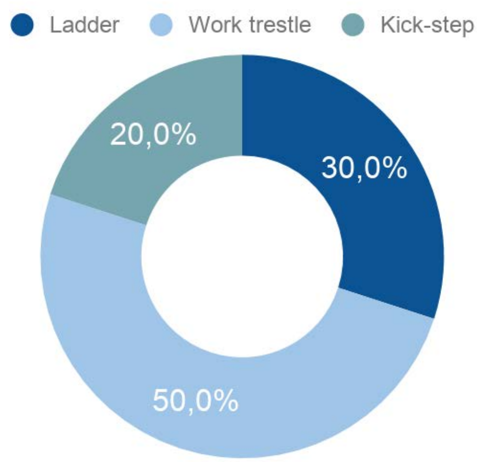


Figure 7.4. Distribution of answers regarding reaching aid.

7.2.2. Lifting

Some IT equipment can weigh over 50 kg (Wiwynn, 2017a), which is too heavy for two technicians to lift safely by hand (Arbetsmiljöverket, 2012). A tool that can be used to support the lifting and transportation of heavy IT components is a server lift. It can reach and hold IT equipment at different heights in the racks and can be rolled in and out of the MDC. However, heavy components do not often need to be moved out of the IT racks. Therefore, it is not viable to include equipment for these tasks in each MDC. The solution is instead that the technicians bring a server lift in the service vehicle to the assignments which requires lifting of heavy components. Alternatively, the entire racks could be brought to a facility outfitted with the required equipment.

7.2.3. Upgrading

Replacing server hardware can be a time-consuming process that includes lifting many servers. There are, however, tools available to help with reducing physical strain when removing and mounting hardware in racks. The tools available for this purpose are often quite large, even whilst stored. And for this reason, these tools are not ideal for MDCs, and their size also makes it difficult for technicians to bring them to the location.

Server racks are roll able and can be rolled out filled with equipment. It can weigh up to 1500 kg and therefore needs to be done by two or more technicians. The floor also needs to be as flat as possible to allow the racks to be rolled smoothly. Thresholds, therefore, need to be covered with a flat plate so the wheels do not get stuck. It is also important to minimize the height difference between the floor of the data center and the surrounding areas, any height difference should be bridged by a ramp at a maximum gradient of 1:12 (Open Compute Project, 2018b).

7.2.4. Offloading

Technicians often bring spare parts and tools to the data center for their work tasks, but usually do not have a dedicated place for offloading. From the survey it was found that different types of service technicians all need some kind of offloading for their laptop, hand tools or spare parts such as cooling filters and fans. Different ideas for how the offloading can be solved was developed through ideation and then evaluated and compared. The four ideas not eliminated in the early phase are described in table 7.2 below.

Table 7.2. Offloading ideas with result from evaluation.

Idea	Advantages	Disadvantages
Carriage	Flexible, can be used anywhere in the data center and by any technician	Space inefficient
Foldable separate table	Space efficient when not in use Flexible	Difficult to move Requires folding and unfolding
Foldable wall mounted table	Space efficient when not in use	Inflexible Requires folding and unfolding
Wall mounted hooks	Easy to access and use Space efficient	Inflexible Limited to objects that can hang

Because of the variety of work tasks performed in a data center and the small size of the MDC concept, fixed tables are not as useful as more flexible solutions. This is because different technicians performing different tasks need the offloading possibility in different areas of the MDC. Having fixed solutions for each service area would take up much space, even with foldable fixed solutions since it requires wall space and floor space when folded out.

The most flexible solution, the carriage, was therefore combined with the space efficient, but still rather flexible solution, the foldable separate table (figure 7.5). It allows technicians to use the offloading aid anywhere in the MDC, without it taking up much space when not used. Through benchmarking existing solutions were found that can be applied to the MDC solution.

Figure 7.5. Example of a roll able and foldable table (Carlisle, 2018).

The foldable and roll able table can be placed against or hung on a hook on a wall. When folded the example table is as narrow as 220 mm (The Home Depot, 2018), and while unfolded, the table area is 406 mm wide and 749 mm long. The specific table can hold up to 158 kg, which allows the user to put away tools, spare parts and their laptop, and take it with them to different service areas by rolling the table. Since different types of technicians need the offloading possibility the table should to be stored close to the main entrance, as this is where all technicians start their work there inside the data center. With the placement of the other systems in the solution, the best way to store it is against the wall on the right side of the entrance. It is easy to access when entering and not in the way for any service tasks.

A good complementing solution is wall mounted hooks which fulfils other needs than the roll able table and takes no floor space. It allows technicians to hang their outerwear, and therefore should be mounted close to the entrance. In the concept, the hooks are thus placed on the left side of the entrance, which also keeps them out of the way for most work tasks.

7.3. Conclusion

On this fourth and final level of development, detailed design solutions were developed for the interaction between service technician and MDC. The result is presented with the requirements defined for the interaction and the detailed design solutions for the concept.

Work environment
The concept should:
- Have 500 lux lighting during maintenance
- Keep working space temperature between 20-26°C during maintenance
- Allow technicians to plug in electrical equipment or tools

The concept provides interaction surfaces with sufficient light for the work tasks performed when technicians are in the MDC. This to support the performance of the tasks and avoiding physical discomfort with too low or high light intensity. To further keep the working environment comfortable for technicians the temperature is kept between 20-26°C during maintenance. The temperature is remotely decreased prior to maintenance so that the temperature is at an acceptable level when the technicians arrive at the MDC.

In the MDC, service outlets are included to allow electrical equipment like laptops to be plugged in. The concept has two variations for possible placements where cords connected to it would not interfere with any equipment in the MDC.

Emergency
In case of emergency the concept should:
- Support technicians to exit safely

The MDC needs to follow the standards for emergency lighting and signs for emergency exit to support technicians to exit if the ordinary lights goes out. An emergency torch is also recommended to be included in the MDC, to further support exit and troubleshooting.

Heavy tasks
The concept should:
- Support rolling racks in and out
    - Have a flat floor
    - Have a maximum gradient of 1:12 for any ramps
- Support heavy lifting

By not adding any thresholds inside the MDC the concept supports rolling racks inside, however, since sites for installation differs some MDCs might need to have a ramp by the entrance. To support heavy lifting in the MDC, tools can be brought in to help technicians roll racks or lift heavy hardware in or out of the racks.

Offloading The offloading solution should: - Allow offloading of tools, spare parts and laptop - Be flexible - Be suitable for all types of service technicians - Take up a small storage space

A roll able and foldable table is included in the concept to be stored in the MDC. It is flexible, space efficient when stored and can be used by all the different types of technicians, since it is mobile and can be used anywhere in the MDC.

Another solution included in the data center is wall mounted hooks, which allows technicians to put away their jackets and other belongings brought to the data center. The hooks are mounted close to the entrance where the jackets are not in the way for the technicians' work tasks.

Reaching The reaching aid should: - Support reaching above racks   - Support service technicians to reach up to 2700 mm up - Be flexible - Be safe to use - Take up a small storage space

A foldable work trestle is a solution applied to the concept to support the technicians to reach components placed higher up, like servers and cables. It is an aid that is stable, and also space efficient when stored.

08
Final concept

In this chapter the final concept is described and related to the objectives of the project. First the main key findings and the overall design built on the findings, is presented. It is followed by a presentation of the concept details and a description of how the concept fulfils the project goals.

This chapter summarises the design decisions described in chapter 4-7 by presenting the final concept as a whole. It can be read on its own by people knowledgeable within the area of data centers, giving an overview of the concept developed.

Design for Edge Computing

The final concept is a design for a prefabricated data center designed to be used for Edge Computing. To meet the needs of different uses and customers, the design is scalable in size and thereby capacity, allowing for maximum capacities from 40 kW to 200 kW (Chapter 5.3.1).

There will be many geographically distributed data centers in an Edge Network and all will at some point require service. Service technicians, which are the primary users (Chapter 4.2), will work in several data centers in the Edge Network, thus the design is coherent in the layout through different sizes (Chapter 6.3.2).

Figure 8.1 shows a prefabricated data center capable of providing 100 kW of data power. It is based on a scalable design, adapted for OCP hardware as well as maintenance. Unlike most prefabricated data centers it is not built from an ISO container, instead the data center is built from scratch in Swedish Modules factory. Because of this the data center can be as wide as 4450 mm and still be easily transported (Chapter 6.3.1). Since the data center is designed for OCP hardware, there is no need to access the hot aisles. This along with the maximum allowable width makes it possible for this data center to have two rows of racks (Chapter 6.3.2), with a shared cold aisle and contained hot aisles, separating the hot air from the cold. This allows the data center to be shorter compared to other prefabricated data centers, and at the same time still provide ample space for IT maintenance.

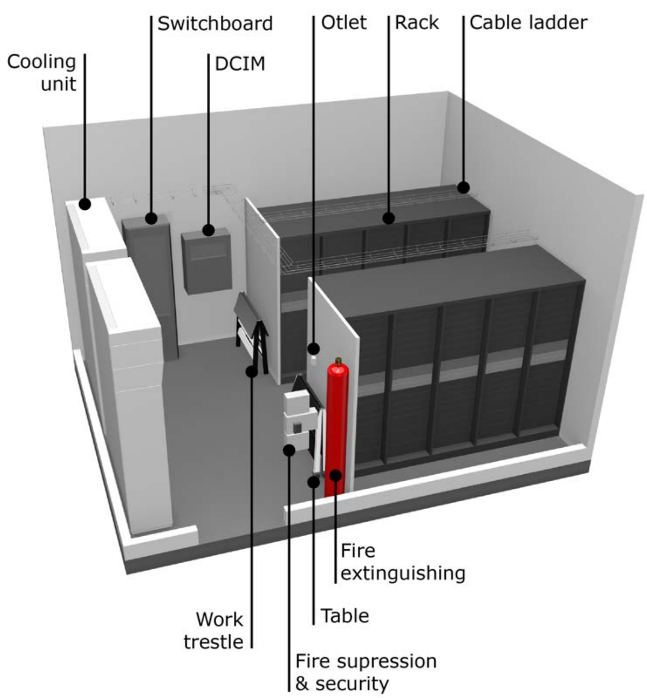


Figure 8.1. The final MDC concept with 10 racks.

Cooling is distributed by units placed against the wall (Chapter 6.1.1), the units are easily accessible for the purpose of maintenance and the method of cooling can be adapted based on customer or environmental needs. The remaining systems in the data center are all gathered on one side of the rack rows (Chapter 6.3.2), minimizing the interaction that non-IT technicians have with IT hardware. With this layout the cold aisle is not used as a passage, meaning technicians will not interfere with each other's work or accidently bump into the IT hardware. IT racks can also be individually rolled in and out of the data center with relative ease as the cold aisle is 1200 mm wide and the floor is even throughout the data center.

The extinguishing agent and the fire suppression system are placed just inside the main entrance, which is beneficial for the purpose of maintenance as well as emergency, since they are easy to access (Chapter 6.3.5).

Scalable

This data center was designed with Edge Computing in mind, which makes its scalability an important factor. The data center is possible to produce in sizes ranging from 4-20 racks (figure 8.2) whilst still keeping more or less the same layout (Chapter 6.3.2). This means it is easy to adapt the capacity of the data centers to the specific needs of the intended use or site, and the maintenance will remain similar across different sizes.

For sizes larger than 10 racks the design includes an emergency exit, this ensures that cold aisle is not the only exit path from far end of the data center. Due to the cooling units' spatial requirements for airflow this emergency exit can be included without increasing the size of the data center. The scalable design also simplifies the production aspect of the data center.

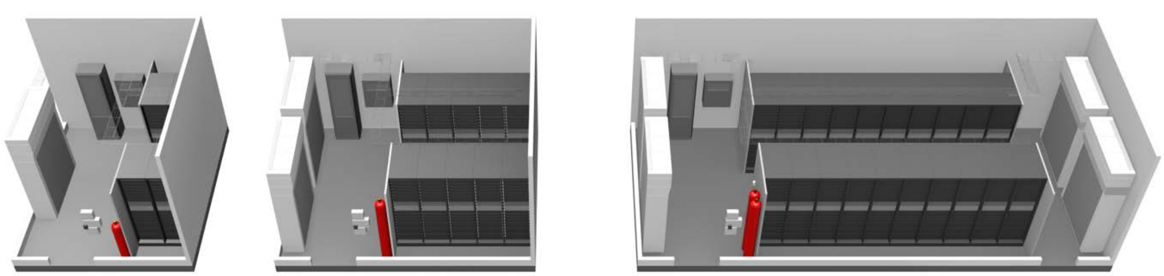


Figure 8.2. The final concept in three different sizes; 4, 10 and 20 racks.

Utility area

The core part of the data center is the utility area, where the DCIM, switchboard, fire suppression and security systems are located (figure 8.3). This part has a layout that is more or less identical across all different sizes. It is only the amount of cooling units and the size of the fire extinguishing container that scales up.

All systems included in the utility area have been placed based on safety requirements, ease of maintenance and the opinions of experienced service technicians (Chapter 6.3.5). The switchboard is placed next to the DCIM and has more than enough clear distance to allow for safe maintenance. The extinguishing agent is placed right inside the main entrance, minimizing the distance it needs to be moved when replaced. The alarm system and sniffer system are also placed in conjunction with this so that most of the related maintenance can be performed from the same location.

The similar layout across the different sizes of data centers makes easier for maintenance to be performed, as technicians will be familiar with the location of systems, something that is definitely beneficial in the case of a technician supporting another over the phone.

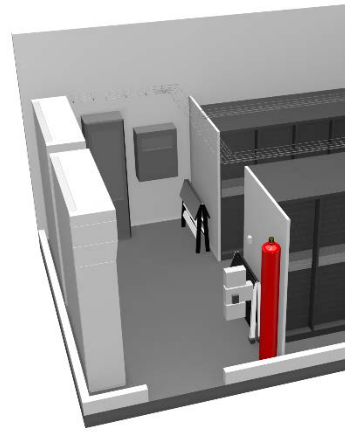


Figure 8.3. Utility area of the MDC concept.

Cooling

The data center uses cooling units from SEE Cooling (Chapter 6.1.1), these are very energy efficient and are placed against the wall. This type of unit is preferred from a maintenance standpoint as they are easily accessible, it is also the most suitable for this design as they do not require hot aisles access, like for instance in-row cooling would. The hot air reaches the top of the units through a return air plenum, the air is then cooled and directed towards the cold aisle (figure 8.4). The cooling units can be connected to different cooling systems, the cooling method can thus be adapted to achieve the most energy efficient cooling based on the location of the data center.

Due to the data center being unmanned the majority of the time it is possible to keep a higher temperature without causing discomfort for technicians. Some OCP hardware is capable of running at higher temperatures than traditional hardware which allows the MDC to keep a higher temperature, and thereby have a more energy efficient cooling system. However, to prevent creating a poor work environment for technicians the temperature can be adjusted remotely to a more comfortable range prior to planned maintenance visits.

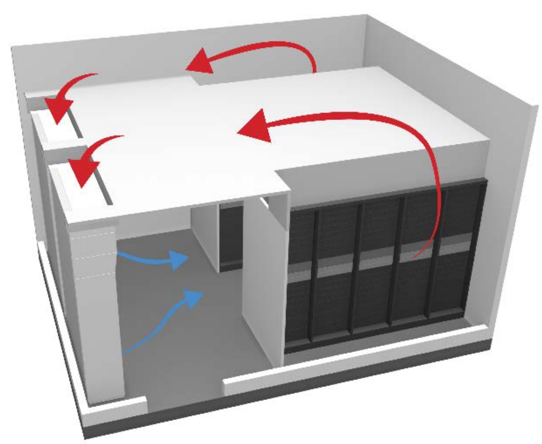


Figure 8.4. Hot air containment.

Backup power

The core data center module does not come equipped with backup power as standard, this allows the customer a higher degree of flexibility, especially with the advent of Edge Computing offering new possibilities for network-based redundancy. Should backup power be desired it can easily be added in the form of a separate module, this module can for convenience be placed on the short side of the data center providing a short distance between the generator and the main distribution board. Using a separate module for the backup power has the added benefit of not risking accidental contamination of oil or fuel in the data center.

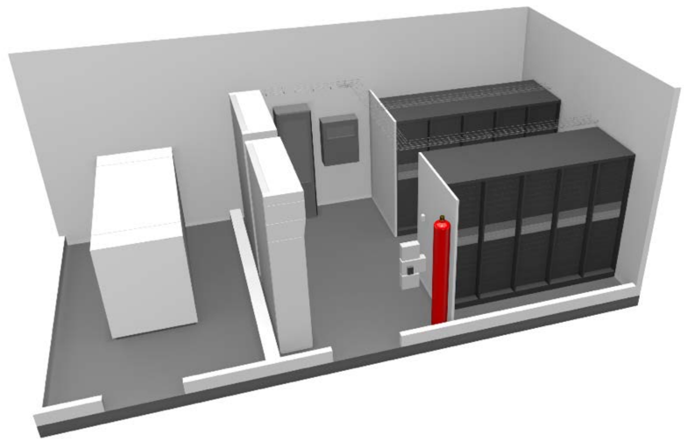


Figure 8.5. Backup power module applied to MDC.

Maintenance

Since the data center has been designed with maintenance in mind, the systems all have their separate zones allowing technicians to work on different systems at the same time. Having two or more technicians on location also allows them to assist each other with tasks such as heavy lifting, and also increases the safety of working in remote locations. The data center is outfitted with a work trestle and a foldable roll able table to assist maintenance work, this means that the technicians will not have to bring these commonly utilized tools themselves.

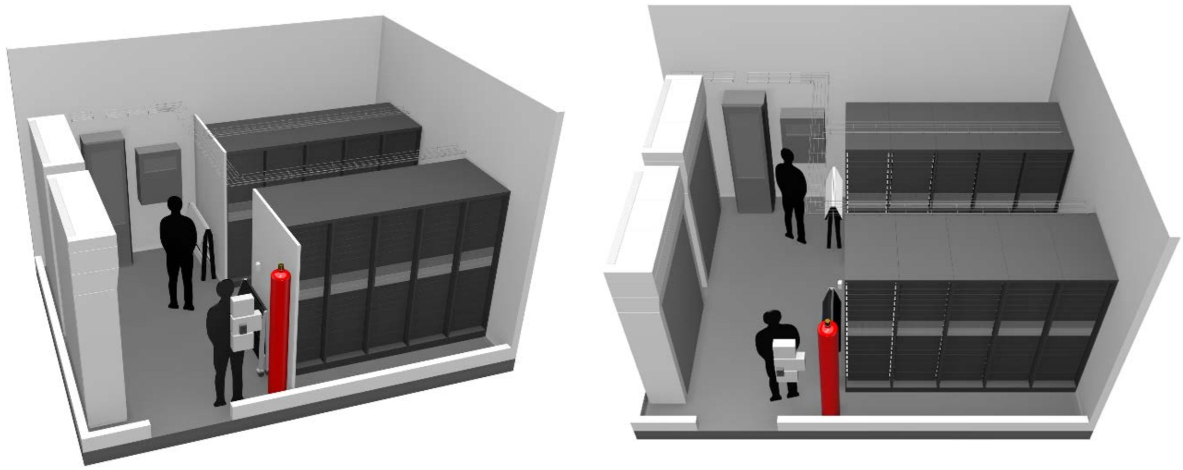


Figure 8.6. Two technicians working in an MDC.

Upgrades and expansion

The design of the data center allow for racks to be moved in and out through the main entrance. Thanks to the width of the cold aisle, combined with a solid flat flooring, this can be done without the use of spreader plates or complicated rearranging of the interior. To further support rolling racks in and out, the data center module should be installed with the inside floor in level with the outside foundation or surface, to remove the need for a ramp. Should equipment, such as a server lift, be needed it can also then easily be brought into the data center.

In the case of expansion being needed the module can be swapped for a larger module or another module can be added to the location. This way the hardware will not be susceptible to dust due to on-site construction, as all construction will be performed in the Swedish Modules factory. This also means that the functionality of the data centers can be ensured through testing before being transported to the location.

Summary

To summarise the findings and the final concept, a data center concept designed for Edge Computing need to be flexible to suit different needs. Thus, the final concept is a scalable design, allowing different cooling methods and optional backup power. The concept is spacious yet compact, allowing it to be easily transported and installed. The data center provides each technician with sufficient working space and to further facilitate maintenance the layout is coherent through different sizes. By also implementing aids to support reaching and offloading, as well as having a design that supports technicians to work in pairs, safe, ergonomic and efficient maintenance is further facilitated.

09
Future work

To ensure that this concept is feasible more work is required, some assumptions will need to be verified and some technical aspects has to be tested. This chapter provides the reader with recommendations for future development of the concept and should be read after the previous chapter, describing the final concept.

Edge Computing

The desired capacity range for edge computing data centers will need further investigation. The range specified in this project is based on articles and benchmarking of existing solutions, however this range will need to be verified by prospective customers or experts in the field. The cost of the complete solution will also need to be calculated to ensure that the solution can be produced at a competitive price point. Both capital and operational cost need to be considered, and if any type of service will be included in the solution this will also need to be included as an added value.

Cooling

The dimensioning of the cooling as well as the design of the containment will need to be further looked into. The dimensioning of the cooling system is based on a general airflow of 0.55 m^3/s for a 10 kW rack, when more specifics regarding the hardware requirements is know this can be verified or adjusted.

The rather narrow hot aisle will also require verification to ensure the back of the servers do not overheat, although an expert has been consulted and the width is believed to work there is no real way of knowing for sure other than testing or performing accurate calculations or simulations. If needed the width of the hot aisle could be increased through the use of shorter racks or thinner walls, given that it is possible to manufacture thinner walls with the same resiliency. It is also possible to increase the height of the return air plenum to better allow the air to expand.

Figure 9.1. Issue with switchboard and cooling units being close to each other.

With the current measurements for the concept layout there is a possible problem with the distance between the switchboard and the closest cooling distribution unit (figure 9.1). This could mean that there are difficulties with removing the right-side panel of the cooling distribution unit. If it turns out to be a hindrance the switchboard and DCIM could be moved closer to the server racks, or the length of the module could be increased to move the cooling distribution unit further away from the switchboard.

Maintenance

Although layout and dimensioning of the data center should be appropriate for all types of maintenance it is possible that some aspect has not been brought to light during the project. It is therefore advisable to further consult technicians and test layouts and ideas, in the event of further development. This should be done with all the different types of technicians and the suggested combinations of technicians in mind.

10
Discussion & Conclusion

In this chapter the project process and result are discussed and conclusions drawn. It is also discussed what the future might be like with the developed concept. The discussion facilitates further development and highlights some of the main findings.

10.1. The final concept

The project aim has been met with the final concept since it is a design for an MDC optimised for Edge Computing and maintenance, with a layout designed for OCP technology. It is optimised for what has been predicted to be required for Edge Computing, through a scalable design with optional backup power. Furthermore, the concept is designed for maintenance through a thoughtful and coherent MDC layout providing each technician with sufficient space and possibility for support. Through the layout design having narrow, non-accessible hot aisles, and a cooling system not requiring hot aisle access the concept is also designed for OCP technology. In this report the concept has been described in text and visual material including floor plans, which was what the project was intended to result in.

The final concept stands out among existing solutions aimed to be used for Edge Computing, because of the focus on maintenance, implementation of OCP technology and the form factor. By focusing on maintenance, questions have been raised regarding to what extent a data center should be designed to suit the hardware. One of the main benefits with OCP hardware, that it can operate in higher temperatures making data centers more energy efficient, was questioned by the user focus. If the data center climate is adapted to the hardware the environment will be unsuitable for service technicians, meaning it would not allow maintenance on site.

Another aspect the final concept solves is the ergonomic support for service technicians work tasks which has not been seen to the same extent in other data centers. To really convince stakeholders user centric design of data centers is important the concept highlights the benefits coming with it. With more efficient and safe work, money can be saved on operating costs. Technicians will also perform better when working in the environment designed from their needs. Thereby less errors will occur which is beneficial for all of the users.

10.2. The complexity of the context

Because of the complexity of the product and the context studied the project have not included in-depth details of the different parts. Instead the project has had a more holistic approach, researching how subsystems interacts in a complete MDC system. This has resulted in a design on a conceptual level including some possible variations, allowing for further development.

The complexity has likely led to some aspect not being taken into consideration in the study and product development. This depends to a large extent on the limited knowledge regarding the area of data centers among the project members, as neither had substantial knowledge on the subject at the start of the project. People with more experience in the area would therefore most likely be able to find more detailed solutions, because of their knowledge. This is also why it has been important to include experts in the project through interviews and verification of ideas developed.

10.3. Uncertainty about the future

One of the major aspects of the project has been Edge Computing which is an experimental technique. Because of it being in an experimental phase even experts within the area of data centers and Cloud Computing does not know for certain how it will be used in the future. Thus, from information gathered from experts, literature and videos, many assumptions have been made throughout the project. This way of developing a concept have led to many new questions being asked to experts, which have opened up discussions in the OCP network. It is going to be interesting to see where this lead and to what extent the findings from this study will be incorporated in future solutions.

The main effect this uncertainty had on the concept was the need for it to have a scalable design, to fulfil different possible future needs. Together with existing technologies it also has affected the size range of the concept.

10.4. Project process

During the project a lot of time was spent on verifying the validity of ideas and concepts at different levels. Visiting a prefabricated data center that was designed with edge in mind answered many important questions for this purpose. Ideally this visit should have happened earlier on in the project but in this case the opportunity did not present itself until later on. Visiting more similar data centers would have likely also provided much useful knowledge of data center design.

As maintenance was a focus in the project, finding relevant users was important, but due to the level of expertise of the primary users in this project, finding participants was difficult. However, for this project a good range of technicians were interviewed and several of them were able to provide more input throughout the project, which was key for the evaluation processes. Something that would have been beneficial for the project is the opportunity to observe maintenance work performed, and also to interview someone with maintenance experience of OCP hardware. Similarly, it would have been beneficial to visit a data center where OCP technology was used.

Throughout the process many assumptions have been made and many decisions have been based on theory gathered through literature studies. Due to the conceptuality of the project as well as the difficulty of finding participants, testing of ideas has not been very limited in the project. For evaluation purposes input from different experts throughout the project has been extremely valuable. At some stages more input would have been desirable but was problematic to get, due to the experts limited available time for the project.

10.5. Societal and ecological aspects

Reducing the cost of MDCs both in terms of manufacturing as well as their operational costs will allow for the implementation of an Edge Computing infrastructure. The physical presence of the MDCs, being geographically distributed, does not necessarily have an effect that is either positive or negative for the side users, but it is an aspect to consider. The greater impact will come from the use of Edge Computing, which will affect the everyday lives of anyone living within its reach, through for example IoT. Another big shift will be the introduction of fully automated vehicles, which has the potential to reduce accidents as well as energy consumption, benefitting not only vehicle owners but the society as a whole.

From an ecological standpoint producing and installing thousands of MDCs will require a lot of resources, and the energy consumption from running them will be significant. In the long-term this is likely to see a return on the investment however, as Edge Computing will allow for technological advances. It is therefore also important to develop more energy efficient solutions for MDCs and make use of residual energy and heat.

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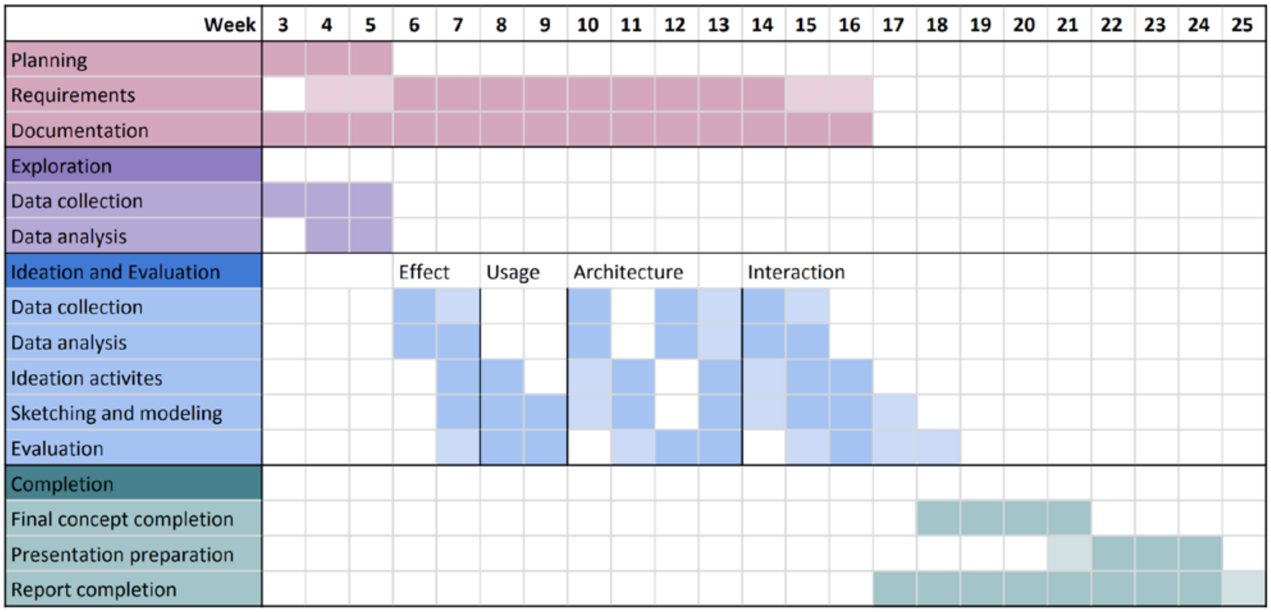
Appendix

A1. Project schedule



A2. Interview guide exploration phase

Hej, välkommen till vår intervju!
Vi går på ingenjörsutbildningen Teknisk Design på Chalmers och gör nu vårt examensarbete för Swedish Modules. Vi arbetar med att ta fram en design på ett modulärt datacenter för Edge Computing, som är anpassat för service. Därför vill vi prata med dig om arbetet som servicetekniker.

Till att börja med;

1. Vad är det för åldersspann på de som arbetar som servicetekniker på Coromatic?
    a. Hur gammal är du?
2. Vad krävs det för utbildning eller yrkesbakgrund för att jobba som servicetekniker?
    a. Vad har du för utbildning(ar) och yrkesbakgrund?
3. Vilken typ av service är det du genomför?
    a. På vilka delar i DC?
    b. Är det även uppgradering?
4. Hur länge har du jobbat med service av datacenter?
    a. Vad är det bästa/sämsta med jobbet?

Process

5. Om du skulle dela upp processen i flera delar, hur skulle det då se ut? (Skriv/rita)
6. Vilka steg i processen är fysiskt krävande? Med fysiskt krävande menar vi tung belastning, statiskt arbete, dålig arbetsposition, osv.
7. Vilka av stegen i processen är kognitivt krävande? Med kognitivt krävande menar vi steg som kräver bedömningar, uppskattningar eller problemlösning.
8. Har du några knep för att effektivisera processen?

Innan

9. Hur ofta åker man ut på jouruppdrag? Hur annorlunda är det mot inplanerade uppdrag?
10. Vilken information får man innan man åker ut till ett DC?
11. Hur får man information om vad uppdraget gäller?
    a. Vad som ska bytas/ kontrolleras/repareras? Plats?
    b. När får man den informationen?
12. Förbereder man något innan man beger sig till DC? (T.ex. packa med speciella verktyg baserat på informationen du fått?)
    a. Finns det några redskap eller verktyg på plats i DC?

Under

13. Hur lång tid befinner man sig i DC vid service/uppgradering? (ca 6 racks)
14. Hur stor skillnad är det på att serva ett DC med 10 racks kontra ett med 2? Ökar tidsåtgången proportionerligt?

15. Skiljer sig service av kylsystem mycket för mindre och större DC?
    a. Vilken typ av kylsystem brukar det handla om?
    b. Vilket kylsystem föredrar du att serva?
16. Hur kommer man in i DC?
    a. Behöver man torka av skor, hänga av sig kläder eller liknande?
17. Vad får man för information i DC?
    a. Hur får man den informationen?
    b. Hur hanterar man informationen och hur agerar man utifrån det?

Fel

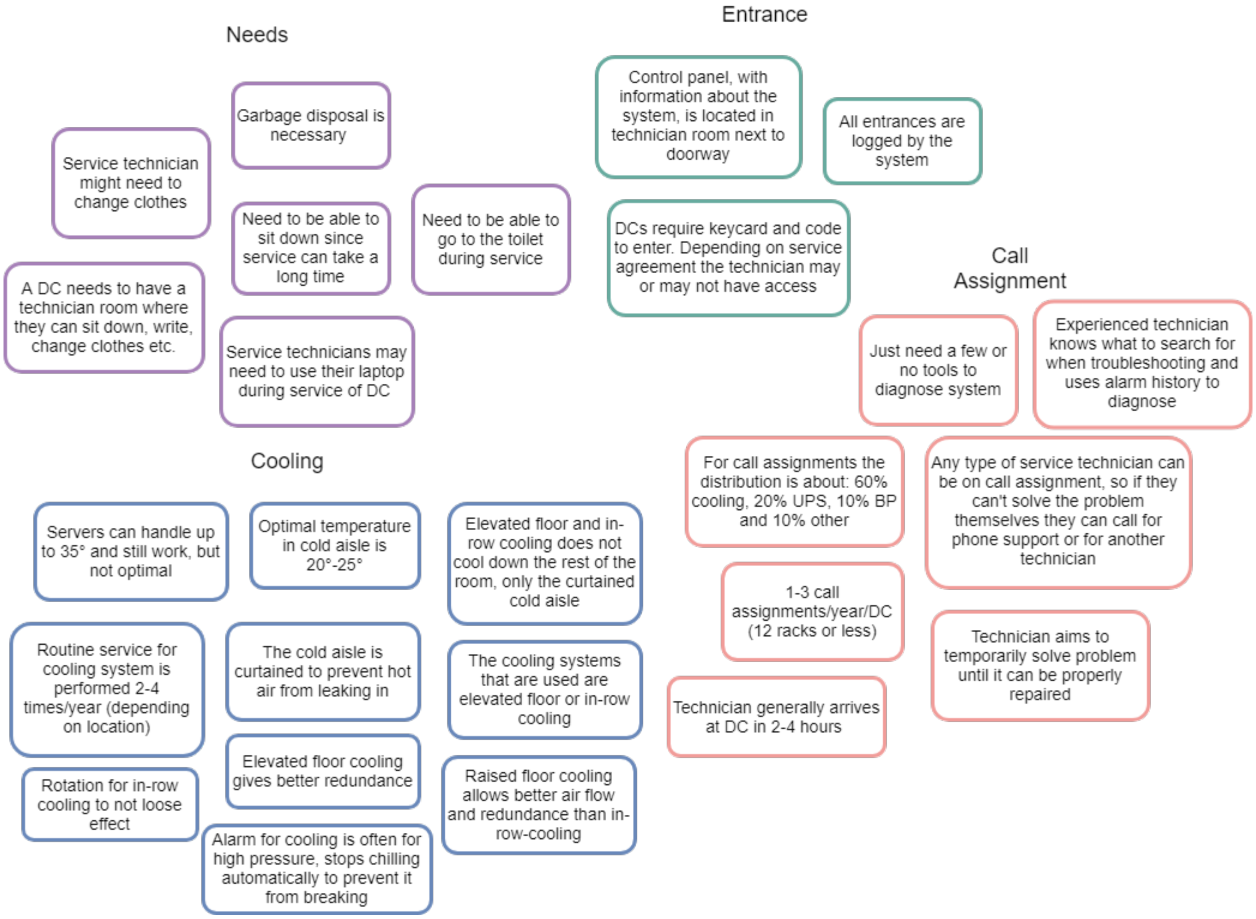
18. Vad kan gå fel när man servar ett DC?
19. Vad är det värsta som kan hända? Hur gör man då?

Efter

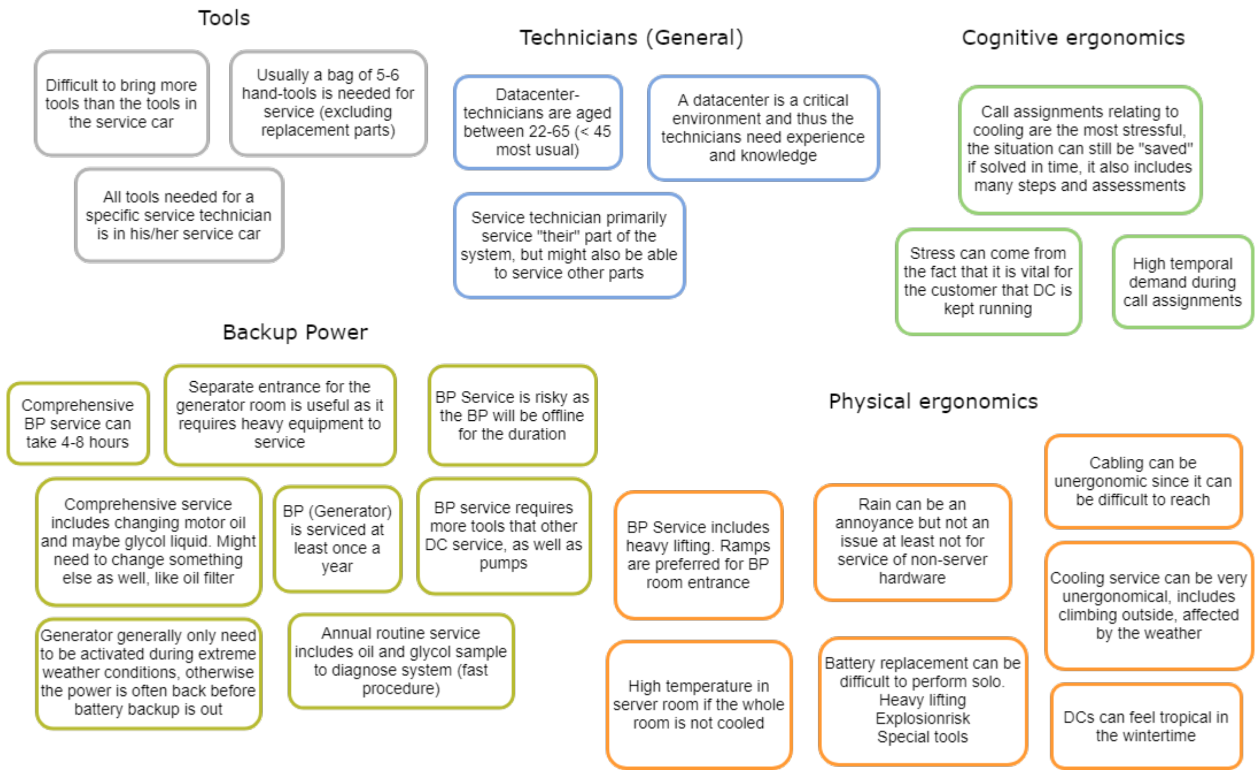
20. Städar man DC i någon utsträckning när man är klar?
21. Har du något förslag på vad som skulle kunna förbättras från DC sidan?

Tack så mycket för att du ställt upp. Går det bra om vi kontaktar dig igen, längre fram i projektet, för att komma i kontakt med fler servicetekniker och träffa dig igen?

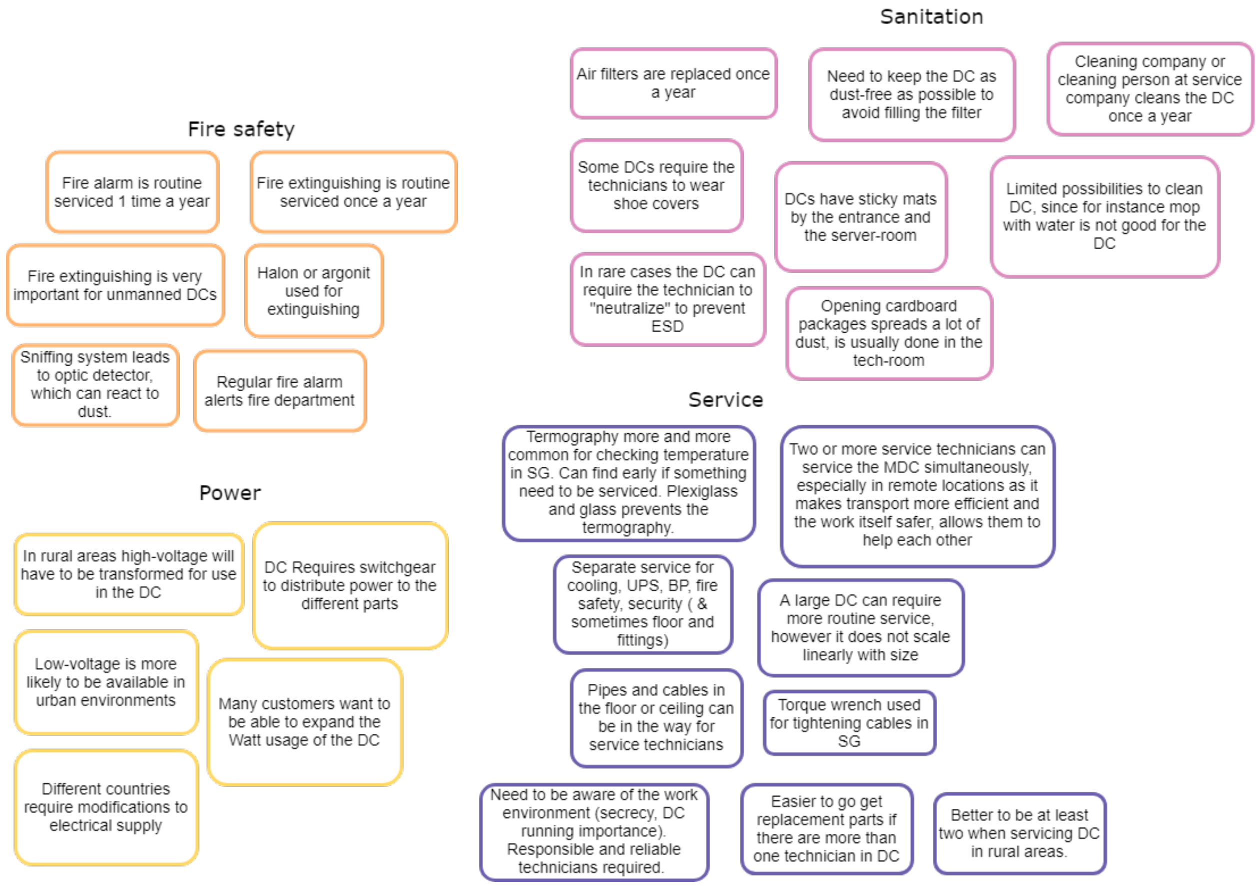
A3. KJ-analysis exploration phase

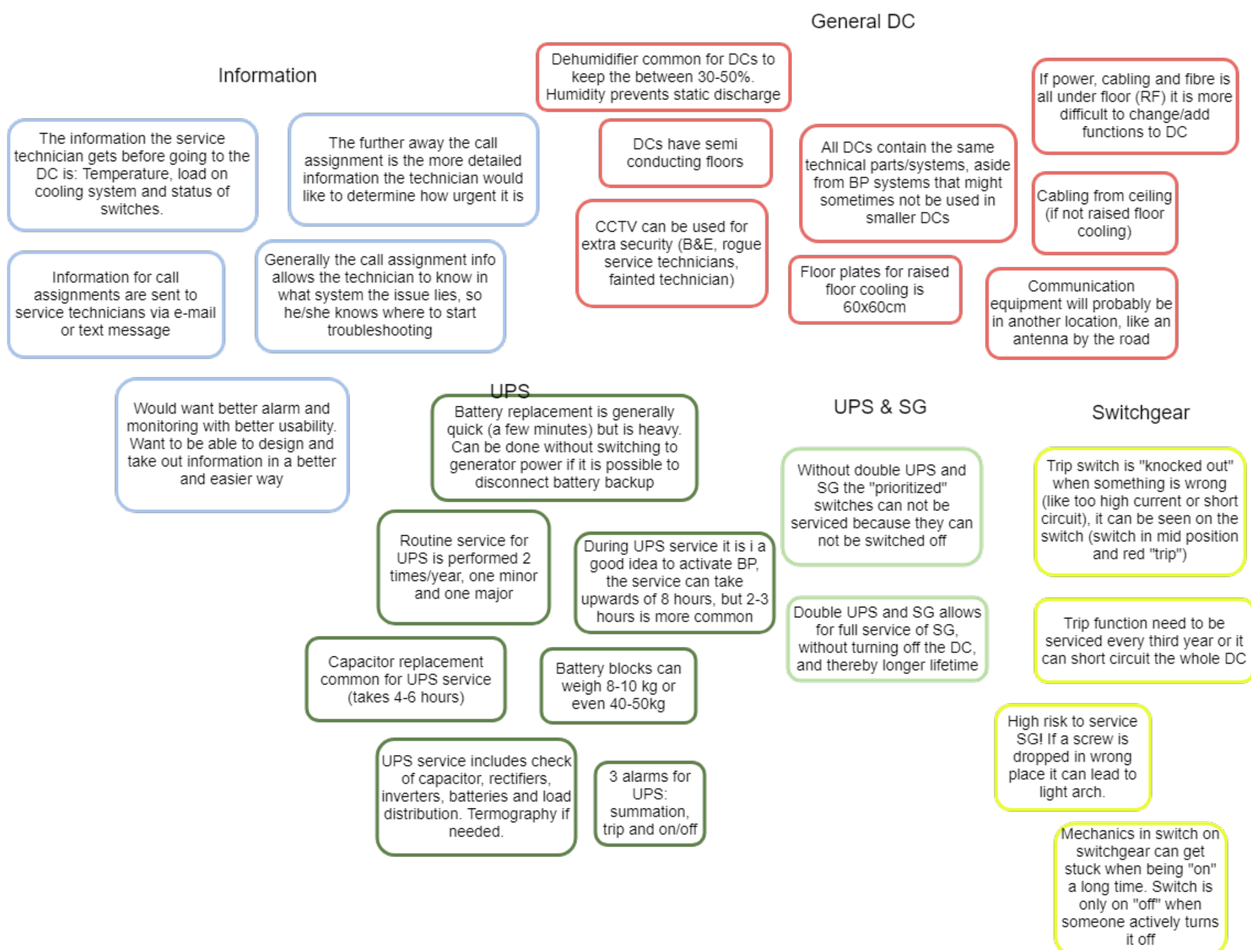


(1 of 4)


Tools
Difficult to bring more tools than the tools in the service car
Usually a bag of 5-6 hand-tools is needed for service (excluding replacement parts)
All tools needed for a specific service technician is in his/her service car
Technicians (General)
Datacenter-technicians are aged between 22-65 (< 45 most usual)
A datacenter is a critical environment and thus the technicians need experience and knowledge
Service technician primarily service "their" part of the system, but might also be able to service other parts
Cognitive ergonomics
Call assignments relating to cooling are the most stressful, the situation can still be "saved" if solved in time, it also includes many steps and assessments
Stress can come from the fact that it is vital for the customer that DC is kept running
High temporal demand during call assignments
Backup Power
Comprehensive BP service can take 4-8 hours
Separate entrance for the generator room is useful as it requires heavy equipment to service
BP Service is risky as the BP will be offline for the duration
Comprehensive service includes changing motor oil and maybe glycol liquid. Might need to change something else as well, like oil filter
BP (Generator) is serviced at least once a year
BP service requires more tools that other DC service, as well as pumps
Generator generally only need to be activated during extreme weather conditions, otherwise the power is often back before battery backup is out
Annual routine service includes oil and glycol sample to diagnose system (fast procedure)
Physical ergonomics
Cabling can be unergonomic since it can be difficult to reach
BP Service includes heavy lifting. Ramps are preferred for BP room entrance
Rain can be an annoyance but not an issue at least not for service of non-server hardware
Cooling service can be very unergonomical, includes climbing outside, affected by the weather
High temperature in server room if the whole room is not cooled
Battery replacement can be difficult to perform solo. Heavy lifting Explosionrisk Special tools
DCs can feel tropical in the wintertime

(2 of 4)


Fire safety
Fire alarm is routine serviced 1 time a year
Fire extinguishing is routine serviced once a year
Fire extinguishing is very important for unmanned DCs
Halon or argonit used for extinguishing
Sniffing system leads to optic detector, which can react to dust.
Regular fire alarm alerts fire department
Power
In rural areas high-voltage will have to be transformed for use in the DC
DC Requires switchgear to distribute power to the different parts
Low-voltage is more likely to be available in urban environments
Many customers want to be able to expand the Watt usage of the DC
Different countries require modifications to electrical supply
Sanitation
Air filters are replaced once a year
Need to keep the DC as dust-free as possible to avoid filling the filter
Cleaning company or cleaning person at service company cleans the DC once a year
Some DCs require the technicians to wear shoe covers
DCs have sticky mats by the entrance and the server-room
Limited possibilities to clean DC, since for instance mop with water is not good for the DC
In rare cases the DC can require the technician to "neutralize" to prevent ESD
Opening cardboard packages spreads a lot of dust, is usually done in the tech-room
Service
Termography more and more common for checking temperature in SG. Can find early if something need to be serviced. Plexiglass and glass prevents the termography.
Two or more service technicians can service the MDC simultaneously, especially in remote locations as it makes transport more efficient and the work itself safer, allows them to help each other
Separate service for cooling, UPS, BP, fire safety, security (& sometimes floor and fittings)
A large DC can require more routine service, however it does not scale linearly with size
Pipes and cables in the floor or ceiling can be in the way for service technicians
Torque wrench used for tightening cables in SG
Need to be aware of the work environment (secrecy, DC running importance). Responsible and reliable technicians required.
Easier to go get replacement parts if there are more than one technician in DC
Better to be at least two when servicing DC in rural areas.
(3 of 4)


General DC
Information
Dehumidifier common for DCs to keep the between 30-50%. Humidity prevents static discharge
If power, cabling and fibre is all under floor (RF) it is more difficult to change/add functions to DC
The information the service technician gets before going to the DC is: Temperature, load on cooling system and status of switches.
The further away the call assignment is the more detailed information the technician would like to determine how urgent it is
DCs have semi conducting floors
All DCs contain the same technical parts/systems, aside from BP systems that might sometimes not be used in smaller DCs
Cabling from ceiling (if not raised floor cooling)
CCTV can be used for extra security (B&E, rogue service technicians, fainted technician)
Information for call assignments are sent to service technicians via e-mail or text message
Generally the call assignment info allows the technician to know in what system the issue lies, so he/she knows where to start troubleshooting
Floor plates for raised floor cooling is 60x60cm
Communication equipment will probably be in another location, like an antenna by the road
Would want better alarm and monitoring with better usability. Want to be able to design and take out information in a better and easier way
UPS
Battery replacement is generally quick (a few minutes) but is heavy. Can be done without switching to generator power if it is possible to disconnect battery backup
UPS & SG
Switchgear
Without double UPS and SG the "prioritized" switches can not be serviced because they can not be switched off
Trip switch is "knocked out" when something is wrong (like too high current or short circuit), it can be seen on the switch (switch in mid position and red "trip")
Routine service for UPS is performed 2 times/year, one minor and one major
During UPS service it is i a good idea to activate BP, the service can take upwards of 8 hours, but 2-3 hours is more common
Double UPS and SG allows for full service of SG, without turning off the DC, and thereby longer lifetime
Trip function need to be serviced every third year or it can short circuit the whole DC
Capacitor replacement common for UPS service (takes 4-6 hours)
Battery blocks can weigh 8-10 kg or even 40-50kg
High risk to service SG! If a screw is dropped in wrong place it can lead to light arch.
UPS service includes check of capacitor, rectifiers, inverters, batteries and load distribution. Termography if needed.
3 alarms for UPS: summation, trip and on/off
Mechanics in switch on switchgear can get stuck when being "on" a long time. Switch is only on "off" when someone actively turns it off

(4 of 4)

A4. Interview guide development phase

Hi,

So as we described in the email, we are Industrial Design Engineering students involved in the Modular Data Center project. We are working with development of a prefabricated data center for edge computing, and we are focusing on improved maintenance. Therefore we want to talk to you about the OCP... Is it ok if we record this call so we can go back and listen to it, so we don't miss anything? We will not publish the audio.

1. Could you introduce yourself?
2. Regarding hot aisle requirements of the Open Rack V2 our initial understanding was that access to the hot aisle was not needed, however we have received some input that contradicts this. We were looking to confirm whether or not access to the back of the rack is needed for the purpose of service and/or installation?
    a. Switches?
3. We have also heard that 500mm is a sufficient hot aisle width for the purpose of airflow, do you know whether or not this is the case?
4. Our goal is to create a design for a scalable prefabricated data center, and in terms of cooling we want to use fresh air cooling to the extent possible. However, other cooling systems will need to be combined with or replace fresh air cooling where the climate is not always suitable for fresh air cooling. What do we need to consider when designing a data center that needs to be flexible in terms of its cooling systems?
5. If you use rollable racks for the purpose of moving the racks into and out of the datacenter, what are important aspects to consider?
6. Are any tools required to service the data center? (Table? Laptop?)
7. What maintenance work is time consuming and how long does it take?
8. What maintenance work is physical demanding? With physical demanding we mean heavy load, static tasks, poor working positions etc.
    a. What makes it demanding?
9. Do you have any suggestions on how maintenance of a prefabricated data center could be made easier?
10. What do you think is important to consider when designing a DC that will be unmanned the majority of the time.

IT and racks

11. What type of physical maintenance work, on site, is performed on OCP IT-Hardware and Open Racks?
12. What does the life cycle for OCP hardware look like?
    a. At what intervals would components be swapped
    b. How often does the components of the IT hardware need to be upgraded? How long does it take?
13. Will the PDU's need to be checked or maintained?

a. How is it done?

14. How are BBU's in the racks checked and swapped?
15. How are PSU's in the racks checked and swapped?
16. Do you ever need to reach the busbar in the rack?

Do you have any suggestions on how maintenance of OCP IT-hardware and racks could be made easier through the design of the DC?

A5. Survey questions

Utveckling av prefabricerat modulärt datacenter för edge computing

Vi är två studenter på programmet Teknisk Design på Chalmers som gör vårt examensarbete för Swedish Modules, där målet är att utveckla ett prefabricerat modulärt datacenter för edge computing. Datacentret ska vara optimerat för service, och vi behöver därför din hjälp för att utvärdera våra koncept. Vi är därför väldigt glada över att du vill bidra med input till hur framtidens datacenter ska se ut.

Att svara på enkäten tar ca 5 min och du är helt anonym när du svarar. Alla tankar och åsikter är värdefulla för projektet, så svara gärna så utförligt som möjligt. Tack på förhand!

Serviceområde

Har du erfarenhet av att serva kylsystem?

- Ja, jag jobbar med det nu
- Ja, jag har jobbat med det tidigare
- Nej

Konceptutvärdering

Konceptet bygger på en layout med IT rack i två rader, med en gemensam kall gång och inneslutna varma gångar, samt ett område för övriga system. All IT-hårdvara i racksen servas framifrån och därför är konceptet designat så att det inte går att vara i de varma gångarna. I enkäten används en modul med 8 IT rack som exempel, men tanken är att datacentret ska vara skalbart upp till 20 rack. Modulen ska även vara anpassad för att tillåta två tekniker att vara på plats samtidigt av säkerhets- och effektivitetsskäl.

Med enkäten hoppas vi få input om placering av olika system och redskap för att optimera servicearbetet.
Svara därför gärna så utförligt som möjligt. Alla tankar och åsikter är värdefulla!

Vilken typ av service har du erfarenhet av?

- IT-hårdvara
- Brandsäkerhetssystem
- Säkerhetssystem
- El
- Reservkraft

- Övrigt:

Vilket av följande alternativ på hjälpmedel skulle du föredra att använda vid service?

- Stege
- Arbetsbock
- Kick-step
- Vet inte

Motivera ditt svar:

Vilket av följande alternativ på placering av system skulle du föredra?

- Alternativ 1
- Alternativ 2
- Vet inte

Motivera ditt svar:

Vilket av följande alternativ på placering av kylsystem skulle du föredra?

- I rack-raden
- Ovanför rack-raden
- Vid väggen i kalla gången
- Vet inte

Motivera ditt svar:

Hur lätt tycker du det är att serva ett kylsystem som är placerat i rack-raden?

- 1 Väldigt svårt
- 2
- 3
- 4
- 5
- 6 Väldigt lätt

Motivera ditt svar:

Hur lätt tycker du det är att serva ett kylsystem som är placerat ovanför rack-raden?

- 1 Väldigt svårt
- 2
- 3
- 4
- 5
- 6 Väldigt lätt

Motivera ditt svar:

Hur lätt tycker du det är att serva ett kylsystem som är placerat vid väggen?

- 1 Väldigt svårt
- 2
- 3
- 4
- 5
- 6 Väldigt lätt

Motivera ditt svar:

Hur viktigt skulle du säga att det är med avlastningsytor vid service?

- 1 Onödigt
- 2
- 3
- 4
- 5 Väldigt viktigt

Motivera ditt svar:

Skulle ett rullbart och ihopfällbart avlastningsbord vara önskvärt att kunna tillgå vid service?

- Ja, oftast
- Ja, ibland
- Nej

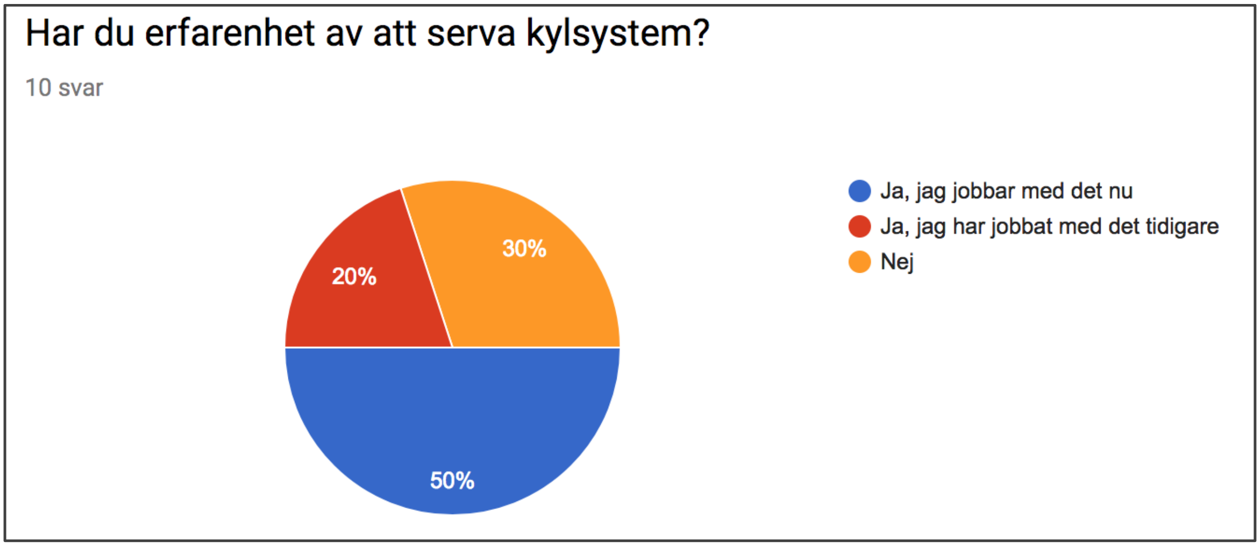
Motivera ditt svar:

Övriga kommentarer:

Tack så jättemycket för din input, den är verkligen värdefull för projektet!

Tack för ditt bidrag till utvecklingen av framtidens datacenter!
Har du några frågor eller funderingar kan du höra av dig till...

A6. Quantitative survey results



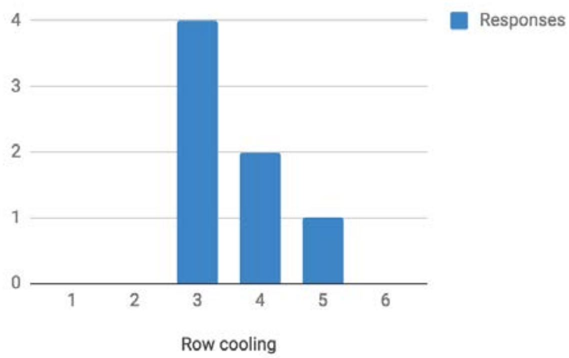
Vilket av följande alternativ på hjälpmedel skulle du föredra att använda vid service?

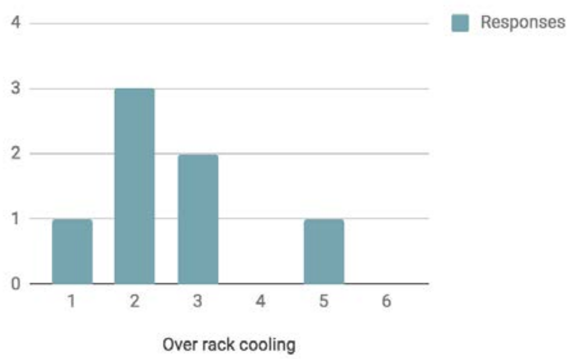
Aid	Responses
Ladder	3
Work trestle	5
Kick-step	2
Don't know	0

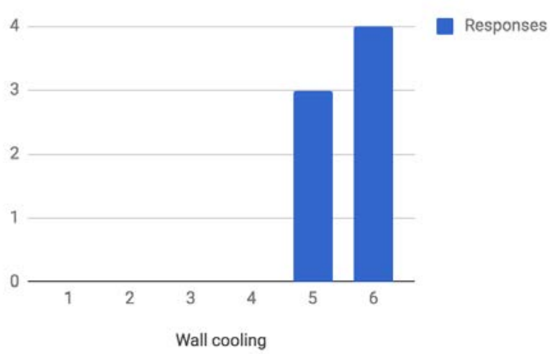
Vilket av följande alternativ på placering av system skulle du föredra?

Layout	Responses
Alternative 1	1
Alternative 2	5
Don't know	4

Hur lätt tycker du det är att serva ett kylsystem som är placerat i ...? (1 = väldigt svårt, 6 = väldigt lätt)







A7. KJ-analysis survey

Layout

El och övervakning hör ihop. Släck bör ställas i annan zon eller i annat rum.
(alt 2)

Oväsentligt för kyljobb.
(Vet inte)

Jag ser gärna släcket innanför dörren.
(alt 2)

Om man bara skapar tilläcklig åtkomst så alternativ 1 (utgår f n p.g.a. elcentral som blockerar?) Alt 2 så står släcktub utsatt/i vägen
(Vet inte)

Ingen större skillnad, lite mer yta för hjälpmedel.
(alt 1)

Elcentralen alt 1 blockerar baksida rack något
(alt 2)

Gillar inte designen på något alternativ då det blir väldigt plottrigt och tight med utrymme. Alternativ 1 ser ut att gå bort pga elcentralens placering.
(alt 2)

Mer utrymme för åtkomst i elcentral
(alt 2)

Kylning

Ovanför racks

Kan vara bökigt att nå och komma åt överallt ordentligt
(2/6)

Oftast svårare att serva något som hänger i tak ovan något annat.
(3/6)

1. Trångt.
2. Arbete över axelhöjd och på stege medför alltid svårare moment
(2/6)

Dessa aggregat stöter jag väldigt sällan på och är nuförtiden väldigt ovanliga.
(3/6)

Kortast väg för värmen/kylan [ovanför racks]

Utrymme på minst 40 cm måste finnas för service mellan rack och undersida kylmodul för ex fläkt och filterbyte
(5/6)

Sitter de i taket blir de svåra att komma åt och det finns såklart risk att verktyg tappas ned i racken.
(2/6)

Arbete på höjd, tunga lyft, risk för läckage över rack osv.
(1/6)

Väggkyla

Bättre än de andra lösningarna, mer fritt utrymme
(5/6)

[Väggkyla] Lätt åtkomligt
(6/6)

Det är ofta en bra arbetshöjd och bättre plats i aggregaten.
(5/6)

Lättare åtkomst framifrån vid service
(6/6)

Lättåtkomligt från samtliga håll.
(6/6)

Vid väggen för att man har en möjlighet att komma åt att både mäta värden samt byta felande delar lättare.

Mest van med denna lösning
(6/6)

Förutsätter att man kommer åt kylmaskinernas delar från en sida
(5/6)

Radkyla

"Vanlig service" [av radkyla] utan akut felavhjälpning går utmärk. Vid stora ingrepp bör aggregaten kunna flyttas in och ut. vid kylsystem med sk direktexpansion innehållande köldmediegas är alternativen för flexibel förflyttning något begränsad.
(5/6)

Oftast är det svårt om man behöver byta ett aggregat [radkyla]. Men även service kan vara svårt med dagens utformning av aggregat. Då de ofta är kompakta
(3/6)

Drygt med blåst i ögon, ofta svårt att komma åt ordentligt.
(3/6)

Beror på vilken typ av aggregat det är, dvs om de måste vara åtkomliga från sidan. Tex modellen CRV från Vertiv (inrow) klarar att kyla 5 rack och kan således stå längst ut i detta exempel, vilket vore att föredra.
(3/6)

Förutsätter att kymaskinerna går att dra fram och access i varm o kall gång
(3/6)

Utan att se några mått så ser det lite trångt ut.
(4/6)

I rackraderna är det ofta trångt i maskinerna men de bör vara designade så att man kommer åt alla komponenter fram/bakifrån.
(4/6)

Hjälpmedel

Alla alternativ [på hjälpmedel] behövs för olika saker.

Stege

I de fall man får plats med stege känns den mest stabil

Säkrare att stå på trappstege med plattform och båge. Helst vill man slippa stege.

Bättre säkerhet, lättare att komma upp över aggregatet vid behov.

Arbetsbock

Valet av hälpmedel beror på situation, måste jag nå hela vägen upp till taket så är stegen klart bättre. Annars är arbetsbocken både stabil och lätt att flytta med sig.

Bäst stabilitet förutsatt ej för hög höjd

Lätt att ha med [arbetsbock]. Normalt behövs ingen högre höjd

Åtkomst från två sidor, stabil (jmfrt kick-step)

Man kan då stå 2 samtidigt [på arbetsbock] från varsitt håll för ev lyft

Kick-step

Fördelen med Kick-step är att den är lätt att flytta med sig och bra att sitta på!

[Kick-step] Kräver minst golvyta vid arbete.

Avlastningsyta

Minst 1m2 går åt för reservdelar vid ex ett fläktbyte. [avlastningsyta] (5/5)

För mindre komponenter samt verktyg [rullbart bord] (Ja, oftast)

Det underlättar mycket att kunna ställa upp en dator och verktyg på ett bord så man slipper skriva upp värden med datorn i knät eller på golvet. (6/6)

För dator av bekvämlighetsskäl (Ja, ibland)

Vid längre pågående felsökning/programmering där arbete med laptop behövs (Ja, ibland)

Underlättar mycket [med rullbart bord] (Ja, oftast)

Räcker med plats för verktygsväska samt eventuellt filter och befuktare som skall bytas. Det måste iofs även finnas plats för eventuellt fläktbyte liksom för kompressor och förångare som kan gå sönder och behöva bytas. (2/5)

Bra hjälpmedel (Ja, oftast)

Eftersom att det ofta är många aggregat på en gång som ska servas så kan det vara skönt att kunna rulla med sig arbetsbänken, där den behövs såklart. (Ja, ibland)

Kan vara bra om man ska koppla upp datorn på maskinen (Ja, ibland)

Använder oftast golv och fickor (2/5)

Brukar gå bra med övriga ytor (2/5)

Oftast använder man golvet [för avlastning] (3/5)

Avlastningsytor gåt att skapa tillfälligt vid behov. (2/5)

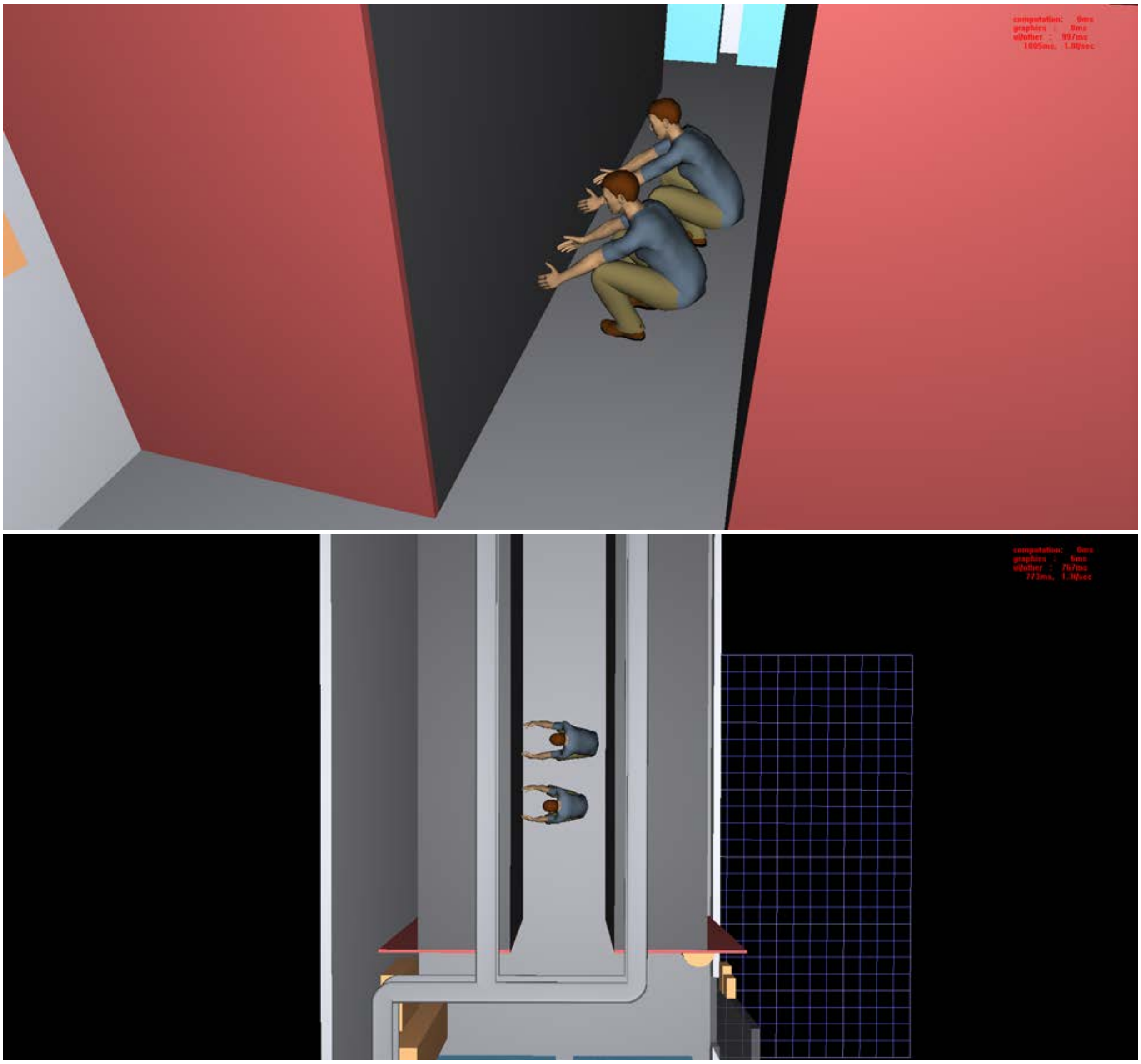
Iblan blir det mycket verktyg och då kan det vara bra att ha någonstans att lägga de man inte använder för tillfället itsället för på golvet. (3/5)

Behövs ej [rullbart bord] (Nej)

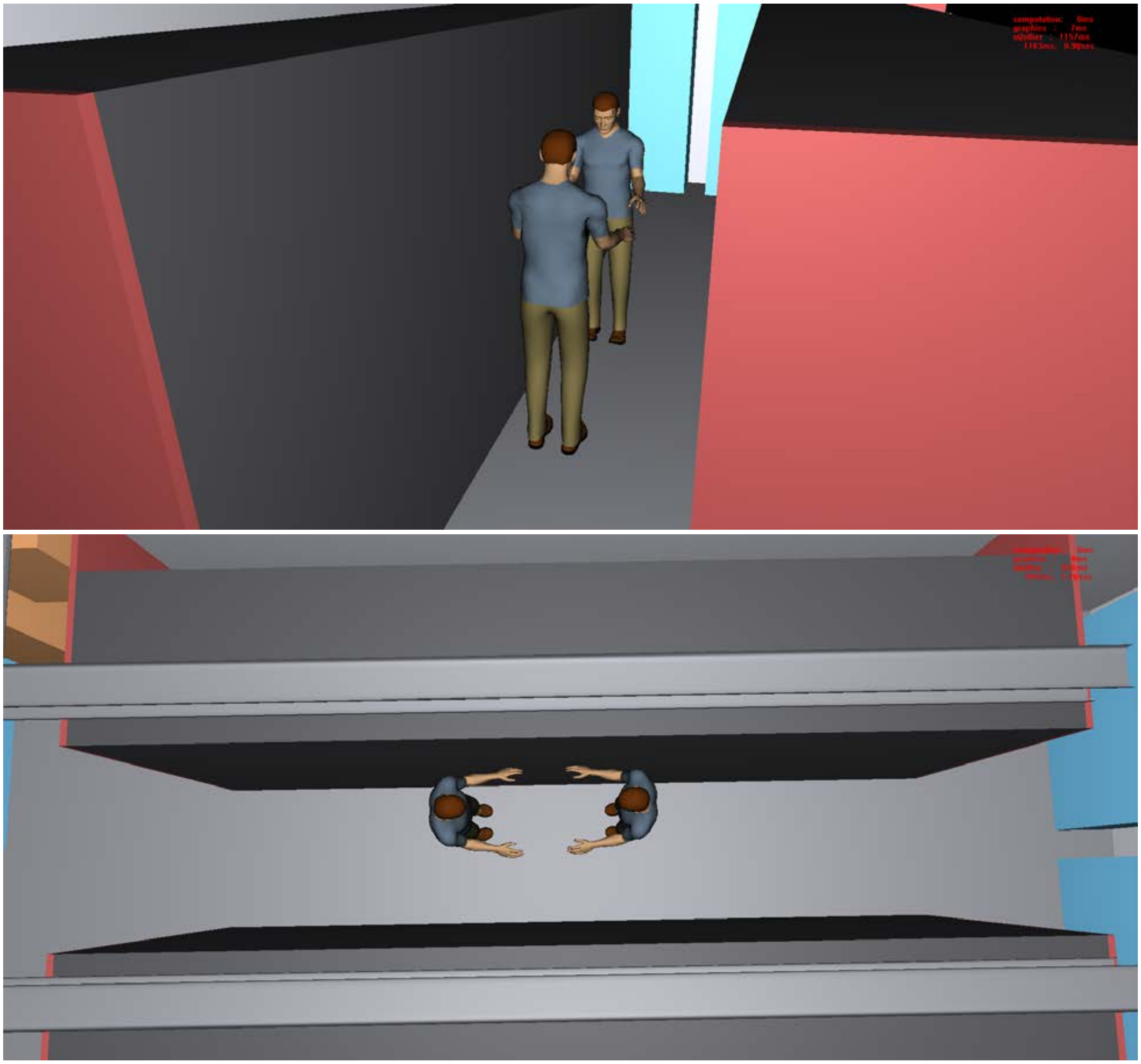
Behövs ej. (Nej)

Ej så relevant för den relativt korta tiden som service vanligtvis tar. Vid större arbeten så bytes förslagsvis större komponenter vilket gör det till ett in/ut-jobb. (3/5)

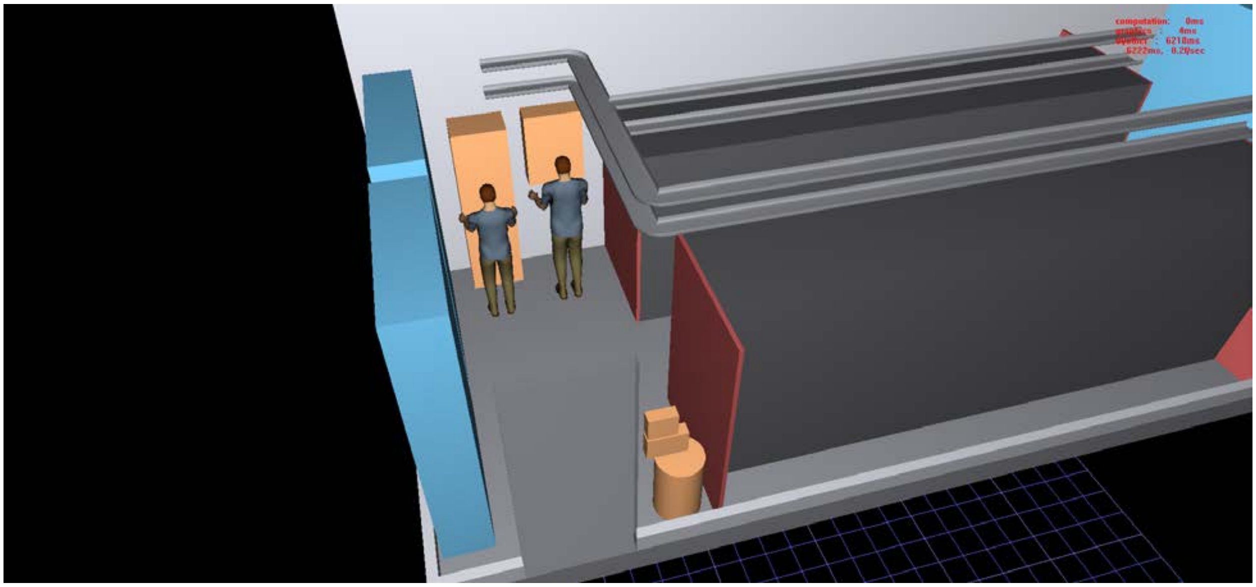
A8. Jack working space evaluation

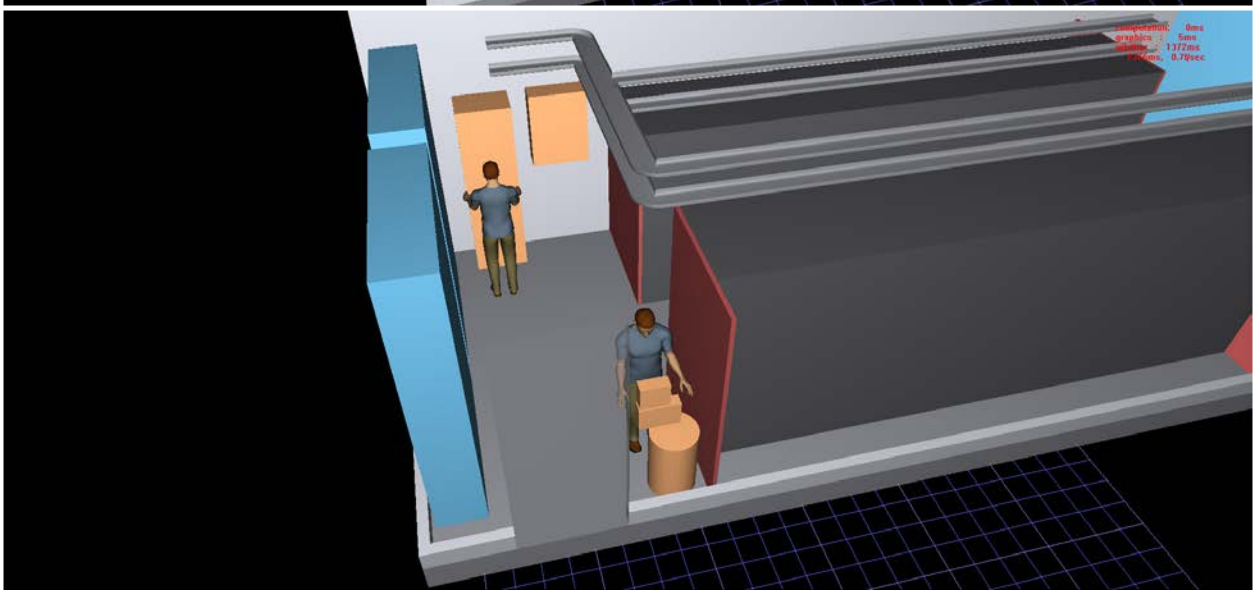


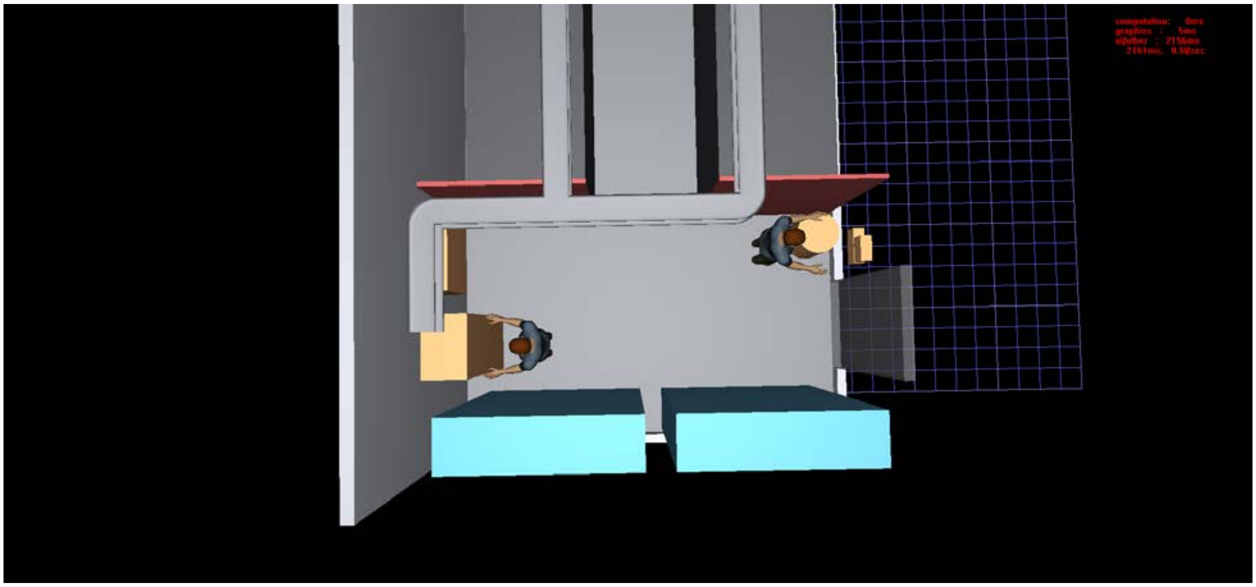
Squatting in cold aisle, both average male as well as 95th percentile male.



Cold aisle cooperation.







Spatial availability for multiple systems in the base part of the data center.

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