Aalto University

School of Science

Master's Programme in Computer, Communications and Information Sciences

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Energy Efficiency of Modern Datacenter

Master's Thesis

Espoo, May 26, 2018

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ABSTRACT OF THE MASTER'S THESIS

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Title of the thesis: Energy Efficiency of Modern Datacenter	
Number of pages: 7+61	Date: 26.5.2018
Major: Software and Service Engineering (Enterprise Systems)	
Supervisor: Martti Mäntylä, Professor	
Thesis advisors: Matti Tella, MS.c. (Tech.) & Kari Hiekkanen, D. Sc (Tech.)	

Digitalization is here and everyday more and more data are being stored or transferred over the internet. That means that more datacenters are needed and with their growing number the question is if this development is sustainable for energy efficiency. That is why this thesis studies what are the essential factors contributing to the energy efficiency, so the datacenter owners can maximize their energy efficiency and keep the outlook for future sustainable.

Through studying 3 datacenters here in Finland and holding interviews this thesis has gathered the following essential factors that contribute to the energy efficiency: business model, datacenter size, reuse of waste heat energy, location, renewability, transparency and open innovation. Concentrating on these factors and making sure that they align with their own business case, datacenter owners can make sure that they can also retain sustainability with their datacenters in future.

Keywords: datacenter, energy efficiency, reuse of waste heat	Publishing language: English

AALTO YLIOPISTO
Perustieteiden korkeakoulu
Maisteriohjelma Tietokone, Viestintä- ja Informaatiotieteissä

DIPLOMITYÖN TIIVISTELMÄ

Tekijä: Santeri Korhonen	
Työn nimi: Modernin Datakeskuksen Energiatehokkuus	
Sivumäärä: 7+61	Päivämäärä: 26.5.2018
Pääaine: Ohjelmisto- ja palvelutekniikka (Yritystietojärjestelmät)	
Valvoja: Martti Mäntylä, Professori	
Työn ohjaajat: Matti Tella, DI & Kari Hiekkanen, TkT	

Digitalisaatio on täällä ja joka päivä yhä enemmän dataa tallennetaan tai siirretään internetin yli. Tämä tarkoittaa, että tarvitaan yhä enemmän datakeskuksia ja niiden kasvavan lukumäärän vuoksi voi kysyäkin, että onko tämä kehitys kestävää energia tehokkuuden kannalta. Tämän takia tämä diplomityö tutkii mitkä ovat olennaisia tekijöitä energiatehokkuuden kannalta, jotta datakeskusten omistajat voisivat maksimoida heidän energiatehokkuutensa ja pitää tulevaisuuden näkymät kestävinä.

Tutkimalla 3 datakeskusta täällä Suomessa sekä pitämällä haastatteluita tämä diplomityö on kerännyt seuraavat olennaiset tekijät, jotka edistävät energia tehokkuutta: liiketoimintamalli, datakeskuksen koko, hukkalämmön hyötykäyttö, sijainti, uusiutuvuus, läpinäkyvyys ja avoin innovointi. Keskittymällä näihin tekijöihin ja varmistamalla että ne sopivat yhteen oman liiketoiminnan kanssa, datakeskus omistajat voivat varmistaa, että he säilyttävät kestävyyden myös tulevaisuudessa datakeskustensa kanssa.

Avainsanat: datakeskus, energiatehokkuus, hukkalämmön uudelleenkäyttö	Julkaisu kieli: Englanti

Preface

This thesis has been the culmination of my studies at Aalto University and being funded by Telia to work on this has been a great opportunity for me.

I would thank my supervisor Martti Mäntylä, my advisors Matti Tella and Kari Hiekkanen for guiding and inspiring me through the process of writing this thesis.

I would also thank my parents for always supporting me.

Espoo 26.5.2018

Santeri Korhonen

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Abbreviations

AC	Alternating Current
CRAC	Computer Air Handling Unit
DC	Data Center
DCIE	Data Center Infrastructure Efficiency
ERF	Energy Reuse Factor
ERE	Energy Reuse Effectiveness
IaaS	Infrastructure as Service
IT	Information Technology
OPEX	Operating Expenses
PDU	Power Distribution Unit
PaaS	Platform as Service
PUE	Power Usage Efficiency
SaaS	Software as Service
SPUE	Server Power Usage Efficiency
Telco	Telecommunications
TCO	Total Cost of Ownership
UPS	Uninterruptible Power Supply

1 Introduction

1.1 Background

Datacenters are a very current topic that has seen considerable publicity in recent years and for good reason, New York Times and Independent among the publishers (Bawden 2016, Wash 2013). Biggest reason datacenters have risen so much is because of the digitalization. Digitalization requires more datacenters as the data keeps growing constantly (Wash 2013). There have been some doubts whether this development is sustainable, and especially can the energy efficiency keep up with the constant growth of data (Bawden 2016).

Similar things can be seen from Telcom environment. Networks are changing from 3g to 4g and energy consumption is constantly multiplying. Also, the support grid for teleconnection need to be denser. (Vereecken 2011)

What is common to all these environments is that data is their business. Only difference really is whether they are storing or processing data. And whatever it is they all need is electricity. Electricity consumption is rising constantly. (EIA 2017)

Also, the rising energy consumption is something that people doesn’t seem to be too much caring about (Wash 2016). Honestly though they don’t really see the effects by themselves, but the operators of data do notice these developments. Environmentalism does these days give some pressure for the operators to watch for their energy efficiency though, but there often their aim is to appear environmental than to truly cut their revenue for overall better environmentalism. (Murugesan 2013)

Greatest question here is what is energy efficiency really? Energy is not cheap so there is good motivation to keep high energy efficiency. With datacenters there are for example borders for them to gain cheaper electricity taxes if their datacenters are big enough. In Finland it requires 5MW datacenters, but in Sweden it’s only 0.5 MW for example. (EK 2014, Business Sweden 2017)

Datacenters have long history behind them and it isn’t uncommon for there to be over 12 years old datacenters that are completely outdated these days. The biggest issue in datacenter overall energy efficiency is not how efficient exactly new datacenters are, but the old datacenters that inefficiently keep draining electricity and keep the overall energy efficiency for datacenters low. (IBM 2009)

Datacenters can also have multitude of different business models. Most common of these are mega datacenter/corporation datacenters for the personal use of the company holding the datacenter. This is the old way of making datacenters where the companies have big datacenter building or smaller ones in their basement to fulfill all the company needs. More modern solutions are co-location datacenters where data center operators offer location for companies to set up easily their servers without themselves needing to bother with datacenter upkeep. And then there are the cloud service datacenters that companies like Amazon, Google or Yandex use to operate their clouds. Estimations are that in future cloud service datacenters will dominate most of datacenter business and older ones will start to transfer into them. (CyrusOne 2018, Dignan 2018)

In this master thesis I have studied 3 different datacenter cases in more detail. They include the new Helsinki Data Center in Helsinki, Pitäjänmäki by Telia. Mäntsälä Data Center by Yandex and Tähtitorninmäki in Helsinki by Telia. These all represent very different kinds of datacenters. Pitäjänmäki being the newest one of them offering co-location services and fulfilling Telia's own Telcom needs. Yandex operating a cloud service data center for their search engine. Tähtitorninmäki being example of old datacenter that includes many kinds of operations inside it, including co-location and Telia's Telcom operations. I have also examined Finland as data center location and gathered some overall data on current situation.

1.2 Research Questions

The research questions on this thesis concentrate on the energy efficiency of datacenters, how the different business models and environments affect them and what are the most important factors for energy efficiency.

What are the essential factors contributing to the energy efficiency of datacenter with different business models including 1) co-location datacenter 2) cloud service datacenter and 3) telco rock shelter site?

What are the means for datacenter owner to maximize energy efficiency?

1.3. Contents of Thesis

I will first present and describe how datacenters work to have a clear picture of the energy requirements of such facilities and what operations there are critical for energy efficiency. Then I will continue to actual energy efficiency to see what it is all about, how it can be measured and of what it consists of. After that I will continue into the different business models the datacenters have and especially what kind of effect they have on energy efficiency. After that I will give an overview of Finland as datacenter location and what kind of operators there exist in Finland. In empirical part of the thesis I present all the 3 different datacenter cases describing the datacenters in more detail and what kind of solutions they possess for energy efficiency. I will be comparing the cases and showing how their different business models and environments affect their energy efficiency and why this is. In the conclusion I will present the factors that contribute most for energy efficiency with different datacenters and how the datacenter owners can maximize their energy efficiency.

1.4. Methodology

For literary review I have gathered different literature through Google Scholar, Scopus and the references given in other literature to gather overview picture what is known of the subject and how researches have answered to the topic. In empirical part I have visited 3 different kinds of datacenters. Datacenters being from Telia Tähtitorninmäki property and Helsinki Data Center at Pitäjänmäki, and to have a datacenter outside of Telia as a case I have also visited Yandex's datacenter at Mäntsälä. At each location I have interviewed experts on each datacenter as well as reviewed some of the confidential material shown by the operators of these datacenters. Also, I have had discussions with Invest In Finland and gained access to their material on datacenters in Finland.

2 Data Centers

2.1 What is Datacenter

Data center are centered, trustworthy and confirmed working environments for IT equipment in all simplicity. It includes cooling, power, supervision, UPS, fire security and reserve energy systems among other things. (Hoon 2014) IT equipment includes servers, routers, and switches. Data centers also possess some special qualities as buildings as they are combination of physical and technical properties. Their location is critical for planning the datacenter and the lifecycles of datacenters are much shorter than many other buildings. (Hoon 2014)

History behind the data centers is a long one reaching to the 1940's when first computers were originally made, and they required large server rooms for the huge computer machinery. (IBM 2009) This changed in the 1970's when microcomputers were invented and there was no need for such large rooms anymore. In the 1990's more modern servers were created and with the IT-bubble servers became popular. Finally, at the start of 21st century when cloud services became dominant data centers truly became prolific. (IBM 2009) Development of data centers is swift and even 7 years old data centers are considered obsolete by modern standards. Still average data center age is 12 years, so there is still lots of history inside many data centers. (IBM 2009)

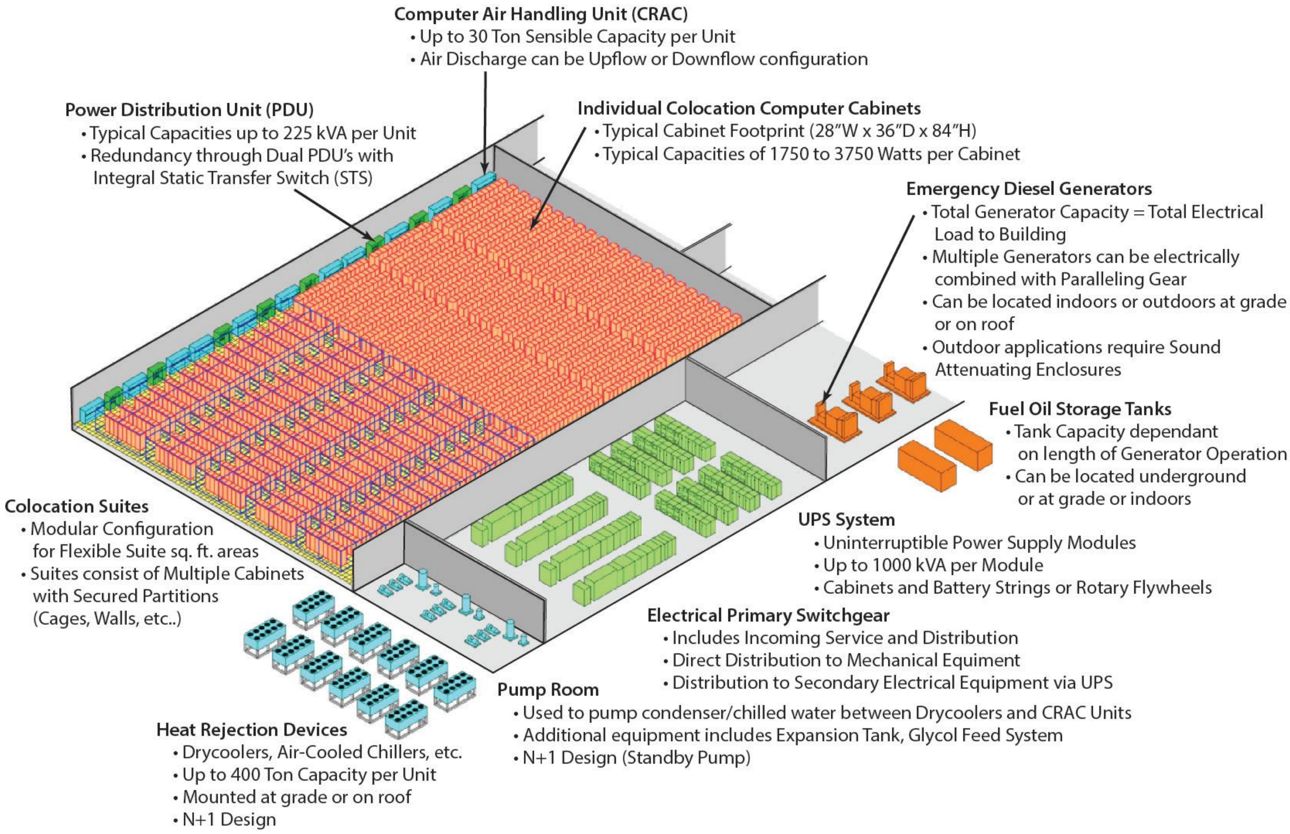


Image 1. Typical Data Center (Barroso 2013)

2.2 Data Center Power systems

There are many kinds of important equipment inside the Data Centers to keep them up. One of the most critical are the power systems. Such as transformers, reserve power systems, batteries, and generators. Commonly the main power comes from national electricity networks and generators are being used for reserve power. (Barroso 2013) Power sharing system which offers the reserve power, adjusts the voltage and changes into AC power when required (Brown 2007). The point of all these reserve systems is that when something fails there is another one to keep up power. This is redundancy and takes some extra expenses but also very critical to reach high levels of trustworthiness. (Brown 2007) Service providers do desire to reach 100% availability for their services and power upkeep must be secure that this can be reached. (Laitinen 2011) UPS is the reserve system that makes sure that there are no breaks in power input and works as reserve copy for the system. (Brown 2007) Basically what it does is that it protects the equipment from under or over voltage, prevents data from getting destroyed or lost and enables high usage for networks.

2.3. Datacenter Cooling

Cooling equipment is another very critical part of data centers and especially considerable part of the expenses data centers have. There are lots of data going through telecommunication networks and it heats up IT-equipment. And this heating up causes disturbances in the equipment. And this lowers their reliability and shortens their lifecycles. (Beloglazov 2010) Especially as the microprocessor industry is constantly advancing and more of transistors are fit for the chip and the clock rates keep climbing up and all this considerably rises the heat dissipation density. And the most common cause of component failure is high temperature. Cooling system needs to reach full environmental control that includes air temperature, humidity, and pollution concentration. (Capozzoli 2015) Also almost all the power in datacenter is converted into heat, a proper cooling system is simply a requirement. Cooling system should be highly energy efficient, have a low cost and be reliable (Capozzoli 2015).

In the white rooms where IT equipment is kept the floors are usually ascended so cooling equipment and cables can be hidden beneath the floor. The roof also might be descended so cables can be hidden there as well if possible. Floor is basically a grid that is covered with plates. The pipes beneath the floor push the cold air for IT equipment (Cisco 2011).

Air cooling is the most common cooling solution today. It is commonly based on ventilation machine that transfers the cooled air to the racks through the ascended floor. The cooled air then goes through the IT equipment and removes the waste heat behind the racks. (Cisco 2011) In modern settings it is advisable to avoid the mixing of hot and cold air as that weakens the efficiency of ventilation. This is the reason there are specific hot and cold spaces between racks. Hot air is also lighter than cold air, so it rises from the IT equipment and circles back up to the ventilation systems where it goes through inductor which is filled with cooling fluids and then circled back down to cool again the IT equipment. (Cisco 2011)

Typically, cooled air is around 16-20 degrees (Dai 2016). Many though keep the temperature too cold as actually the highest allowed temperature for servers is 27 degrees and keeping it too low only spends unnecessary energy. (Laitinen 2011)

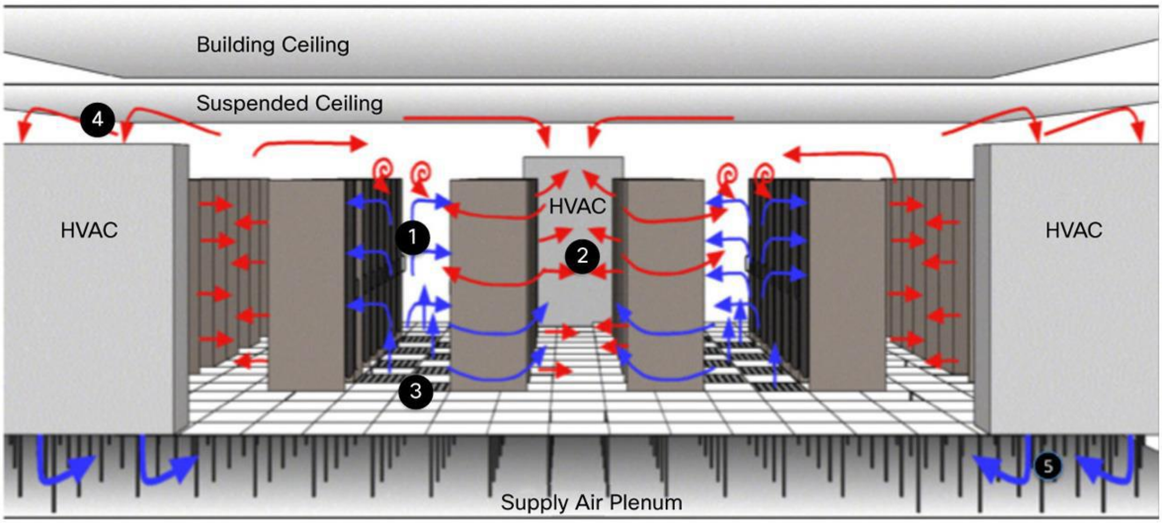


Image 2. Typical example of air flow diagram (Cisco 2011)

Water cooling is the second popular option for cooling. It's a newer and energy efficient option for data centers. (Stenberg 2015) In this solution water is used to transfer the warmth. Every rack has their own cooling fluid circling. Cooling fluids are brought as close as possible to the IT equipment, so the spaces around the racks are not cooled and cooling power goes directly into the IT equipment. (Stenberg 2015) Liquid-based cooling systems also allow higher PUE values traditionally than air cooling with air cooling having 1.48 for example and similar liquid cooling 1.14 PUE. (Capozzoli 2015)

Finally, Free cooling is one more option. In it the environmental temperatures are used to benefit the cooling. Lakes, sea, cold outside air, and similar environments can be used for this. System is based on transferring naturally cold air or water through transference of cooling into the datacenter with cooling water. In this we don't need specific ventilation machines and we don't need energy to constantly cool the water with every cycle it goes through the IT equipment. If the environment allows for this, it is usually the energy efficient solution. (Laitinen 2011)

2.4. Data Center Misc. Systems

The other equipment data centers have includes house techniques such as fire alarm systems for fire security (Siemens 2015). As well as passage control systems for automatically supervising data center activities. This can be controlled by centralized system that optimizes the energy usage with controlling cooling equipment/power sharing systems/lighting of the rooms and all security systems. (Rittal 2018)

Then there is the actual IT equipment like the servers, routers/switches and all the supervisory and upkeep equipment for data center. IT equipment are kept inside of racks and as they are producing lots of energy that transfers into heat they are cooled to avoid overwarming and shortening of their lifecycles. (Lettieri 2012)

2.5. Data Center Tiers

Another very specific system used to compare data centers on their equipment is through tier levels. There is a certification system based on TIA-942 standard developed by Uptime Institute. There are 4 different levels of tiers and depending on their reliability and other modifiers datacenters can apply for different levels between 1 and 4. (Uptime Institute 2012)

Table 1: Tier Requirements Summary

	Tier I	Tier II	Tier III	Tier IV
Active Capacity Components to Support the IT Load	N	N+1	N+1	N After any Failure
Distribution Paths	1	1	1 Active and 1 Alternate	2 Simultaneously Active
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerance	No	No	No	Yes
Compartmentalization	No	No	No	Yes
Continuous Cooling	No	No	No	Yes

Image 3. Tier Requirements (Uptime Institute 2012)

2.5. Data Center as Investment

Data centers are costly investments of multiple hundred million euros for larger facilities and are comprised of multitude of costs. Capital costs of site infrastructure and IT are over 70% of total annualized costs. Energy costs and other operating expenses take rest. (Koomey 2007) 10% taken by energy costs might not sound as huge, but it is big amount when this 10% comes from hundreds of millions of euros. So, there is a good motivation for datacenter operators to optimize energy costs all the way from planning the investment on building the new datacenter. Below is an example of partially used datacenter total costs of ownership to represent somewhat more realistic picture how the costs look to many operators. (Barroso 2014)

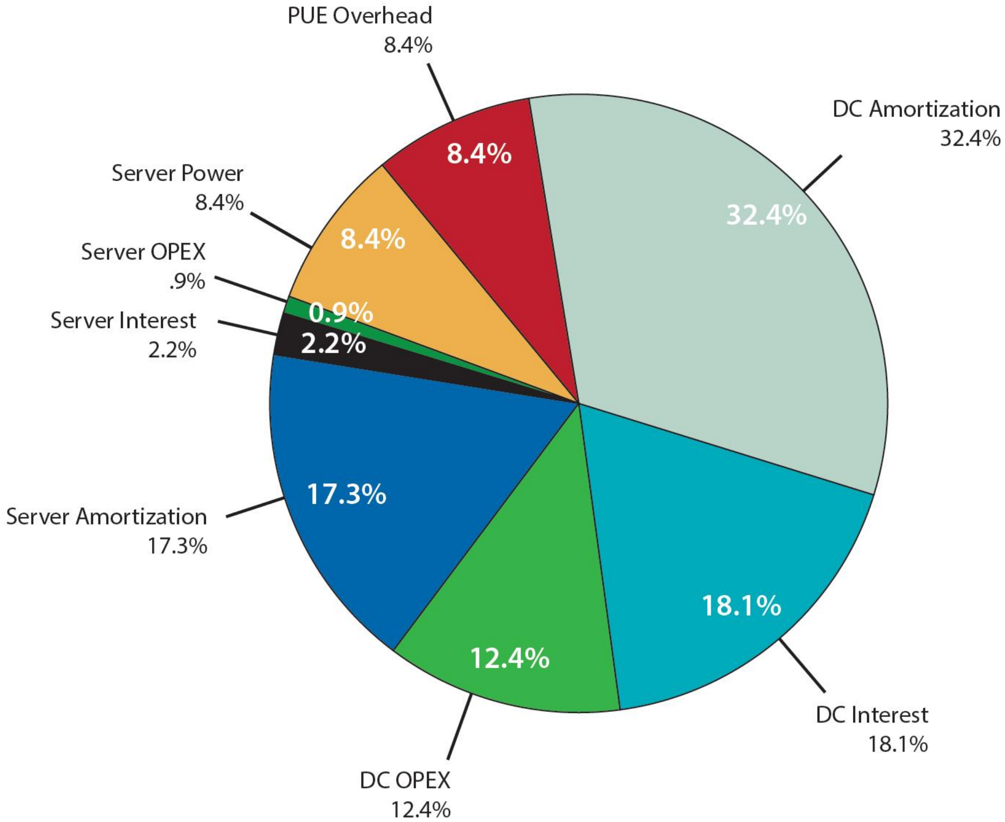


Image 4. TCO example for a partially filled datacenter (Barroso 2014)

When considering the investment on building datacenter there are some special considerations to process. Lehtoniemi (2017) has presented few most important properties to consider: business model, geographical factors, property factors, facility factors, energy and waste heat, telecommunication networks and security. For facility investors business model, geographical factors, property factors and facility factors are usually the most important ones. For datacenter operators then the focus is on telecommunication networks, energy, and waste heat. Both parties are considering their own requirements for revenue. (Lehtoniemi 2017)

3 Energy Efficiency with Datacenters

Energy is very expensive and as such energy efficiency is a very important consideration for datacenter operators. Traditionally this hasn't been as clear for datacenter operators as reliability has been the most important consideration, but today with environmentalism and better methods for energy efficiency it has become a high interest for all operators. (Avgerinous 2017)

3.1. Energy consumption

Energy consumption is very considerable with data centers and with it the energy efficiency. When 50% of the operating costs comes from energy expenses you need to be efficient in it. (Nissilä 2015) Already between years 2000 to 2005 the energy consumption by data centers was doubled and in 2010 1,3% of world's energy consumption went to Data Centers. (Koomey 2011) In 2016 already 3% of world's electricity with 2% of the greenhouse gas emissions was produced by datacenters. That makes them equally as big consumer as airline industry. (Bawden 2016) These developments have made energy efficiency as competitive factor for datacenters to truly aim for. (Laitinen 2011) Energy expanses also are quite linear with couple server racks being few kilowatts when big mega datacenters like which Google have go for 100 Megawatts.

The biggest energy consumption targets are the servers with their IT equipment and cooling. For example, in Finland servers use 46% and cooling 23%. (Laitinen 2011)

The idea behind in aiming for high energy efficiency is to enable low energy costs, low gas emissions and excellent productivity. (Brown 2007) These can be achieved through automatization, lighting of the data center, optimizing cooling and UPS. Simply by having equipment that are energy efficient and taking benefit from waste heat can bring a long way already. (Laitinen 2011)

3.2. Energy Efficiency Losses

In a typical and conventional older datacenter most of the energy efficiency losses come from cooling overhead. Power losses when transforming the voltages of electricity coming into the datacenter is another source of energy efficiency loss albeit smaller than with the cooling typically. Historically efficiency has not been important criteria and only in recent 5 years the situation has started to considerably improve. (Barroso 2013)

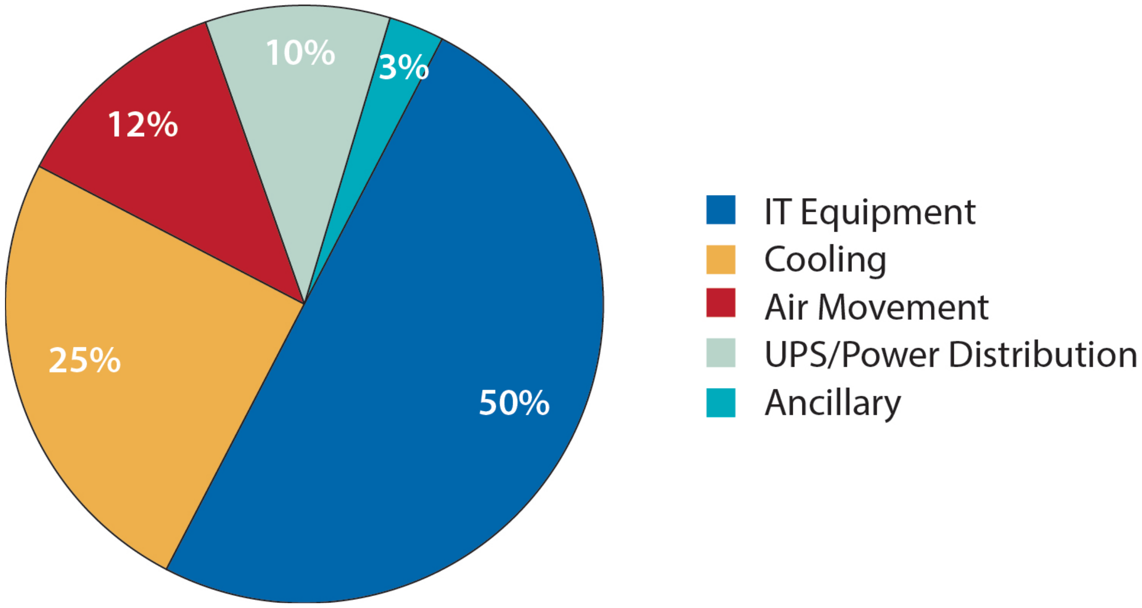


Image 5. Power Losses in a typical older datacenter of PUE 2.0 (Barroso 2013)

Typical steps to improve the energy efficiency and minimize the losses include better air flow handling, elevated temperatures in cold aisles, free cooling, and better power system architectures. (Barroso 2013) These steps are easy to achieve and are already done with modern datacenters that are built these days. But improving further when most losses are dealt with is much harder. In mechanical and power conversion side there is not much to improve, but more possibilities lie with computer science and engineering for new solutions. (Barroso 2013)

Most important steps in energy efficiency that can be still improved is to better manage the power and the energy so operational costs are minimized. Much of the overall facility cost comes from the power as the construction cost is highly defined by the maximum power draw the facility will have. (Barroso 2013) The energy use in overall determines the electricity costs of the facility and often datacenters do not reach their full power draw eliciting waste costs. With power capping or other management solutions this can be partially done, but for the sake availability there need to option to reach peak power in case of emergency of increased traffic or because of another datacenter failing. (Barroso 2013) Another is how the power usage acts with light loads. The less power the facility is using compared to its maximum power draw, less efficient it usually is. With better hardware control turning off hardware which is not needed this can be achieved, but it requires software able to manage all the servers when needed. (Barroso 2013) Some high-tech datacenters as with Yandex are already reaching into this. Also, energy optimization requires an excellent coordination between all the way from hardware to application they are used on. One suboptimal part of the chain can greatly degrade the efficiency and it is not easy to have one system that can manage and control through the full chain. Most important still is to keep the servers on constant use, servers not utilized only spent energy without no benefits. (Barroso 2013)

3.3. Energy Efficiency Metrics

Energy efficiency is also very interesting metric to compare when possible. There are few popular metrics that are commonly used. Power Usage Efficiency (PUE) is the most commonly used metric. It tells how much of the consumed energy goes to the IT equipment. The lower the number the more efficient is the data center. An average value for PUE metrics was 2 at 2005. In 2011, it was predicted to be around 1.9 and was counted we ideally could reach 1.2 PUE. (Barroso 2013) PUE though is not a very good metrics ultimately as some companies have strategies that only improve the PUE without caring for the big picture. (van de Voort 2017). Data Center Infrastructure Efficiency (DCIE) is another quite common one. It describes the ration between the centers' infrastructure's energy consumption to IT equipment energy consumption in percentage. (Wright 2014)

PUE = (Facility power) / (IT Equipment power)

Barroso (2013) also believes PUE metric though is not a good metrics as the measurements are not similar between datacenters with different overheads and there is a huge difference between average PUE and what it may in best cases be for a short moment in a very cold winter night for example. Also, vendors might use design PUE numbers for optimal conditions according to calculations without actual details to support these. Also, if PUE is calculated manually or don't have enough meters to fully measure all of datacenter the values might have error margins. (Barroso 2013) Basically PUE should be measured constantly in real time, so operators can see how it acts through different times and notice mistakes somewhere faster if the values are different than what is expected. (Barroso 2013)

One way to improve metrics is to combine different metrics into one in attempt to reach better energy efficiency metric. Barroso etc. (2013) have offered one of their own where they have PUE, SPUE and the energy efficiency of computing combined into one. This includes the Server Power Usage Efficiency(SPUE) besides the facility's PUE as well the computing efficiency in a more total metrics of the facility's energy efficiency. (Barroso 2013)

$$\text{Efficiency} = \frac{\text{Computation}}{\text{Total Energy}} = \underbrace{\left(\frac{1}{\text{PUE}}\right)}_{(a)} \times \underbrace{\left(\frac{1}{\text{SPUE}}\right)}_{(b)} \times \underbrace{\left(\frac{\text{Computation}}{\text{Total Energy to Electronic Components}}\right)}_{(c)}$$

Image 6. Data Center Energy Efficiency Metric (Barroso 2013)

Green cloud is a known producer of different metrics and they have been long working to develop their metrics that aim to improve the energy efficiency and PUE is just their most famous one. (Wright 2014). There are others with similar and aims and The Green Grid specifically has made a metric called Energy Reuse Effectiveness (ERE) that especially tries to determine how green is the energy efficiency in datacenter. (Patterson 2012)

3.4. Energy Efficiency History and Statistics

Energy Efficiency historically hasn't been as big requirement as old datacenters used so much less energy. Old data centers were relay based and didn't really need that much energy, so consumption was counted at kilowatts even for whole datacenters of 1970s or 80s. (Karjalainen) Nowadays it is of course much different with more efficient equipment and computing requiring easily megawatts even for smaller buildings. 15 years ago, also people stored their data on PC's when now they are in the clouds and accessed through mobile devices. So, the energy consumption required of data centers is massively different. In overall datacenters have through time changed from smaller basement datacenters towards modern large well optimized datacenters operated by with highest energy efficiency. (Barroso 2013)

Location is also critical component in energy efficiency. Locating the datacenters near where electricity is produced it gives a steady and efficient way to gain access to electricity for datacenter. (Li 2017) Also, it gives an opportunity to possibly return waste heat for the electricity company back if they can process it through district heating for example. One global example of this is Western North Carolina where Google, Apple and Facebook have their mega datacenters magnitudes of 40-100 MW between them. (Li 2017)

Also, it is good to note that half of the actual energy consumption made by data centers are produced by the small and medium sized companies. Even though the big data centers are more seen on the news and more public, there are still lots of small and old datacenters in the cellars of companies. (Li 2017) Also as companies have historically neglected the energy efficiency the average in data center scene if not calculating the well-known and public mega datacenters etc. is quite bad in energy efficiency. Average datacenter might waste even third of its power easily. (Barroso 2013)

Data centers naturally have a very high energy intensity when compared to regular commercial buildings. This difference can be even 100 to 200 times higher for data centers. (Huang 2015) Improving this intensity from inefficient to efficient has been noted as one of the biggest opportunities in improving energy efficiency. Usual failures here are with power infrastructure, cooling, airflow management and information technology. Opportunities here could include having more efficient server and data storage equipment and managing the servers and data storages with more efficiency. Virtualization is also key method that has been embraced with improving the efficiency. With virtualization multiple applications can be run with one physical server instead of them each having their own servers. (Huang 2015)

There are lots of datacenters in the world. 2012 there was over 500 000 datacenters consuming as much energy as 30 nuclear plants can provide for. (Glanz 2012) 2013 the datacenters in USA used 91 billion kWh of energy and that was double of what city of New York would require to be powered. It was expected then that the energy consumption would keep rising to 140 billion kWh in USA alone. (Zik 2016)

3.5 Reusing Waste heat

Datacenters naturally produce lots of waste heat. It is removed from the centers either through cooling water, removal air or getting processed by the cooling machines. This is something that data centers should aim to take benefit from. (Stenberg 2015) Some simple solutions are to use the heat to warm up the data center and buildings nearby. The only requirement here would be that the utilization of waste heat is cheaper than the energy it would be used to replace. (Laitinen 2011) There still exists many kinds of techniques that can be used to capture the heat recovery. District/plant/water heating is among the simpler ones, but also absorption cooling, direct power generation such as piezoelectric or thermoelectric can be used. Also, indirect power generation, biomass co-location and desalination are included in a list of techniques that have been studied for this. (Ebrahimi 2014)

What solution is most suitable for waste heat recovery depends on how the cooling is done on datacenter. Water cooling or two phased cooling grants higher quality waste heat streams than with air cooling, and as such almost all solutions are possible with it. (Ebrahimi 2014) In study absorption cooling and indirect power generation with organic Rankin Cycle were found as the most promising ones. Absorption cooling offers extra source of chilled water for additional cooling load and indirect power generation with organic Rankin Cycle grants direct electricity generation from the waste heat stream onsite. (Ebrahimi 2014)

Many datacenters just pump the waste heat out, but it has become more common for data centers to start using it for their benefit. If the data center use district heating, this energy can be sold to electricity companies for their use in their districts. (Stenberg 2015) Electricity companies consider data centers as the second most interesting source of waste heat after forest industry. (Bröckl 2014) Data centers can use heat pump to utilize their energy into district heating networks. Utilizing the waste has been calculated to bring very considerable savings to lifecycle costs and in improving the energy efficiency. (Stenberg 2015)

Green cloud has built architecture models to lower datacenter energy consumption and costs with the aim of ensuring their efficiency at the same time. (Liu 2009) Also in cooling the free cooling is especially known to be extremely efficient in improving energy efficiency. (Malkamäki 2012)

3.6 Environmentalism

Environmentalism is another important factor in energy efficiency and it's especially important for the public image of the company and brand behind the data center. If environmentalism also improves energy efficiency that's nice, but honestly, it's often just for the public image. Green Data Centers are one term used with data centers and environmentalism. (Murugesan 2012) The basic idea is to minimize harmful environment effects from the use of technology. In Green Datacenters all IT-equipment, building systems and everything is planned from the start with environmental point of view. Especially using of renewable energy sources is the main principle with green data centers. (Murugesan 2012)

Renewable sources are another thing that some companies market their datacenters with. Renewable sources can be good in reducing energy costs and peak power costs in some cases, but they also have own problems. For example, wind and solar power have lots of fluctuations in their production and data centers require constant electricity for upkeep. (Li 2017)

In 2016 data centers consumed 3% of world's electricity and produced 2% of the greenhouse gas emissions. This is as much as airline industry consumes and produces. (Bawden 2016) Data centers also aren't becoming any smaller phenomenon, so their consumption is expected to rise. Going full of renewable sources isn't solution either as it still would be too big strain the global power systems. (Bawden 2016) So, data centers are an ever-rising part of the global warming crisis.

3.7 Cost-Efficiency

Companies doesn't want to improve energy efficiency just for the principle of it. They seek many kinds of benefits from it. Cost-efficiency is one of those things. Energy efficiency directly improves the cost-efficiency so there is a one good reason straight away. (Brown 2007)

Building any kind of datacenter is an expensive and long project. Of course, having smaller machine hall in basement is quite common for smaller or medium companies but that is not often that efficient solution cost wise. Another thing with data centers is that they get obsolete fast and it's not easy to most companies to transfer into new things. (Barroso 2013) Data Centers are expensive to build, and the lifecycles are not that long. It is a long investment that many companies are not eager to look for. That's one of the reasons why colocation datacenters are excellent options for smaller companies that have no need for mega datacenter levels of cloud and servers. Of course, in the future, companies probably need less and less actual own physical servers and will slowly transfer into cloud services. It is usually much cheaper to buy the computing as cloud service than use your own machines that probably just are dusting on racks without much use at least good portion of days. Cloud services are optimized for full constant use and they can be much more cost-efficient in service providing than what smaller companies can optimize with few of their own servers with not constant use. Cost efficiency is what all the companies want from their projects and as energy efficiency has become increasingly important cost driver as well it has become a major part when designing datacenters (Barroso 2013).

4 Data Center Business Models

There exist three most common different business model categories that data centers can be used with. The mega/corporation datacenters, colocation datacenters and cloud services.

4.1. Mega/Corporation Datacenters

Datacenter built for single corporation are the most common previous model on datacenters. These are slowly becoming more uncommon, but still hold a huge portion on the older datacenters. Mega datacenters specially then are huge corporation datacenters that are built on huge properties and are always significant investments. These are made for single user such as Google for example. (Rath 2011) The idea behind building these huge centers and only for one customer is to save in expenses and maximize the reliability when everything can be optimized and tested only for the single requirement. (Barroso 2013) Though as the cloud services are becoming more common, most of the mega datacenters are changing slowly into cloud service datacenters. In energy efficiency viewpoint mega datacenters benefit from being built for clear single objective and being operated by single entity from beginning to the end and as such can be well optimized.

4.2. Co-location Datacenters

Colocation datacenters instead are made for multiple users. The operator operating the datacenter offers the services of the center such as the energy, cooling, racks, telecommunication networks and IT-equipment services. (Toivonon 2016) These are smaller centers than the mega datacenters and easier and less risky for users to use than building their own datacenters. Pricing is usually based on monthly rent and this is a much smaller investment with better security and technology than just putting up your own racks in company basement. (Deloitte 2014) The users just rent racks, space from racks or capacity from cloud services as much as they require. They don’t need to pay from anything they don’t need. In Finland Tieto, Equinix and Telia for example offer Colocation services. From energy efficiency viewpoint co-location datacenters are slightly more problematic as the datacenter operator can’t control everything inside their datacenter as clients can bring their own servers. Also, with co-location datacenter it’s rarer for datacenters to run with full capacity making datacenter naturally more inefficient.

4.3. Cloud service Datacenters

Cloud services are third kind of business model for Data Centers. Cloud services and cloud computing are basically a model for enabling on-demand network access to shared computing resources. (Mell 2011) Most important characteristics among cloud services are the on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. Cloud services are also further categorized into multiple groups inside of them. First by deployment model. Private Clouds are for just single user or organization. Community clouds are for specific community that have shared concerns. Public Clouds are for then larger groups of users that represent the public. Finally, there also exists Hybrid clouds that are combinations of some of the previous but are bound together with standardized technology with application portability. (Mell 2011) The basis with cloud services is to only pay from the time and capacity used. (Ambrust 2010) On service side then there are three different models how the service can be provided. IaaS (Infrastructure as service) offers the physical and virtual resources fully for the use. PaaS (Platform as service) offers application platforms and infrastructure to the user. And SaaS (Software as a Service) offers all the applications, installing, upkeep and updates for the user to be payed depending how much is used. (Salo 2010, Mell 2011) Amazon Web Services, Microsoft's Windows Azure and Google App Engine are some of the most dominant past cloud services (Zhang 2010). Facebook, Dropbox, and YouTube are all also some examples of cloud services. Cloud service datacenters also have similar energy efficiency benefits as with mega datacenters. They are operated by single entity and can fully optimize their operations. Also, cloud grants them extra benefits as they can easily share their loads between different datacenters and easily control that all can run at the optimal capacity.

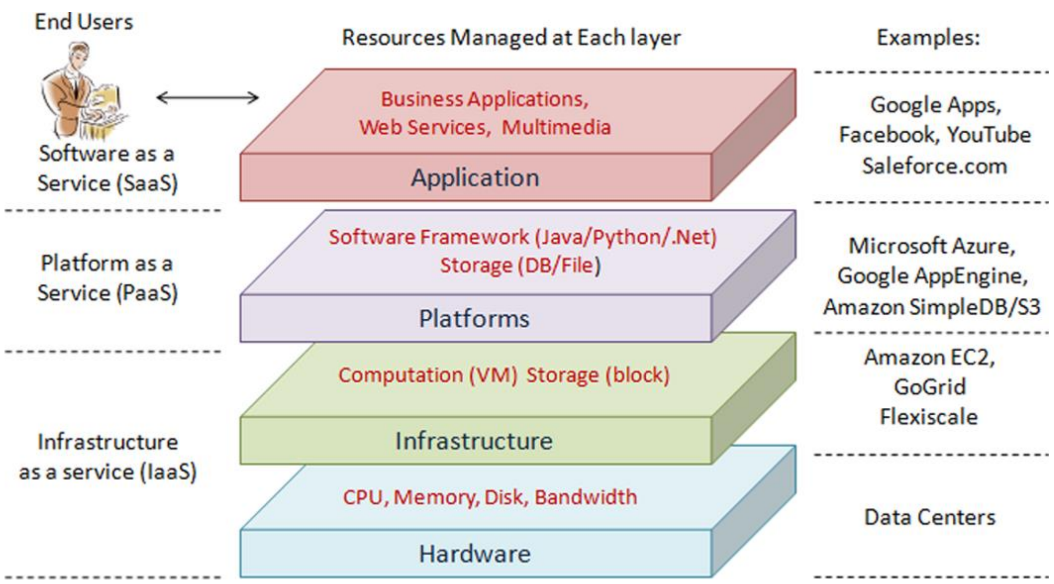


Image 7. Cloud Services Architecture (Zhang 2010)

4.4. Other Datacenter types

Beside the previous 3 different kinds of datacenters, datacenter function can also separate between them as well. Most commonly between corporate business, internet service and telecommunications. Internet service datacenters store websites and connects sites and applications between each other on internet. (Louwerens 2014) These are quite often cloud service based today. Then telecommunication datacenters enable telecommunication grids and are often situated around the area to have full coverage for networks. (Louwerens 2014) Telia for example have some telecommunication network activity practically in all its datacenters. Then corporate business datacenters which are centered on supporting corporation's own business are traditionally on their own corporation datacenters but these days they can be co-located or even on the cloud. (Louwerens 2014)

The basic idea of Co-location datacenters also has some different variations for business models. When traditional co-location datacenters have lots of small and medium sized companies as clients, wholesale datacenters have even larger capacity and have only few very big customers. (CyrusOne 2018) Dedicated hosting is another way to operate where server capacity is offered for single customers with usually no additional services. Managed hosting is another version of this with more detailed additional services offered for customers. And finally, there is shared hosting with the customers sharing the same server capacity and operator offering user interfaces for clients to configure their services. (CyrusOne 2018)

4.5. Comparison of Business Models

All these business models have very different business environments. Corporation and cloud service datacenters are built solely for their own use and as such they are not as major part of the actual business value as the colocation datacenter is for their own operator. (Barroso 2013) For cloud services the cloud is their business and datacenters are just obligatory costs for upkeeping the cloud. For co-location operator they are selling their racks for clients and they need to sell their business idea for clients. Also, if co-location datacenter is down, the whole business of that operation is down and not making money. For cloud service provider losing one datacenter is not a big deal, it costs money, but the service remains up through the multitude of other datacenters and users probably won't even notice the difference.

In energy efficiency perspective cloud and corporation datacenters have clear advantage in their procedures as they have full control. They might have not similarly high interests on actual energy efficiency as they don't need to sell their efficiency values for customers and they have more money to spend on datacenters, so they might produce more revenue by investing on different areas than the energy efficiency of their datacenters. Of course, they aim for best energy efficiency as possible, but they won’t consider as major investment focus. For colocation datacenters selling their PUE values is more valuable and as such look to gain every benefit possible even though they can’t control the server efficiency of the clients and every matter in the datacenter.

Business model dictates much on how datacenter operators approach energy efficiency, but ultimately it is about how cost efficient is it for them. There are ultimate approaches this for example with bit mining where some operators basically set up a datacenter inside a barn as cheap as possible to mine bits to cover the costs soon as possible and not caring about power failures or the lifecycle of the datacenter as it is all temporary. (Datacenter Dynamics 2015) These are rare exceptions though and ultimately it the balance between cost-efficiency and energy efficiency for optimal results that matters.

5 Data Centers in Finland

5.1. Finland as Datacenter Location

Finland as a location is geographically competitive for data centers. Finnish climate is very appropriate for cooling solutions. Also, the location between Europe and Asia connects many networks. Politically stable nation with minimal society problems is also liked by data center investors. There also are no earthquakes and stable granite bedrock which makes Finland one of the most hazard free locations in World. (Invest In Finland 2018)

Finnish data center scene has lots of small data centers or “tele halls”. Recently though Finland has become quite hot spot for new data centers as Finland has geographically many advantages. The coldness, location etc. AT 2012 Finland had 2800 datacenters and among them 5 of them spent over 5MW of electricity. (Nissilä 2015) But even with these there are still lots of old centers and it’s not easy for companies to get rid of their old small centers and change into bigger and more efficient ones.

Some big players here in Finland at datacenter business are Google(Hamina), Yandex(Mäntsälä), Telia (Helsinki, Pitäjänmäki), Hetzner(Tuusula) and other telecommunication companies Elisa and DNA have something as well at least for their telecommunication services. (Invest In Finland 2018)

Google’s Datacenter in Hamina is especially well known and has been seen on papers often. It’s built on old Stora Enso’s paper mill and uses seawater for free cooling and is one the most modern datacenters Google has built. (Google 2016b) It was an investment of over 800 million euros for Google. (Nissilä 2014) Hetzner Online has a colocation center at Tuusula. (Finpro 2015) Also CSC and IBM have built extremely efficient datacenter at Kajaani. (CSC 2014)

Basically, why all these datacenters have been placed in Finland is because of our location and politics. The Climate is cool and very suitable for energy efficient solutions. Our politics are stable, and our electricity grids and telecommunication networks are stable and reliable. Overall, Finland is very competitive location for Datacenters. (Data center risk index 2016) Also government and local industry desires for foreign investments and supports them. Invest in Finland being one example of these supporting organizations. (Gearshift group 2014)

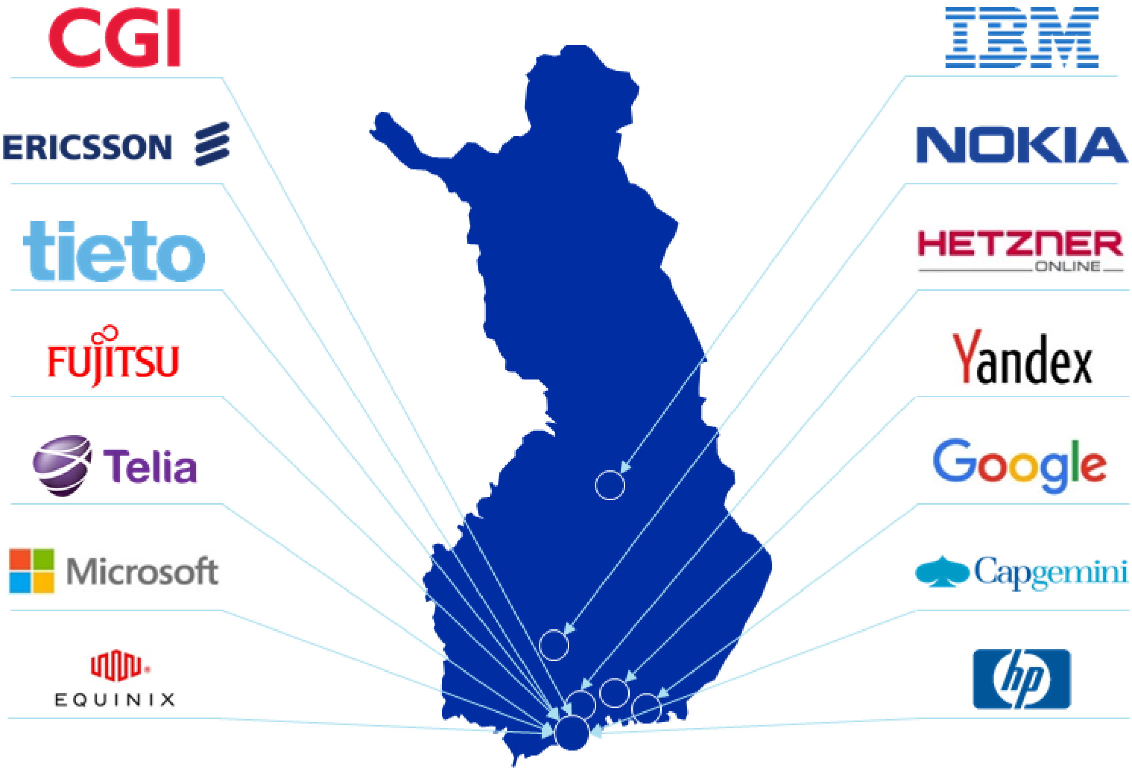


Image 8. Global Corporations in Finland's Data Center Business (Invest in Finland 2018)

Finland has some global major corporations that have set up businesses in Finland including corporations like Google, Microsoft, and IBM. Google has the largest capacity in Finland at single datacenter, but Telia, Hetzner Online and Yandex are other examples of major companies having considerable sized datacenters in Finland. (Invest in Finland 2018)

Data Center Operator	Total Capacity (Estimated)
Google	Ca. 20 MW (Exists differing estimates)
Telia	30 MW (When HDC is finished)
Yandex	10 MW (40 MW when site fully finished)
Equinix	20 MW
Hetzner Online	20 MW
Fujitsu	10 MW
Microsoft	10 MW

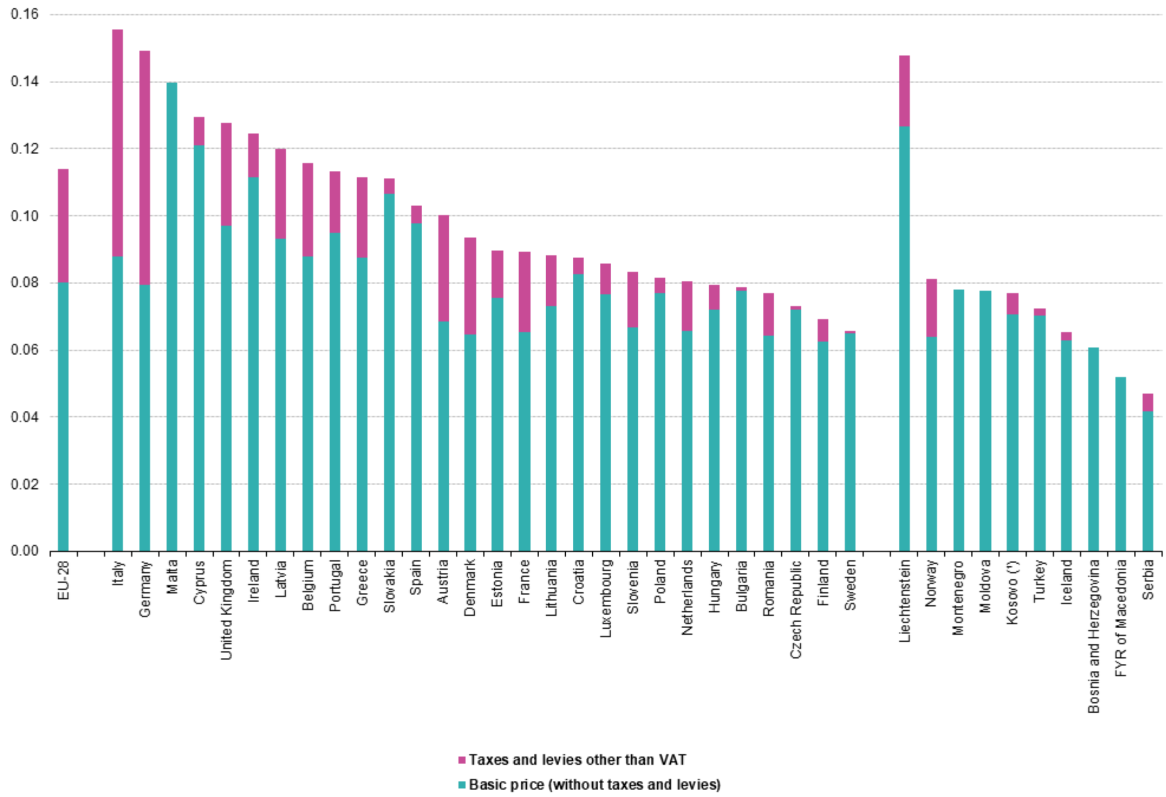
Image 9. Estimated Total Capacities of some Finnish major Data Center Operators (Invest in Finland 2018/Greenpeace USA 2017)

5.2. Data Center as Investment in Finland

Real Estate investors are also very interested on the business. Co-Location companies for example are very good investments for smaller companies with smaller investments. (Delforge 2014) Really Big companies can build their own mega data centers or use multiple smaller ones by themselves alone. (Brown 2007)

The investors get their revenue based on business, geographical factors, and location. Availability of electricity, telecommunication networks and utilization of waste heat are the requirements. Finally, security and technical building factors are the greatest uncertainty for investments. (Lehtoniemi 2017) Also electricity being one of the highest costs, Finland has quite low and predictable electricity costs with lowered electricity taxes. (EK 2014)

C-lion telecommunication cable is also another weapon Finland has on the scene granting them direct connection into the rest of Europe. This makes Finland to possess high capability network connection between eastern and western Europe. (Cinia 2018) This has greatly improved upon Finland data transfer latency and security. Especially the Swedish spying rights that their government granted to their reconnaissance was a great risk as Finland had to transfer their data through Sweden before the new cable, (HS 2015) Also another cable has been made with Russia, through Northern Sea Route. (HS 2013)



Note: annual consumption: 500 MWh < consumption < 2 000 MWh. Excluding VAT.
(¹) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.
Source: Eurostat (online data code: nrg_pc_205)

Image 10. Electricity Prices (EUR per kWh) for Industrial consumers at 2016 in Europe (Eurostat 2016)

Finland had 2016 the second cheapest electricity inside EU. Only Sweden had cheaper because of lower taxes making Finland very competitive location based on electricity costs. (Eurostat 2016) Cheap electricity has been one of the main reasons operators have brought datacenter into Finland. Still other countries have their own benefits such as having more business opportunities and educated workforce compared to comparatively small population and remote location of Finland. Legislation and taxes is also important factor on electricity prices. Finland has cheaper taxes for datacenters over 5MW when in Sweden the same is offered for over 0.5MW allowing even smaller sized datacenter operators benefit from the same reductions. (EK 2014, Business Sweden 2017)

Image 11. Colocation Data Centers in Europe 2017 (Cloudscene 2017)

Finland is not certainly a true giant in Data Center Business. Sweden has almost the triple of the amount of colocation datacenters Finland has and most of European datacenter business is concentrated on the western-central Europe. (Cloudscene 2017) Ultimately most important thing for datacenter operators is how much revenue they can make and how cost-efficient they are. Finland is a very excellent location in energy efficiency but has still some work to do to catch on cost-efficiency the larger datacenter markets of western Europe.

6 Case Pitäjänmäki

The following case uses as material: Interview with Ville Toivanen. Documents shared by Telia. Personal visit to the location.

6.1. What is Pitäjänmäki?

Helsinki Data Center is a new Data Center by Telia that just finished it's building in Pitäjänmäki, Helsinki. It is a co-location datacenter offering services to numerous clients beside the own needs of Telia as telecommunication operator. Helsinki Data Center wish to be more open datacenter in its practices and offer new kinds of opportunities for clients and datacenter business in Finland. In designing the facility energy efficiency has been one the main selling points from the start making it excellent case for this thesis. How to recover the warmth and how to recirculate it is a very important part of the datacenter. Renewable and coal free electricity also were important points datacenter needed to include from the start for the design.

The building is 34 000 square meters with 15 000 square meters reserved for equipment halls. IT power will be 24MW and it will fit 5000 racks with 200 000 servers. The heat they will circulate will be around 200 000 MWh/year. The aim is to use renewable energy for electricity and that the waste heat will be transferred into district heating.

The data center has LEED and CEEDA certifications and will be Tier III level data center offering high security and reliability.

The business model of the datacenter is colocation where Telia as operator will sell shelf space/equipment halls for rent with all the possible extra services they can provide. The key selling points are security/high level maintenance and easy accessibility for clients.

Cooling in the datacenter is based on water-based cooling including the dry condensers, water coolers and heat pumps. The halls themselves are cooled with regular air recirculation machines. Free cooling is also possible during 11 months of the year. Power reliability is enforced through doubled connection with Helen's electricity grid. The datacenter will also have 2 of their own 50 MVA transformers. Reserve power is arranged through own generators and UPS.

6.2. History and Background

Helsinki Data Center is not a produce of short planning. The project itself started 8 years ago on concept levels and took 5 years of planning and reports for the construction to finally start 3 years ago 2015. The Idea for datacenter started when Telia needed more IT power for themselves. Tähtitorninmäki and Käpylä simply couldn't fulfill all the needs Telia would have for its future in Finland and there were really no expansion opportunities left in those locations. Co-location services were not really a priority at the start, but it was a business opportunity that was soon found to be possible for the project. 8 years ago, Co-Location was a new thing, but now it's also starting to slightly pass. Companies are moving towards cloud services instead of even co-locating their servers. Even Pitäjänmäki will probably be co-location datacenter only for a time, until ultimately moving towards cloud service-based business model.

> *"Now it is a product that sells well, but this a passing phase. All are moving towards cloud services instead of having their own servers."*
>
> *-Ville Toivanen (Translated from original in Appendix B)*

Business model for the datacenter has multiple parts on it. Co-Location is the most nominal service offered by them with additional services. Cloud services can also be bought from the datacenter and their daughter companies Cygate and Nebula offer more refined services for clients. Naturally Telia's own telecommunication needs are also part of the business model equation as it is always with Telia's datacenters.

6.3. Design

For Telia's own use requirements for IT power would be around 6-8 MW, but with outside clients using the datacenter as well 24 MW was quite soon seen as the target number for the data center. The exact number is ultimately based on the location and on the property, they had gotten for the datacenter any larger datacenter wouldn't fit well or they would have to lesser their standards.

One of the most important things about the location is that they have easy and stable access for energy and Pitäjänmäki fulfilled that near both Helsinki's and Espoo's electricity grids. Also, location granted possibilities for reusing the waste heat energy sending it back to either Helsinki or Espoo through district heating. Also, Finland is in quite special position as most countries outside of Finland, Sweden, Denmark, some Baltic countries, and Poland just don't use the district heating grids that make possible the easier benefiting of waste heat. Norway one example not having the district heating as they have long access to cheap oil and mountainous territory where it's hard to setup pipes for district heating. Meaning globally, it is still impossible for district heating to be used as universal solution for district heating.

"If we had an international standard that heat should be reused, only us, Sweden and Baltic with perhaps Northern Germany would prosper, but it wouldn't work elsewhere."

-Ville Toivanen (Translated from original in Appendix B)

The location in Helsinki metropolitan area was also important part of the design from the start. Especially considering the waste heat energy, in smaller cities it will become difficult to find recipients for all the heat. In metropolitan area people in Espoo, Helsinki, and Vantaa each use around 100 MW of heat even in summer time. When Espoo is using 500 MW of heat in winter, at summer it is still 80-85 MW. Reusing 20-25MW from the Pitäjänmäki Datacenter would allow Fortum in Espoo to shut down their Vermo power plant totally for the summer. Energy companies are more interested in the datacenter heat during the summer than in the winters.

When designing the datacenter Telia also studied if they could use air cooling and compete with even better PUE results, but there were too many difficulties with that plan. The ventilation would have required immense structures and most of the security would have been lost from the facility.

Tier certification was something that Telia didn't consider important to certificate, but they still made sure that the design solutions would fit for at least Tier 3 and even better in some areas that required even more reliability.

6.4 Energy Efficiency

Datacenter has IT Power of 24 MW with PUE being maximum of 1.2 according the plans. This is the plan though and it is hard to estimate will this be the same 5 years in the future though.

The reason Telia chose 24MW is a sum of many factors. From the electricity grid facility could take 50MW, but the question came to optimization and the building permit Telia had. Basically, little less than half of the facility is white space with technology built around them and seeing how far they can go within the building permit they had. Original objective was to reach over 20MW and 24MW was the optimal fit for the permit they had. 40MW was something they also though earlier, but that was too much to be fit in the area they had.

”It is a question of optimization, how much space and money is available and how the space is allocated there.”

-Ville Toivanen (Translated from original in Appendix B)

PUE is something that is always discussed when talking about energy efficiency, but Ville has pretty clear ideas on this topic and considers that PUE is something that should not really be used with data centers. PUE is too easy to fabricate and it doesn’t ultimately give a very concise picture of the whole energy efficiency. For Pitäjänmäki the energy efficiency comes from using renewable energy and then reusing the waste heat through the district heating grid.

”My understanding is that nobody should ever speak about PUE, it is mistake in two ways. First if you tell a marketing guy that there is a datacenter with low PUE, he immediately starts to hype and distort it. … Another thing with PUE is that if it goes to some CEO that sets it up as direct objective of having as best PUE as possible, it will lead to malpractice.”

-Ville Toivanen (Translated from original in Appendix B)

ERF (Energy Reuse Factor) is a metrics commonly used when calculating how well is the waste heat being reused and is something Telia also wishes to keep high at Pitäjänmäki. 80% would be a number that would make Telia happy. For example, the biggest datacenter that has reused all the heat is in Sweden and is a 10MW datacenter, so reaching this with bigger datacenters would be a quite an achievement in Ville Toivanen’s opinion. But beside the technical and environmental aspects the economic aspects will determine whether this is optimal target ultimately or not.

Cooling at Pitäjänmäki is based on liquid cooling, the most optimal technique with tighter spaces in Telia’s opinion. Implemented traditionally with elevated floors, that are kept empty beside obligatory fire safety systems to keep air circulation free. Also closed cold aisles with exceptionally tall racks to make sure any kinds of machines the clients want to bring in to be able to be fit in.

Free cooling from the air is also naturally used and incase the weather for some reason would not allow for it, they have compressors for it. 4 watercoolers with each 2.5 MW power make sure of the cooling, but plan is that air cooling makes these unnecessary for most of the time.

Using air cooling instead of liquid cooling had multitude of issues why liquid was chosen as the cooling technique. Major reasons included security reasons, reusing the waste heat, cube form of the building and the size of the building permit.

Cube form is in overall excellent form to efficiently place all server rooms, but for air ducts is not optimal at all, as in in air cooling it would require the ducts go all the way through the building destroying all the high security the facility would have. Also, in reusing the waste heat standpoint the heat is easier to reuse when it's already bound into liquid.

Also, the possibility for using seawater was not optimal for the datacenter. Firstly, at Helsinki's coast there not enough deep water continuing to the open sea. Shipping lanes weren't an option and digging new channels in the rock to the open sea would be too costly operation.

One interesting cooling solution thought was to use all the snow falling in Helsinki for cooling. Sadly, this amusing thought could only even in best case at winter cool couple Megawatts leaving the idea as side thought.

Telia maximizes the energy efficiency of the facility, but IT energy efficiency of the servers that clients bring is up to them. Telia though makes sure that installation discipline is strict, and all the servers are installed correctly to make sure the datacenter overall is kept efficient. Even 30% of energy efficiency could be lost with wrong installations as Ville noted.

6.5. Renewability and Future

"Even if we want to reuse heat, we have to financially justify that the heat is worth it to collect and reuse."

-Ville Toivanen (Translated from original in Appendix B)

Even though reusing the waste heat energy is environmentally good idea, there needs to be a good business case for it as well. The price of district heating and the technique used them vary in Finland. Grids with different ages might require heat between 90-115 Celsius degree. Reusing waste heat is not exactly a business that makes a lot of money. They were able to build a business case that reusing the waste heat is slightly cheaper than what it would have been with just free cooling. Also using liquid cooling made reusing the waste heat easier and with that more efficient.

"We are not making money selling district heating."

-Ville Toivanen (Translated from original in Appendix B)

Another important topic is the energy taxes of datacenters in Finland. Datacenters over 5MW go to tier II taxing class. The law has some problems though in details. The law is based on exclusiveness and defining what are not datacenters and what are not datacenters. The interesting undefined question here is whether heat pumps belong to lower energy tax class or not. The law is being atm. Rewritten more into Sweden's direction where the limit is at 0.5 MW. As such Finland must drop their own limits for international competitiveness. This is also an opportunity to define it more exactly and help the business case.

"It would significantly help the business case that is formed from reusing waste heat."

-Ville Toivanen (Translated from original in Appendix B)

Environmentalism is a big thing for all major internet companies today. The fact is still though that even Google can't spread all its heat for Hamina at their datacenter there. Simply Google is producing too much heat that the society around them could use it. Ville heavily believes that big cities and district heating grids will be important factors in deciding where datacenters will be built in the future.

"Network businesses are quite conscious these days, some of course are mining bitcoins without caring the environmental effects, but all kinds of giants of Internet are taking good care that they are green."

-Ville Toivanen (Translated from original in Appendix B)

The investments made to build co-location datacenters is usually payed back between 3 to 6 years. In Pitäjänmäki case it isn't that easy to calculate as much is leased and it's harder to calculate for payback, but Ville can note that datacenter will be going positive as soon as facility Is using over 5MW of IT power.

The building has a rental agreement for 30 years that is quite uncommon in datacenter business where investment plans are not usually made for over 6 years. So, the lifecycle for the rental agreement is 30 years and the building should have a lifecycle of 50 years. Telia has a habit for bringing their telecommunications into a building and staying long there. Another of the cases Tähtitorninmäki is a good example of this. Considering all the active equipment Telia has in Finland, there is one that has been practically always online since 1953. As a telecommunication company Telia indeed has their own specialty in long lifecycles for their businesses. There is of course some equipment with lower lifecycles such as batteries with only 7 years. Frame pipes, transformers, reserve power machines then are again on the longer lifecycle with some even having been in use for 40 years in some cases. In the actual server halls, the equipment that handles data, 12 years start to be maximum. At that point the racks for cooling start to be end of their road. Telia plans to have hall circulation inside the datacenter, so the load can be transferred to other halls when one is being refitted back to date.

Ville also sees Finland as a quite good location for datacenters. Most important positives being: moderately cheap energy, reliable electricity grid, good society that's very IT-friendly and secure signal espionage laws. Finland even is with privacy of data one of the privacy leaders in Europe with Germany. Also, liberal society, direct sea cable to Germany, educated workforce, waste heat reusing possibilities and solid renewable energy sources are major benefits. For example, in Denmark it's up to weather if the energy is renewable or not.

7 Case Mäntsälä

The following case uses as material: Interview with Ari Kurvi. Personal visit to the location.

7.1. What is Mäntsälä?

Yandex data center at Mäntsälä is another quite well-known data center in Finland that has gained much publicity in recent years and has been quite open on how they work. Russian search engine company Yandex built the data center at Mäntsälä, Finland on property of 8 acres. Main reasons on its location was safety and secured energy receival. One of the main targets of the center was to benefit from waste heat and transfer it into district heating.

7.2. History and Background

The whole project started 2013 when the property was bought in Mäntsälä and the building of the site started. Data center manager Ari Kurvi has himself been with the project since it was built in Mäntsälä at 2014. IT-parts of the building were started up then and in 2015 the office building was done, and the employees moved into it. Data center has 17 employees with most of them working on shifts, so the datacenter has upkeep and maintenance around the clock. Security and other personnel directly not involved with datacenters are outsourced.

Yandex is Moscow based global public company listed in Nasdaq whose business is based on their search engine. The company does mostly their business in Russia and the data center in Mäntsälä is their only one outside of Russia. All the datacenters by Yandex are also built similarly with around the same size so that they synchronize well and are easily maintained as they are all part of the same cloud service network. The concept is to build 4 buildings each with 10 MW input for total of 40 MW per site. Then when the site is fully operating, another site can be started to build somewhere else.

Mäntsälä and Finland was a choice made by the company then to increase their global growth and Finland is quite natural location for Russians to start their expansion westwards. Finland was especially known as stable and secure location to build their datacenter. Legislation was noted as predictable with no surprises, the energy prices were low. But most importantly maybe the reuse of waste energy was something that makes the location quite unique and special today. It was not clear from the start that this would happen during the construction, but when Ari Kurvi joined the project he made sure that this would need to happen and now as it would be so much harder to include later if it was not part of the datacenter from the start.

Yandex limited company here in Finland offers internal cloud services for their global mother company Yandex. The Finnish Yandex had revenue of 56 million euros at 2016 making some nice profits for the company as well.

7.3. Design

Main priorities when starting with the design of data center was how to remove the heat most energy efficiently. They don't like to use the PUE metrics, but of course low PUE is always an aim. That is why all Yandex datacenters are with the direct air cooling, according to them it is the most energy efficient way to remove heat. Also, the servers in the datacenter belong to Yandex, so they can adjust the correct volume of air to be pushed through the center easily as they know how much exactly the servers need. That is one thing that makes them quite different to colocation datacenters as they know exactly what kind of hardware they have there, and they also fully control it.

Mäntsälä data center is also quite free to innovate as they want. Headquarters in Moscow understand that things work differently in Finland and western countries and they need to freedom here to pursue correct choices. Of course, innovations made here are copied and used when Yandex builds elsewhere new datacenters. The next datacenter built by Yandex after Mäntsälä does similarly have to ability to take use of the waste heat energy. They though don't have similar buyers for the heat like they here in Mäntsälä do. But company is now prepared for it and all future datacenters can benefit if they have possibilities for partners.

> *"When we are here in Finland and mother company is in Russia, we are quite free to innovate here as they understand that how things are done here in Finland and western countries are different compared to how they should be done there."*
>
> *-Ari Kurvi (Translated from original in Appendix B)*

As the Yandex datacenters are part of the cloud, they don't as such require tier certifications as the redundancy comes from the other datacenters part of the same cloud. Meaning that one single datacenter doesn't require as strict redundancy certifications. But still in practice Yandex Datacenter is partly on both Tier I and Tier II levels. There are for example power inputs from two different directions, there are 2 main transformers, there is diesel confirmation, number of generators is N+1, but after that the power dispensation is singular N all the way to the racks, making it indeed be

Tier II in some cases and Tier I in the rest. But calculating by the weakest link, facility would be calculated to be Tier I, but as they are part of the same cloud with other Yandex datacenters they don’t have a need to get any official certifications.

7.4. Energy Efficiency

Currently the Mäntsälä datacenter has maximum IT Power of 10 MW as they have so far only built the one building on the possible 4 that are included in Yandex datacenter designs. There are discussions and plans to start the expansion for the next building at 2019, but all that is still under discussion at this moment.

The current energy load of the datacenter is at 8MW and should grow to the potential of the 10 MW by the end of the year. Around 7.7 MW of that is going for the servers and the rest 0.3 MW are mostly taken by the large facility and offices they also have on the site. That would make the partial PUE of the IT cooling section to be around 1.08, but the rest of the site and all the infrastructure of course take more. Still similarly to Ville Toivanen, Ari Kurvi neither likes much to talk about PUE.

”We don’t like PUE and we wouldn’t want to use PUE, but in a way small as possible PUE is still one of our objectives.”

-Ari Kurvi (Translated from original in Appendix B)

ERF is one of the metrics Yandex likes to use to follow their waste heat energy reusing. Current ERF is around 0.3 so Yandex is reusing around one third of the energy they are using. On the side of IT load, they are trying to achieve 100% or at least close as it is possible to that aim. The heat load on the site is not something they can reuse, but the IT side they are planning to fully reuse the energy. Having 1.0 ERF is not something Yandex expects to reach in next few years, but it is nevertheless the objective they are going for.

Yandex isn’t really using many metrics on their site, the budget, money coming in and coming out being probably the only important one. The thing with Yandex really is that they don’t have the need to measure as they are only producing internal cloud services for their mother company. For example, the users of Yandex Search Engine probably wouldn’t find much value on hearing some metrics of the datacenter which is part of the cloud that is offering this service to them. Biggest difference being to colocation datacenter like what Telia has, that Yandex doesn’t need to sell their service to any clients.

Cooling in Mäntsälä is completely based on air cooling. Ari Kurvi at Yandex prefers to speak more about transferring the heat than cooling it. Transferring the heat is reusing it and cooling it is more about wasting the heat. Also, as the air cooling is coming from the outside, it is free cooling as well when temperatures allow it. Datacenter uses 25-degree air, so it is not often in Finland that the temperatures are higher than that beside some days of the summer, there is almost all year around free cooling opportunities.

Outside air is brought in and circulated through the datacenter and then the heat is taken by the heat pump and sent into the district heating grid. Current ERF is around 30%, but the aim is to improve the energy reuse as close as possible to 100% in the future.

Yandex datacenter is also using the regular cold and hot aisles that are natural with air cooled datacenters, but the air is driven with difference of pressure instead of temperature difference here. That makes that aisles need to be 100% sealed and there can't be mixture of cold and hot air in the aisles. It can't be though fully avoided always and if the IT loads are light, there might be even need for allowing the air to go freely through at some point without the heavy pressure difference.

There are no elevated floors or suspended ceilings at Yandex datacenter and the air is simply flowing through all the racks and the whole system. Cool air is heavier so it's being descended for the racks as much as they need, but no more. The cooling process at Yandex is not based on the temperature of the air coming, but on the amount of how much it is brought. Compared to traditional cooling process where the amount of air is constant, and it is just driven through the cooling machines even if it's not required to be cooled, the Yandex system-based air pressure and amount of the air is more energy efficient.

Air circulation process begins from cool air being taken from outside and mixed with the warm air coming from the server halls so that the air when entering back to server halls the air 25 degrees again. Theoretically the air could be at 32 degrees to be still sufficient for cooling, so there is some reserve in air temperature if need to be adjusted. Then part of the air is reused back into circulation mixed with the outside air, and part is sent outside on the other side of the facility. When the outside air is cold, then mostly the air being circulated is outside air. When the outside air reaches 25 degrees, then mixing with the outside air will be stopped and the free cooling ends for that time. Fans at server halls are on the racks and there are no specific fans for each server, so it is very important that temperature is kept stabile in the halls. This is to ensure that the lifecycle of servers and hard drives stays long as possible.

7.5. Renewability and Future

Reusing the waste heat is a priority at Yandex or reusing the heat as Ari Kurvi at Yandex prefers to say. When the waste heat is not going to waste, a better term would be just reuse heat without the negative term of the waste as reuse heat is an excellent thing to have.

Environmentalism has also been important factor for Yandex from the beginning. Renewable energy though is not necessarily the best option in their mind as the amount of renewable energy produced currently is not that high and it is not more efficient that Yandex specifically would use it instead of the common population at their own homes. Yandex has chosen not to care so much about what kind of energy they are getting, but what kind of energy is coming out of them. Reusing their heat to produce coal-free heat is Yandex's way of participating into environmentalism. Also, this means that the energy companies buying this energy coming out of Yandex don't need to produce that energy from other sources lowering the carbon footprint.

Main improvements Yandex is currently looking out with their data center and energy efficiency are to improve their ERF and to increase the consumption for their reused heat. One of their main objects is now looking for new partners to neighbor them to consume their growing production of reused heat. For example, new greenhouse is coming up to Yandex's neighbor as one kind of innovation to take benefit from the reused heat. Energy company of Mäntsälä is the main consumer of the reused heat and already the current building could facilitate 80% of the whole city's heating. Of course, during the summer there is not so much need for district heating and that's one of the reasons why the ERF is only at 30% for the year average.

Ari Kurvi also presented some criticism on huge datacenter complexes of 100's of MW or even of GW size, that they can't really have enough consumption for all the reused heat they could produce close enough for them. Meaning that all that heat would go to waste with them making them quite energy inefficient on that side. If the size remains between 50-100 MW it could be still reasonable to have enough industry or population to reuse the heat making that more optimal size for datacenters.

Another side how Yandex feels they support overall energy efficiency is how they offer reserve power for the national grid meaning that FinGrid doesn't need to build so many reserve power plants when datacenters can offer these services as well. After all, Yandex has done the investment already for their datacenter so why not also offer it for the national grid as well if Yandex doesn't need it for themselves now. It is much better after all if they can prevent the national grid from falling than to use the power only for themselves after the grid has fallen.

Previous being another example how Yandex feels that the overall benefit of everyone is often also the best case for Yandex as well. Ari Kurvi also believes this is the future where all the big actors in the business will slowly move towards. Their transparency is part of it. They freely tell how they have done it and even hopes that others will also try that and maybe start using it with their own datacenters. Hopefully through cooperation both will learn even better ways to operate.

"We want to be open and we want to tell how we have done it. It can be used or tried freely. And together we can find out better ways. We have no reason to keep secrets or cover up from anyone. We see it as important social responsibility question."

-Ari Kurvi (Translated from original in Appendix B)

In the close future Yandex expects to start planning for the next building onsite to increase IT-Power to 20MW. Also, after learning from the previous building the next building should have ERF of 85% from the start making the reuse heat even more important from the start.

Life cycle for Yandex data center in Mäntsälä on facility side is 20 to 40 years at least. Infrastructure with power input and cooling though might require some modifications in 10 years' time already.

Also, how much heat servers produce and how much air circulation is required will change through the time, it is already clear that temperature will be growing and the amount of air moving through the system is lessening, so all these need to be modified in the infrastructure later. Also, good part of the energy efficiency comes from minimizing the energy required on removing the heat from the servers.

For building new datacenters Ari Kurvi considered the most important thing is for to municipalities to understand that datacenters need to be close enough to communities that can consume the heat that datacenters can provide. Another problem is that energy companies have not yet fully understood all the benefits of the heat provided by datacenters. Many still think that energy should be provided by burning fuel as Ari Kurvi wonders with his own words.

"Energy companies are really unwilling to reuse the waste heat energy for some reason. I don't know why, but the lamentable impression of energy companies is that heat can only be produced by burning something."

-Ari Kurvi (Translated from original in Appendix B)

8 Case: Tähtitorninmäki

The following case uses as material: Interview with Reijo Karjalainen. Documents shared by Telia. Personal visit to the location.

8.1 What is Tähtitorninmäki?

Tähtitorninmäki is quite special data center as it’s situated underground beneath Helsinki, Tähtitorninmäki in a bomb shelter. The property is owned by the government and Telia through its predecessor Sonera has long operated in the property. That’s why there can be found IT equipment from multiple decades and it makes it a very interesting location for data center. Can be said that there aren’t similar active datacenters many left in Finland anymore. The specialty of location also makes it very different case when compared to other datacenters that have been studied in this thesis.

8.2 History and Background

The excavations to build the underground property beneath Tähtitorninmäki began already at 1960’s and it started operating at 1970s. Telia and its predecessors have been operating the site from the start. The location has been hotspot for Finnish telecommunications since then. It was not really a datacenter from the beginning as we now consider datacenters to be. Property also used to hold large personnel around 200 people, but through time it has faced many changes and slowly there was need for less and less people onsite. Reijo Karjalainen had been working onsite already at 1980’s and remembers those times well, Today the site is still guarded but otherwise there are no personnel posted onsite beside personnel visiting to make check-ups time to time. The property is still active datacenter and holds still important position in Finland’s telecommunication network.

”There was almost 200 people working at that time and now it has been slowly run down and guys commanded up to groundside.”

-Reijo Karjalainen (Translated from original in Appendix B)

8.3 Design

On business model wise Tähtitorninmäki has quite different setups inside of it. There are client servers inside as colocation datacenter, but on quite small scale. Clients also are mostly old clients that have had their servers running there possibly for decades and are slowly being transferred into newer setups built inside Tähtitorninmäki or possibly Helsinki Data Center when possibilities for it arise. Datacenter activity mostly though is for Telia's own telecommunication operations and other needs.

As Tähtitorninmäki is built underground beneath rock, security reasons have been main reasons for the location from the start. That is also reason even this thesis can't go into too much detail onto location, but all the high security of the locations makes the case intriguing and very different to the other cases in this thesis. The site is very well secured against hostile attempts and safety is location's main selling point. There are many secure safe fails and procedures built but should be sufficient to say it is built to survive even if Helsinki would face nuclear strike or EMP strike. That is a thing most datacenters cannot really offer in their services. Most datacenters are built on open spaces and large halls to maximize cooling and energy efficiency. All these factors make the location quite special.

8.4 Energy Efficiency

20 years ago, the site used 1 MW and today it is around 4MW, so the energy consumption hasn't grown so much through the years. Biggest rises in energy consumption have come when new datacenter halls have been built on old storages. The site is especially important as telecommunication hotspot, and many of the actual data center operations are mostly built upon the free halls that have come free when older equipment has been removed as outdated. Still there is lots of history and servers that have been active for decades even.

Most important selling point in location's energy efficiency is the free cooling through sea water which offers very efficient cooling solution if the sea water is cool enough for it. Otherwise the location is not optimal as the space is tight and inside a rock, so larger air ventilation solutions would be very hard to build on location.

8.5 Renewability and Future

In 2015 Granlund wrote a report on datacenter, of its current situation and how to improve upon it. Costs in the property mostly came from electricity with 93,8%, heat with 5,5% and 0,7% on water. Heat was mainly to warm up the air ventilation and water for cooling pools when they required filling or installation.

Electricity as main cost went mostly for ICT equipment with 67%, air ventilation machines with 11% and water cooling machines with 7%. As the datacenter is just by the side of Finnish Gulf the data center greatly uses free heating through the seawater as cooling solution when possible, meaning mainly during the winter season.

Granlund noted multiple improvements that can be done in the datacenter. With setting up of heat pump the waste heat could be circulated and there would be no need for outside district heating. Air recirculation machines could also be renewed, and circulation made more efficient. The temperature of cooling systems also could be made higher as if warmer water could be used for free cooling, center could benefit from it even outside of winter temperatures. UPS equipment was outdated and needed renewal. Lighting also could be renewed and made more efficient. If these all reforms would be made, 81,7% of electricity consumption should come from ICT equipment 3,6% from IV-machines ja 3,8 from pumps. This all would increase the PUE from original 1.50 to around 1.22 in best case.

Some of these recommendations were completed in recent years but some also were left for future potential. In total though in the recent years there has been significant improvements on energy efficiency coming close to numbers predicted by Granlund.

Tähtitorninmäki is still nevertheless somewhat outdated location considering modern specifications for datacenters, but the location still holds so many important functions that the activity onsite will surely continue through the next decades still as well. Shutting down the site is not anywhere near in our future.

9 Case Comparison

	Mäntsälä(Yandex)	Pitäjänmäki(Telia)	Tähtitorninmäki(Telia)
Business Model	Cloud Services	Co-location	Shelter Site (Co-location and telco)
Operated since	2016	2018	1960's
IT Data Power	10 MW (40 MW when site fully constructed)	24 MW	4 MW
PUE	1.08	1.20	1.50 (2016)
Cooling Technique	Air	Liquid	Liquid
Free Cooling	Outside Air	Outside Air	Sea Water
Lifecycle	20-40 years	30 years	Decades
Tier	I-II	III	II (Ca.)

Image 12. Summary of the specifics of the case datacenters

There are numerous differences between cases I have presented in this thesis. Everyone has different business model from cloud services and co-location to telecommunications. Mäntsälä and Pitäjänmäki represent newer more modern datacenters when Tähtitorninmäki is example of decades old site. Mäntsälä and Pitäjänmäki have high IT Data power capacity with Tähtitorninmäki being much more conservative in size. All have even surprisingly good PUE values, but as everyone has told in interviews they don't put much value on it, as it's not truly representative of energy efficiency, but anyways it still tells that overall efficiency is still pretty good. Datacenter have different cooling techniques with Mäntsälä using Air Cooling and Telia's datacenters trusting on Liquid techniques mostly because of space constraints as air cooling solutions require more remote locations and much more space. Free cooling options are in each datacenter with all taking benefit of Finland's cool weather either through air or sea water. Mäntsälä and Pitäjänmäki as new datacenter naturally have long lifecycles ahead of them as datacenters, even Tähtitorninmäki is not going anywhere as it still possesses high importance for Finnish telecommunication networks. Tier levels are only calculated for Pitäjänmäki as a co-location datacenter they need high reliability and wish to offer especially secure environment for government clients etc. They also have the highest Tier at III. Tähtitorninmäki remains more private on its reliability and security details, but it probably would be around Tier II and Mäntsälä is also Tier II partially, but as cloud service provider they don't really need that high reliability for the whole datacenter, making them practically tier I facility.

Going in more detail in their business model differences. For Cloud Service provider such as Yandex in Mäntsälä the datacenter is only for the operator's own cloud use.

They have no outside clients and their customers are customers for the cloud service not for the datacenters. There is no need to sell the datacenter business to anyone. Also cloud service companies usually have comparatively quite much more money to spend as a single datacenter is quite small part of their whole business expenses. With co-location datacenter such as Telia's Pitäjänmäki things are quite different. Co-location datacenter has their own clients that need to be sold on the datacenter. In this case it's more important that there are different metrics and that can be proven how good the datacenter is for prospective clients. Telecommunication services then that are the main priority at Tähtitorninmäki are essential part of the national telecommunication network. As such they require high stability and security for the site. Also, different legalities dictate much more on the datacenter as they might require very extensive security and energy reserve methods that might not be really that practical but must be done because the law requires. In Pitäjänmäki one example is requirement to have huge battery reserves to keep the service for running for hours in case of downtime even though realistically such need should never come.

Reliability requirements are very different with each datacenter. For cloud services the reliability is not really that important from single datacenter side. Their reliability comes from the cloud network itself that is supported by multitude of datacenter. If there are enough datacenters to keep the cloud grid up, one datacenter being down is not a problem. Users of the cloud service practically shouldn't even notice if one datacenter would burn and get destroyed. There are quite extensive reserves on cloud network capacity for different downtime problems. With co-location services the need for higher reliability is much higher. They don't have a network of other datacenters in cloud to back them up and they need to minimize every possibility for downtime they can. Paying customers expect that the servers they have delivered are kept running at 100% availability or at least close as possible to that. That means that Co-location datacenters such as Pitäjänmäki naturally aim for higher tiers with more extensive reliability solutions through multiple power inputs, extra power reserves or batteries. Telecommunication services are in this case similar, they also require high security and reliability, but are also enforce by the law.

Energy efficiency solutions possible and focuses differ greatly between the cases as well. Cloud service-based datacenters don't need to be so energy-efficient inherently as they don't need to sell high PUE values or any other metrics to anyone. Also, slightly higher energy expenses are quite small matter to cloud service giants who have even tens of datacenters around the globe. Of course, though they want the best energy efficiency that is cost efficiently possible and cloud service does offer a good base for this. Firstly, they can be optimized very well as they control everything inside the datacenter from beginning to the end. Secondly, they don't have to worry about their capacity not running in full use as they can easily organize through the cloud that every datacenter goes with optimal capacity and makes it easy to make sure it keeps running in energy efficient ratio. With Co-location one of the main energy efficiency issues can be that they can't always run with full capacity as it depends on how their clients are using the server side. As such co-location datacenter doesn't have full control on everything inside their datacenters. Of course, in Pitäjänmäki for example they can make sure that their own datacenter is as efficient as possible though. Also, by billing their clients by the electricity they use they can nudge them towards making sure that their server side as well remains energy efficient. With telecommunication services once again, the higher security and reliability constrains the possibilities, but aim is to have the highest energy efficiency the situation still allows.

Reusing waste heat energy is a very important topic on new modern datacenters and the same is with Pitäjänmäki and Mäntsälä as well. Mäntsälä has had it as very high priority from the early days of the building since Ari Kurvi joined the project. And through the building of the first facility they have understood it better and it has become more and more important part of their energy efficiency. Ari considers the reuse of waste heat energy the most important energy efficiency matter to consider at this moment. The hope is that ERF 100% could be reached that all the energy that comes for the datacenter can be reused as heat someplace else. This is not something that can be reached with all the facility energy as there are more energy losses there, but a possible goal with the actual datacenter side. Telia at Pitäjänmäki has also considered the reuse of waste heat energy very important similarly and it was one of the reasons why the current location close to electricity grids both of Espoo and Helsinki was chosen for location. Telia also hopes to reach as high as possible ERF here. With older site like Tähtitorninmäki this is harder to take into action and requires investments that are not to be paid back anytime near, so it is not such a critical matter there. On new facilities though where this can be taken notice from the start though is quite unanimously considered a very important topic to make sure of it being possible.

Reasons and motivations why these datacenters were built differ more between each other. Yandex wanted access to Western Markets into Europe from their main business area in Russia. For this Finland is quite natural starting point for Russian companies. Also, the stable politics, cheap electricity and cold weather were very good motivational factors. Telia then needed more IT-power for their own operations and started planning on new datacenter. During that soon they noticed they could at the same time offer co-location services and through that Helsinki Data Center was finally born. Tähtitorninmäki site then was built when world was quite different, and the main motivations were to have secure shelter in Helsinki for Finnish telecommunications. It can be said to be matter of national security and stability at the time.

IT data power Mäntsälä and Pitäjänmäki are quite considerable in Finnish datacenter environment but globally aren't still near the biggest ones by Google or other major global datacenter businesses. Yandex datacenter is built with the same basic specifics their other datacenters have with 4 10MW datacenters in one facility complex per location. Being identical in output to other datacenters it makes it easy to combine to the same cloud network. Also 40 MW is what Ari Kurvi considers as the optimal maximum size for datacenter. More than that and the nearby society can't reuse all the waste heat energy datacenters can be provide. Meaning any larger datacenters would be most certainly forced to really waste the potential heat energy. Exact IT data power at Pitäjänmäki is not a result of such predetermined specifics and is more based on the size of building permit they were able to get and how much capability could be fit there with keeping the high energy efficiency. Telia needed only 8MW for their own operations but 24 MW was the final size including the co-location for the full facility. Ultimately how much of this is used is based on how many clients they will have, but that is the maximum capacity site can offer. Telecommunication networks such as in Tähtitorninmäki don't really need that high IT data power and 4 MW is plenty for what they have. What matters more for telecommunication networks is high density on the telecommunication grid and small locations around the country.

Transparency also is something that interests both Yandex and Telia as can be seen with this thesis as well. Yandex are very transparent on their datacenter and they are very willing to tell everyone on their methods and techniques. All that they want is to be as efficient as possible, they don't really need to keep secrets as ultimately in cloud service business the winners are not decided on which service has slightly more efficient datacenter but by their quality of services itself. As such if by sharing their own energy efficiency methods they might learn later from others and improve their own that is only beneficial for them and everyone else. Telia also believes same with Pitäjänmäki, but because of telecommunication services and higher security they can't be as open with everything, but energy efficiency matters though can be mostly shared very transparently. Transparency is also helpful for clients, so they know better what they are paying for. With Tähtitorninmäki transparency though is much lower on natural security reasons, but transparency on some more overall energy efficiency matters is fine, if it can be for common benefit.

All these datacenter sites have still a long future ahead of them. Every one of them is planned to remain here for decades to come. Yandex in Mäntsälä will likely slow build up to their full capacity of 40MW as their needs arise and they can build up the business society around them to benefit from waste heat energy they provide. Ari Kurvi at Yandex hopes Mäntsälä becomes an example of what datacenter can do for the people living nearby and be a model datacenter for future construction designs. Pitäjänmäki after being opened at the end of April 2018 is slowly building up to their full capacity as they get clients to full all their machine halls. As a modern facility it can be easily expected to run for next 30 years with some equipment upgrades through the years of course. Even Tähtitorninmäki is expected to run for decades to run. It still possesses important telecommunication equipment that is not so easy to move as it requires equally secure site for them. Some upgrades also done inside to modernize the site and maybe we'll see full 100 years for the site to be operated, but that's is up to whether before that there are any new investments made to build a new site for telecommunication services.

	Mäntsälä(Yandex)	Pitäjänmäki(Telia)	Tähtitorninmäki(Telia)
Business Model	Cloud Service	Co-Location	Co-Location/Telcom
Data Center Size	Moderate (10 MW, Max 40 MW)	Big (24 MW)	Small (4 MW)
Location	Remote countryside, Industry built around	Industrial Area near metropolitan area with building permit limitations	Underground bomb shelter, middle of city
Reuse of Waste Heat	Cooperation with electric company	Opportunities to cooperate with electric company	Non-essential
Renewability	Through reusing the waste heat	Reuse of waste heat and options for renewable energy	Non-essential, sea-water cooling
Transparency and open innovation	Strong trust for transparency and open innovation	Transparency one of the selling points	Very limited transparency because of security

Image 13. Summary of Essential factors in studied cases

10 Conclusions

At the start of thesis there were two research questions this thesis was written to answer for. They were: What are the essential factors contributing to the energy efficiency of datacenter with different business models including 1) co-location datacenter 2) cloud service datacenter and 3) telco rock shelter site? And what are the means for datacenter owner to maximize energy efficiency? In this conclusion we see what kind of answers there were found for them.

What are the essential factors contributing to the energy efficiency of datacenter with different business models including 1) co-location datacenter 2) cloud service datacenter and 3) telco rock shelter site?

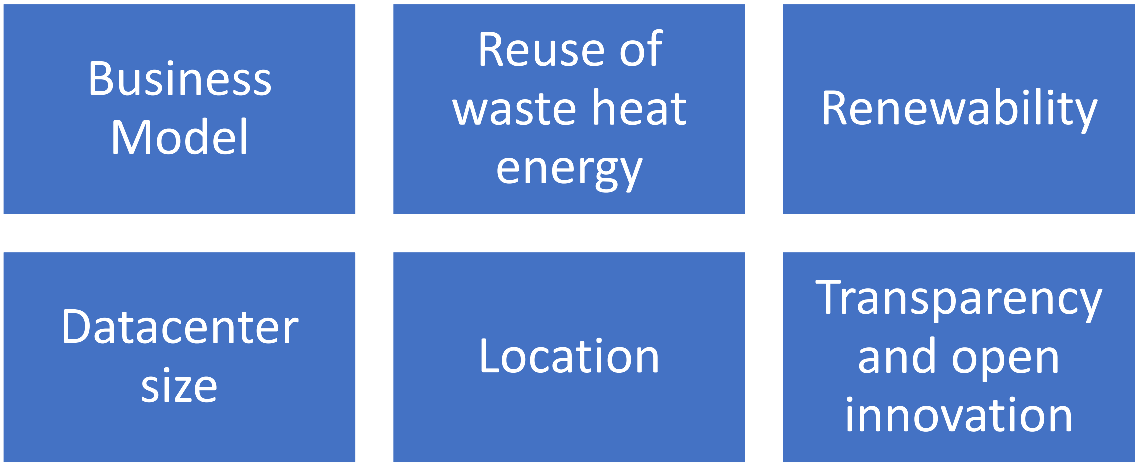


Image 14. Essential Factors contributing to the energy efficiency of datacenter

Business model is the first main factor contributing for the energy efficiency of datacenter. Mega/corporation datacenter or cloud service datacenter where they use their own servers and can optimize everything is very different from colocation datacenter that offers the facility for client to set up their servers into. On colocation side they can optimize the facility side as much as they can, but they can’t really affect on what’s inside the racks expect by billing on their energy expenses. Cloud service datacenters have optimized systems with possibly multiple datacenters all around the world making sure the datacenter and servers inside them are globally on the most optimal load and best energy efficiency. The different business models have totally different kind of requirements from their datacenters as well and that affects their energy efficiency. For co-location energy efficiency is more important metrics, but for cloud services it is easier to optimize as they fully control the whole of datacenter. Also overall was notified that PUE metrics is not a trusted metrics for datacenter operators for energy efficiency. PUE is expected to be good for modern datacenters but it doesn't give truthful big picture of the energy efficiency.

Reuse of waste heat energy was the most essential singular factor for energy efficiency in opinion of datacenter operators. They had high interests on it and both Telia and Yandex really want to take use of it as much as possible. The main issue here is to find enough recipients for all the heat energy the datacenters can provide.

Renewability and renewable energy is another factor that has been noted by datacenters. Still it isn't believed to be ultimate resolution for energy efficiency or even renewability. If it's offered nearby and with cheap costs it can be used, but otherwise it just exists as an opportunity if clients for extra costs wish that their service is being run on renewable energy. As more reasonable solution both Yandex and Telia believe that the reuse of waste heat energy can offer better renewability through reusing the waste heat and putting it back to energy circulation instead of using the more expensive renewable energy options.

Datacenter size is also important factor for energy efficiency. Usually optimization can be more efficient with larger the facility is but larger datacenters can also find problems especially with their capability to reuse the waste heat energy as the society nearby them can't consume all the heat they can provide.

Location is as well essential factor. It especially dictates the cooling and free cooling solutions available. Remote location and lots of space allows building of huge halls for air cooling solutions. Smaller sites like in Pitäjänmäki makes air cooling harder and benefits more from water cooling solutions as more efficient option. Also, availability to seawater like in Tähtitorninmäki grants easy access to free cooling as well as the cold climate of Finland for air free cooling for datacenters.

Transparency and open innovativeness are also factors that have become more essential for datacenters. Both Telia and Yandex believe in this and are willing to share how they do their business quite openly to competition as well and hope all can benefit from building better and more efficient datacenters.

Business Model	Dictates how energy efficiency can be approached.
Datacenter Size	Larger size equals more opportunities for optimization. Too large though will waste their opportunities of reusing waste heat.
Reuse of waste heat energy	Renewability without renewable energy. Economical way of environmentalism.
Location	Dictates cooling solutions, possibility of reusing waste heat
Renewability	Environmentalism, common future
Transparency and open innovation	Benefits all. High energy efficiency benefits everyone in competition.

Image 15. Summary of the effects of essential factors to energy efficiency

What are the means for datacenter owner to maximize energy efficiency?

For datacenter owner to maximize their energy efficiency they need to understand their own business model and use all the possibilities granted by it to optimize their energy efficiency with any means they have. Reusing their waste heat energy is the most current topic for datacenter owners to think about. Modern technology allows quite efficient capture of the waste heat energy and the main issue here to consider is more about arranging enough recipients for the energy not to go to waste. Studying other datacenter is another important means for owners as most are more and more transparent these days and much can be learned. Also by allowing datacenter openly innovate and try new things can allow new solutions found in surprising places. Considering how the digitalization moves on and more and more data exists in this world data center operators need to be even more energy efficient and keep up with the development so that one day the evolving of data networks would not stop.

Further Research

The research had limited scope with only actual 3 different datacenter cases so with having a larger scope with more cases could bring more value in future research. Also, the financial significance of energy efficiency is interesting aspect that could merit more in-depth research than what has been studied in this thesis.

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Appendix A: Interview Questions

Ville Toivanen, Telia, Real Estate Development Manager

(1-hour interview)

- Name and job description
- Concept
    - Overall?
    - Objectives of project?
    - The beginning?
- Design
    - Energy efficiency from the start?
    - Environmentalism?
    - Cost-efficiency?
      -Lifecycle?
    - Tier classification?
- Energy Consumption
- Energy Efficiency
    - PUE target
    - Air/Water cooling
    - Free cooling
- Business Model
    - Co-Location
    - Cloud services?
    - Clients?
    - Revenue?
- Location
    - Why Pitäjänmäki
    - Finland as location

Ari Kurvi, Yandex, Data Center Manager
(1-hour interview)

- Name and job description
- Datacenter
    - Design?
    - Business model?
    - Lifecycle?
    - Tier classification?
- Yandex
    - What kind of company?
    - Why this datacenter?
    - Why Finland and Mäntsälä?
- Energy Consumption
    - How much?
    - PUE?
    - Energy efficiency factors?
- Energy efficiency solutions
    - Air/Water cooling?
    - Traditional cold/warm aisles?
    - Any other?
- Environmentalism?

Reijo Karjalainen, Telia, Production Management
(30 min interview)

- Name and job description
- History of Tähtitorninmäki?
- Activities today at Tähtitorninmäki?
- Cooperation with government
- High security and reliability of location
- Future?

Appendix B: Original Quotes

Ville Toivanen

Quote 1.

> *"Nyt se on tuote mitä kyllä menee paljon, mutta se on ohimenevä vaihe, kaikki siirtyy pilvi palveluihin sen sijasta, että olisi omat serverit."*

Translated Into

> *"Now it is a product that sells well, but this a passing phase. All are moving towards cloud services instead of having their own servers."*

Quote 2.

> *"Jos me saataisiin kansainväliseksi standardiksi, että lämpöä tulisi käyttää uudestaan, me, ruotsi ja Baltia voitaisiin paksusti ja ehkä joku saksan pohjoisosa, mutta se ei onnistu muualla."*

Translated into

> *"If we had an international standard that heat should be reused, only us, Sweden and Baltic with perhaps Northern Germany would prosper, but it wouldn't work elsewhere."*

Quote 3.

> "Kyse on optimoinnista, että miten on tilaa ja rahaa käytettävissä, miten se tila allokoidaan sinne."

Translated into

> *"It is a question of optimization, how much space and money is available and how the space is allocated there."*

Quote 4.

“Mun näkemys asioista on, että kenenkään ei koskaan pitäisi puhua PUE luvusta, se on kahteen suuntaan virhe, ensinnäkin jos kertoo markkinamiehelle että on datacenter jossa matala PUE, niin sen hehkuttaminen ja vääristäminen alkaa välittömästi ... toinen asia PUE luvussa ongelmana on se, että jos se menee jollekin yritysjohtajalle, joka asettaa sen suoraksi tavoitteeksi, että PUE luku on mahdollisimman hyvä, niin se johtaa välittömästi väärinkäytöksiin.”

Translated Into

”My understanding is that nobody should ever speak about, it is mistake in two ways. First if you tell a marketing guy that there is a datacenter with low PUE, he immediately starts to hype and distort it. … Another thing with PUE is that if it goes to some CEO that sets it up as direct objective of having as best PUE as possible, it will lead to malpractice.”

Quote 5.

”Vaikka meillä on halu ottaa lämpö talteen, niin meidän tulee taloudellisesti perustelemaan, että se lämpö tulee kannattaa ottaa talteen ja kierrättää.”

Translated into

”Even if we want to reuse heat, we have to financially justify that the heat is worth it to collect and reuse.”

Quote 6.

”Me ei tehdä rahaa kaukolämmön myynnillä.”

Translated into

”We are not making money selling district heating.”

Quote 7.

” Antaa merkittävän potkun sille business caselle, mikä lämmön talteenotosta muodostuu.”

Translated into

”It significantly helps the business case that is formed from reusing waste heat.”

Quote 8.

”Verkossa bisnestään tekevät firmat ovat aika valveutuneita nykypäivänä, jotkut toki louhii bitcoineja ympäristövaikutuksista välittämättä, mutta erilaiset internetin suuret ovat kovasti kiinnittäneet huomiota siihen että ovat vihreitä.”

Translated into

”Network businesses are quite conscious these days, some of course are mining bitcoins without caring the environmental effects, but all kinds of giants of Internet are taking good care that they are green.”

Ari Kurvi

Quote 9.

“Kun olemme täällä Suomessa ja emoyhtiö tuolla Venäjän puolella, meillä on täällä aika vapaat kädet innovoida, koska ymmärretään se, miten asiat täällä tehdään on tietysti Suomessa ja länsimaissa eri asioita kuin mitä heidän kannattaa siellä tehdä.”

Translated into

”When we are here in Finland and mother company is in Russia, we are quite free to innovate here as they understand that how things are done here in Finland and western countries are different compared to how they should be done there.”

Quote 10.

”Emme tykkää PUE:sta, emmekä haluaisi käyttää PUE:ta, mutta kyllä mahdollisimman pieni PUE on tietyssä mielessä meidän tavoite.”

Translated into

”We don’t like PUE and we wouldn’t want to use PUE, but in a way small as possible PUE is still one of our objectives.”

Quote 11.

“Me halutaan olla avoimia ja me halutaan kertoa, että me tehtiin se näin. Voi käyttää, voi kokeilla. Ja voidaan yhdessä katsoa parempia tapoja. Meillä ei ole mitään syytä salata tai peitellä tätä keneltäkään. Me nähdään se tärkeänä yhteiskunnallisena yhteiskunta vastuukysymyksenä.”

Translated into

“We want to be open and we want to tell how we have done it. It can be used or tried freely. And together we can find out better ways. We have no reason to keep secrets or cover up from anyone. We see it as important social responsibility question.”

Quote 12.

”Energiayhtiöt ovat todella haluttomia tämmöisen uusiolämmön käyttöön jostain syystä. En tiedä miksi, koska energiayhtiöitten valitettava käsitys on, että lämpöä voi tuottaa vain polttamalla jotakin.”

Translated into

”Energy companies are really unwilling to reuse the waste heat energy for some reason. I don’t know why, but the lamentable impression of energy companies is that heat can only be produced by burning something.”

Reijo Karjalainen

Quote 13.

> *“Siellä oli silloin vajaa 200 henkilöä töissä ja nyt se on sitten pikkuhiljaa ajettu alas ja komennettiin sitten maanpinnalle porukat.”*

Translated into

> *”There was almost 200 people working at that time and now it has been slowly run down and guys commanded up to groundside.”*