Tri Nguyen
Anh Hoang

# Reusing Waste Heat from Cryptocurrency Mining to Heat Multi-Family House

Metropolia University of Applied Sciences

Bachelor of Engineering

Sustainable Building Engineer

Thesis

15 April 2018

Metropolia

| | |
|---|---|
| Author | Tri Nguyen, Anh Hoang |
| Title | Reusing Waste Heat from Cryptocurrency Mining to Heat Multi-Family House |
| Number of Pages | 81 pages + 8 appendices |
| Date | 15 April 2018 |
| Degree | Bachelor of Engineering |
| Degree Programme | Civil Engineering |
| Professional Major | Sustainable Building Engineering |
| Instructors | Sergio Rossi, Lecturer<br>Jorma Säteri, Head of Department |

The objective of this thesis was to find solutions for reusing waste heat from cryptocurrency mining process to supply the heating demand in Finnish detached house. The focus of the study was on identifying and proposing suitable and optimal technologies to integrate systems. The proposed technologies were tested in practical case to strengthen its capabilities and possibilities. Since mining cryptocurrency creates a lot of waste heat and Finland requires a lot of heating supply in cold period, this study provided useful information and optimal solutions for this problem.

To achieve its objective, this study reviewed the Finnish heating system and market, and provided information about heating and cooling technologies. Then, the concept of cryptocurrency and its mining process were introduced to give a brief understanding of the problem. Later, integrating solutions were analyzed from existing strategies and innovative suggestions. The practical case was the Hyrsylä Co-housing project in Lohja. The targets were to calculate the building heating demand by IDA ICE and identify the possible number of mining rigs to supply the heating demand of the project. Some practical solutions were suggested to avoid the overheating problem in the summer.

As a result of this project, three possible solutions were presented for using the waste heat from cryptocurrency mining process and sufficient information related to heating and cooling technologies, cryptocurrency concept and mining technologies. It was possible to reuse heat from two mining rigs to supply the domestic hot water consumption in the project.

| | |
|---|---|
| Keywords | cryptocurrency mining, waste heat, data center, domestic hot water, heating demand, recycling waste heat |

Metropolia

## Contents


1 Introduction 1

1.1 The Objective and Research Question 2
1.2 The Structure and Research Team 2

2 Domestic Heating Market in Finland 4

2.1 Heating Energy in Finland 4
2.2 Heating Technologies in Finland 8
2.2.1 District Heating 8
2.2.2 Heat Pump 10
2.2.3 Biomass – Wooden Pellet 16
2.2.4 Mechanical Heat Recovery Ventilation 17
2.3 Combined Technologies 19

3 Cryptocurrency and Its Mining Process 22

3.1 Concept of Currency 22
3.2 Cryptocurrency 25
3.2.1 Definition 25
3.2.2 Blockchain Technology 26
3.2.3 Future of Cryptocurrency 29
3.3 Cryptocurrency Mining Process 31
3.3.1 Definition 31
3.3.2 Modes of Mining Processes 32
3.4 Mining Processors 34
3.5 Problems in Cryptocurrency Mining 38

4 Exploitation of Waste Heat from Processor 40

4.1 Cooling of Mining Processors 40
4.1.1 Chilled Water System Cooling 43
4.1.2 Pumped Refrigerant for Chilled Water Systems 44
4.1.3 Computer Room Air Conditioning 45
4.1.4 Self-Contained Cooling System 47
4.1.5 Direct Fresh Air Evaporative System 47
4.1.6 Indirect Air Evaporative System 48

4.2 Reusing Waste Heat Solutions 49
4.2.1 Stand-Alone System 50
4.2.2 Combined to Another system 51
4.3 Innovative Integrating Strategies 52
4.3.1 Combined with Air-to-Water Heat Pump 52
4.3.2 Combined with Exhaust-Air Heat Pump 53
4.3.3 Combined with a Compact Heat Pump Unit 55
5 Practical Case Introduction 58
5.1 The Hyrsylä Co-Housing Project 58
5.2 Building Structure and Thermal Envelop Detail 60
5.3 The Existing HVAC System 61
6 Research Approach and Method for Testing 63
6.1 Building Energy Simulation 63
6.2 Data Input in IDA ICE 64
6.3 Method of Testing the HVAC System and Feasibility of Mining Rig 66
7 Results and Discussion 69
7.1 The Heating Demand of Hyrsylä School 69
7.2 Heating Supply from Mining Rig 71
7.3 The Final Result and Discussion 72
8 Conclusion 75
References 77
Appendices
Appendix 1. Architectural Drawing of Hyrsylä Co-Housing Project
Appendix 2. Heating and Energy Report for Hyrsylä Co-Housing Project

## List of Abbreviations

| | |
|---|---|
| ICOs | Initial coin offering. Start-up cryptocurrencies that is to be released in the future once the call for initial investment completed. |
| HDD | Hard disk drive. A data storage device, allows storing or transferring data. |
| USB drive | Universal Serial bus drive. A device for storing data with a smaller capacity than HDD. |
| CPU | Central Processing Unit. Computer component, handles basic IT tasks. |
| GPU | Graphics Processing Unit. Computer component, handles advanced graphics tasks. |
| HVAC | Heating, ventilation, and air conditioning. Building services system. |
| COP | Coefficient of Performance. A measurement to calculate the efficiency of a heat pump. |
| MVHR | Mechanical ventilation heat recovery |

# 1 Introduction

The increasing popularity of cryptocurrency creates an increasing amount of interest in people. Cryptocurrency can bring a tremendous profit in a short time. Therefore, more and more money is invested in this business. There are two ways to make a profit on cryptocurrency: one is from trading, the other is from the mining activities. The value of cryptocurrency is still a question mark, it is unstable and unpredictable. Therefore, trading in cryptocurrency is considered a risky investment. Thus, the mining process is believed to be the safer way to make a profit. However, this process produces a massive amount of thermal energy. It creates an overheating problem and can cause facilities breakdown during the mining process. A cooling solution needs to be applied to deal with this high thermal energy, and extra energy is consumed. (Khemarattana 2017: 3-9.)

A Finnish multi-family house also consumes a vast amount of energy for heating due to the extended cold period in the country. The energy used for heating comprises 70 % to 80 % of the total energy consumption of the house and the lifetime of a building is usually around 50 years to 70 years (Statistic Finland 2017). That makes the total consumption for heating demand a major question to be solved. To be sustainable, a reduction in heating demand is desirable, and better HVAC systems need to be developed.

The heating energy problems from the mining process and a Finnish multi-family house may be linked to be an interesting study. Pedro Aibeo who is an architect and Mikko Loukola who is a cryptocurrency investor, are contemplating a combined solution to apply to their Hyrsylä project. It is a renovation project of a hundred years old school to a co-housing dwelling located in Lohja. Its aims are to create new living spaces and sharing spaces for local people and business. Finding solutions to integrate the waste heat from mining production to the HVAC system of the building can bring a double benefit to house owners. The extra heat from the mining process can be used to supply a home's heating demand. The profit from cryptocurrency mining can also bring extra benefits for the owner. However, there is no primary research on this issue since cryptocurrency is still an unknown topic and no one can be sure about its future. This study can fill this gap and, perhaps, can encourage future research.

## 1.1 The Objective and Research Question

This thesis aims to investigate the possibility of reusing waste heat from a mining system by integrating it to the HVAC system in a Finnish multi-family house. The primary focus is on finding optimal options to increase the energy efficiency of the building. The options are tested at a project in Hyrsylä to establish the best-integrated one. Energy simulation software IDA ICE is used to simulate the options and evaluate the energy performance and feasibility of the system.

The output of this thesis brings benefits to the involved parties. First, the architects and engineers of the project in Hyrsylä receive the energy report of the heat recycling solution in their house. Second, the feasibility of the project can be evaluated. The study also introduces a handful of information related to cooling and heating technologies. Cryptocurrency mining system is similar with small data centre system. Decentralize data center to home scale may be an option in the future. Thus, it can benefit for future research to propose better solutions and systems

## 1.2 The Structure and Research Team

This research looks into cryptocurrency mining technology and cooling/heating technology. Primary data were collected from an interview with Mister Pedro Aibeo and Mister Mikko Loukola.

The first chapter of this thesis introduces the general goals and subjects. The background and motivation of the research are presented; the objectives and research question are found in chapter 1.1; the basic structure of this thesis is introduced in chapter 1.2. The second chapter, written mostly by Tri Nguyen, introduces the heating system, heating sources, and heating market in Finland. It also provides information on the operation of various heating systems. The technical concepts behind each heating source are explained briefly. The third chapter introduces cryptocurrency, a novel concept. The definition, technologies, future and technical problems of cryptocurrency facilities and its mining process are explained principally by Anh Hoang. The fourth chapter, also by Anh Hoang, discusses the combination between a cryptocurrency mining system and building services systems. This chapter provides a general concept of how to deal with the heat

problem of mining facilities. Furthermore, innovative ideas for the recycling methods are listed in this chapter.

The fifth chapter by Tri Nguyen is a brief introduction to the practical case. The information is provided by the architect and engineers of the Hyrsylä project. Technical drawings and the current condition of the house are introduced in this chapter. The sixth chapter, by Anh Hoang discusses the testing method of the solutions proposed in chapter four. IDA ICE is used as energy simulation software. Also, the process of data collection and inputting is presented. Finally, the results of the final year project are presented in chapter seven, and a concluding discussion is the topic of chapter eight.

# 2 Domestic Heating Market in Finland

In chapter 2, the Finnish heating consumption is explained briefly to provide general energy situation in Finland. After that, different heating sources and technologies available for Finnish detached houses are researched and defined to identify integrating methods. Chapter 2.1 describes the energy sources and consumption market for Finnish households. Chapter 2.2 introduces different familiar heating sources and technologies available in Finland. Finally, chapter 2.3 lists all possible current technologies to accumulate and recover the unused heat.

## 2.1 Heating Energy in Finland

Heating energy is necessary and essential for Finnish climate which has an extended cold period during the year. The yearly average ambient temperature was around from 1 to 6 degrees Celsius in 2016. The cold period commonly lasts for about five to six months (Statistic Finland 2017). Thus, the heating demand for space heating and domestic hot water is evident and significant throughout the year. There are several energy sources for heating production in Finland. The most common one is from the Combined Heat and Power plant (CHP) which generates a massive amount of hot water and electricity. Thus, district heating plays a vital role as an energy source. Besides that, heat can also be produces in a small scale for a multi-family house by fuel combustion. The fuel used for burning can be peat, biomass or oil, depending on the combustion system. Electrical heating energy source also cannot be ignored since there are so many technologies developed with a high coefficient of performance such as heat pump, mechanical ventilation, and condensing boiler. Also, electricity comprises a significant share in the total energy sources for heating demand in Finland. (Statistic Finland 2017.)

According to Statistics of Finland, there are three sources of energy for space heating: district heating, wood, and electricity. Figure 1 briefly presents the energy consumption in Finnish households by energy source in 2016. (Statistic Finland 2017.)

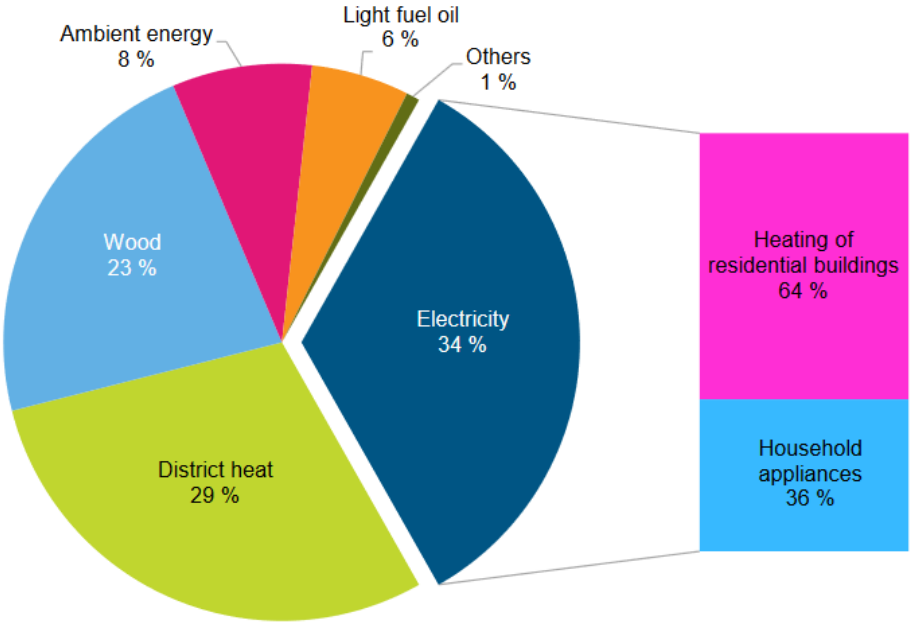



Figure 1. Energy Consumption in households by energy source in 2016 (Statistic Finland 2017).

Figure 1 indicates the total share of heating sources. Electricity took 34 % of the share. In that portion, 64 % was used for heating of residential buildings and only 36 % was used for household appliances. The conventional energy sources, wood burning and light fuel oil are still in the market. Light fuel oil covered 6 % of the total energy in 2016, and it was decreasing due to building renovations and upgrading to more energy efficient heating systems. District heat and electricity consumed most energy. Followed by wood with 23 % of the total energy consumption. (Statistic Finland 2017.)

Depending on type and size of the building, the share of heating sources is also different. Based on Statistic Finland, figure 2 shows heating sources for different common types of residential building. (Statistic Finland 2017.)

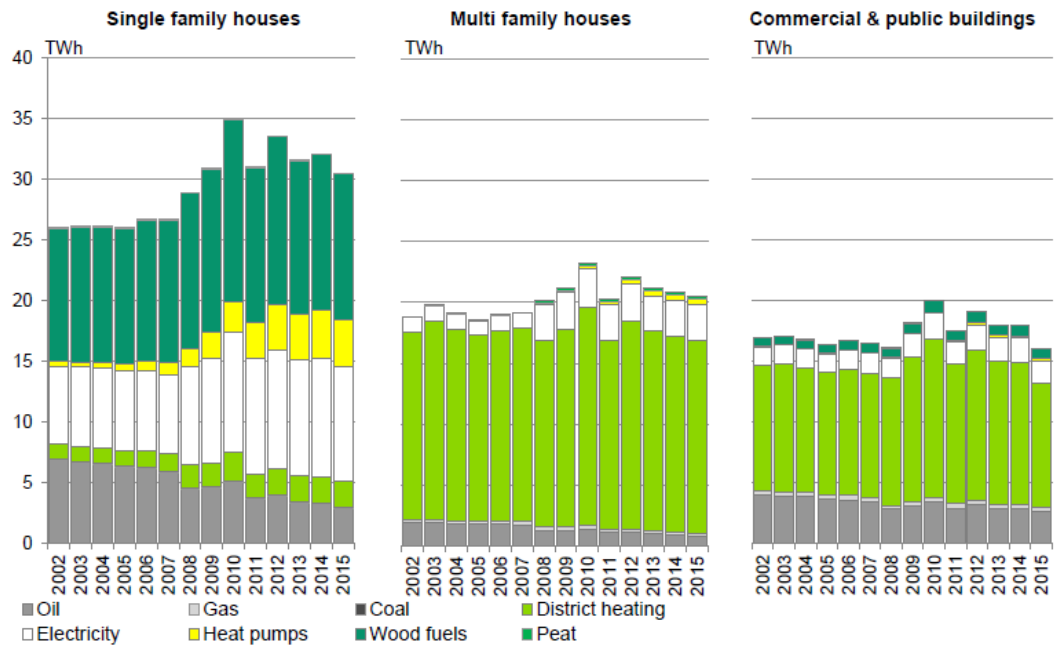



Figure 2. Energy sources for space heating by building types (Statistic Finland 2017).

As depicted in figure 2, a single-family house mostly uses from wood or peat and electricity for space heating. The amount of heat pump usage keeps increasing due to the improved technology and its efficiency. Multi-family houses use mostly energy from district heating, although some use oil and direct electricity. District heating system is not used a lot for single-family houses because of lack infrastructure and high initial cost. Finally, the commercial and public building also use mainly district heating system and oil for supplying heating. However, some heat pumps are used for space heating in office-buildings. Moreover, this amount increases every year from the year of 2000. Thus, the electricity consumption for heating also increased because the electricity used for heat pumps is considered as heating electricity consumption. In new buildings, a heat pump is often used to replace fuel oil. (Statistic Finland 2017.)

Heating energy is mainly used for space heating and domestic hot water production. Many factors affect the heating demand of the building. The most significant one is the building size. A bigger building always consumes more energy. Furthermore, the climate, thermal envelope, building orientation, occupant behavior and heating system also contribute to the differences in building heating consumption. (Santin, Olivia, Guerra, Itard, Laure and Visscher, Henk 2009.) The energy consumption in Finnish households change from year to year due to the changing in outdoor temperature. The total Finnish housing energy consumption in 2016 was 67 terawatt hours (TWh), an increase of 12 % in space heating and 5 % in household appliances compared to the previous year. The weather

in 2016 was colder than in 2015, leading people to use more electricity to heat up their houses and cars. The energy consumption in households 2016 was introduced in figure 3 (Statistic Finland 2017).

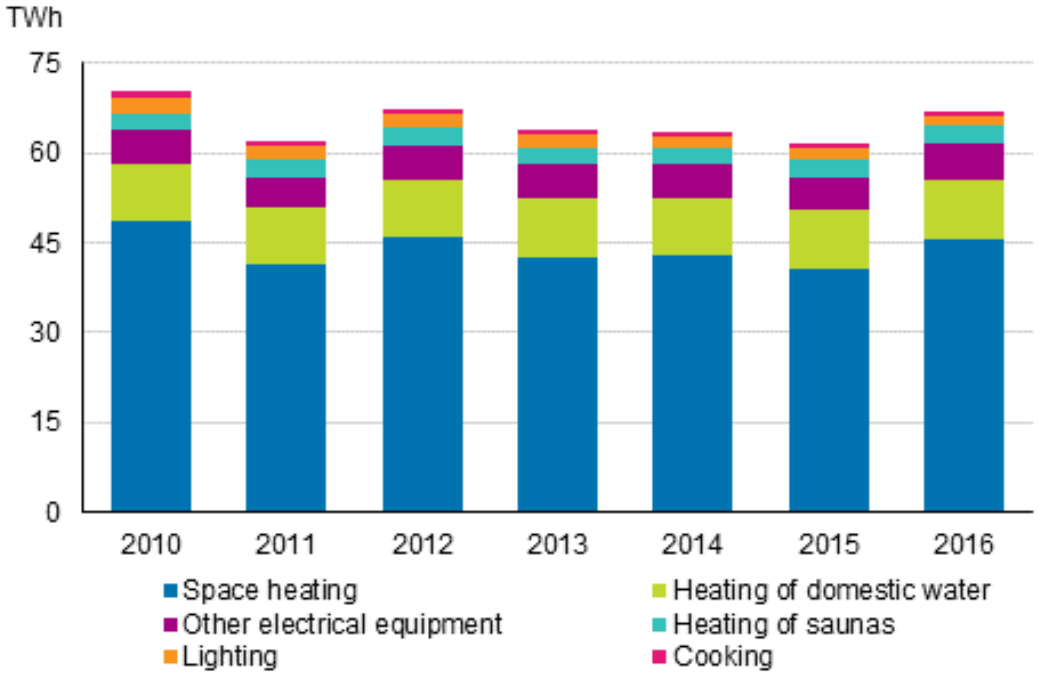



Figure 3. Energy consumption in households 2010-2016 (Statistic Finland 2017).

Figure 3 shows that space heating covers 68 % of the total consumption. The heating of domestic hot water is 15 %. The percentage is fairly constant since the population of Finland does not increase dramatically. In 2016, the heating of space and water of residential buildings consumed 46 TWh of energy. Another category of energy usage is electrical equipment, lighting, and cooking which cover 13 %. Finally, the last category, sauna is 5 %. The electricity consumption for housing appliances take around 20 % of the final energy consumption. There was also some indication of improvement in energy efficiency from 2010 to 2016. The energy consumption rises fairly slow although the heating area increases one percent per year. (Statistic Finland 2017.)

## 2.2 Heating Technologies in Finland

An overview of standard technologies provides a general understanding of the heating sources for residential building in Finland. This chapter discuses four common and sustainable heating technologies, district heating, heat pump, biomass, and heat recovery ventilation, to understand the primary function of the system.

### 2.2.1 District Heating

District heating is the most common heating source in Finland. It was introduced to the market in the 1950s. It is getting more and more popular, and it is available in almost every Finnish town. According to Finnish Energy Industries, about 2.5 million Finns who use a district heating system for their heating source in 2007. Also, more than 60 % of public buildings and offices, around 95 % of apartments, and 50 % of terraced houses also use district heating as a heating source. The consumption of district heating increases, and more detached houses considers it as a sustainable and economical option. The district heating system is getting more sustainable as renewable sources such as biomass, biogas, and residential wastes are used as fuel. District heating can be considered as a renewable and reliable future energy source. (Finnish Energy Industries 2007.)

According to Danfoss, a leading company who provides district heating system equipment and design and consultant services, district heating is a thermal energy network which provides hot water to a building through pre-insulated pipes. The hot water acts as a heat transfer liquid and can be connected directly or indirectly, i.e., with or without heat exchanger from the production site to the end user. District heating conveniently can provide space heating together with domestic hot water. Therefore, in summer the district heating can be operated to supply domestic hot water. The district heating system can be divided into three parts: production site, distribution system, and consumption system. Figure 4 shows a primary district heating system with substations from the production site to a consumption visa the distribution channel. (Danfoss 2018.)

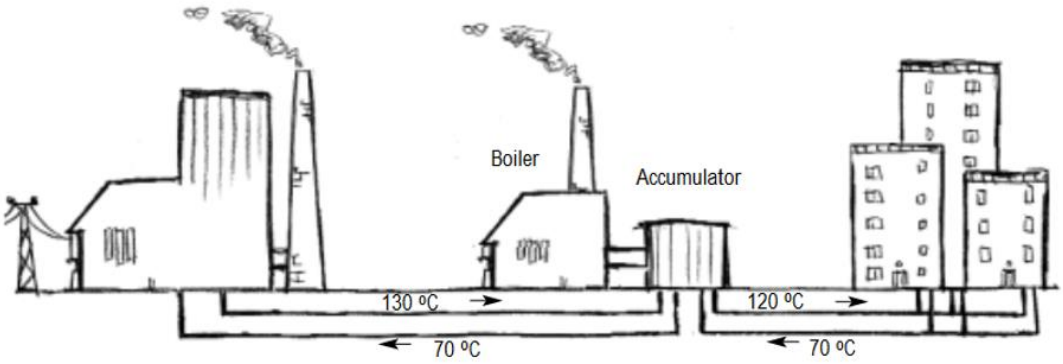



Figure 4. District heating system. (Danfoss 2018.)

As seen in the figure 4, the hot water can be generated by heating plants, pure heat producers or from wastewater in combined heat and power plants (CHP) at the production site. In Finland, the district heating is mostly coming from CHP plants which are energy efficient and sustainable. The distribution system includes the pre-insulated piping network which connects the production site to the consumption system. Usually, the pipping supplies the hot water with the temperature around 120 $^0$C and temperature of water in return pipe is around 60 $^0$C. Circulation pump maintains the circulation of hot water at the production site. When the distribution distance is long, boosting sub-station with a heat exchanger can be installed to maintain the pressure and temperature. In Finland, there is additional heat exchanger at the consumption place to separate the water and control the heat input to the building. (Danfoss 2018.)

A district heating system is the best for dense areas with high energy demand. The fuel used in CHP or boosting station can be flexible and come from renewable sources. Thus, the security of supply is improved and enhanced. With a district heating system, the HVAC system at the end user can be simplified and easy to install. The system needs minimal maintenance fee, required less space, and is very safe compared to other technologies such as a combustion boiler. Finnish district heating provides not only hot water but also cooling water as well. Thus, the system facility can be used all the time. However, there are some limitations to the system such as the availability of the facility. The initial cost can be higher than that of another system if the district heating system cannot available nearby. It is not suitable for small buildings less than 160 m$^2$ and requires an emitter to transfer the heat by floor heating or radiator. Where available, district heating always is the best option as a heating source, and it is an economic and sustainable source.

### 2.2.2 Heat Pump

Number of heat pumps in Finland has been increasing and become the most common heat source in new detached houses. According to Sulpu, the Finnish heat pump association, more than 70 % of new detached houses have chooses to use heat pump as heating sources. In 2017, more than 60,000 heat pump units were sold, and the market sale was up to half a billion euro a year in Finland. Thus, the heat pump plays a significant role, and it could be considered a renewable heating source with various technologies such as air source heat pump, ground source heat pump, and air-to-water heat pump. The most common one in the single-family house is an air-to-air heat pump. Followed by a geothermal heat pump or an exhaust-air heat pump. Furthermore, the heat pump is replacing oil-fired boilers, but they still cover small portion of the total market. (Sulpu 2018.)

The heat pump has become more popular because its coefficient of performance (COP) is higher than other heating source technologies. It means that heat pump can save electricity and is an optimal option to replace boiler or event district heating. According to the Finnish heat pump association, heat pumps reduces 50 % of district heating or other energy consumption in apartment buildings (Sulpu 2018). Heat pumps can be a suitable alternative for scarcely populated areas or if there are no district heating system available. With a high COP (up to COP 6), a heat pump can save more electricity, and could be supplied by renewable electricity, such as power voltage or wind turbine.

In general, a heat pump extracts heat from one place and transfers it to another place by evaporation and condensation. This basic technique is not new and has been used for decades in air conditioners, and refrigerators for example. The energy for running a heat pump is electricity since it needs an operating circulation pump inside the device. However, the electricity consumption of a heat pump is considered low, and it can generate a lot of heat through the process. Figure 5 from the Natural Resources Canada's office of energy efficiency explains the general concept of heat pump comprehensibly. (Natural Resource Canada 2004.)

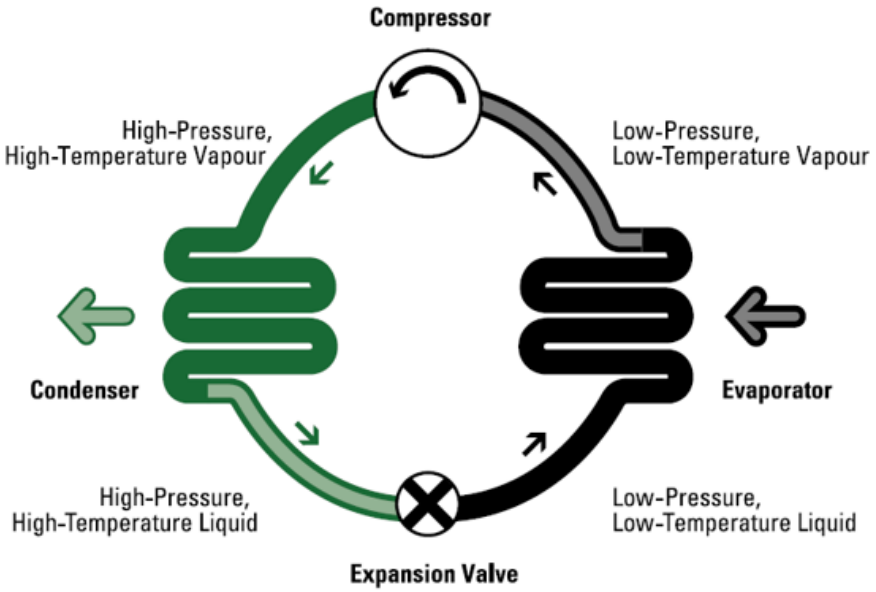



Figure 5. Basic Heat Pump Cycle. (Natural Resource Canada 2004.)

In figure 5, the concept of the heat pumps system is easy to understand because it is the concept of a refrigerator reversed. The system consists of a compressor, an expansion valve, an evaporator, and a condenser. In the evaporator and condenser, there are heat exchanger coils to maximize the surface area that help to absorb or release more heat. A liquid substance called refrigerant is circulated through the condenser and evaporator. In the evaporator, the refrigerant is in an evaporated stage and absorbs heat. Then it goes through the compressor and is pressurised and condenses into a liquid in the condenser. At this point, the heat is released, and the cycle starts again. The whole cycle runs with a small circulation pump and only consumes a little electricity. The COP of a heat pump depends also on the temperature on the cooling side. If the temperature is below -15 degrees Celcius, the COP of a heat pump drops dramatically, and the heat pumps become inefficient. In addition, there are many developed technologies that the heat pump could utilize as a heat sources for example from ambient air or ground source. (Natural Resource Canada 2004.)

**Coefficient of Performance**

As mentioned above, COP describes how efficient the heat pump works. The COP must be considered carefully to design a heat pump system properly. There are formulas to calculate the COP as shown below.

$$COP_{Carnot} = \frac{\text{T cond [K]}}{\text{T cond} - \text{T evap}} = \frac{\text{P cond}}{\text{P cond} - \text{P evap}} = \frac{\text{Q}}{\text{W}} \quad (1)$$

$$Carnot\ efficiency = \frac{\text{COP real}}{\text{COP carnot}} \quad (2)$$

Where:
*T cond* is the temperature of the condenser
*T evap* is the temperature of the evaporator
*P cond* is the power of the condenser
*P evap* is the power of the evaporator
*Q* is the output energy production
*W* is the input energy required used by the heat pump

The data for formula one and formula two were gathered from (Collie 1979; Powers 2013: 2; Zottl, Nordman & Miara 2012: 10). Formula one shows the method to calculate the theoretical COP of the heat pump. The temperature used in the formula one is given in Kelvin. There are many alternative ways to calculate the theoretical COP, such as using the power between condenser and evaporator. A heat pump used for cooling purpose is called a refrigerator or air conditioner. In this case, the COP is equal to the cooling effect divided by the work input (Powers 2013: 2).

Formula two is used to calculate the actual efficiency of the heat pump. The COP Carnot calculated by formula one is a theoretical performance that can be reached only in ideal condition. In practice, many factors affect the COP of the heat pump, such as heat loss, the efficiency of components, pressure drops or deforestation of working fluid. To calculate the real COP, the Carnot COP can be multiplied to the efficiency percentage of the system. The average value for the Carnot efficiency is from 50 % to 70 % depending on heat pump system. (Collie 1979; Powers 2013: 2; Zottl, Nordman & Miara 2012: 10.)

**Air-Source Heat Pumps**

The air-source heat pump draws heat from surrounding air and transfers it to another place. There are three types of air-source heat pumps. The most common one in Finland was an air-to-air heat pump. The others are an air-to-water heat pump, and an exhaust-air heat pump. The air-source heat pump has low investment capital, and it is a suitable

alternative for a new detached house in Finland. In 2017, there were more than 47,000 air-to-air heat pumps; 4,000 air-to-water heat pumps; and only 3,000 exhaust-air heat pumps were sold (Sulpu 2018). On average, an air-source heat pump can save up to 40 % to 60 % of the total heating demand annually. The difference among the three types is the output. An air-to-air heat pump takes heat from the outdoor air and transfers it to indoor. An air-to-water heat pump is slightly different. It uses heat from the air and transfers it to water. The hot water is distributed inside and can be store in a water tank or connects to the hydronic systems such as a radiator or floor heating. Some of the recent technology can provide domestic hot water as well. The exhaust-air heat pump is connected to the ventilation system and uses heat from the exhaust air to heat up the supply air or to produce hot water. (Sulpu 2018.)

In Finnish climate, the air-to-air heat pump is inadequate to supply the heating source for the standard building in Finland because the COP of the heat pump relies on the ambient air temperature. If the outdoor air temperature drops below -20 $^0$C, the COP can be around 1. It means that the heat pump acts as an electric resistor to heat up the air or liquid. The lower the outdoor temperature, the less heat energy the heat pump can supply. Thus, for a low energy house, the air-source heat pump can be the only primary heating source. In fact, the air-to-air heat pump can be added to the system and work together with another heating source such as a boiler or district heating in old house or retrofit building. The temperature of the supply air in a heat pump unit can vary from 0 $^0$C to 45 $^0$C, and it can operate more efficiency in that range of temperature. The cost of air-to-air heat pump vary from €1,500 to €2,500. (Sulpu 2018.)

The air-to-water heat pump operates with the same concept except the output is hot water. It has better efficiency and can save more electricity because water stores heat better than air and the heat energy can be stored at a cylinder. An air-to-water can be functioned in lower temperature such as -26 $^0$C compared to an air-to-air heat pump. The hot water can be connected to hydronic system (floor heating and radiator). Usually, floor heating operates with maximum 35 $^0$C hot water to circulate in the system. Therefore, the air-to-water heat pump can produce the heat with less electricity consumption. However, an air-to-water heat pump is cost more than an air-to-air heat pump. The normal price varies from €8,000 to €12,000 include the cylinder. In new buildings, an air-to-water heat pump can be the primary heating source. (Sulpu 2018.)

The exhaust-air heat pump system is developed to solve the problem of low outdoor temperature in the winter. It is the most energy efficient heat pump right now. The exhaust air temperature in most of the buildings is a constant 20 $^0$C – 25 $^0$C around a year in Finland. Thus, the COP of the heat pump is getting better, and the overall energy efficiency is improving. The cost of an exhaust-air heat pump system is from €6,000 to €10,000. It is cheaper than an air-water heat pump. The exhaust-air heat pump system package includes ventilation device but excluding channel installations. (Sulpu 2018.) Up to 40 % of the heating energy compared to district heating can be saved (Pippuri 2012). Figure 6 shows the scheme of an exhaust-air heat pump system.

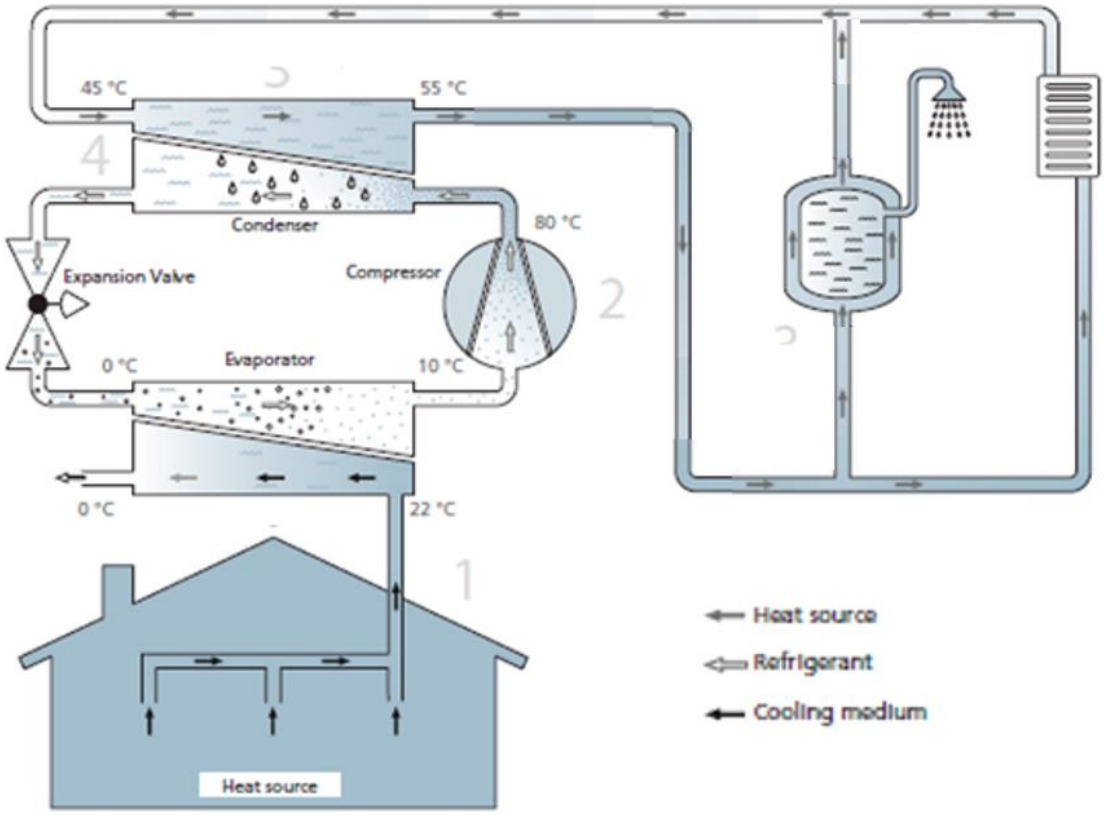



Figure 6. Exhaust air heat pump. (Nibe 2018.)

Figure 6 shows the flow system of an exhaust-air heat pump. The warm exhaust air goes through the heat exchanger transferring the heat to the refrigerant and circulating in the heat pump system. The exhaust air temperature can be around 0 $^0$C and goes out of the house. The efficiency is better than that of an air-to-air heat pump because the heat source, the exhaust air is always around 20 $^0$C. The compressor raises up the heat to 80 $^0$C by increasing the pressure of the refrigerant. The heat energy can be stored in a

cylinder or connected directly to a hydronic emitter to heat a house. At the condenser, the refrigerant is condensed into a liquid and goes through the expansion valve to turn into gas. At the evaporator, it continues to collect the heat from the exhaust air and circulates again. (Nibe 2018.)

The average COP of an exhaust-air heat pump is around 2.2, which is lower than that of a geothermal heat pump. During the coldest season, there is not sufficient heating capacity, and the house needs to be heated by an auxiliary heat source such as electric resistors or wood boiler. The situation is the same with an air-to-air heat pump, but with a better COP. For smaller single-family house or low energy house, it is sufficient since the heating demand of the house is quite low compared to a regular house. (Nibe 2018.)

**Ground Sources Heat Pump**

A ground source heat pump extracts the constant heat from the ground, usually soil or water. The radiation from the sun heats up soil and water, and the ground stores the heat in its large thermal mass. The temperature is around 10 $^0$C around the year. The depth of bore hole is around 2 m to 10 m depending on the ambient temperature and location. A ground source heat pump's water piping can be installed either vertically and horizontally. Therefore, this is an excellent heat source that can generate heat in the winter or cooling in the summer. The technology has been studied and utilized since the 1970's, and a number of usage keeps growing steadily although the high investment at the beginning. A geothermal heat pump is the most energy efficient heat pump. Its average COP is 3 throughout a year. However, due to its high investment cost, a house with a large treated floor area over 150 m$^2$ is suggested to install a geothermal heat pump. Furthermore, the depth can be deeper in Finland, and it is difficult to dig down because of the bedrock foundation. (Pippuri 2012.)

A ground source heat pump is easy to use and require minimal maintenance. The heat energy from a ground source is constant and can reduce the electric consumption for the circulation pump. When the price of electricity increases, the return of investment time of ground source heat pump is shorter. And more people is going to use it. The ground source heat pump can also be installed to the old house if there is a hydraulic emitter heating system available. A ground source system can be used with forced air also and can be designed and connected to the cylinder to provide hot water as well. (Pippuri 2012.)

A ground source heat pump can save more than 40 % compared to air-source heat pump. A ground source heat pump can be the only heating source and still function well. The saving varies depending on the climate, the efficiency of the system and other factors. The disadvantage of this technology is the refrigerant. The refrigerant can be harmful to the ozone level and caused greenhouse gas emission. Right now, there is better refrigerant available in the market, and the heat pump will become more and more popular in the future. (Pippuri 2012.)

### 2.2.3 Biomass – Wooden Pellet

Biomass is organic matter material produced by photosynthesis on the earth's surface. It can be vegetation, trees, bio-waste from humans and animals, or even forestry and agricultural residues and some types of industrial (Klass 2004). Finland has more than 75 % of country area cover by forest, and about 86 % of land area is forestry land (Finnish Forest Association 2014). It is a vast potential renewable resource for heating as biomass. To convert energy from biomass to heat energy, the biomass is burned by different technologies. The most basic and ancient way is using the fireplace, then other modern technologies are furnace or boiler. When heating a single-family house is often using wood log and pellets as energy sources. (Statistic Finland 2017.)

The fireplace is a traditional heating system. It had been used for centuries all over the world. The system is simple and straightforward. The fuel is burned, and the formed hot combustion gases are captured by the vast thermal mass structure of the fire place during the burning process. The fireplace transferred heat into building through convection or radiation. A new modern fireplace can also generate hot water and transferred it to the water tank to supply the domestic hot water demand in the building. In fact, the conventional wood burning fireplace is not energy efficient because of the substantial portion of heat lost through the chimney while an only small portion of the heat warms the space. There are also many problems related to fire safety, air pollution, massive air consumption, and reduced combustion. A modern fireplace system is more efficient and can avoid all the problems. The most prominent advantage is that wood is a renewable fuel well available in Finland. (Alakangas 2008.)

A furnace is similar to a fireplace but more compact and with higher efficiency. The system generates heat from combustion and transfers heat via air to a designed space by distribution ducts. However, this technology is not efficient in Finland, and the air is not

a perfect heat transfer material. The fuel is used in the furnace can be biomass, gas or oil. Another technology similar to furnace is a boiler. A boiler uses the same technology except it uses water to transfer heat. The boiler can be connected to the hydraulic emitter system of the house or to a hot water storage. Therefore, boiler gives more controllable to the design temperature of the room. Instead of a fan and duct system like with a furnace, a boiler uses a small pump to circulate the water through the system. Similarity to a furnace, a boiler can also use other fuels such as gas or oil. An advanced piece of boiler technology is a condensing boiler with gas that can produce heat with a maximum thermal efficiency up to 109 %. (Kou, et al. 2003.)

The advantage of using wood or pellet as fuel is cost-effectiveness. The wood pellet is a recycled product from forestry, and its price is often stable compared to fossil fuel. Wood and pellet are also environmentally friendly materials and renewable energy. In addition, when using a wood pellet boiler, the waste from forestry can be recycled which helps the local economy to grow. However, there are also some disadvantages when using wood pellets. The system requires frequent cleaning and maintaining for heat exchanger to work effectively. Furthermore, ash needs to be emptied often. Fuel storage can also be a problem since space is valuable in an urban area. The significant initial costs are also a challenge. There are many advanced technologies with lower cost but better efficiency than the boiler. (National Energy Foundation, 2009.)

### 2.2.4 Mechanical Heat Recovery Ventilation

Ventilation is a process of controlling the air of the building to maintain a comfortable living condition without contaminants, and humidity, while providing good temperature, and oxygen level. There are three approaches to ventilate building: natural ventilation, simple extract/ supply air system, balance system with heat recovery. Natural ventilation buildings are often not air tight because the supply air comes from windows and leakages of the wall. Therefore, in Finnish cold climate, the natural ventilation system can cause drafts, uncomfortable and consume much heating energy than other types of ventilations. With an uncontrol supply air, the indoor air's quality and temperature is difficult to maintain. Therefore, the concept of building air tight and control indoor air by mechanical ventilation with heat recovery is becoming popular. Mechanical ventilation with heat recovery can reduce up to 50 % of the heating demand and offer better energy efficient to a building. (Feist 2003.)

Heat recovery from ventilation exhaust air was invented and developed in Sweden in the late seventies (Mats Fehrm, Wilhelm Reiners and Matthias Ungemach 2002). Mechanical ventilation heat recovery (MVHR) with post-heating can be the primary heating source in extremely energy efficient building such as Passive House. With low heating demand (heating demand is 90 % less than the regular house), Passive House can be heated by the only MVHR with post-heating. (Passipedia, 2008.) They are also a good option for new standard building or even old building to save energy when combined with other heating technologies. Thus, the indoor air quality can be maintained at the highest level with lowest energy consumption.

The MVHR is designed to use heat from exhaust air for heating up the supply air via the recovery unit. There are many types of recovery units such as fixed-plate, heat pin, rotary wheel, or run-around coil units. (Office 2015.) Figure 7 illustrates the operation of the HRMV from Homeowner Protection Office Canada.

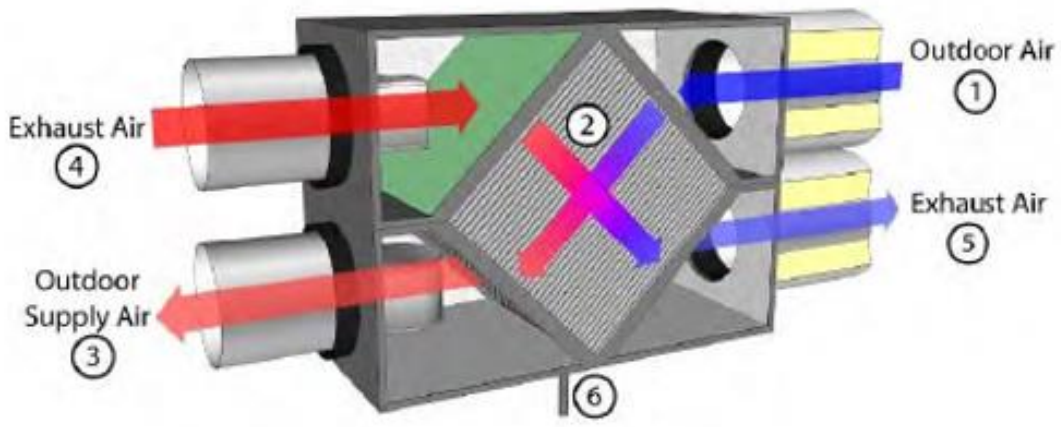



Figure 7. Mechanical ventilation with heat recovery unit. (Office 2015.)

As seen in the figure 7, the outdoor air (1) goes through the ventilation unit via the outdoor air pipe and passes the heat recovery unit (2). Then the air is heated up by the exhaust air (4) to a specific temperature and leaves the ventilation unit through the outdoor supply air ducts (3). At this point, the supply air can have a temperature up to 18 $^0$C, or 21 $^0$C with a post-electric heater. In a passive house or a very energy efficient house, the air supply to a room can be heated up to 50 $^0$C to provide space heating. The exhaust air (4) that comes from the room is around 20 $^0$C to 21 $^0$C. It passes the heat recovery unit

(2) and exchanges heat with outdoor air (1) and leaves the house through an exhaust air (5) pipe. In the coldest season, some frost protection, run by electricity must be installed to prevent damage. Typically, the frost protection is activated when the temperature drops below -3 $^{0}$C. The condensation that occurs during the heat exchange process is collected through the drainage pipe (6). The process is running simultaneously and create a balanced system of ventilation. The recovery rate can be varied from 60 % to 95 %. (Mardiana & Riffat 2013.) The benefit of MVHR is undeniable. It provides continuous, balanced ventilation with high energy efficiency and enhances indoor air quality, thermal comfort. In contrast, the significant disadvantage is that MVHR requires a duct system and higher initial investment than that of natural ventilation. (Office 2015.)

## 2.3 Combined Technologies

In chapter 2.2, various heating-source technologies were introduced. On the other hand, not all of them can accumulate or recover heat from another source. There are two capable technologies which are heat pump and recovery ventilation. These technologies can be applied separately or in combination. This small chapter discussed the combine option of heat recovery unit and exhaust air heat pump to generate heating supply for the multi-family house.

There is technology to combine all the building service (heating, ventilation, hot water and cooling) of the house into one single unit. It is called a compact heat pump unit and it has been widely used in low energy demand buildings such as Passive House building. According to European Standard, various technologies are shown in figure 8.

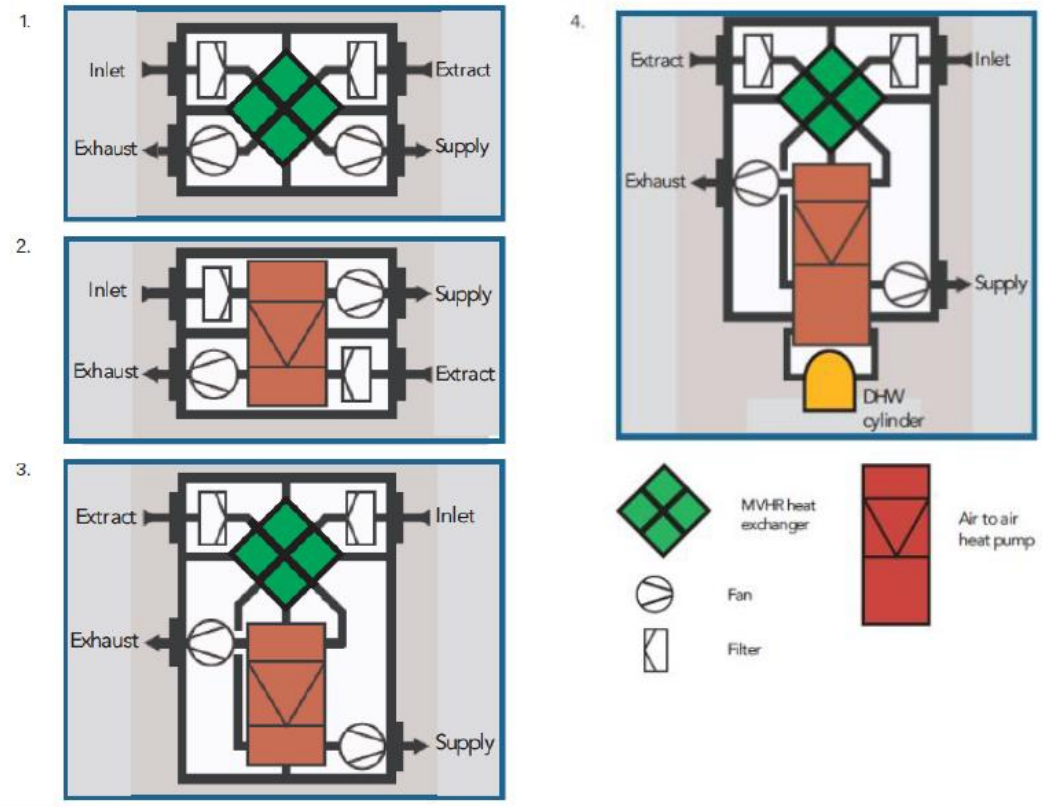



Figure 8. Development of compact unit. (EN 12792:2003 2011.)

Figure 8 shows the first system which is heat recovery ventilation. The heat recovery ventilation unit recovers heat from the exhaust air pipe and delivers it to the supply air pipe (1). The heat recovery efficiency can be up to 92 %. The next systems is replacing the heat exchanger by an air-to-air heat pump (2). The heat pump can extract the heat from the exhaust air pipe and transfers it to the supply air pipe with a higher COP than a regular heat pump. The exhaust air still contains some heat energy after heat exchanging and its temperature is around 5 $^{0}$C to 10 $^{0}$C. Therefore, the combined heat pump and heat exchanger are developed to overcome the limitation of the heat pump and MVHR (3). At a combined heat pump and MVHR, the exhaust air at a stable 21 $^{0}$C to 25 $^{0}$C degree temperature exchanges heat energy to the intake air via heat exchanger. Then, the exhaust air continues passing the air-to-air heat pump again. The heat pump extracts the remained heat to increase temperature of the supply air to the design temperature. Commonly, in the MVHR, the electric coil is often used to de-frost of post-heating. The electricity consumption is only used for ventilation fan and circulation pump. And the heat pump is running with COP around 2 to 3. In this type of development technology, the electric consumption can be saved due to the two time reusing heat energy from exhaust air. This development unit supplies only heat via air. (EN 12792:2003 2011.)

To extend the usability of this type of technologies the fourth generation is developed (4). It gives the technology more option to provide the space heating. By simply replace an air-to-air heat pump by an air-to-water heat pump, the system now can provide hot water for heating space and domestic water. The hot water can be stored in a cylinder or connect to the hydronic heating system as well. With this type of compact unit, all the building services can be provided by only one unit with high efficiency. This unit comes with high initial investment. Therefore, it is not used commonly in the market. Another limit for this system is not suitable for high heating demand house. The heat energy of this system is taken from the exhaust air. In the coldest season, there is not much heat for the heat pump to recover if the demand is too high. Therefore, it is not enough heat energy to supply the high heating demand. Then the compact unit uses electricity to heat up the desired demand and consume more electricity. This compact unit is suitable for low energy efficient houses. The system may perform better if there are an extra heat source supply to the unit. The additional heat source can come from air source, ground source or indirect heat source system. (Passive House 2009.)

# 3 Cryptocurrency and Its Mining Process

Cryptocurrency and its mining process have developed expeditiously in recent years. Cryptocurrency trading and mining are still illegal in some countries, and their potential is still a big question mark. Hence, this chapter explains what cryptocurrency is and how it functions, and discusses its mining process and technologies behind it. Chapter 3.1 presents the concept of currency. Then, the concept of cryptocurrency is briefly introduced in chapter 3.2. The available technologies for mining are discussed in chapter 3.3.

## 3.1 Concept of Currency

A currency is a tool for barter. As the society develops, the demand for value exchange between people increases; therefore, a currency was born as a representation of value so that goods and service could be traded by converting to it. In other words, the currency plays a role as a medium in trading, and standard measurement of value. (Davies 2002: 9-11.)

The demand for barter arose with the history of the society. Currency appeared in many forms. Before the advent of money, commodities were considered as a preferred item used to trade. Because they had a high usable value, they were easy to change or move and lasted long. Items with more of the mentioned qualities had a higher preference in trading. (Davies 2002: 10.) It was, however, the evident that classic goods to goods barter had some disadvantages. For example, it was very hard to find any standard value to be compared to commodities' value. Furthermore, it was more likely to conflict between purposes of the traders (Davies 2002: 14-15). For example, it was difficult to find traders needing to exchange a bag of coffee for a bag of apples. Additionally, even if a person who wanted a bag of apples were found, the rate of exchange between an apple and coffee could be a problem. The more commodities were traded in the market, the more complicated exchange rate was required between commodities (Davies 2002: 14-15). For instance, if three items were traded, only three exchange rates were needed but with four commodities, the number of necessory rates was six.

Because of the many disadvantages of the first currency, metallic currency began to be used. Metallic currency is linked to more advanced communities as from the Stone Age. People learned that metasl are rare and usable in many applications. (Davies 2002: 45.)

In particular, since the development of metallurgy, metals were categorized based on their characteristics and scarcity. Gold, silver, bronze, and copper are well known as materials for money before the appearance of iron and aluminum. In the early days, metallic tools, such as knives, or even necklaces were used as money. Metals gradually surpassed other primitive money and became the primary currency. Metallic money was more likely to be the sign of a more advanced civilization before digital era because of their apparent characteristics, such as popularity, benefits, convenience in storing, divisibility, durability, the stability of value and unity in society. Furthermore, the speed of transaction was enhanced because it is clear that metals could be separated into pieces. In other words, Metallic currency's pieces were easier to be counted than weighting. Hence, the metallic coinage concept was born. (Jevons 1910: 31.)

Along with printing, paper currency was first born in China. The paper currency was born to resolve the shortage of metals used to make coinage. Additionally, paper currency also dealt with the massive weight of metal which was inconvenient. Despite the advantages of paper currency, it quickly lost its credibility. In 1020, there was a tremendous amount of cash, equivalent to 2,830,000 ounces of silver. This cash was sent to the Northern enemies for the exchange of peace with China, causing a domestic shortage of cash. The Chinese authorities attempted to supply the shortage by printing new paper notes, causing an inflation which devalued the paper currency. Afterward, the Western countries combined its simple alphabets letters with Chinese experiences in printing to issue banknote afterward and apparently it was successful. Using alphabets made the cost for printing banknote is much lower and the speed of transaction was enhanced. (Davies 2002: 181-184.)

Inheriting from the legacy of Chinese in money printing, Western countries started to find a solution to deal with the disadvantages of the paper money. Britain was the pioneer in making a gold standard system to secure the paper money. Previously, although paper money had appeared a long time before and its trading methods based on paper had been used in Europe for 400 years, there were still no methods to limit the uncontrollable money printing. In other words, there was no approach or idea to deal with the inflation. Finally, to deal with the depreciation of the national paper currency of Britain, caused by a long war, an innovative concept of cash was suggested. Gold replaced silver to be the standard of value, and the flexible supply of money was able to be covered and guaranteed. The history has shown the success of this method, the banks successfully handled the drain of gold reserves by intentionally controlling the money supply printed, and with

the links between paper and gold, the price of the paper money or the value that the paper represented was kept steady. With this compromise between gold and cash, Britain was cable of taking full advantage of the new gold supply taken from its colonies to fund and develop the economy. (Davies 2002: 284 - 286.)

After the era of traditional money, the era of digital began so that the money did not necessarily have to exist in tangible, or fiat currency, forms. One of the intangible forms of money is virtual currency. The virtual currency is a concept with no central bank to neither print the currency nor authorize its public agency. Additionally, virtual currency is used by a legal person and can be stored electronically. In other words, it is stored intangibly on computers and does not represent any value of fiat currency. Although it is used for human purposes, it is not guaranteed legally. For example, a discount point earned with a super market's discount cards is virtual currency. The supermarket owner is the person issuing the discount points with an unlimited supply. However, its transaction volume is low because it is only valid within tiny scales, such as the supermarket or its branches. Also, virtual currency is not secured by law. The person holding virtual currency is not protected by law that granting him the right to use his virtual currency to pay for his legal monetary debt or convert virtual currency to fiat currency. (European Banking Authority 2014: 11-13.)

Digital currency is the next category of electronic currencies. The definition of electronic currencies is general and unspecific because the concept of digital currency implies any currencies operated and stored digitally. It is not only decentralized currency stored in the personal computer, but also centralized currency regulated by legislation (Committee On Payments and Market Infrastructures November 2015: 4-5). The decentralized currency is discussed in the next section. Centralized currency is the currency that regulated by legislation. For example, the digital money in the balances from a bank account that are given by the central bank or the commercial banks. This kind of money grants a person rights to use for any types of payment.

Considering the variety of the digital currencies, there are two main characteristics of digital currencies which are centralization and decentralization. The centralized digital money is equivalent to the actual fiat currency that a person can deposit in a bank. With digital money, it is possible to withdraw physical cash or swipe for online payment. Because of digital currencies' application and protection by the legislation, liquidity of digital currencies is much higher than that of the virtual currency. Nevertheless, as

opposed to decentralized digital currency, the disadvantages of centralized digital currency is its centralized storage which means that controlling, printing and storing activities are centralized in a single source, such as banks or trading platforms. Therefore, the source can be exposed to damage if the money are stolen by hackers (Committee On Payments and Market Infrastructures 2015: 9).

## 3.2 Cryptocurrency

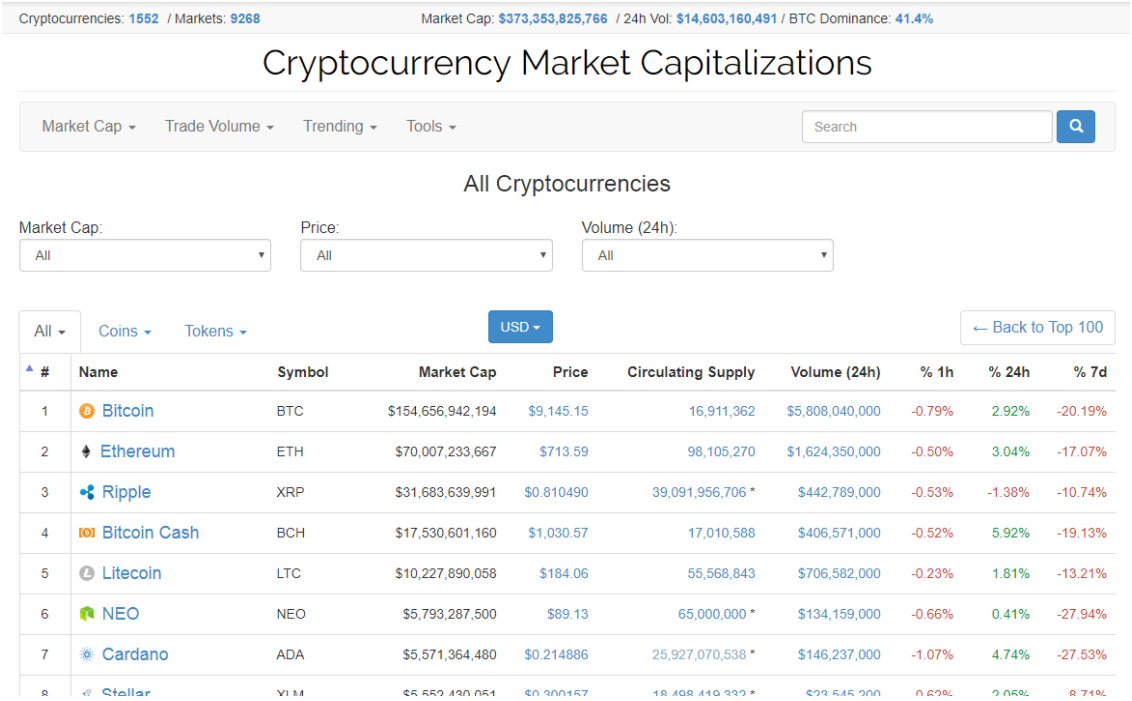
Cryptocurrency has developed rapidly in the recent years. In this section, its definition, origin, and the blockchain technology that is used to mine it is discussed to demonstrate.

### 3.2.1 Definition

Besides, the traditional digital currency which is backed by governments, there is a type of currency called cryptocurrency. Cryptocurrencies are currencies which are encoded electronically with scripts. These currencies were invented with the intention to give an alternative to the official, government-backed currencies. As seen in its name, cryptocurrency is the combination of cryptography and currency. Cryptography is used to encode the data of the transaction with this currency. The use of blockchain technology guarantees high confidentiality. Furthermore, cryptocurrency has the characteristics of any other normal currencies when it can potentially change traditional currency in term of finance and commercial. (UBS AG and UBS Financial Services Inc. 2017: 2.)

Cryptocurrency is commonly mistakenly considered to be the same as Bitcoin. Bitcoin is cryptocurrency, but cryptocurrencies do not include only Bitcoin. Bitcoin was the first famous cryptocurrency which was created by Satoshi Nakamoto in 2009 (UBS AG and UBS Financial Services Inc. 2017: 2; Khemarattana 2017: 3). Table 1 below shows the current situation of the cryptocurrencies market on the 10th of March 2018.

Table 1. Cryptocurrency market cap on the 10th of March 2018 (Coinmarketcap 2013).



Cryptocurrencies: 1552 / Markets: 9268 Market Cap: $373,353,825,766 / 24h Vol: $14,603,160,491 / BTC Dominance: 41.4%

Cryptocurrency Market Capitalizations

Market Cap Trade Volume Trending Tools Search

All Cryptocurrencies

Market Cap: All Price: All Volume (24h): All

All Coins Tokens USD ← Back to Top 100

| # | Name | Symbol | Market Cap | Price | Circulating Supply | Volume (24h) | % 1h | % 24h | % 7d |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Bitcoin | BTC | $154,656,942,194 | $9,145.15 | 16,911,362 | $5,808,040,000 | -0.79% | 2.92% | -20.19% |
| 2 | Ethereum | ETH | $70,007,233,667 | $713.59 | 98,105,270 | $1,624,350,000 | -0.50% | 3.04% | -17.07% |
| 3 | Ripple | XRP | $31,683,639,991 | $0.810490 | 39,091,956,706 * | $442,789,000 | -0.53% | -1.38% | -10.74% |
| 4 | Bitcoin Cash | BCH | $17,530,601,160 | $1,030.57 | 17,010,588 | $406,571,000 | -0.52% | 5.92% | -19.13% |
| 5 | Litecoin | LTC | $10,227,890,058 | $184.06 | 55,568,843 | $706,582,000 | -0.23% | 1.81% | -13.21% |
| 6 | NEO | NEO | $5,793,287,500 | $89.13 | 65,000,000 * | $134,159,000 | -0.66% | 0.41% | -27.94% |
| 7 | Cardano | ADA | $5,571,364,480 | $0.214886 | 25,927,070,538 * | $146,237,000 | -1.07% | 4.74% | -27.53% |
| 8 | Stellar | XLM | $5,552,430,051 | $0.300157 | 18,498,419,332 * | $23,545,200 | 0.62% | 2.05% | 8.71% |

Table 1 is the home page of the most famous website for cryptocurrency market (Alexa, 2014). According to this website, 1,552 cryptocurrencies released and operated until the 10th of March 2018. In addition, there were also thousands of (Initial coin offering) ICO projects were calling for the fund and created by thousands of startup companies day by day (ICObench 2017). There were 9,268 trading flatforms were operating.The other information gathered from the table 1 was about Bitcoin, it was illustrated as the most dominant cryptocurrency with market capital funded occupied about 41.4 % total market capitalizations which were about $154,656,942,194 and was more than double the second position cryptocurrency named Ethereum. (Coinmarketcap 2013.)

### 3.2.2 Blockchain Technology

The backbone technology used for cryptocurrencies is known as blockchain. Blockchain, in general, is decentralized or distributed system, as opposed to the traditional centralized system. The traditional centralized system is used in database management, as servers (UBS AG and UBS Financial Services Inc. 2017: 6-7). Figure 9 below describes these two systems.

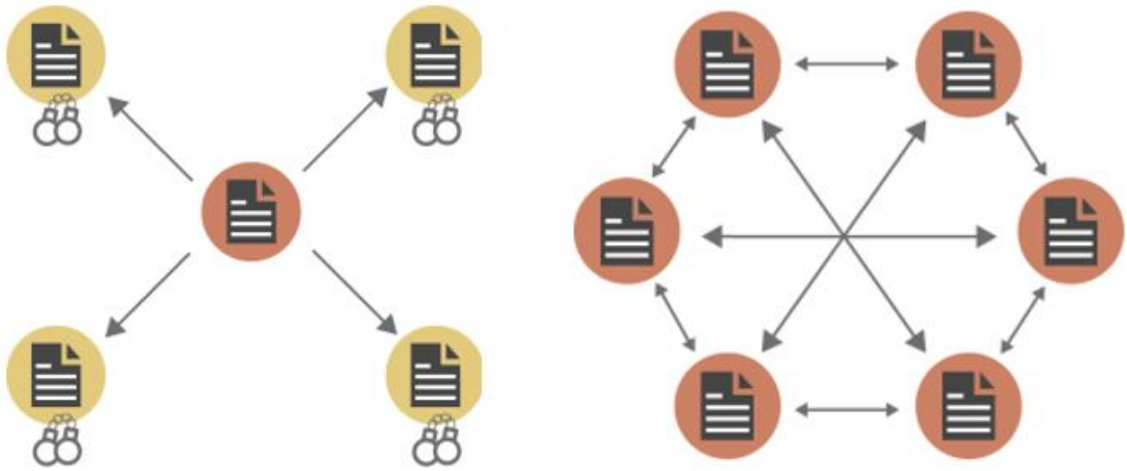


Figure 9. Centralized system (left) and Decentralized system (right) (UBS AG and UBS Financial Services Inc. 2017: 6-7).

The system on the left in figure 9 is a centralized system. Only the central party has the right to update information. The updated information is shared with the other parties (UBS AG and UBS Financial Services Inc. 2017: 6). For example, a bank is a centralized system. When money transfer is made between people, the bank plays a vital role as a middleman to supervise, validate and confirm the order. Then the money transfer is approved. In contrast, there is a distributed networks called decentralized system. This system attempts to erase the middleman to reduce the transaction cost. Furthermore, data transaction is stored digitally by all individuals across the blockchain network. Therefore, any potential modification or update to the data must be accepted and verified by the majority. The majority are individuals who are in the networks and used the cryptography to encode the data (UBS AG and UBS Financial Services Inc. 2017: 7). With this system, intermediation is no longer needed to validate a transaction; this method relies on peer-to-peer transactions.

A blockchain is composed of three parts. Each part contributes to the operation of the system. The first part are the hash values, or the cryptography methods or algorithms for the encryption of a transaction. The second part is the content, such as a transaction, account address, balance for exchange or smart contract. The content depends on the blockchain technology. Blockchain 1.0 can handle data transfers, for instance, Bitcoin. Blockchain 2.0 can process data transfers and smart contracts. The newest version, blockchain 3.0, can handle many functions from trading, and payments to cloud or internet of things. Lastly, the final part of blockchain is the ledger. It has the same function as a HDD or USB drive, it is used to store data on a physical device. However, the data

recorded to the ledger is digital, stored and managed in a synchronized manner by all individuals across the blockchain networks. Additionally, a ledger records many consecutive blocks chronologically, and each block contains data of many transactions (UBS AG and UBS Financial Services Inc. 2017: 7; Rosic 2017.)

With the support from the blockchain technology, cryptocurrency works in a stable process. Figure 10 below depicts the process of cryptocurrency operation.

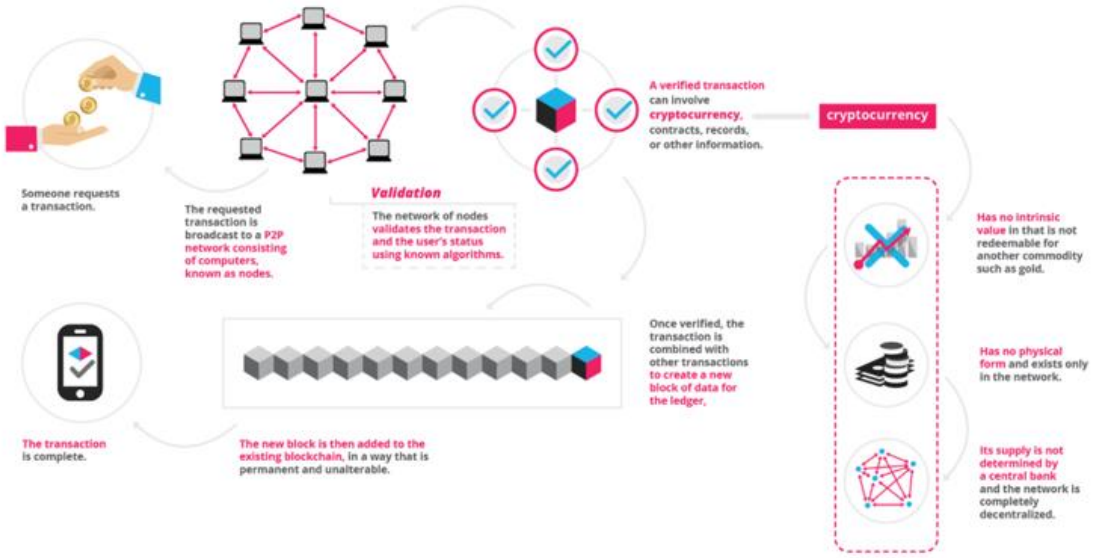



Figure 10. The process of cryptocurrency (Rosic 2017).

Figure 10 demonstrates how a peer-to-peer transaction system works. First, a transaction is requested between people, and that transaction order appears on the blockchain network so that all individuals in the network must check and confirm if the transaction is possible, for example, checking the previous balance to confirm there is enough money remaining to execute the transferring order. The transaction plays the role of the content part mentioned in the structure of blockchain above. Once this content part is verified, hash value is attached to the content part to encode and write it on a new block. The hash value is the first part of the blockchain as mentioned above; it is a unique random string of characters and numbers which improved the security by transforming data to mathematical data. After encryption, the transaction goes together with multiple other transactions around the network, in order to be recorded and stored on the blocks in the ledger. For each ten minutes, the block is closed and a new block is created and ready for the next transactions. Once the previous blocks are recorded on the ledger, it is nearly

impossible to change any previous data; because if the data is altered, the hash string would be different. Additionally, the network is supervised, and data on the ledger is stored in a synchronized way by all individuals across the networks. If one individuals refused the change, the modification would not be approved. Therefore, any data using the blockchain technology is strictly confidential and cannot be manipulated or hacked into a single entity. (UBS AG and UBS Financial Services Inc. 2017: 7-8.)

### 3.2.3 Future of Cryptocurrency

Cryptocurrencies uses blockchain as core technology so it has the same appications as blockchain technology applications. Blockchains keep evolving their content part, they have many potential applications. The financial application described above is one of the first featured applications as it guarantees to remove the intermediation. Thus, the costs can be reduced. Additionally, the confidentiality is guaranteed with a cryptographic and decentralized concept. Therefore, trading can be executed faster with lower cost and less hacking risk. Legal compliance is the next application. Because of the transparency of the blockchain, banks or authorities can attach digital identities to clients. Any laundering transaction can be tracked easier. Manufacturing can be faster and time would be saved as the blockchain allows confidential and quick communication between a manufacturer and a retailer. The database and identities of a blockchain can also be used in healthcare service to track down medical history of patients. Public services can use blockchain technology to manage the population or public elections. Finally, the smart contract is one of the features of blockchain which enables a healthy economy by playing its role as a trusty middleman. It helps to avoid fraud and breach of contract. (UBS AG and UBS Financial Services Inc. 2017: 11-13.)

Historical data of cryptocurrency is used to forecast its potential in finance. Bitcoin has been the most dominant cryptocurrency so that its growth has affected the whole market. Hence, an analysis of its price shows the volatility of the market, as can be seen in figure 11 below. (Coinmarketcap 2013.)

Figure 11. Price and market capitalization of Bitcoin (Coinmarketcap 2013).

Figure 11 shows the volatility of the price and market capitalization of the Bitcoin, also known as the king coin of the cryptocurrencies market. Its price fluctuated from an unknown position when 10,000 bitcoins were traded for only two pizzas in 2010. The highest value of Bitcoin was about $20,000 per coin on the 17th of December 2017. (Price 2017; Coinmarketcap 2013.) In 2016, the price was only about 800$, exactly one year before the peak value. In other words, the value had grown 2,500 % since Bitcoin was introduced to the market. Moreover, on 10th of March 2018, it had decreased to about half of the highest price. (Coinmarketcap 2013.) It is evident that an investment in cryptocurrency is a high risk one, but may give a high reward.

Cryptocurrencies still face many challenges. One of them is an attempt to be a wide-known medium of exchange. Because no cryptocurrency is backed by official governments, taxes or gold, it is not accepted as an official payment method. Not many governments have legalized cryptocurrencies or allow free trading and mining. Consequently, it has not been accepted as an official currency. Therefore, a person who holds cryptocurrencies has to convert it to fiat currencies if a purchase is to be made. The risk of exchange is transferred to the traders, except for some limited or underground exchange. For example, cryptocurrencies are used primarily on the Deepweb for the exchange of illegal goods, slaves, guns or drugs. Furthermore, the value is a challenge. It is big idea when cryptocurrency was created in order to transfers the financial power from the central bank or official authorities to all people. Additionally, cryptocurrency helps to avoid the inflation caused by money printing from the banks. However, it is

impossible to decrease the supply of some cryptocurrencies so that it is hard to balance the price in the same way as the fiat currencies in case of a fall in demand. (UBS AG and UBS Financial Services Inc. 2017: 3-5.)

## 3.3 Cryptocurrency Mining Process

As mentioned in subsection 3.1 above, fiat currencies are backed with gold and cryptocurrencies share the characteristics between virtual currencies and digital currencies. Therefore, they also share the concept of mining gold. On the one hand, traditional mining requires human labor and mining tools, such as shovel or pickaxe. Computational power or hash rate and energy resources are required by the cryptocurrency mining process.

### 3.3.1 Definition

Mining process is the process that new blocks are added to the ledger of a blockchain by computational power (Hileman and Rauchs 2017: 88). As mentioned in the subsection 3.2.2 above, a transaction is processed by millions of individuals on the blockchain network with the aid of mining equipment with high efficient computing power. The individuals are computer nodes or, more commonly, miners. Sophisticated algorithms are analyzed and solved by the miners so that data is processed and stored on the ledger in exchange of cryptocurrencies as a reward.

The cryptocurrency mining process has many methods. One of the first methods is solo mining. It is a simple idea that a single individual runs his/her mining system. Because the blockchain selects individuals from its networks randomly, therefore, probability is divided among users to be selected for each block in the ledger. Hobby miners with can stick with this method because it requires a low initial budget. However, this method gives a low probability to win a block in exchange. The personal miners can also raise their initial budget to buy more mining machines. The more mining equipment is run, the higher efficiency and chance to find a block. (Sterry 2012: 21.)

As opposed to self-mining, pooled mining is the next activity. The mining pool is kept running by the pool operators who are usually mining hardware manufacturers. Instead of a single individual or organization running multiple mining machines, miners can join

mining pools or communities to cooperate with other miners around the globe to win and mine the blocks. The computational resources are gathered together to boost the probability of winning blocks. The profit is going to be divided to each contributor depending on their mining system's operating time and hash-rate. Hash-rate is the efficiency of how many hashes a mining machine can find within a given period. Because of the increase of the complexity of the algorithm and the enhancement of mining efficiency, small and big miners can participate in the mining pool methods.(Sterry 2012: 22; Hileman and Rauchs 2017: 88-89.)

Besides these two activities, there are also cloud mining services and remote hosting services. These two activities are merely extension services for mining activities. Cloud mining services lend their hash rate to other miners while remote hosting services operate, manage and maintain mining equipment for their clients. These services are evident for the miners who lack initial funds, facilities and time. (Hileman and Rauchs 2017: 88.)

### 3.3.2 Modes of Mining Processes

The cryptocurrency developers regulates the mode of a mining process of a specific cryptocurrency. Proof of work is one the first and most known mode of the mining process. It requires expensive computational resources to process the bundle of transaction on each block of the blockchain. There are two main tasks in this method. The first task is verification. It is a random selection among all miners on the network so that the selected miner verified the legitimacy of the transaction on the block. The second task is decryption or creating new digital currencies step. New digital coins are the prize requires miners to solve the asymmetrical mathematical puzzle that verifies transaction, executes it and saves it on the block on the ledger. The disadvantages of this method are low efficiency and harming the environment. Because the system selects randomly among miners, the higher number of miners in the system, the less chance to get selected, the less profit divided to all the miners. Furthermore, as this method requires a vast computational resource to increase the chance to get selected and the speed to solve the mathematical puzzle. The mining equipment consumes a massive amount of electricity. (BitFury Group 2015: 5; Rosic 2017.)

Bitcoin, the king coin of cryptocurrency, is an excellent example of the proof of work method. Multiple transactions between Bitcoin users are stored in each block available

for each 10 minutes on the blockchain network (Rosic 2017). Furthermore, the process of verifying transactions is highly transparent and can be tracked globally by all Internet user, as can be seen in table 2 below (Blockchain Luxembourg 2017).

Table 2. Bitcoin's blocks on the blockchain (Blockchain Luxembourg 2017).

LATEST BLOCKS SEE MORE →

| Height | Age | Transactions | Total Sent | Relayed By | Size (kB) | Weight (kWU) |
|---|---|---|---|---|---|---|
| 514605 | 24 minutes | 13 | 25.01 BTC | BTC.TOP | 10.86 | 42.1 |
| 514604 | 24 minutes | 1059 | 2,353.14 BTC | Unknown | 494.44 | 1,810.01 |
| 514603 | 27 minutes | 1512 | 7,984.86 BTC | AntPool | 1,072.05 | 3,992.61 |
| 514602 | 44 minutes | 226 | 1,158.64 BTC | ViaBTC | 335.65 | 1,288.22 |

Table 2 shows the mining process of Bitcoin in real time. Many transactions are bundled together into blocks in the ledger so that miners can verify the reasonability of the transaction. With each transaction verified and a mathematical puzzle solved, miners are rewarded by a cryptocurrency prize, in this case, Bitcoin. Finally, the transaction can be executed and its data can be recorded to the ledger. For example, the remaining balance of involving parties will be recorded and saved by all the miners in the system. Therefore, a blockchain is very secured and hard to hack. (UBS AG and UBS Financial Services Inc. 2017: 7-8.)

The next invention was the proof of stake (POS), to cover the shortage of proof of work (POW). While POW gives a reward to the miner who solves the mathematical puzzle to validate the block. POS gives the prize to its stakeholders (BitFury Group 2015: 6; Rosic 2017). Explicitly, in a POS mode, the rewards, and new digital currencies are given proportionally according to the amount of the digital currencies that the miners are holding. Therefore, the reward is given by each transaction fee instead of each block. There are also risks in the POS mode. The most wealthy stakeholder has the most advantage. They can manipulate the blockchain and its mining process. This problem conflicts the main idea of cryptocurrencies and blockchain technology which is decentralization, as mentioned in subsection 3.2.2. (UBS AG and UBS Financial Services Inc. 2017: 7-8.)

The next mode to be invented was the master node, to deal with the risks mentioned in POS. A the third party can be hired, or a personal computer can be set up to run a master node. The master node serves as a normal node or miner in the system. There is a requirement on the number of stakes a master node needs to hold or create. Furthermore, there is always a capacity limit of the stake for each master node. If the limit is exceeded, a new master node has to be created so that it is less likely for anyone to have the most significant stake in the system. This mode is also suitable for small miners who can join in order to operate a single master node. However, in case of hiring trustworthy third party, there is a risk of fraud. Hence, the approach suggestes that a third party running a master node has to deposit funds into the system. (Khatwani 2018.)

Finally, delegated proof of stake (DPOS) is the supplement of the POS and master node. A delegated person known as the validator will be elected and serves adequately as a normal node to valid blocks in the ledger. Funds given to validator will be deposited into a time-locked security account which will compensate to contributors in case of fraud. Validators can be elected based on their wealth or the number of stakeholders. Additionally, it is possible for other investors to vote for a validator; validators with high votes can be selected and validators breaching their commitment can lose their right as delegates. (BitFury Group 2015: 7.)

## 3.4 Mining Processors

In general, with the booming of cryptocurrency market, there are not only increasing concerns about its applications, but also an increase in the number of people taking benefit of it. (Khemarattana 2017: 1.) As mentioned in subsection 3.3, mining activity is one of the activities that creates benefit from the cryptocurrency market without making an effort on the exchange and business. Hence, the technologies used for a mining process develop quickly, as shown in figure 12 below.

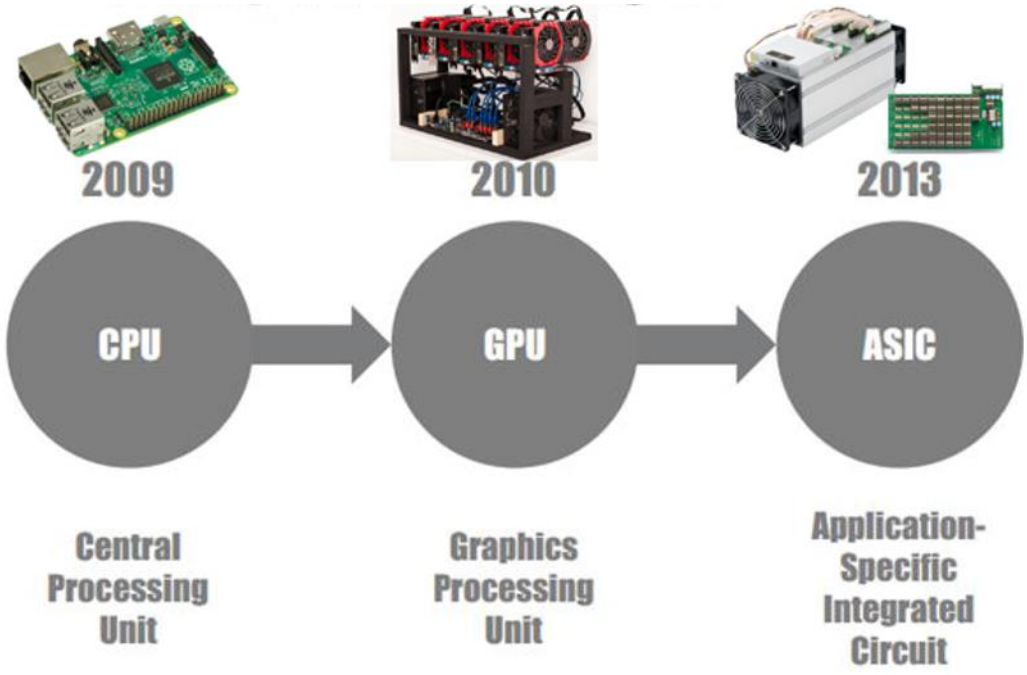



Figure 12. The development of mining technology of cryptocurrency market (Khemarattana 2017).

As described in figure 12, there are three main milestones in the mining technology development. The first and the second ones can be grouped into one group as they are two popular available components from personal computers. The third technology is an application-specific integrated circuit (ASIC) with devices that are designed primarily for specific purposes, such as mining activities or data center. (Khemarattana 2017.)

Mining with a personal computer's hardware, as mentioned in the paragraph above, is a standard method for the majority of miners. It uses the fundamental parts of a personal computer or laptop to mine cryptocurrencies. Because of the wide variety of personal devices, a wide range of efficiency could be achieved. Because of the second step of mining process mentioned in subsection 3.3.2, a stronger and faster computer device which is good at repetitive tasks can obtain the higher mining efficiency. From the birth of the first popular cryptocurrency Bitcoin, the CPU has been the fundamental way to mine. A CPU which is a standard part of computer designed for necessary performance, such as task switching. A GPU was the next evolution of the mining process. Its function and constitution were more complicated than those of a CPU. The computer can work without a GPU but not without a CPU. The processing speed of a GPU can be faster than it of a CPU about more than 100 times as it is designed for geometry and graphic tasks. (Sterry 2012: 13-14.)

ASIC is the newest technology in mining hardware. ASIC was designed with a specialized chip created for only mining purposes. It can out-perform the standard hardware mining in speed and efficiency. For example, one of the first pieces of ASIC hardware was designed by Butterfly Labs inspired from its experience in developing Field Programmable Gate Array (FPGA) which was also highly efficient processors was stronger than both CPU and GPU (Sterry 2012: 14). That Butterfly Labs' ASIC miner design was a robust equivalent to 16 FPGA. (Langland & Skordal 2015: 12-13.)

Because of the enhancement of efficiency, the technology of ASIC continues to develop rapidly. There is an increasing number of miners using ASIC based hardware. Therefore, more and more types and brands of mining hardware also appears on the market to satisfy wide diverse of demand of miners, as can be seen in table 3 below. (Bitman 2013; Bitcoin Mining 2017; Tuwiner 2018; Bitshopper.de 2017.)

Table 3. Some featured cryptocurrency mining hardware (Bitman 2013; Bitcoin Mining 2017; Tuwiner 2018; Bitshopper.de 2017)

| Processors | Hash rate per second | Maximum power consumption (Watt) + % discrepancy | Power efficiency (Joules / Giga hash) + % discrepancy | Work temperature | Price (USD) |
|---|---|---|---|---|---|
| **Antminer S9** | 14 TH/s ±5% is expected | 1340 W + 10% | 0.096 J/GH + 12% | 0 $^0$C - 40 $^0$C | 1864 |
| **Avalon 6** | 3.5 TH/s ±5% is expected | 1080 W | 0.29 J/GH | 0 $^0$C - 35 $^0$C | 499.95 |
| **Antminer D3 (practical case)** | 17 GH/s ±5% is expected | 970 W + 7% | 57 J/GH + 7% | 0 $^0$C - 40 $^0$C | 550 |
| **Antminer R4** | 8.7 TH/s ±5% is expected | 845 W + 9% | 0.1 J/GH + 9% | 10 $^0$C - 40 $^0$C | 1000 |
| **Antminer L3** | 504 MH/s ±5% is expected | 800 W + 10% | 1600 J/GH + 10% | 0 $^0$C - 40 $^0$C | 1270 |
| **Antminer S5** | 1155 GH/s | 590 W | 0.51 J/GH | 0 $^0$C - 35 $^0$C | 413 |
| **GekkoScience** | 8 GH/s | 6 W | 0.33 J/GH | 0 $^0$C - 35 $^0$C | 49.95 |

Table 3 illustrates some prominent cryptocurrency mining processors. The data in table 3 is collected from many sources of the manufacturers and online market on the Internet. The price has most likely changed after the time of this report. The hardware chosen are mainly from the same manufacturer, Bitman. In order to make a comparison between the given miner Antminer D3 in practical case and the other mining hardwares, the reference list includes Antminer S9, Antminer R4, and Antminer S5 coming from the same factory.

Otherwise, there are also Avalon 6 coming from different manufacturer and GekkoScience which is USB hardware. All the Antminer hardware is coming from the same brand. This brand has the mining pool which names as Antpool and it is occupying 18 % of the market share of the pool on the world (Khemarattana 2017: 15). Based on the information in table 3, the most suitable mining hardware can be recommended for the practical case study in section 6 below.

In the table 3, the hash rate is the efficiency of the mining hardware. The higher hash rate per second, the faster mining hardware can process data on the blockchain per second.

The next important indicator is the maximum power consumption which describes the amount of electricity the hardware consumed. Power efficiency indicates the amount of electricity needed heat emitted by the mining hardware to process an amount of hash. As stated by the principle of conservation of energy, the electrical energy consumed is converts into heat energy. Table 3, power efficiency shows the amount of electricity in Watt and heat emitted in Joules for processing one million of hash, giga-hash (GH), on the blockchain. This indicator depends on the efficiency of the power supply unit and ambient temperature. (Bitcoin Mining 2017.)

Work temperature is the next statistic used to consider the suitable miner. It is optimal range of temperature for hardware to work. Almost hardware from the table 3 stops to work at temperature above 40 degrees Celsius. To be on safe side, the mining rigs shall be kept around at 35 degrees Celsius so that the mining chip can be operate fully. (Bitcoin Mining 2017.)

The list of the processors in table 3 shows the general comparison between processors. For example, Antminer S9 is the most expensive and the highest mining efficiency with $1,864 and 14 Terahash per second (TH/s) respectively. The given Antminer D3 has a lower efficiency and cost with 17 Gigahash per second (GH/s) and $550, as can be seen in the table 3 (Bitman 2013; Bitcoin Mining 2017; Tuwiner 2018; Bitshopper.de 2017). The data comparison is used to predict the feasibility of the practical project in the section 6 below.

## 3.5 Problems in Cryptocurrency Mining

One of the first problems of cryptocurrency mining is the noise. The reason for noise is that the design of mining processors includes an integrated fan so that the system is going to be kept at an appropriated working temperature. The Antminer S5 and Antminer S7 have a noise level at 75 decibels (dB) and 62 dB, respectively (Tuwiner 2018). The noise is quite a severe problem in the residential area as seen in figure 13 below.

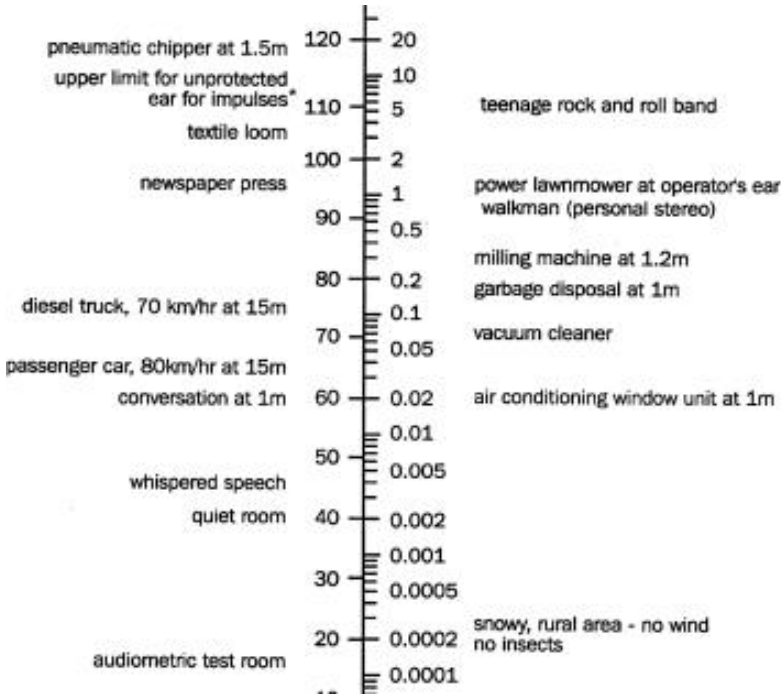



Figure 13. Sound source and noise level (Goelzer et al. 2001: 33).

In figure 13, the Antminer S7's noise is equivalent to light traffic. The Antminer S5, on the other hand, has the noise level of a vacuum cleaner. The primary noise solution is just to change the fans or using other cooling methods. (Goelzer et al. 2001: 33.)

The next challenge of mining process is the electricity consumption. As mentioned in subsection 3.3, the cryptocurrency mining activities are thirsty for energy. Specifically, the POW mode requires a massive amount of computational resources operating all the time, as well as, a cooling system to serve those computers, to get the optimal profit. Therefore, the electricity bill should be decreased as much as possible. A practical example is Iceland, the country where the amount of electricity used for Bitcoin mining is

more than the amount of electricity used in households 840-gigawatt hours compared to 700-gigawatt hours, respectively (Perper 2018).

Last but not least, the waste heat is also on of the disadvantages of the mining process. Recycling waste heat into useful energy in a building is also the topic of this thesis. Because the mining hardware requires appropriate temperature to work correctly, the low-temperature areas and countries have more advantages because the cost of cooling can be kept optimally (Hileman & Rauchs 2017: 94). As seen in table 3, all hardware emitted some thermal energy while operating. This problem is going to break the heat balance of the building between seasons. For example, a building is more likely to overheat in the summer when there is no demand for space heating. Each input of electric energy produces a heat output. The solution is discussed in details in the practical project in the section 6 below to recycle the waste heat of mining system so that the cost of energy for the whole building can be minimized.

# 4 Exploitation of Waste Heat from Processor

In this chapter, exploitation of waste heat from processor is only discussed from a small-scale mining point of view. The purpose is to study existing strategies and propose some ideas on how to reuse heat from the mining process. There are several existing studies on the concept of air distribution and hardware cooling methods for big scale mining. The studies suggest how to remove and recycle waste heat from mining activities as a backup heating source. In a small data center, the waste heat can be reused by a heat pump, be connected to a district heating system or provide a heat source for nearby houses. However, there are not many studies on family scale mining, therefore, it is challenging to be one of the pioneer in family scale mining. The first subchapter introduces the cooling strategy for a mining rig. Later, chapter 4.2 introduces an existing strategy for reused waste heat in a family-scale opertation. Chapter 4.3 lists some of the innovative technologies which can be applied in the future. Some of the advantages and disadvantages of the strategies are also mentioned about each strategy.

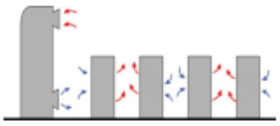
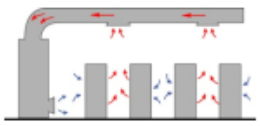
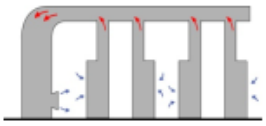
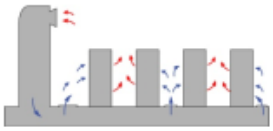
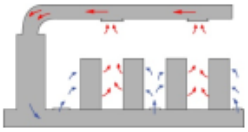
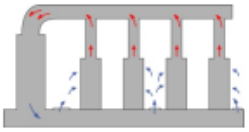
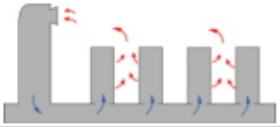
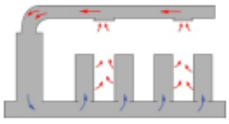
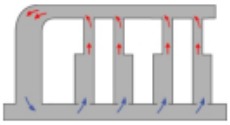
## 4.1 Cooling of Mining Processors

In this subsection, the various cooling methods for a typical data centre are illustrated. As mentioned in subsection 3.3 above, cryptocurrency mining centre can be considered as same as other typical data centres (Hileman and Rauchs 2017: 88.). Therefore, the listed cooling methods below are expected to also work in cyptocurrency mining centres. These cooling methods listed below are compared in terms of process and components so that the most suitable cooling method can be recommended for the practical case in section 6 below.

As mentioned in subsection 3.5, heat has always been a central problem in data centers or mining rigs (Hileman & Rauchs 2017: 94). Hence, cooling is one of the essential parts when building and operating a mining center. In this chapter, various methods of cooling a mining center are suggested, and two central concepts of cooling, based on refrigeration cycle and air distribution, are introduced.

Air distribution means controlling the airflow through controlling the supply and exhaust air to reach the targeted indoor air quality and thermal comfort of a space (Rasmussen 2017: 3). The primary approaches to air distribution are illustrated in table 4 below.

Table 4. Air distribution types (Rasmussen 2017: 4).

| | Flooded return | Targeted return | Contained return |
|---|---|---|---|
| Flooded supply |  |  |  |
| | **Small LAN rooms < 40kW**<br>Not recommended for most data centers<br>Low cost, simple installation<br>Least energy efficient of all air distribution architectures because 100% of the cold supply air is allowed to mix with hot return air. Supply air temperature extremely unpredictable above.<br>Distribution type can cool up to 3kW per rack | **General use**<br>Not recommended for most data centers<br>Low cost, ease of install<br>More energy efficient than flooded return since 40-70% of IT hot exhaust air is captured and delivered back to the cooling unit. Supply air more predictable than flooded supply since less hot air is allowed to mix with cold supply air.<br>Distribution type can cool up to 6kW per rack | **Large data center / colocation**<br>Upgradeable (vendor specific)<br>Most energy efficient of all air distribution architectures since it allows increased cooling unit supply temp resulting in increased economizer hours. 70-100% of IT equipment hot exhaust air is captured and delivered back to the cooling unit. Supply air is most predictable since no hot air is allowed to mix with cold supply air.<br>Distribution type can cool up to 30kW per rack |
| Targeted supply |  |  |  |
| | **Data centers with static power densities**<br>Not recommended for new designs – unable to keep up with power density projections<br>More energy efficient than flooded supply since more IT equipment hot exhaust air is diverted back to the cooling unit.<br>Distribution type can cool up to 6kW per rack | **Small to medium data centers**<br>More energy efficient than flooded return since 60-80% of IT equipment hot exhaust air is captured and delivered back to the cooling unit. Supply air more predictable since less hot air is allowed to mix with cold supply air.<br>Distribution type can cool up to 8kW per rack | **Hot spot problem solver**<br>Upgradeable (vendor specific)<br>More efficient than targeted supply and return since 70-100% of IT equipment hot exhaust air is captured and delivered back to the cooling unit. Supply air is most predictable since no hot air is allowed to mix with cold supply air.<br>Allows increased cooling unit supply temp resulting in increased economizer hours.<br>Distribution type can cool up to 30kW per rack |
| Contained supply |  |  |  |
| | **Mainframes / racks with vertical airflow**<br>More energy efficient than targeted supply but less efficient than contained return. Containing the supply air, forces the rest of the room to become the hot aisle which limits the number of economizer hours. Supply air is more predictable since little hot air is allowed to mix with cold supply air.<br>Distribution type can cool up to 30kW per rack | **Mainframes / racks with vertical airflow**<br>More energy efficient than targeted supply but less efficient than contained return. Containing the supply air, forces the rest of the room to become the hot aisle which limits the number of economizer hours. Supply air is most predictable since no hot air is allowed to mix with cold supply air.<br>Distribution type can cool up to 30kW per rack | **Harsh non-data center environments**<br>Slightly less efficient than contained return with flooded or targeted supply - requires more fan energy.<br>Allows increased cooling unit supply temp resulting in increased economizer hours.<br>Distribution type can cool up to 30kW per rack |

As can be seen in table 4, there are three basic types of air distribution and, thus, nine combinations of supply and exhaust air. The first type of air distribution is flooded distribution. The supply and exhausted air flows are enclosed inside the building envelope of the room, such as walls, ceiling, and floors and distributed through single route. This type of distribution allows the temperature of both airflows mix. The second type of distribution is targeted distribution. The supply and return air flows are directed within 3 meters of the intake and outtake of the mining processors by the mechanical equipment, such as a duct, perforated tiles or air handler. The third type of distribution is contained distribution. The supply and exhaust air flows are isolated, and directed entirely by a specific

envelope in a specific direction so that the supply and exhaust air flows do not mix. Depending on the case, a different combination of these types of distribution is used. The cooling methods base on this concept is also described in the last two rows in figure 14 below. (Rasmussen 2017: 4.)

Refrigeration cycle is the concept mentioned in subsection 2.2.2 above; the cycle works in the same way as the cycle used in a heat pump. The methods of cooling used in this cycle are also described in figure 14

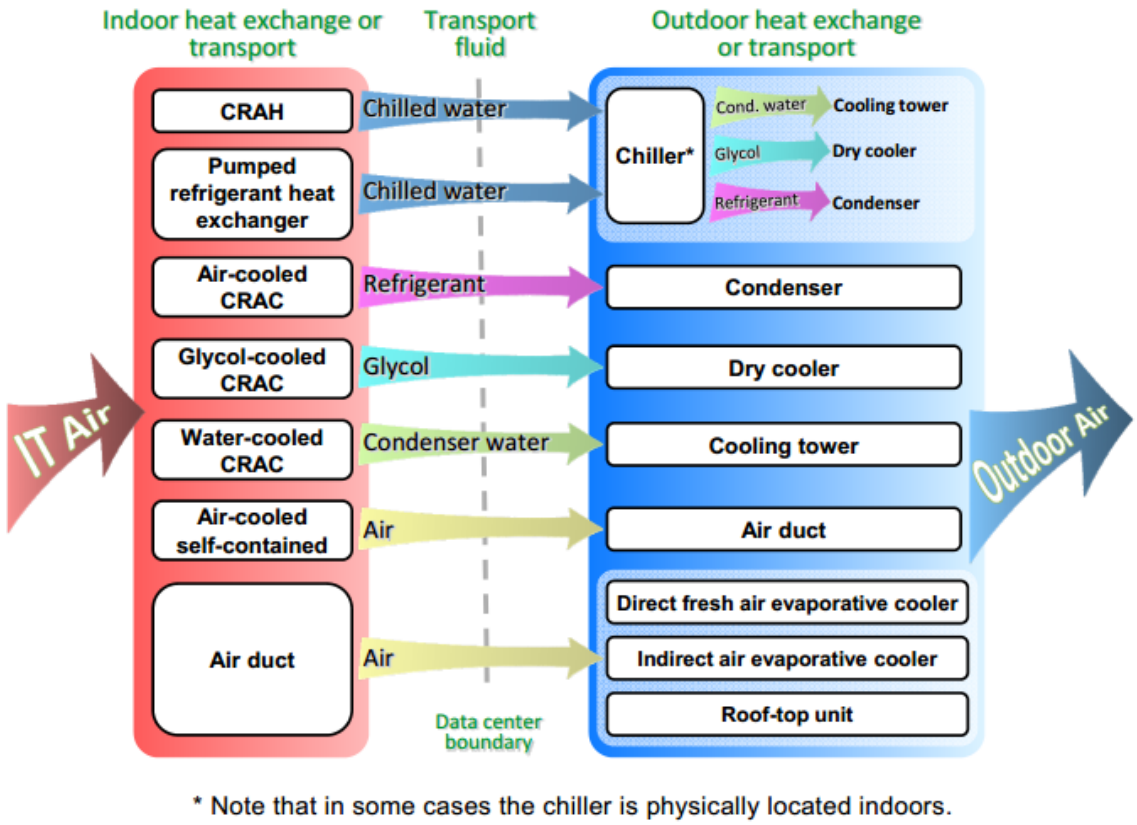



Figure 14. Heat removal methods (Evans 2012: 3).

Figure 14 shows how the overheated indoor air is transported out. The heat is transported by various refrigerants and types of air distribution to be emitted outside. Furthermore, there is a heat exchanger, usually located outdoors, to cool down the refrigerant fluids to be reused in a loop so that the indoor temperature can be cooled down.

### 4.1.1 Chilled Water System Cooling

The first alternative to cool a cryptocurrency mining equipment is to use computer room air handler (CRAH) connected to a chiller which produces cooling water. Figure 15 below describes how the system works.

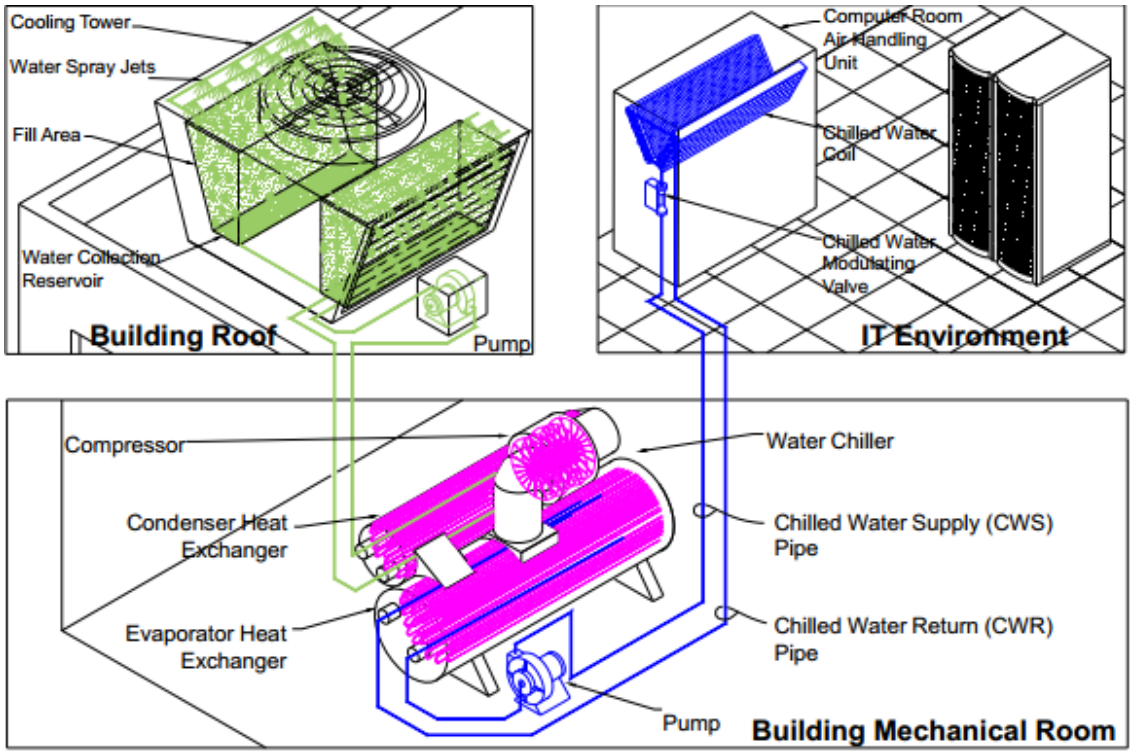



Figure 15. Chilled water system (Evans 2012: 4).

As can be seen in figure 15, the system consists of three main parts which are the CRAH in the data center room, the chiller from the mechanical room and the cooling tower from outdoors. The chilled water is pumped into the chilled water coil inside the CRAH at a temperature of 8 $^0$C – 15 $^0$C. The coil absorbs the heat from the environment around, and the heat is taken by the return water in chilled water return (CWR) pipe to the water chiller. In the chiller, the heat is taken from the return chilled water and transferred to the condenser water. Additionally, the condenser water with the heat flows through the cooling tower outdoors. The heat is rejected to the outdoor environment in the cooling tower with spray jets and a fan. Warm condenser water is sprayed onto a sponge material so that the water spreads out to be ready for evaporation. The fan speeds up the evaporation process. The evaporation process cools the remaining water in the same manner that the sweat cools the human body. Finally, the cooled water is collected and pumped back to the chiller to re-supply the chilled water coil for the next cycle. (Evans 2012: 4.)

There are also other alternatives than a cooling tower to cool the return chilled water. The options are glycol cooled chillers and air-cooled chillers. They work in the same way as the cooling tower, but the difference is the type of fluid and the connecting devices that are used. A glycol cooled chiller is connected to a dry cooler instead of a cooling tower and uses glycol fluid in the condenser as a container of heat, while air-cooled chillers uses a refrigerant and the heat is rejected by an air-cooled condenser. (Evans 2012: 5.)

### 4.1.2 Pumped Refrigerant for Chilled Water Systems

The next method is a combination of a pumped refrigerant heat exchanger and a chiller. The cooling unit used a refrigerant to absorb heat in a mining center in the same way as in the previous case. The pumps are used instead of compressor because of the high density of the refrigerant (Evans 2012: 6). The system is described in figure 16 below.

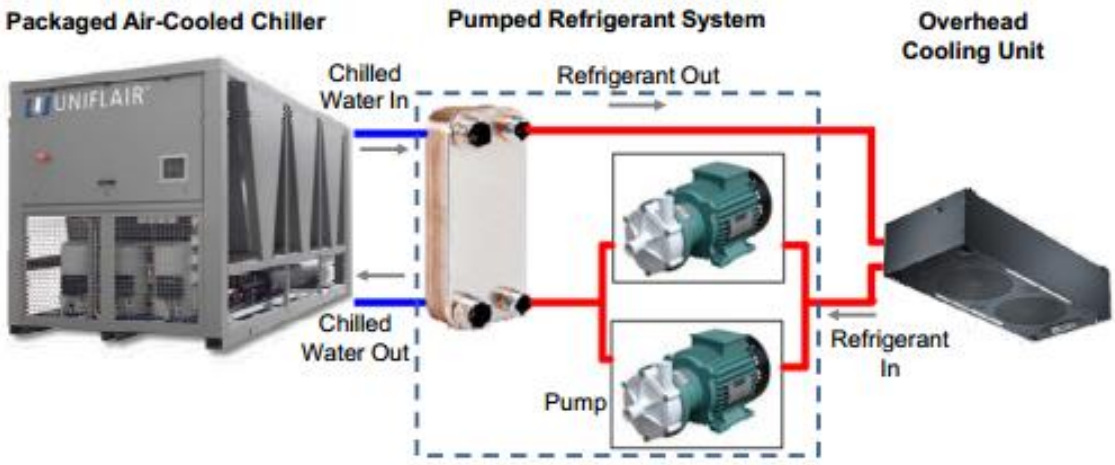



Figure 16. Pumped refrigerant for chilled water systems (Evans 2012: 6).

Figure 16 illustrates how a pumped refrigerant for chilled water systems works. The chiller uses water to cool the refrigerant and this chiller is located outside the data centre so that the risk of water leakage inside the data center environment is lower. The cooling unit uses a non-conductive fluid as a refrigerant to reject heat. The warm refrigerant is pumped out of the cooling unit to the heat exchanger. Simultaneously, the chilled water from the chiller flows into the heat exchanger. Then, the heat from the refrigerant is transferred to the chilled water and this return water flows back to the chiller. The cooling

refrigerant can finally be pumped back to the cooling unit to start a new cycle. (Evans 2012: 6.)

### 4.1.3 Computer Room Air Conditioning

The third method of cooling a cryptocurrency mining equipment is a computer room air conditioner (CRAC) and condenser. This is the most used system in small and medium scale mining because of the convenient installation. The air-cooled system is shown in figure 17 below.

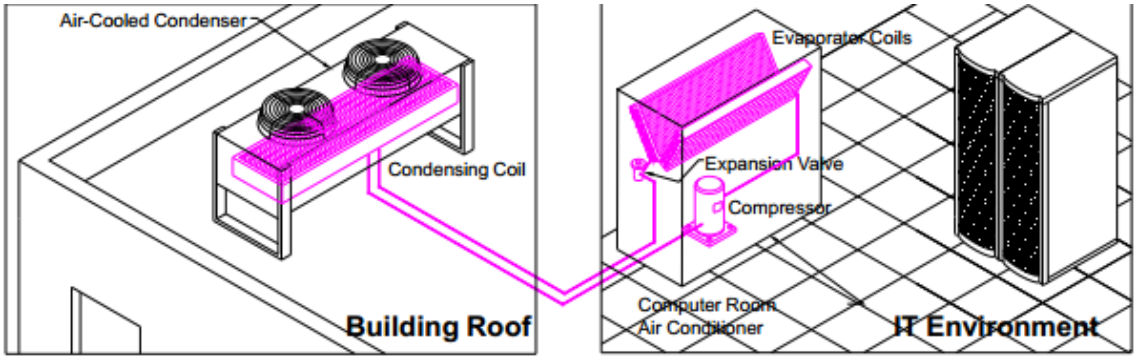



Figure 17. Air-cooled system (Evans 2012: 7).

Figure 17 demonstrates the scheme of the system. The CRAC, located indoors, contains most parts of the refrigeration cycle, such as expansion valve, evaporator coils, and compressor. The other part or a condensing coil is located outdoor. The system works in the same way as the refrigeration cycle of the heat pump which is mentioned in subsection 2.2.2. The circulation of the refrigerant rejects the heat. Heat is obsorbed by the refrigerant at the evaporator coils and runs through the compressor to go to the condensing coil. At the condensing coil, the heat is emitted to the outside environment. Then the cooling refrigerant continues to run through an expansion valve to flow back to the evaporator coils. (Evans 2012: 7.)

A combination of a glycol-cooled CRAC and a dry cooler is the alternative way of computer room air conditioning method mentioned in above paragraph. As stated in the name, glycol, a mixture of water and ethylene glycol, is used in this system, as described in figure 18. (Evans 2012: 8.)

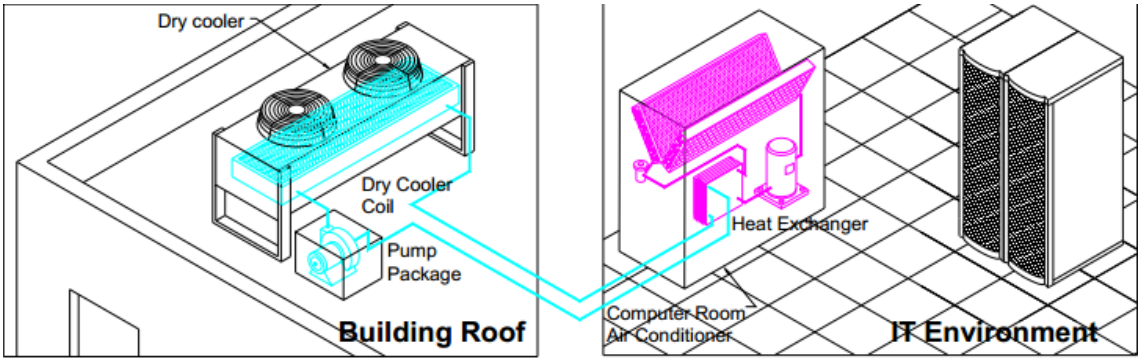



Figure 18. Glycol-cooled system (Evans 2012: 8).

Figure 18 shows the process of the glycol-cooled system. The condenser is replaced by a smaller heat exchanger, while the other parts of refrigeration cycle are integrated into a single CRAC. The refrigerant is to absorb heat. Glycol which has a high efficiency in heat containment and conductivity is used to take the heat from the refrigerant in a heat exchanger to a dry cooler coil for heat rejection to the outdoor environment. After being processed at the dry cooler, the refrigerant can be pumped back the heat exchanger for a new cycle. (Evans 2012: 8.)

The last CRAC solution is the combination of a CRAC and a cooling tower. The CRAC is located indoors while the cooling tower is located outdoors, as can be seen in figure 19 below.

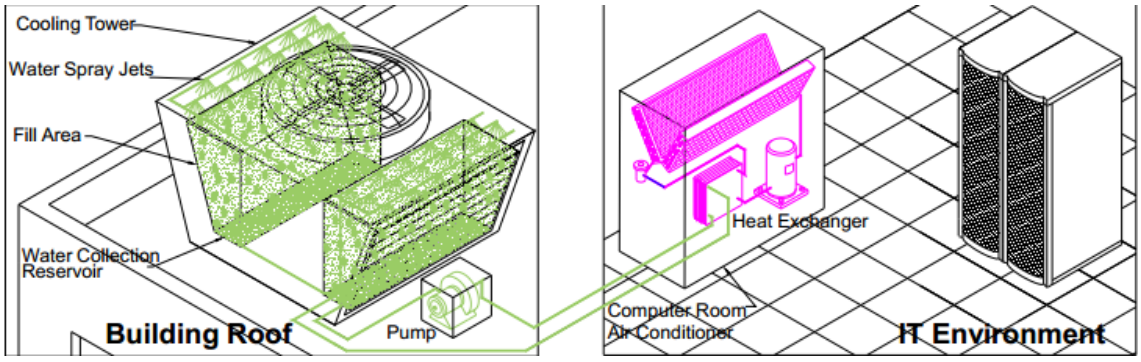



Figure 19. Water-cooled system (Evans 2012: 9).

Figure 19 shows the process of a water-cooled system. This method worked in the same way as the previous methods, except for the glycol being replaced by water as a cooling fluid. Moreover, the dry cooler is replaced by a cooling tower to reject heat. (Evans 2012: 9.) The cooling tower process is explained above in subsection 4.1.1.

### 4.1.4 Self-Contained Cooling System

The sixth method to cool a cryptocurrency mining equipment is the combination of airs cooled self-contained and air ducts. This method uses both the refrigeration cycle concept and the air distribution concept, as can be seen in figure 20 below.

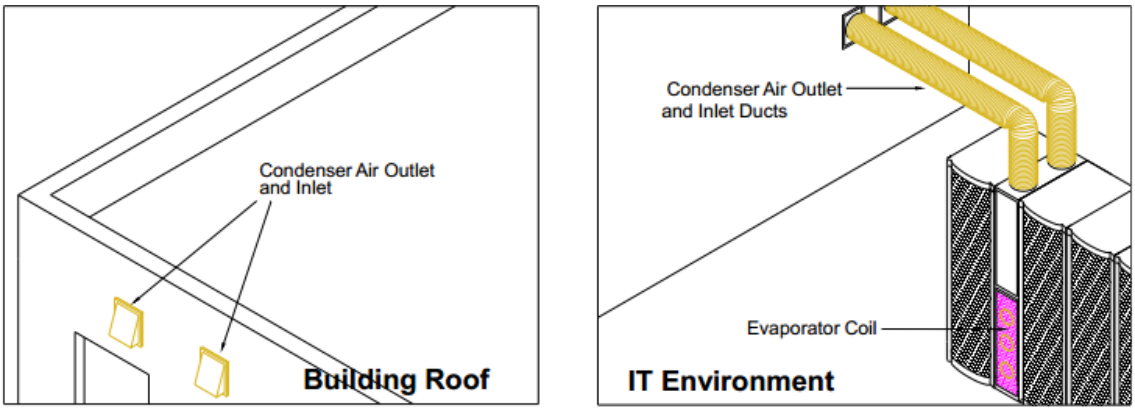



Figure 20. Air-cooled, self-contained system (Evans 2012: 10)

Figure 20 shows the scheme of an air-cooled, self-contained system. The refrigeration cycle components including the evaporator coil are isolated completely. The exhausted air is hot and it is routes out through the duct to ensure cooling. It is also possible for the exhaust air to be rejected above a false ceiling as long as the building's air conditioning system can handle the emitted heat load. (Evans 2012: 10.)

The next alternative to cool a cryptocurrency mining equipment is a self-contained roof-top system. It works in the same way as the air-cooled, self-contained system mentioned in figure 20 above. The difference between the methods is the location of the isolated unit. In this case, the location of the roof-top unit is on the roof which usually offers a larger space. (Evans 2012: 11.)

### 4.1.5 Direct Fresh Air Evaporative System

The seventh method to cool a cryptocurrency mining equipment is the connection between the air duct and the direct fresh air evaporative cooler. Fans and louvers are used to draw the supply and exhausted air flow directly, as can be seen in figure 21

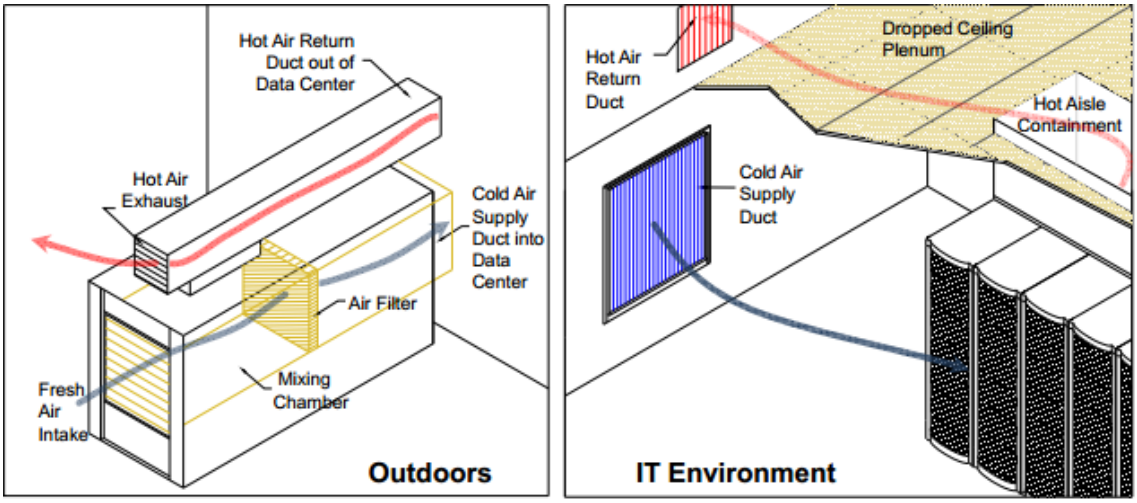



Figure 21. Direct fresh air evaporative cooling system (Evans 2012: 12).

Figure 21 shows the process of direct fresh air evaporative cooling system. Exhausted air emitted by the processors is drawn outdoors by the ducts while the supply air is drawn directly back indoors through filters. The supply air is not usually cool enough. Hence, it is combined with evaporative cooling which cools down the across air flow by spraying water onto a surface or into the airstream, the same way as the cooling tower concept mentioned in subsection 4.1.1. The humidity usually raises by this cooler. Thus, it is not recommended for humid climates. (Evans 2012: 11.)

### 4.1.6 Indirect Air Evaporative System

The eighth method to cool a cryptocurrency mining equipment is the same as the previous case except for an indirect air evaporative cooler is used. The exhaust air from processors is cools by the outdoor air when the outdoor temperature is lower than the temperature of the inlet air of the processors. This method led to high efficiency in energy performance, as can be seen in figure 22. (Evans 2012: 12.)

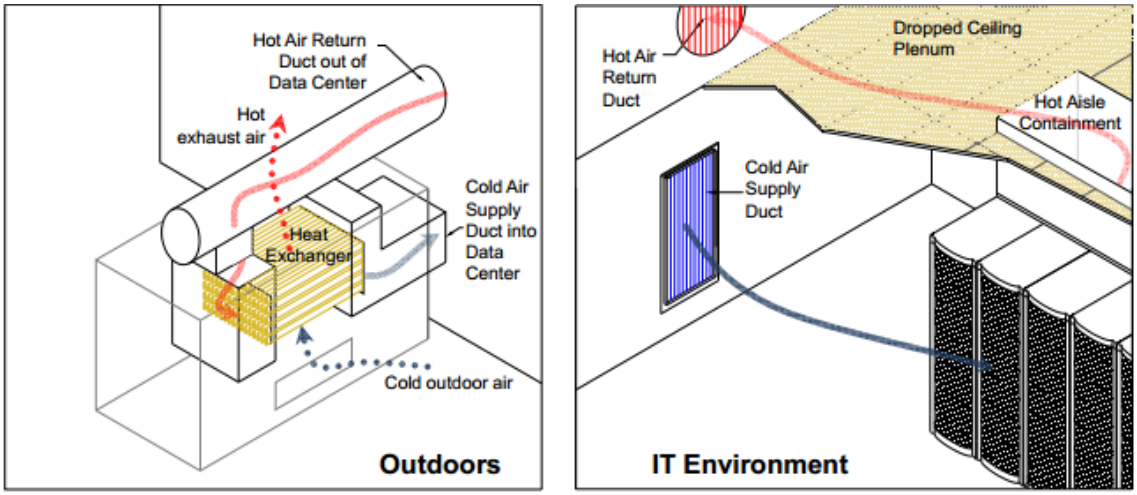



Figure 22. Indirect air evaporative cooling system (Evans 2012: 13).

Figure 22 shows the process of secondary air evaporative cooling system. The exhaust air from processors is directed through the louver to the heat exchanger outdoor and simultaneously, the cold outdoor air is blown by the fan to the heat exchanger so that the outdoor air cools the exhaust air at the heat exchanger. The cooled exhaust air flows back to the data center to cool the mining rigs. The evaporative cooling system can be used to assist the process to lower the temperature further. (Evans 2012: 13.)

## 4.2 Reusing Waste Heat Solutions

When a mining processor is running, heat is released from the chipset. With that waste heat, it could be easy to heat the house by directly locating the mining rig in the designed place. It would be an entirely free heat gain in the winter, and saving can be made during the mining production. There are several strategies to reuse waste heat. They can be divided into two groups: a stand-alone strategy which is used as an individual heater and a combined strategy which is connected to another heating system in the detached house.

### 4.2.1 Stand-Alone System

The most common strategy to exploit the waste heat caused by cryptocurrency mining is to use the mining processor as a direct electric heater. The processor acts as an electric heater and users can place it in designed heating space. Places such as a garage, warehouse, or tiny house can be used. In such a place, an indoor comfort is not strictly required. There are many example of DIY projects that use this strategy such as Rahdi Fakhoury who runs the bitcoin mining machine in the basement to heat a space in North Carolina. The figure 23 shows how his system works. Moreover, it is a real DIY project without any knowledge of HVAC design. (Hu 2017.)

Figure 23. The stand-alone heater from mining processor. (Hu 2017.)

In figure 23, the heat is blown out from the processor to the room by rig fans. Then a small fan is used to recirculate the surrounding air to keep it below 40 $^{0}$C degrees. There are several problems with overheat in the summer. Fakhoury must use an air conditioner to cool down the basement during hot days, or the system must be stopped when the room temperature goes over 40 $^{0}$C. (Hu 2017.) The noise from the rig fans also is a big problem. The rig fans can generate up to 70 Db sound level, and it could hazard to the indoor living space (Goelzer et al. 2001: 33).

Figure 23 also shows a commercial unit. The unit can mine cryptocurrency and works as a radiator. It is called bitcoin heater produced by Quarnot. The company has upgraded this system to a new level. The product QC.1, shows in figure 23, is the first modern, beautiful and flexible crypto heater. The user can locate it anywhere in the house. The QC.1 has 0 dB noise level and up to 500 W power to generate heat. (Quarnot 2018.) However, this stand-alone strategy is not optimal if there can be an overheat problem in the summer, and the noise level from the fan may be high. Therefore, the strategy could not be a solution applied to a bigger scale.

### 4.2.2 Combined to Another system

Another strategy to exploit the heat from a mining processor is to combine the system with another HVAC system. The first invention uses some water pipes running around the processor to collect the heat then transfers it to hydraulic systems such as floor heating or radiators. It can be done, but such a system cannot reach the highest efficiency since some heat is lost during the distribution. This strategy could only work in a very small house where the heat lost through distribution heats a space. In addition, the heating demand of a tiny house is not significant, so it only requires a low temperature floor heating system. Thus, when a heating system connects with mining processors, there may not be a need for heating supply for the house. This strategy was applied by a couple of Russians who live in the 20 $m^2$ house in the Siberian town of Irkutsk. Figure 24 below indicates their simple combined system. (Eldredge 2017.)

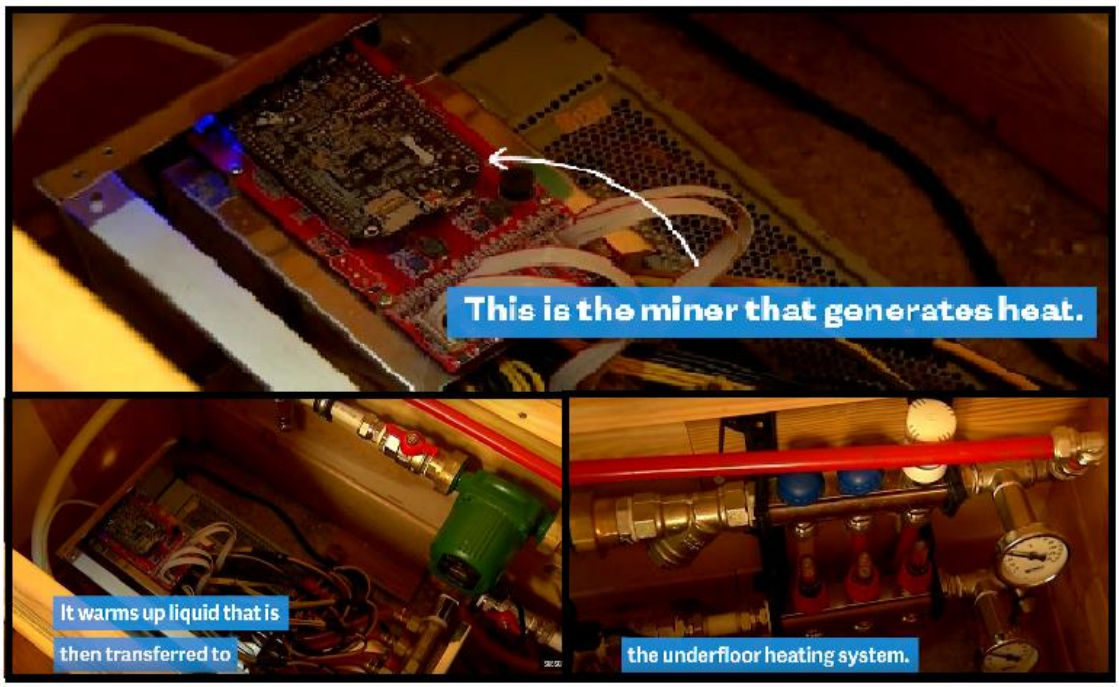



Figure 24. A Russian system in Siberia. (Eldredge 2017.)

As shown in figure 24, the system consists of only two bitcoin rigs. The hydraulic piping system runs around the holding case and connects to the floor heating system. The heat transfers from air to liquid and goes to floor heating. They owners of the system state that the demand for space heating is zero. At the same time, they can make around $430 profit from mining bitcoin. However, this strategy could not be used for large systems. The noise and overheating in summer may break the mining system. (Eldredge 2017.)

Another alternative for combined system is one that connect to the ventilation system. The mining system can preheat the ventilation supply air before it came to the ventilation unit. The heat generated by the mining processor can assist in heating the supply air and contributes to the space heating demand. However, with this strategy, dust could damage the processor, and the temperature of the supply air is not constant around the year. In the summer the waste heat can cause over heat in living spaces. In the winter, the freezing air can damage the mining processor as well. Therefore, this combined system is not suitable for the Finnish weather.

## 4.3 Innovative Integrating Strategies

Despite the problems there are with previous strategies, the three innovative solutions proposed in this chapter could exploit the maximum amount of waste heat and avoide overheating in the summer, as well as reduce the noise during the operation. The first option is simply using air-to-water heat pump to exploit the waste heat from the system. The second option is connected mining system to exhaust air duct and use exhaust-air heat pump to exploit the waste heat. The last option is connected the mining system to a compact unit.

### 4.3.1 Combined with Air-to-Water Heat Pump

Some miners use a heat pump to collect waste heat from mining to produce domestic hot water. Heat pump technology is very suitable for collecting heat from the mining process, and at the same time, it can cool the mining room. Figure 25 introduces a system with this combination (Besttank 2018).

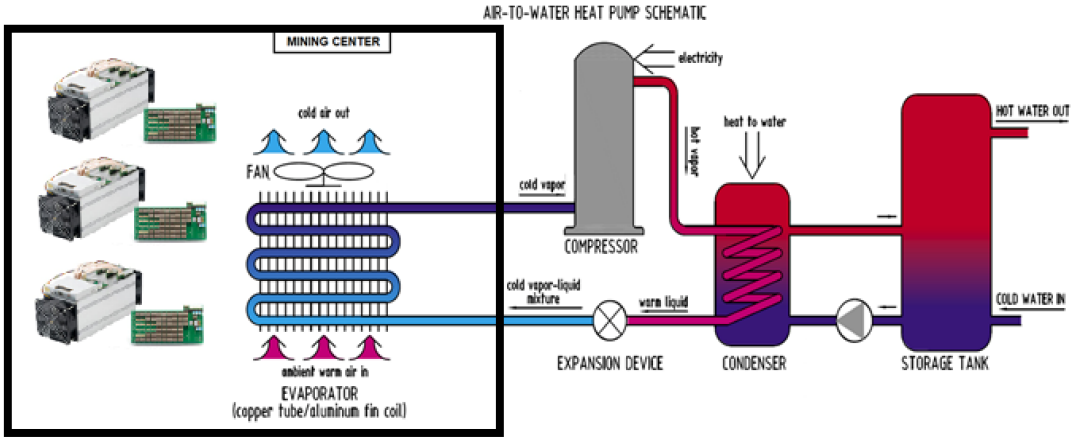



Figure 25. Using air-to-water heat pump to extract heat from mining center and generate hot water. Modified from Besttank (Besttank 2018).

As indicated in figure 25, the collected heat from the mining room can heat water to the design temperature. Then the heated water can be stored in a cylinder with the temperature of water around 60 $^0$C to 65 $^0$C. The size of the water tank is chosen according to the consumption. Thus, the waste heat can be reused during the entire year without interruption. The advantage of this system is that the cool air from the evaporator can cool the mining room. Therefore, the user does not need to worry about the cooling problem in the mining process. The location of the mining system is a challenge, and the return on investment need to be calculated carefully. The mining processor is costly, as is the heat pump itself. The user needs to also consider the consumption of for the heat pump to generate domestic hot water. This concept can be profitable compared to an instant electric hot water device. Another problem is the hot water storage. If the production is more than the consumption of hot water, the heat pump does not operate, and the overheating can occur in the mining room. The system would then not be energy efficient, and the extra energy would be waste energy.

### 4.3.2 Combined with Exhaust-Air Heat Pump

As described in chapter 2, an exhaust-air heat pump system uses the exhaust air to heat a space and domestic hot water. If the exhaust air can pass through the mining processor before it goes through the heat pump, the temperature of exhaust air can be raised to 40 $^0$C degrees. With this temperature, the efficiency of the heat pump would be increased. The exhaust air always has a constant temperature from 21 $^0$C to 25 $^0$C. Thus, it can cool the mining processor and function all year round. In summer, the heat can bypass

to the outdoor if enough hot water generated. Therefore, the designer needs to calculate an optimal ratio of the number of processors and the volume of the water tank to supply the space heating and domestic hot water. This type of combination can be applied to an old or renovated house. These types of the houses frequently use natural ventilation or a simple extract-air ventilation system. It is easy to install the heat pump unit as they are quite compact. The processor can also be installed inside an insulation box to avoid heat loss and noise problem, as illustrated in figure 26, created by Tri Nguyen.

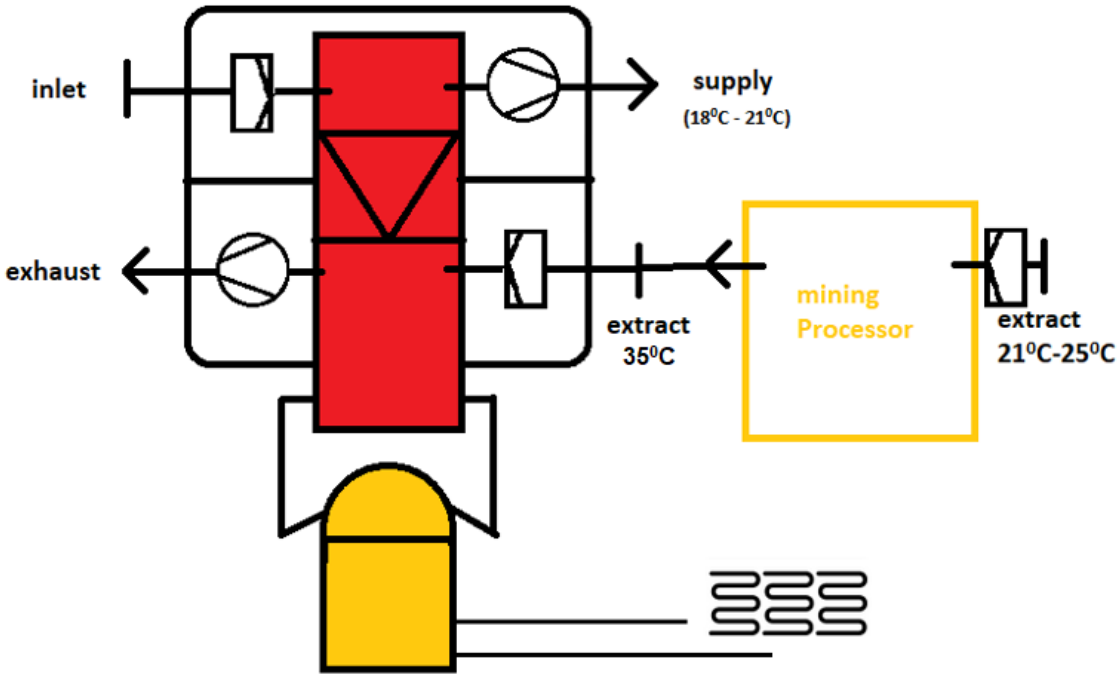



Figure 26. The combined system with air-to-water heat pump.

Figure 26 above illustrates how the mining room connected to the exhaust air system. The temperature of the exhaust air varies from 21 $^0$C degrees to 25 $^0$C degrees during the year. The maximum temperature of the mining room can be up to 35 $^0$C. With this temperature, the heat pump COP can be around 5 or 6 during its operation. Thus, electricity consumption of the heat pump can be decreased, and more hot water can be produced with same electricity as by the system without a mining room. The extra waste heat energy can also help heat pump to heat up the intake air up to 18 $^0$C with less electricity consumption. As result, hot water can be stored in the cylinder and supply to the domestic hot water.

The advantage of this type of a system is that waste heat can be collected by the heat pump. The system could run 24/7 the entire year. If the capacity of the cylinder is large enough, the extra heat can bypass the system and be discharged to outdoor. However, it can ensure that the mining process is running 24/7 and the mining rigs are kept at the designed temperature. Extra storage can be installed to avoid waste heat, or the right quantity of rigs need to be calculated carefully. The mining rigs are installed in a separate box or room with high thermal insulation and noise break. Thus, the noise level can be controlled, and the user can upgrade or change mining rigs without any problems. The exhaust air should be filtered by the filter to avoid dust which can affect the efficiency of the processor. The possible problem could be the ventilation flow rate. It should be calculated carefully to ensure the flowrate of ventilation system matches the flowrate needed to remove the heat energy in the mining room.

With more advanced and combined technology, the mechanical ventilation heat recovery unit can be combined with the mining rig together with a heat pump to create a perfect compact unit. The waste heat can be reused with a higher efficiency, and the exhaust air temperature can be down to 0 $^0$C. This combination is discussed in the next chapter.

### 4.3.3 Combined with a Compact Heat Pump Unit

A compact heat pump unit was discussed in chapter 2. It can provide all building services such as space heating, ventilation, and domestic hot water. The compact unit also possibly connects to the hydronic heating system and integrate with the solar thermal panel such as Stiebel Eltron LWZ SOL model. However, it is quite expensive and is only useful for Passive House or low heating demand house. It is not suitable for multi-family house with the average energy efficient standard in Finland. In fact, a compact unit can improve its efficiency if there are some extra heat supply to the system. In this case, the waste heat from mining professors is an excellent candidate. (Passive House 2009)

As describe in chapter 2, a compact unit recovered the heat from exhaust air to supply air via a heat exchanger. Then a heat pump takes all the left-over heat from the exhaust air to heat the supply air up to 18 $^0$C. At the same time, the unit can also heat up hot water. The efficiency can be improved if the waste heat from the processor can be attached to the system. The exhaust air can be heated up to 35 $^0$C by the mining rigs before it enters the system. That can give extra thermal energy to the compact unit. The compact unit provides ventilation and hot water for space heating and domestic hot water

with a higher efficiency. Therefore, the new combination of a mining room and a compact heat pump unit can be a solution for HVAC system of multi-family house. Figure 27 below indicates the system of combining a compact heat pump unit and a mining rig.

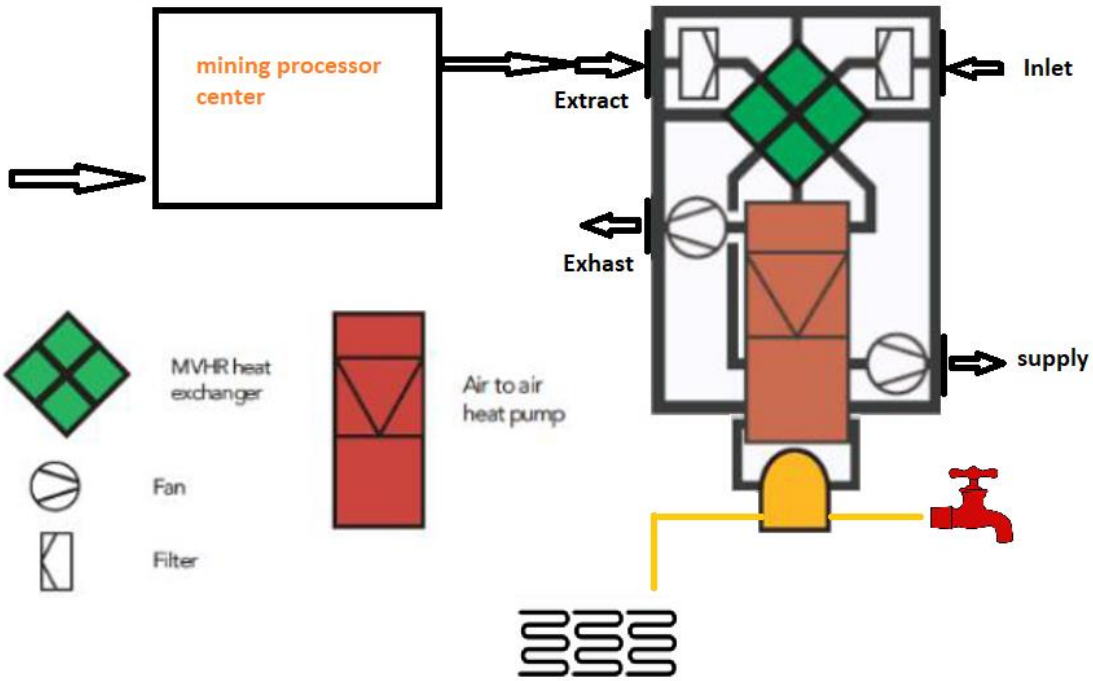



Figure 27. The combination system with a compact heat pump unit. Modified by researcher.

As indicates in figure 27, the feasible option connects the mining processor to the exhaust air before it went to ventilation unit. At first, the exhaust air from each room can go through the mining data center and then continues to the ventilation unit. In the ventilation unit, having been heated to a certain degree by the mining rigs, the heat in exhaust air is transferred to the supply air in a heat exchanger. The supply air can be heated up to the designed temperature without any extra energy consumption. After that, the remaining heat from the exhaust air is still reused by a heat pump to produce hot water for space heating and domestic hot water. In the summer, the heat exchanger can activate a bypass to avoid overheating the house. The exhaust air can cool down the mining processor. In this case, the waste heat is exploited at a high energy efficiency level. An isolated mining room can prevent the noise problem and a heat pump can function with a high COP and save more electricity during its operation.

Despite its advantages, a significant disadvantage of this system is the initial cost and airtightness of the building since compact unit is suitable for air-tight buildings. It is challenging to achieve the required airtightness value with renovated buildings or old buildings. However, with the current building practice, the new house can easily get a good air tightness value. Thus, the integrated strategy with compact unit could be an appropriate solution. Moreover, the integration can allow the compact unit work with the standard multi-family house. In the long run, the money from bitcoin can shorten the return on investment time and may become a good practice to apply.

# 5 Practical Case Introduction

In this chapter, the practical case is introduced, and its current thermal structure detail and HVAC system are analysed. The case study is Hyrsylä Co-housing project in Lohja. An old primary school that is going to be renovated into Co-housing place (multi-family house). The owner wants to know if it is possible to exploit the waste heat from a cryptocurrency mining rig to heat up the house while the mining cryptocurrency can generate money during its operation. This chapter is divided into three parts. The first part introduces the Hyrsylä project. The details of the project are gone through in part two. Finally, the current HVAC system of the school is presented in the last part. Chapter 5 give an overall understanding of the Hyrsylä project to act as foundation to the simulation part in the next chapter.

## 5.1 The Hyrsylä Co-Housing Project

The Hyrsylä Co-housing project is a renovation project which turns an old primary school into multi-family houses. The school is in Lohja, an area 60 km to the west from Helsinki. The school was built in 1905. The school consists of three parts; the first building was completed in 1910, extension building was constructed in 1923 and there is a small sauna building nearby. The extension was connected to the old building to create a traditional L-shaped. A detailed architectural drawing can be found in appendix 1. (Aibeo 2017.)

The town of Lohja decided to sell the school building in Hyrsylä through public tender. The school building is a protected building. Repair and alteration work on the layout of the building as well as any supplementary construction must be carried out so that the building's cultural and historical values are preserved. Requests for an opinion on the layout of the building should be accepted from the Finnish Heritage Agency. The site was considered a cultural heritage area. The school has been empty since 2016 because of poor indoor air quality. A renovation was needed, and the cost may be high due to the building condition. (Hyrsylä 2018.) In figure 28 (Aibeo 2017), the design plan is explained and the architect’s concept for renovating the place is introduced.

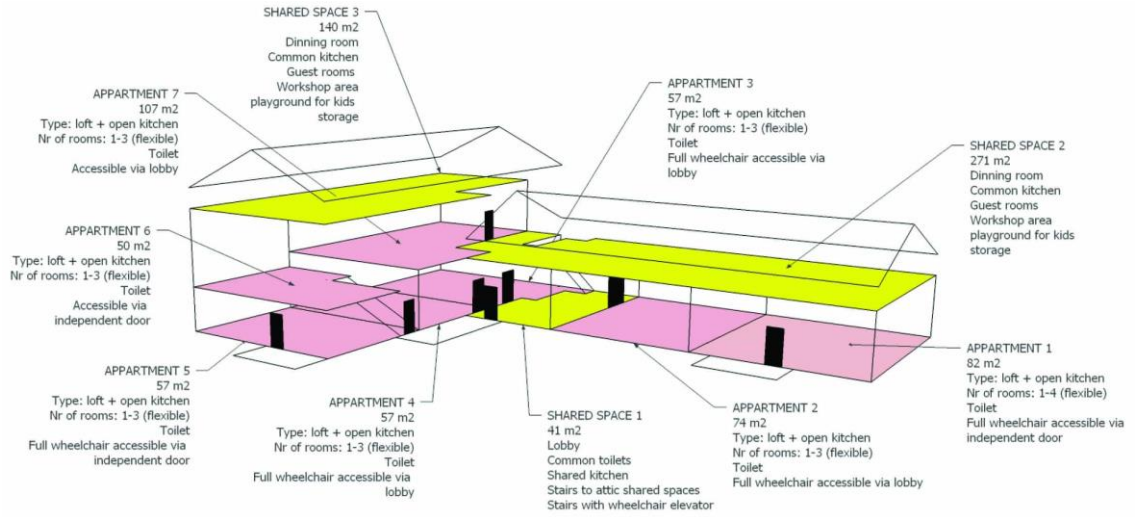



Figure 28. The initial plan for Hyrsylä Co-Housing project. (Aibeo 2017.)

According to architect Pedro Aibeo's plan the design principles are sharing space, creating a high-quality lofty place, and equipping high accessibility. The initial idea was to use 50 % of the space for education facilities, an international research hub, small local business, and guest house. The other 50 % of the space was divided into four to seven private apartments for mixed habitation. Figure 28 presents the design plan. The shared spaces locates in artic areas and a small portion in the first floor. The sharing spaces could be rented out for local business. The total area for shared space is around 452 $m^2$. The apartments are from 50 $m^2$ to 100 $m^2$. The number of tenants for each apartment is flexible. It was estimated around one to three people in each apartment. (Aibeo 2017.)

Mining cryptocurrency can bring tremendous profits, and there are more and more people involved in this business. Therefore, the mining of cryptocurrency in Hyrsylä is possible. It could generate money during building's lifetime and get a better energy efficiency by reusing waste heat from the production. The integration may not only reduce the return on investment time, but also increase the budget to improve the quality of the building. Therefore, optimal solutions to reuse waste heat from mining rigs need to be tested and analysed. Also, the mining processor was not only meant for mining purpose. It could be used as a small decentralized data center. A decentralized family scale data center may be developed in the future where every house needs one artificial intelligence to function. The proposed solutions are considered and may be implemented to the project in the future.

## 5.2 Building Structure and Thermal Envelop Detail

According to the micro-bacteria surveys, the building was built over the bedrock on the hillside of Hyrsylätie street. The school has a wooden structure and consistes of two parts. One part is a two-floors building, and the other part is a one-floor wooden log building. The basement is ventilated crawl space, and unheated artic areas are in both parts of the school. The older part has T-windows with thin glazing and overhangs shading. The newer part consists mostly of standard 0.6mx1m windows. (Insinööritoimisto Airkos 2015.)

The building has been renovated several times during its lifetime. The gable roof was renovated in 2001 with a tin cover, and the façade was covered with partly vertical and partly horizontal wooden façade. The floors of the classroom were replaced in 2007. The building has been cleaned, and a ventilation system was added in 2014. However, the top of the building must be investigated and repaired separately according to the survey. The thermal insulation of the buildings must be expanded by opening the vertical façade of the exterior wall and the horizontal facade of the lower part. Thus, the energy efficiency can be improved. The wooden log structure condition is uncertain and needs more investigation. Some of the wooden logs are rotten and need to be replaced. The general condition of the school is satisfactory. Due to the condition, there is much work and required more resources to renovate this building. (Insinööritoimisto Airkos 2015.)

It is challenging to investigate the wall and foundation structure of the building since there was only one site visit. The structure and component's u-value of wooden log houses in the 1900s were pretty much the same. According to Professor Juha Jokisalo from Aalto University, who conducted HELTH-project in 2013. The project investigated fifteen construction houses from 1700-1938. The typical structures were similar to log frame and board cladding for an external wall. Plank floor was used with a ventilated crawl space. The ventilation system was natural ventilation with a stack effect. Table 5 below shows some of the thermal conductivity values of the typical components and universal airtightness value for building from the 1900s from the HELTH-project. (Jokisalo 2013.)

Table 5. Typical values for building in the 1900s. (Jokisalo 2013.)

| | Structure | U-values [W/m²,K] |
|---|---|---|
| Wall | Log fame (180mm) + board cladding | 0.52 |
| Artic and base floor | Plank 49mm, sand 50mm, moss 200mm and plank 40mm | 0.38 |
| Foundation | ventilated crawl space with 200mm floor slab | 0.52 |
| Window | 2 pane windows | 2.8 |
| Door | wooden door | 2.8 |
| Air leakage rate: | q50 = 12 1/h | |

In table 5, the HELTH project presents some typical value which can be used to represent the Hyrsylä project. The external wall was logwood with dimension from 180mm of log frame and some external board cladding and internal board finishing. The total dimension was around 200mm-250mm gives the u-value around 0.5 W/m$^2$K. The attic space was unheated, and there was thin insulation layer on top of the wooden floor. Typical u-value for artic in the 1900s was 0.38 W/m$^2$K. The windows are common two pane windows and wooden door with u-value around 2.8 W/m$^2$K. The air leakage rate with q50 equalled to 12 h$^{-1}$.

## 5.3 The Existing HVAC System

According to a site visit to Hyrsylä school on the 14$^{th}$ of March 2018, the original heating system of the school was wood-fired stoves which connected to four chimneys on the roof. Due to renovation, the fireplaces were no longer used, and were replaced by an electric heater installed directly at the bottom of the fire stove. Electric radiators were installed later due to the uncomfortable indoor temperature and located below the windows. There are some temperature sensors in the school, which activate the electrical radiators when the temperature drops below the design value. The hot water supply is from an electrical boiler, and there is no cylinder in the building. The heating is mainly run with electricity. District heating is not available in the area.

The ventilation system of the school is a mixed-use one with natural ventilation and simple extract-air system. In fact, the building's ventilation does not work. The supply air valves are installed on top of the windows. They were closed or blocked. The only functional supply air valve is in the dining room. In other part of the house, some of the decommissioned brick furnaces are used as exhaust airducts. In fact, the impurities flow

back to the indoor environment through the furnace because the pressure of the air flow was not maintained correctly. When the supply air valves were blocked, the backup air becomes indoor-air without excessive ventilation via the airways of an impure air area. Therefore, the whole indoor area has bad air quality. Installing heat recovery ventilation unit in the building is necessary to achieve better energy efficiency. (Insinööritoimisto Airkos 2015.)

Another challenge is the airtightness of the building. The building is poorly airtight. A smoke test and air pressure were conducted in the survey in 2015 (Insinööritoimisto Airkos 2015.). Air leakages were found on the floor and the wall area in the study space and another place in the building. Air leakage points were also found in the enclosure structures as well as on the floor of the house. Various and doubtful points were common in the whole building. It was necessary to repair the air leakage with careful sealing correction and by replacing of the inlet valve with air valves. It was difficult and challenging work in a hundred-year-old wooden log house.

# 6 Research Approach and Method for Testing

The solution to integrate the waste heat from cryptocurrency mining rigs to the HVAC system of a multi-family house in Finland is suggested. The solution is also simulated to get the annual result. The purpose is to establish how much of the heating demand of the building that the system could cover, as well as to forecast the feasibility of the mining rig. In this chapter, the method of testing and heating calculation is reported.

## 6.1 Building Energy Simulation

The quality of the indoor environment and the energy consumption of the entire building can be designed with IDA Indoor Climate and Energy (IDA ICE) which simulates dynamic multi-zone energy. Using IDA ICE, the energy demand is categorized into different zones. Therefore, the energy performance of specific areas of a building can be simulated precisely, and the decision making can be made more accurate. It is also possible to connect IDA ICE to other modeling and design-software by exporting and using a standard format file called Industry foundation classes (IFC). With the help of IFC, the process of simulation can be enhanced quickly with a smooth collaboration between teams of construction. (EQUA Simulation Technology Group 2016: 3.)

IDA ICE is chosen as the software to use in the simulation for the Hyrsylä school. The first apparent reason is that IDA ICE can quickly identify the heating demand of a project and process a dynamic energy simulation. The next reason is the age of the building. As mentioned in subsection 5.2, the building was built more than one hundred years ago, so the thermal envelope of the building is less likely to be changed in the case of reuse as a residential building because of the large scale of alternatives and high price. Therefore, the thermal envelope is not the primary focus in this report and thermal envelope can be easily made virtually by IDA ICE. The basic shape of the building has been simulated by the other students attending a master course with Revit software. By cooperating with the other students from master programme, the time used for considering the thermal envelope and making building bodies in IDA ICE is reduced. The final reason for IDA ICE to be chosen is that IDA ICE shows the heating demand and energy for various areas of a building during a specific time period which could be useful in feasibility consideration. Therefore, it is evident that IDA ICE is a better choice than other software,

such as Passive House Planning Package (PHPP) which is an excel-file without IFC support, focusing mainly on the thermal envelope and with no real-time simulation.

## 6.2 Data Input in IDA ICE

The simulation starts with the IFC file with the virtual model of the Hyrsylä School created by postgraduate students. The model can be seen in figure 29 below.

Figure 29. Site picture (top), IFC model (middle) and IDA ICE model (bottom).

Figure 29 shows the real building and its virtual model. The IFC picture is from the IFC file made by master students while the IDA ICE picture is an imported IFC file to IDA ICE. The basic shape of the virtual model is described precisely to the actual building. The IFC version was made with the measurements taken at site. Therefore, with the support from IFC file, the results from IDA ICE are guaranteed to be precise as much as possible.

The initial information is then established for the simulation. The location and climate are in Vantaa, Finland the nearest location available to the school. Hence, the result of the simulation is expected to have a small error.

Then the energy zones are built for the model. The building is divided into zones as can be seen in the last picture in figure 29. Each virtual zone represents for each available area defined in figure 28. This arrangement is more natural when considering and recognizing the heating demand of the specific rooms.

The U-value of the thermal envelopes reveals the thermal transmittance of materials. The higher the U-value is, the worse the insulation characteristics are. All thermal envelopes are simulated according to the date in table 5 so that the U-value of the Hyrsylä school is corrected following the standard survey in the years of 1900s. Except for the attic structure, because the attic had not been used for the living space in the past. Therefore, the U-value of the attic was the assumption of the researchers where the insulation was put on the attic to make it usable as living space thus its U-value was 0.17 $W/m^2K$. Furthermore, the windows and doors must be rebuilt in the simulation to be attached to the zones in IDA ICE. Moreover, the infiltration is the airtight of the building indicating how fast the indoor air is leaking out. This value had been surveyed in the 1900s, and the standard value for infiltration was about 8 1/h.

Finally, the HVAC system is included in the energy analysis of IDA ICE. The site visit shows that the building is degraded. There is no mechanical air handling unit other than pure exhaust air with natural ventilation through windows. Because of the method for heat recycling, an air to water heat pump system is added in IDA ICE, as well as a hot water storage tank. The amount of heating water used is inserted according to the Passive House Institute and D3, Finnish Energy Efficiency of Buildings – regulations, and guidelines 2012. It is 25 litters per person per day and 35 kWh per floor area annually, respectively. These parameters are applied to the position of the apartments instead of the sharing space because people were more likely to use the domestic hot water in their apartments than in shared spaces.

## 6.3 Method of Testing the HVAC System and Feasibility of Mining Rig

The mining hardware chosen for the simulation is Antminer S9. As can be seen in table 3, Antminer D3 is more effective but because of its low efficiency only 17 GH/s, it is not chosen. The Antminer S9 has a higher efficiency in mining with 14 TH/s and higher maximum power consumption with 1340 W. The higher the power consumption, the higher heat production, following the principle of conservation of energy mentioned in subsection 3.5. The power consumption of the Antminer S9 is not much different from the power consumption of the Antminer D3 with 1340 W and with 1080 W irrespectively. However, the S9 produces more profit in cryptocurrency than the D3. Apparently, the S9 is more efficient in the long term when the profit from cryptocurrency can support the cost of the mining operation and of heating demand which the recycled heat cannot cover.

The heat removal and heat recycling method is based on an air to water heat pump. The air distribution cooling method of the mining rigs is assumed to be the contained method for supply and extract air, as can be seen in subsection 4.1. In other words, the mining hardware was put in a well-insulated box to prevent noise and heat affecting the surrounding indoor climate. The heat pump serves as a cooling system and heat is recycled in the building in the same way as explained in subsection 4.1.4. The evaporator of the heat pump is inside the exhaust air system for the mining rig to cool the hardware and collect the heat emitted from the processors. The heat is transferred to the condenser after removal from the mining box. From the condenser which is near the water tank, the heat is recycled to heat the water tank for domestic hot water usage of the building. The virtual model is simulated to calculate domestic hot water because the heating demand

for domestic hot water is kept constant through the year. If simulating space heating coverage, overheating during the summer would occur because the heating demand for the space heating varies between seasons.

The IDA ICE simulatation of the energy demand of the building shows two results for the energy needed to cover the heating demand of the building for one year in terms of space heating and domestic hot water. The first result is based on domestic hot water demand are according to Passive House Institute and the second on D3, Finnish Energy Efficiency of Buildings regulations and guidelines 2012. The higher heating is chosen for the following calculation to be on the safe side.

Next, the COP of the heat pump is calculated. As explained in the COP part in the subsection 2.2.2, the formula (1) was used to calculate the theoretical COP of the heat pump based on the working temperature at the evaporator and condenser. As mentioned above, the evaporator is in the mining box. Hence, the evaporator serves as a cooling device and keeps the temperature in the working range as mentioned in table 3. The temperature in the mining room is 35 $^0$C at most. The temperature at the condenser is 60 $^0$C because following the regulation, the temperature of the domestic hot water was at 60 degrees Celsius to ensure the quality. The theoretical COP of the heat pump is calculated to achieve the input and output temperatures at the evaporator and condenser respectively. Afterwards, the actual COP of the heat pump can be calculated with formula 2. The result is half of the theoretical COP because the actual COP which is 50 % is considered as an efficient heat pump, as explained in subsection 2.2.2.

Next, the heat production at the condenser is tested. To forecast the feasibility of recycling, the amount of heat produced must be calculated. As stated in the initial assumption, the evaporator is inside the mining box. Thus, the power input or heat input at the evaporator was is the same as the power consumption and heat emitted from the mining device shown in table 3. In this case, it is 1,340 W for each mining device handled by the evaporator. Using the formula 1 in subsection 2.2.2, the power of the condenser can be traced back and calculated from the known COP. With the result, heat production at the condenser is known and can be converted to kWh per annum. This parameter is the heat removed from the mining hardware and processed by the heat pump so that it is ready to be recycled.

Finally, the feasibility is judged on the basis of the result. A comparison between the heating demand of the two options for domestic hot water and the heat production of the mining rigs is to made. The data are collected and imported into an Excel file to plot a chart for comparison. The chart showes how much heat a specific numbers of mining processors would produce and how much of the domestic heating demand could be covered as well as how much more heat is required to cover the remaining heating demand for space heating, as well as the time of overheating. Also, the amount of electricity used and saved can be briefly concluded based on the COP when subtracting the power output at the condenser from the power input at the evaporator.

# 7 Results and Discussion

In this chapter, the heating demand of school and the heat production by the mining rig are calculated. Later, a suggestion of how many mining rigs should be installed to cover the heating demand of the project is proposed. Chapter 7.1 presents the heating demand of Hyrsylä school. It includes space heating and domestic hot water demand. Chapter 7.2 shows the result of the mining rig calculation and indicates how much heat energy could be generated from the mining production. Finally, chapter 7.3 concludes the possible solution and offers some suggestions of how to optimize the systems.

## 7.1 The Heating Demand of Hyrsylä School

The heating demand of Hyrsylä school was calculated with IDA ICE simulation software. This chapter presents the results of the simulation for space heating demand, followed by the two possible results for domestic hot water demand. The assumptions used for the domestic hot water are from Passive House Institute and D3 Finnish Energy Efficiency of Buildings regulations and guidelines 2012.

Once the energy model was created in IDA ICE, the software gave some primary energy information about the building. The treated floor area of the school is 1,105.2 $m^{2,}$ and total volume 3,495.1 $m^3$. The area of the envelope, including the roof, wall, and foundation area is 1,747.1 $m^2$. The window and door over envelope ratio is 6.2 %, a quite good value. As suggested by D3 Finnish Energy Efficiency of Building, the maximum ratio is 15 % so that the heat loss from windows and doors can be minimized. The wooden structure has a different U-value for roof, wall, and foundation. The average U-value is around 0.52 W/($m^2$K). This U-value could be improved in the future in order to decrease the heating demand of the project. Another essential ratio to look at is the compactness ratio. It is about 0.5 $m^2/m^3$. This value was used for the energy efficiency calculations of the project.

The IDA ICE simulation provided a lot of useful information. However, in this research, only the heating demand was looked into. Table 6 below shows the results of the simulation.

Table 6. The heating demand of Hyrsylä Cohousing Project.

| Month | Space Heating [kWh/month] | DHW (PHPP) [kWh/month] | DHW (D3) [kWh/month] |
|---|---|---|---|
| Jan | 26332 | 938.6 | 1788 |
| Feb | 23517 | 858.2 | 1634 |
| Mar | 21988 | 952 | 1815 |
| Apr | 11315 | 925.2 | 1765 |
| May | 3755 | 938.6 | 1790 |
| Jun | 1126 | 925.2 | 1765 |
| Jul | 15.1 | 952 | 1816 |
| Aug | 861.4 | 938.6 | 1790 |
| Sep | 5107 | 938.6 | 1790 |
| Oct | 12733 | 938.6 | 1790 |
| Nov | 19889 | 911.8 | 1738 |
| Dec | 24097 | 965.5 | 1840 |
| **Total [kWh/year]** | **150735.5** | **11182.9** | **21321** |

The space heating is the same in two options in table 6. The space heating demand is different from time to time because of the changing outdoor temperature. In winter, the space heating demand is at the highest value in January, 26,332 kWh in total. This space heating demand decreases during the summer and comes close to 0 in July. The total space heating demand is 136 kWh/m$^2$a. The high space heating demand is the result of the inferior insulation layer, airtightness value, and natural ventilation system. The domestic hot water calculated on the basis of D3 Finnish Energy Efficiency of the building was double compared to the calculations based on the Passive House Institute instructions. The average energy for domestic hot water demand with an assumption of 25 l/person a day is 950 kWh/month. In contrast, if the domestic hot water demand was calculated according to the living area, the result for daily water usage almost doubled. The result based on the D3 assumption is 21,321 kWh/year and around 1,800 kWh/month. To be on the safe side of design, the result from D3 assumption is chosen when calculating the possible number of mining rigs could be used in the system.

## 7.2 Heating Supply from Mining Rig

In this chapter, the heating production of a mining rig is investigated, and heat energy output from a heat pump which takes the heat from the mining rig is calculated. At first, the real COP of the heat pump needs to be calculated according to Carnot theory. Then, the energy output can be calculated according to the COP value. The heat energy output then increases according to the quantities of the rig used in the system. After that, the result can be compared to the demand. Figure 30 below indicates the COP of the heat pump, working in a room temperature of 35 degrees Celsius.

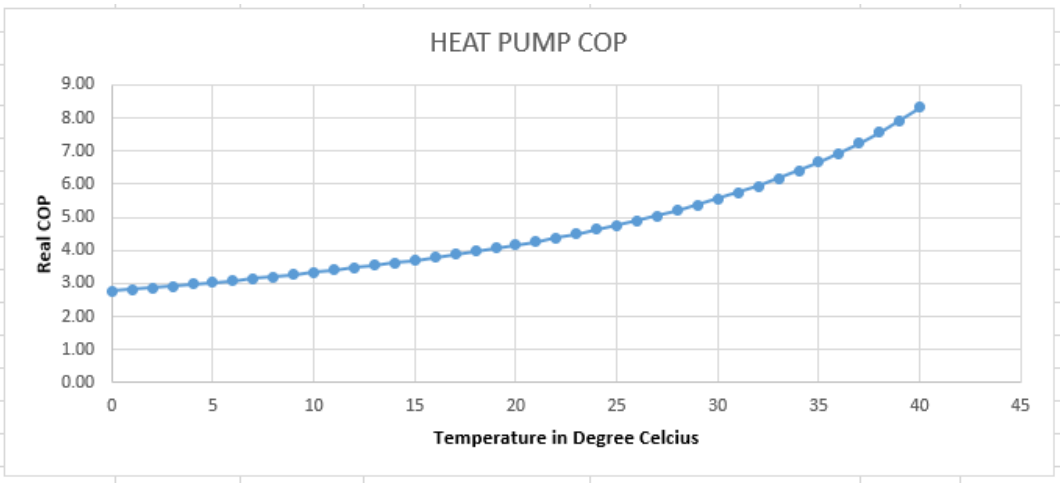



Figure 30. Heat pump COP

Figure 30 shows the changing COP value when the indoor temperature of the mining room changes. The maximum temperature for the mining room is 40 degrees Celsius. However, with this temperature, overheating can occur in the mining rig and this may lead to system breakout. To be on the safe side, the temperature of 35 degrees Celsius is used to calculate the COP of the heat pump and to find the heat energy output. As mentioned in figure 30, the COP of 35 degrees Celsius is 6.6, the highest COP of any heat pump in the market. With the COP result, the energy output of the heat pump can be calculated, it is indicated in figure 31 below.

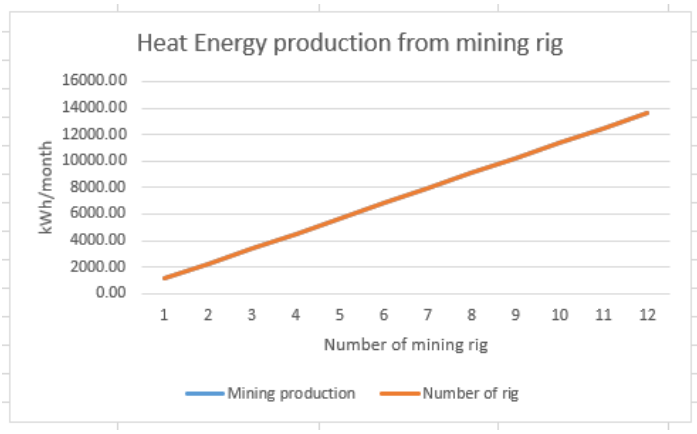



Figure 31. Heat Energy production from mining rigs.

In figure 31, the production of one mining rig is 1,135.26 kWh/month. If the size of the mining rig is increased, the heat production increases also according to the number of rigs. With this information, the heat energy supply and demand can be met. Also, with the heating demand of the project, the number of mining rigs can be calculated so that there is no waste heat energy, thus creating an energy efficient system. The next chapter presents the results and discusses if the project should be dedicated to mining production and be allowed to create more waste heat energy than its needed.

## 7.3 The Final Result and Discussion

After finding the supply and demand, the last step is to match them together and complete the system for this project. The heat energy from the mining production is constant and available at the same level all year around. The space heating demand changes according to the ambient temperature outside. There is no demand in the summer, and a huge demand in the winter. The domestic hot water demand is constant and depends on the habits of the resident. However, it can be considered a constant value throughout the year. The table 7 below shows three values for heating energy production in this project and figure 32 shows the heating demand of domestic hot water and space heating, and the heat production of mining rigs.

Table 7. The heating demand and heat production of mining rigs.

| Number of Antminer S9 devices | Heat production at evaporator [W] | Heat Production at Condensor [W] | Electric use [W] | Electric use [kWh/day] | Heat Production at Condensor [kWh/day] | Heat Production at Condensor [kWh/Month] | DHW demand [kWh/month] |
|---|---|---|---|---|---|---|---|
| 1 | 1340 | 1448.77 | 108.77 | 2.61 | 34.77 | 1043.11 | 1752.41 |
| 2 | 2680 | 2897.53 | 217.53 | 5.22 | 69.54 | 2086.22 | 1752.41 |
| 3 | 4020 | 4346.30 | 326.30 | 7.83 | 104.31 | 3129.34 | 1752.41 |
| 4 | 5360 | 5795.06 | 435.06 | 10.44 | 139.08 | 4172.45 | 1752.41 |
| 5 | 6700 | 7243.83 | 543.83 | 13.05 | 173.85 | 5215.56 | 1752.41 |
| 6 | 8040 | 8692.60 | 652.60 | 15.66 | 208.62 | 6258.67 | 1752.41 |
| 7 | 9380 | 10141.36 | 761.36 | 18.27 | 243.39 | 7301.78 | 1752.41 |
| 8 | 10720 | 11590.13 | 870.13 | 20.88 | 278.16 | 8344.89 | 1752.41 |
| 9 | 12060 | 13038.90 | 978.90 | 23.49 | 312.93 | 9388.01 | 1752.41 |
| 10 | 13400 | 14487.66 | 1087.66 | 26.10 | 347.70 | 10431.12 | 1752.41 |
| 11 | 14740 | 15936.43 | 1196.43 | 28.71 | 382.47 | 11474.23 | 1752.41 |
| 12 | 16080 | 17385.19 | 1305.19 | 31.32 | 417.24 | 12517.34 | 1752.41 |

As described in table 7, to cover the domestic hot water demand of the project, only two mining rigs (Antminer S9) could be used, and they are enough to generate heat and money at the same time. If the mining system use only one Antminer S9 device, the heat production can be around 1043 kWh/month. The electric usage here indicates the electric consumption of heat pump. For one unit Antminer S9, to generate 1043kWh heat energy in one month, the heat pump consumes 2.61 kWh/day. Figure 32 shows the heating demand of Hyrsylän project during a year. The demand for domestic hot water, calculated on the basis of D3, is 1,800 kWh/month, and the heat energy supply for two mining rigs is 2,270 kWh/month. There is a little extra energy from the production which could be considered to be heat loss through the distribution and cylinder. To cover the peak demand of the space heating, the number of mining rigs can be up to 20 mining rigs. However, there would be a massive problem with extra heat energy from the mining process in the summer.

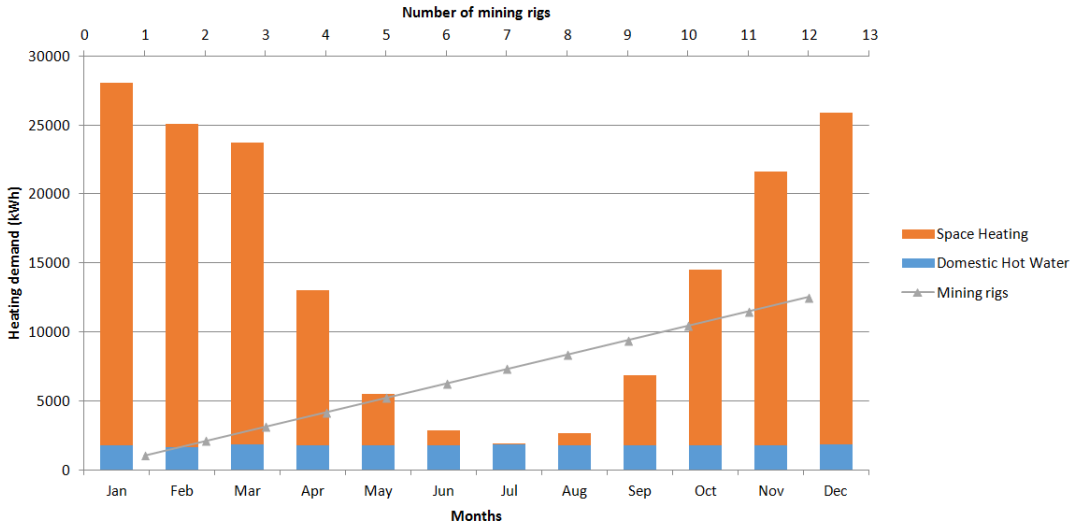



Figure 32. The Heating Demand of project and the production of mining cryptocurrency.

If the Hyrsylä project wants to use more mining rigs to also cover the space heating demand in the winter, there is a possible solution to solve the problems. First, the production could be reduced in the summer and increased to a 100 % capacity in the winter. Secondly, the extra heat energy could be used for another purpose in the summer, for example, for the dry laundry room, for heating the swimming pool, or the basement to remove mold, etc. The substantial amount of heat from the mining rig creates always problems and the system needs to be designed carefully and wisely to be energy efficient.

# 8 Conclusion

In conclusion, the use of waste heat from cryptocurrency mining integrated into building service system was clarified based on theoretical research and simulation. This thesis provides primary knowledge about the mining process, heating systems, and about how to combine them in a practical case. The heat from mining rigs was tested and proved to be usable in building services systems, making the building more sustainable while guaranteeing passive income for the owners.

The thesis contains many unfamiliar concepts for typical businessman to invest in. The first is the current status of the Finnish heating market. Various energy sources that produces heat are listed. Furthermore, it is also demonstrated that heating energy is mostly used almost for space heating and domestic hot water. Moreover, the featured methods of heating are discussed were illustrated. Especially heat pumps, mainly because they were considered the most suitable way to collect and reuse waste heat.

Secondly, the cryptocurrency concept was explained in detail. In addiontion, its mining process was shown to be a process where hardware could not only generate digital currencies but also waste heat. Additionally, its challenges and future were analyzed to show the worth of recycling waste heat. Cryptocurrency mining is an excellent chance to get rich quickly. However, at the same time, cryptocurrency included high financial risks, high cost, and environmental impacts. If waste heat from the mining process is recycled to the HVAC system of a building, the cost and environment of harm would be minimized.

Thirdly, the cooling methods and heat recycling idea were studied. The same cooling technology could be applied to mining rigs as to traditional data centers because they use the same computer technology, operate the whole time and emit enormous amounts of waste heat. Additionally, the authors of this thesis were not the pioneers in the idea of recycling waste heat, mining radiators and mining waste heat removal by hydraulics. However, innovative ideas were presented in the thesis, such as combining waste heat with a heat pump and a compact unit for domestic hot water, space heating for the whole building and cooling for the mining rigs. The idea to combine mining rigs with a heat pump with the containment method to heat the domestic water was chosen because the heating demand was constant so that there was no period of overheating.

Fourthly, the results of the heating demand of and production for a real building were simulated. The comparison between the heating demand and heating production was demonstrated by a chart that considered the number of mining rigs feasible to cover the heating demand for domestic hot water and space heating. The simulation gave the result that two pieces of mining hardware Antminer S9 would be enough to meet the heating demand of the domestic hot water of the building for one year. To apply the waste heat for space heating, twenty mining devices were required, but then, overheating would happen in the summer. The approaches suggested to handle this problem were either to heat other sources, such as a basement, laundry, swimming pool or just directly blowing the heat out to the environment when the condenser was heating the water tank on the roof.

Several applications could be based on this thesis. The architect and miners of the Hyrsylä project could use this thesis for their mining center installation and for making a final decision on pursuing their mining purpose. The cooling methods, heat pump methods and a variety of mining rigs have been analyzed in this thesis. Furthermore, the amount of heat production and electricity consumption by the heat pump were also calculated so that the return on investment or the financial plan could be established. The life cycle cost of the whole project was not calculated in this thesis because it would involve to the cryptocurrency revenue which is very unstable and fluctuates; it is clear that even financial experts cannot predict the trend of the market precisely these days. However, the data about energy and mining hardware calculation in this thesis could be used combined with the assumption to make a full financial plan for a mining center with price in details.

## References

Aibeo Pedro. Svartsa Skola Cohousing [Online]; 2017.
URL: http://svartsaskola.com/2017/10/29/looking-for-a-new-team-for-cohousing/
Accessed 10 March 2018.

Alexa. Traffic Statistics [Online]. Alexa; 2014.
URL: https://www.alexa.com/siteinfo/coinmarketcap.com
Accessed 10 March 2018.

Bitcoin Mining. Bitcoin Mining Hardware Guide [Online]. Bitcoin Mining; 2017.
URL: https://www.bitcoinmining.com/bitcoin-mining-hardware/
Accessed 23 March 2018.

Bitcoin Mining. Frequently Asked Question: Bitcoin Mining [Online]. Bitcoin Mining; 2017.
URL: https://www.bitcoinmining.com/faq/
Accessed 23 March 2018.

BitFury Group. Proof of Stake versus Proof of Work. Washington DC, Bitfury Group Limited; 2015.

Bitman. Shop of Bitman [Online]. Bitman; 2013.
URL: http://shop.bitmain.com/product/main?lang=en
Accessed 23 March 2018.

Bitshopper.de. High performance USB Stick Miner GekkoScience Compac 8-16 GH/s (23 GH/s max.) [Online]. Bitshopper.de; 2017.
URL: http://www.bitshopper.de/shop/sha-256-miner-en/gekkoscience-compac/?lang=en
Accessed 23 March 2018.

Blockchain Luxembourg. Blockchain [Online]. Blockchain Luxembourg; 2017.
URL: https://blockchain.info/
Accessed 11 March 2018.

Coinmarketcap. Cryptocurrency Market Capitalizations. [Online]. Coinmarketcap; 2013.
URL: https://coinmarketcap.com/all/views/all/
Accessed 10 March 2018.

Collie, M. J. Heat pump technology for saving energy. Noyes Data Corporation; 1979.

Committee On Payments and Market Infrastructures. Digital currencies. Bank For International Settlements; November 2015.

Danfoss, 2018. 8 Steps - Control of heating system [Online]. Danfoss; 2018.
URL: http://heating.danfoss.com/pcmfiles/1/master/other_files/library/heating_book/chapter1.pdf
Accessed 10 March 2018.

Davies, G. A History of Money - From Ancient Times to the Present Day. 3rd edition. Cardiff: University of Wales Press; 2002.

Alakangas, E., Heinimö, J., Ranta, T. and Karhunen, A. Efficient and environmentally friendly biomass heating. Helsinki, Technical Research Centre of Finland; 2008.

Eldredge, B. This tiny house is heated by bitcoin mining [Online]. Curbed; 2017.
URL: https://www.curbed.com/2017/11/9/16619032/bitcoin-mining-heat-homes-siberia-russia
Accessed 21 March 2018.

EN 13141-7. Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single fa. BSI; 2011.

EQUA Simulation Technology Group. IDA ICE Retting Started. [Online]. EQUA; 2016.
URL: http://www.equaonline.com/iceuser/pdf/ICE47GettingStartedEng.pdf
Accessed 12 April 2018.

European Banking Authority. EBA Opinion on 'virtual currencies'. [Online]. EBA; 2014.
URL: http://www.eba.europa.eu/documents/10180/657547/EBA-Op-2014-08+Opinion+on+Virtual+Currencies.pdf
Accessed 9th March 2018.

Evans, T. The Different Technologies for Cooling Data Centres. Schneider Electric; 2012.

Feist Wolfgang. Empfehlungen zur Lüftungsstrategie, in Protokollband 23 des Arbeitskreises kostengünstige Passivhäuser, Passivhaus Institut, 2003

Finnish Energy Industries. Correct Use of District Heat. Helsinki. Printing Libris Oy; 2007.

Finnish Forest Association. Finnish Forest Resources [Online]. 2016.
URL: https://www.smy.fi/en/forest-fi/forest-facts/finnish-forests-resources/
Accessed 9th March 2018.

Goelzer, B.  Hansen, C. H. and Sehrndt, G. A. Occupational exposure to noise: evaluation, prevention, and control [report]. Geneva. World Health Organization; 2001.

Hansen Morten, Jein Anna, Hayes Sandra, and Bateman Patrick. English Handbook for Wood Pellet Combustion [Online]. 2009

URL: https://pelletsatlas.info/wp-content/uploads/2015/09/Handbook_English_disclaimer.pdf
Accessed 10 March 2018.

Hileman, G. & Rauchs, M. Global Crytocurrency Benchmarking Study. Cambridge, Cambridge Centre for Alternative Finance; 2017.

Hu, K. Bitcoin miner: 'I haven't paid for heat in three years' [Online]. Yahoo; 2017.
URL: https://finance.yahoo.com/news/bitcoin-miner-havent-paid-heat-three-years-143714695.html
Accessed 21 March 2018.

Hyrsylä. (2018). Taustat [Online]. Hyrsylä; 2018.
URL: http://www.hyrsyla.fi/taustat/
Accessed March 15, 2018.

ICObench. ICO bench [Online]. ICObench; 2017.
URL: https://icobench.com/icos/crypto currency
Accessed 10 March 2018.

Insinööritoimisto Airkos. Hyrsylä koulu rakenteiden mikrobinäytteet. Lohja, Insinööritoimisto AIRKOS Oy; 2015.

Jevons, W. Money and the Mechanism of Exchange. London; 1910.

Jokisalo, J. Technical improvement of energy performance of Finnish houses. Helsinki, Aalto University; 2013.

Khatwani, S. What Is A Masternode And How Is It Useful For Cryptocoin Investors [Online]. Coinsutra; 2018.
URL: https://coinsutra.com/masternodes/
Accessed 11 March 2018.

Khemarattana, C. Cryptocurrency Mining. Bangkok, Fintech; 2017.

Klass, D. L. Biomass for Renewable Energy and Fuels. Encyclopedia of Energy 2004; 1: 193-204.

Kou Guangxiao, Wang Hanqing, and Zhou Jiemin. Maximum thermal efficiency of condensing boiler [Online]. 2018.

URL: http://www.inive.org/members_area/medias/pdf/Inive %5CIAQVEC2007 %5CKou_2.pdf
Accessed 9th March 2018.

Langland, T. & Skordal, K. K. Mining Bitcoins using a Heterogeneous. Trondheim, Norwegian University of Science and Technology; 2015.

Mardiana A., Riffat S.B. Review on Physical and Performance Parameters of Heat. Renew. a. Sust. Energy Rev 2013; (28): 74–190.

Fehrm Mats, Reiners Wilhelm and Ungemach Matthias. Exhaust air heat recovery in buildings. International Journal of Refrigeration 2002; 25: 439–449.

Natural Resource Canada. Heating and Cooling with a Heat Pump. Gatineau QC; 2004.

Nibe. NIBE Exhaust air A new generation of heat pumps. Nibeonline; 2018 [Online]
URL: http://www.nibeonline.com/pdf/439028-11.pdf
Accessed 11 March 2018.

Heat recovery ventilation guide for houses 2015. Burnaby, British Columbia and Canada, Homeowner Protection Office and Branch of BC Housing; 2015.

Passipedia. What is Passive House [Online]. 2018
URL: https://passipedia.org/basics/what_is_a_passive_house
Accessed 11 March 2018.

Passive House Institute. This will only work in a Passive House: Heating with nothing other than fresh air [Online]. 2018.
URL: https://passiv.de/former_conferences/Passive_House_E/compact_system_passive_house.htm
Accessed 11 March 2018.

Perper, R. Iceland may use more electricity to mine bitcoins than it does to power all of its houses this year [Online]. Business Insider; 2018.
URL: http://nordic.businessinsider.com/iceland-bitcoin-mines-are-booming-2018-2
Accessed 23 March 2018.

Pippuri, P. Heating mode choices of Finnish households and the Energy Paradox. Helsinki, Aalto University; 2012

Powers, J. M. Lecture Notes on Thermodynamics: Chapter 10: Cycles. University of Notre Dame; 2013.

Price, R. Someone in 2010 bought 2 pizzas with 10,000 bitcoins — which today would be worth $100 million. [Online]. Businessinsider; 2017.
URL: http://www.businessinsider.com/bitcoin-pizza-10000-100-million-2017-11?r=UK&IR=T&IR=T
Accessed 11 March 2018.

Quarnot. QC.1 The first crypto heater [Online]. 2018
URL: https://www.qarnot.com/crypto-heater_qc1/
Accessed 11 March 2018.

Rasmussen, N. The Different Types of Air Distribution for IT Environments. Schneider Electric; 2017.

Rosic, A. Proof of Work vs Proof of Stake: Basic Mining Guide [Online]. Blockgeeks; 2017.
URL: https://blockgeeks.com/guides/proof-of-work-vs-proof-of-stake/
Accessed 11 March 2018.

Rosic, A. What is Blockchain Technology? A Step-by-Step Guide For Beginners. [Online]. 2017.
URL: https://blockgeeks.com/guides/what-is-blockchain-technology/
Accessed 11th March 2018.

Guerra Santin, Olivia; Itard, Laure and Visscher, Henk. The effect of occupancy and building characteristic on energy use for space and water heating in Dutch residential stock. Energy and Building. Volume 41, Issue 11, November 2009. p. 1223-1232.

Statistic Finland. Energy consumption in households 2016. Helsinki, Official Statistic of Finland; 2017.

Statistic Finland. Finland in Figures 2017. Helsinki, Statistic Finland; 2017.

Sterry, D. R. Introduction to Bitcoin Mining - A Guide For Gamers, Geeks, and Everyone Else [Online]. CoinDL.com; 2012.
URL: http://euro.ecom.cmu.edu/resources/elibrary/epay/IntroductiontoBitcoinMining Sterry.pdf
Accessed 11 March 2018.

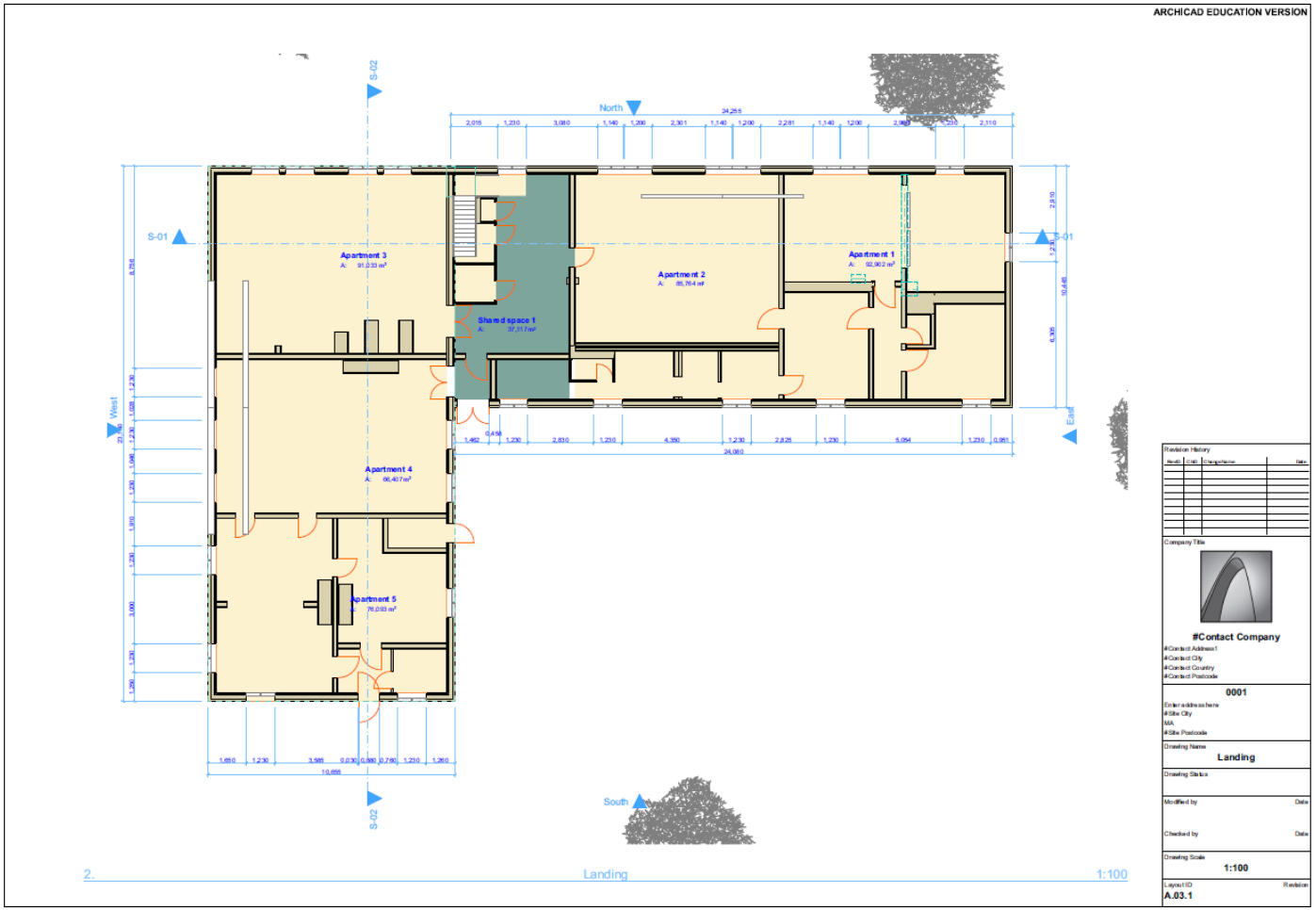
Sulpu. Heat Pump Investments up to Half a Billion a year in Finland. Helsinki, Sulpu; 2018.

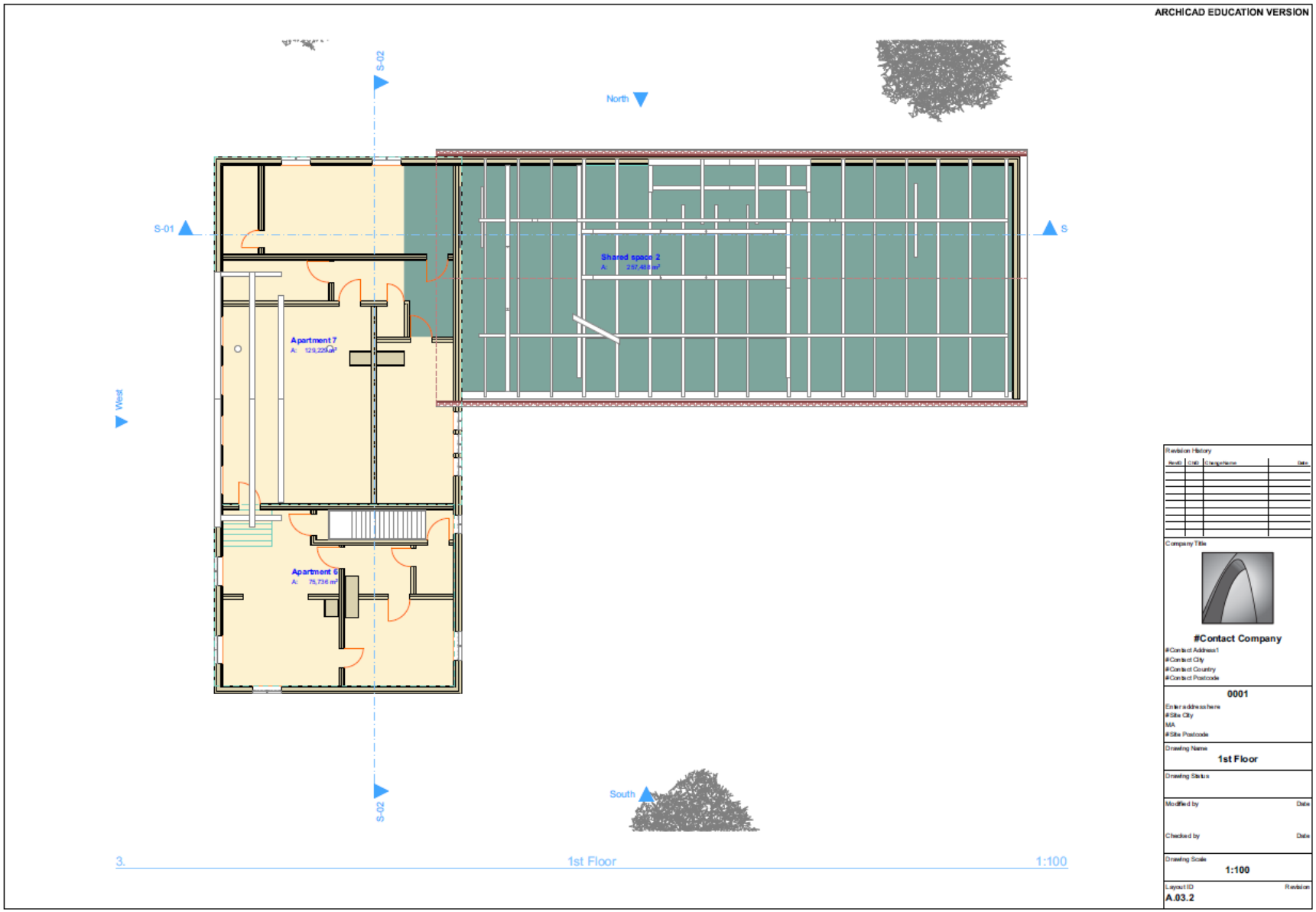
Tuwiner, J. Bitcoin Mining Hardware ASICs [Online]. Buybitcoinworldwide; 2018
URL: https://www.buybitcoinworldwide.com/mining/hardware/
Accessed 23 March 2018.

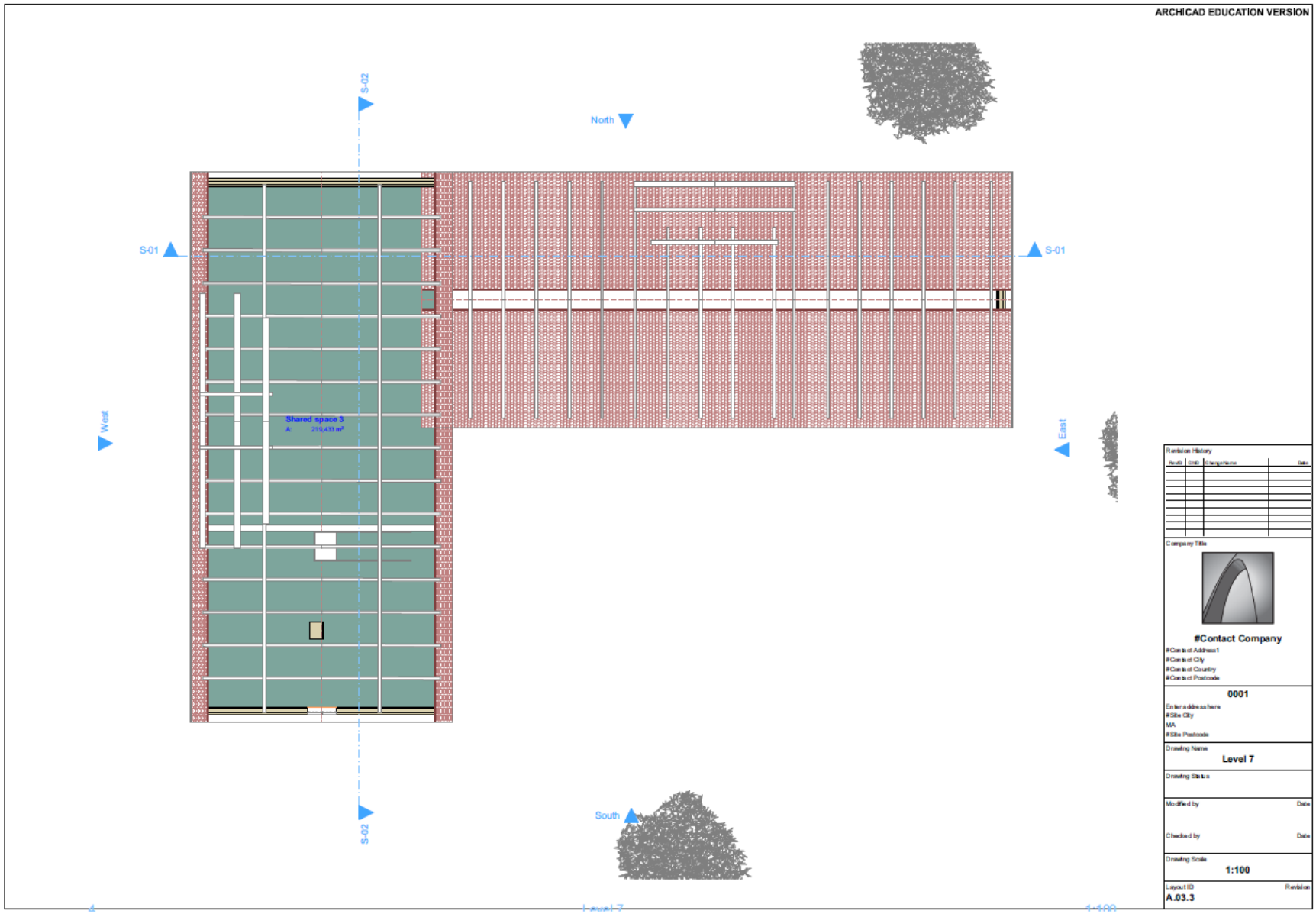
UBS AG and UBS Financial Services Inc. Cryptocurrencies - Beneath the bubble [report]. The United States, Chief Investment Office Americas, Wealth Management; 2017.

Zottl, A., Nordman, R. & Miara, M. Benchmarking method of seasonal performance [report]. SEPEMO; 2012.

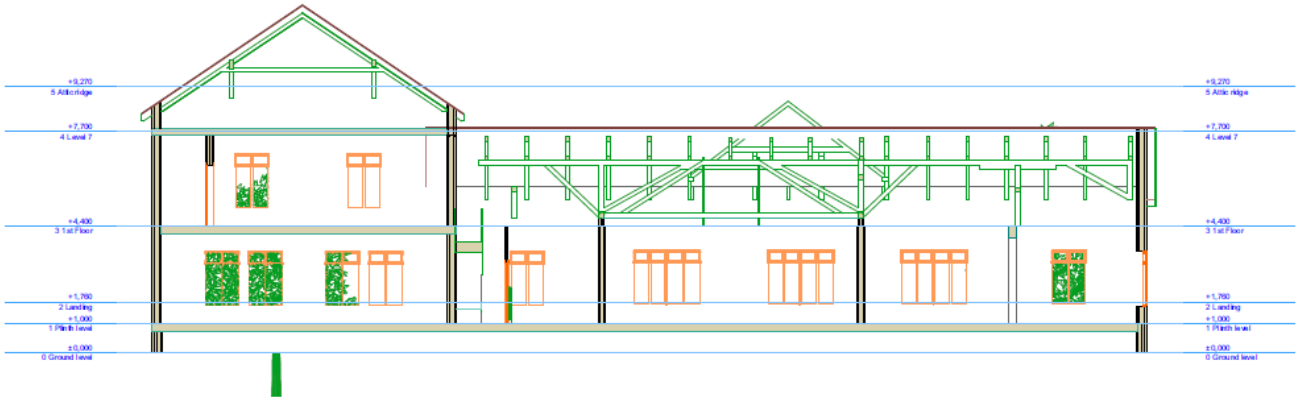
# Appendix 1. Architectural Drawing of Hyrsylä Co-Housing Project



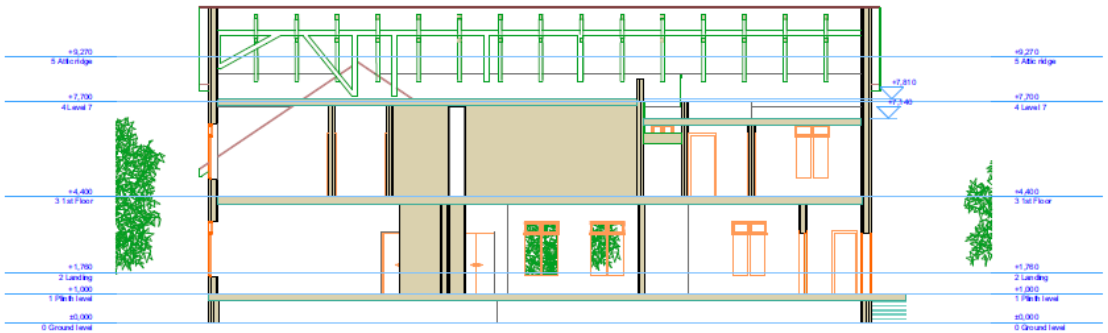

ARCHICAD EDUCATION VERSION
S-02
North
S-01
S
Shared space 2
Apartment 7
West
Apartment 6
South
S-02
3.
1st Floor
1:100
Revision History
#Contact Company
#Contact Address1
#Contact City
#Contact Country
#Contact Postcode
0001
Enter address here
#Site City
MA
#Site Postcode
Drawing Name
1st Floor
Drawing Status
Modified by
Date
Checked by
Date
Drawing Scale
1:100
Layout ID
A.03.2
Revision


ARCHICAD EDUCATION VERSION
S-02
North
S-01
S-01
West
East
Shared space 3
A: 215.433 m²
South
S-02
Revision History
Company Title
#Contact Company
#Contact Address1
#Contact City
#Contact Country
#Contact Postcode
0001
Enter address here
#Site City
MA
#Site Postcode
Drawing Name
Level 7
Drawing Status
Modified by
Date
Checked by
Date
Drawing Scale
1:100
Layout ID
A.03.3
Revision

ARCHICAD EDUCATION VERSION




S-01 Building Section 1:100




S-02 Building Section 1:100

Revision History

| Revit | CAD | Change Name | Date |
|---|---|---|---|
| | | | |

Company Title

#Contact Company
#Contact Address1
#Contact City
#Contact Country
#Contact Postcode

0001
Enter address here
#Site City
MA
#Site Postcode

Drawing Name
**Building Section**

Drawing Status

Modified by Date

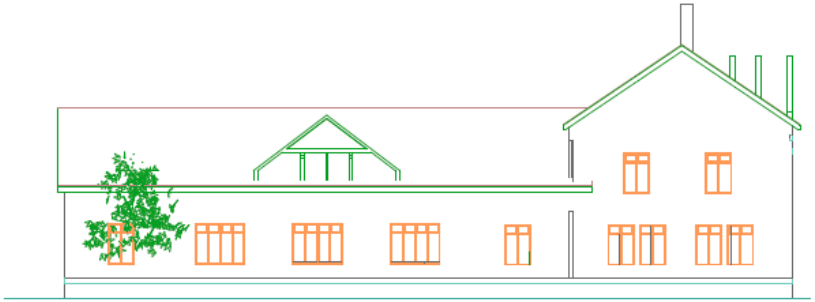
Checked by Date

Drawing Scale
**1:100**

Layout ID Revision
**A.03.4**

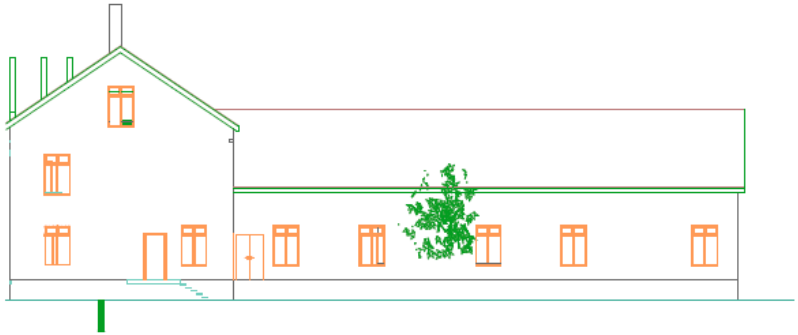
ARCHICAD EDUCATION VERSION

East 1:200



North 1:200

West 1:200

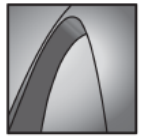


South 1:200

Revision History

| RevID | ChID | Change Name | Date |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Company Title



**#Contact Company**

#Contact Address1
#Contact City
#Contact Country
#Contact Postcode

**0001**

Enter address here
#Site City
MA
#Site Postcode

Drawing Name

Drawing Status

Modified by Date

Checked by Date

Drawing Scale
**1:200**

Layout ID Revision
**A.03.5**

ARCHICAD EDUCATION VERSION

3D 1:200

Revision History

| Rev ID | CHG | Change Name | Date |
|---|---|---|---|

Company Title

#Contact Company

#Contact Address1
#Contact City
#Contact Country
#Contact Postcode

0001

Enter address here
#Site City
N/A
#Site Postcode

Drawing Name
3D

Drawing Status

Modified by Date

Checked by Date

Drawing Scale
1:200

Layout ID Revision
A.03.6

# Appendix 2. Heating and Energy Report for Hyrsylä Co-Housing Project

EQUA
SIMULATION TECHNOLOGY GROUP

## Heating Load Report

| Project | | Building | |
|---|---|---|---|
| | | Model floor area | 1105.3 $m^2$ |
| Customer | | Model volume | 3495.1 $m^3$ |
| Created by | Max Nguyen | Model ground area | 0.0 $m^2$ |
| Location | Helsinki (Ref 2012) | Model envelope area | 1747.1 $m^2$ |
| Climate file | HKi-Vantaa_Ref_2012 | Window/Envelope | 6.2 % |
| Case | Update Version 10.04 35kWh | Average U-value | 0.5278 W/($m^2$ K) |
| Simulated | 4/11/2018 12:55:04 AM | Envelope area per Volume | 0.4999 $m^2/m^3$ |

## Zone Heating Loads

| Zone | Group | Area, $m^2$ | Heat supplied*, W | Time | Room unit heat, W | Vent. heat loss**, W | Temp., °C | Sup airflow, L/s |
|---|---|---|---|---|---|---|---|---|
| Apartment 1 | | 91.4 | 4015.0 | 06 Feb 08:00 | 4016.0 | 0.6 | 21.0 | 0.0 |
| Apartment 2 | | 84.7 | 3289.0 | 06 Feb 08:05 | 3289.0 | 0.6 | 21.0 | 0.0 |
| Apartment 3 | | 77.5 | 2844.0 | 06 Feb 20:09 | 2845.0 | 0.6 | 21.0 | 0.0 |
| Apartment 4 | | 65.6 | 2501.0 | 06 Feb 07:47 | 2501.0 | 0.6 | 21.0 | 0.0 |
| Apartment 5 | | 74.2 | 3725.0 | 15 Jan 02:14 | 3725.0 | 0.6 | 21.0 | 0.0 |
| Sharing Space 1 | | 48.3 | 1886.0 | 06 Feb 08:09 | 1886.0 | 0.6 | 21.0 | 0.0 |
| Sharing Space 2 | | 229.5 | 3630.0 | 15 Jan 05:05 | 3631.0 | 0.5 | 21.0 | 0.0 |
| Apartment 7 | | 143.5 | 3345.0 | 15 Jan 02:04 | 3346.0 | 0.6 | 21.0 | 0.0 |
| Apartment 6 | | 72.8 | 2164.0 | 15 Jan 02:04 | 2165.0 | 0.6 | 21.0 | 0.0 |
| Sharing Space 3 | | 217.9 | 4839.0 | 15 Jan 04:48 | 4839.0 | 0.5 | 21.0 | 0.0 |

* Maximum heat supplied by air and room units

** Heat lost through ventilation and infiltration at time of maximum heat supply

## Air Handling Unit Heating Loads

| Air Handling Unit | Heating*, W | Time | AHU heat recovery, W |
|---|---|---|---|
| AHU | 0.0 | | 0.0 |

* Total (sensible and latent) heat load

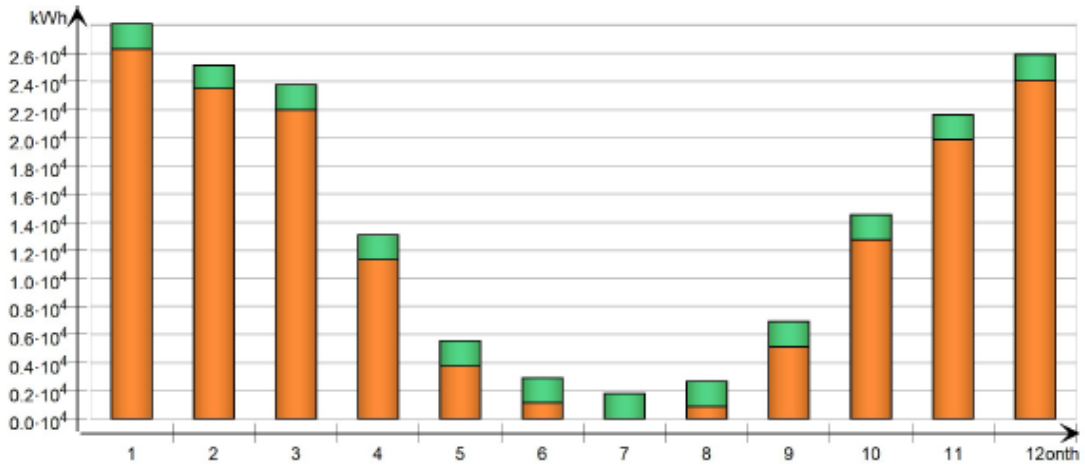
## Total for Building

| | Max., kW | Time |
|---|---|---|
| Zone heating | 32.0 | |
| AHU heating | 0.0 | |
| Total | 32.0 | 15 Jan 02:14 |

**IDA Indoor Climate and Energy**
Version: 4.71
License: IDA40:18MAY/M7L3B (trial license)

| EQUA SIMULATION TECHNOLOGY GROUP | | Systems Energy | |
|---|---|---|---|
| **Project** | | **Building** | |
| | | Model floor area | 1105.3 $m^2$ |
| Customer | | Model volume | 3495.1 $m^3$ |
| Created by | Max Nguyen | Model ground area | 0.0 $m^2$ |
| Location | Helsinki (Ref 2012) | Model envelope area | 1747.1 $m^2$ |
| Climate file | HKi-Vantaa_Ref_2012 | Window/Envelope | 6.2 % |
| Case | Update Version 10.04 35kWh | Average U-value | 0.5278 W/($m^2$ K) |
| Simulated | 4/11/2018 12:55:04 AM | Envelope area per Volume | 0.4999 $m^2/m^3$ |

## Used energy

### kWh (sensible and latent)

| Month | Zone heating | Zone cooling | AHU heating | AHU cooling | Dom. hot water |
|---|---|---|---|---|---|
| 1 | 26332.0 | 0.0 | 0.0 | 0.0 | 1788.0 |
| 2 | 23517.0 | 0.0 | 0.0 | 0.0 | 1634.0 |
| 3 | 21988.0 | 0.0 | 0.0 | 0.0 | 1815.0 |
| 4 | 11315.0 | 0.0 | 0.0 | 0.0 | 1765.0 |
| 5 | 3755.0 | 0.0 | 0.0 | 0.0 | 1790.0 |
| 6 | 1126.0 | 0.0 | 0.0 | 0.0 | 1765.0 |
| 7 | 15.1 | 0.0 | 0.0 | 0.0 | 1816.0 |
| 8 | 861.4 | 0.0 | 0.0 | 0.0 | 1790.0 |
| 9 | 5107.0 | 0.0 | 0.0 | 0.0 | 1790.0 |
| 10 | 12733.0 | 0.0 | 0.0 | 0.0 | 1790.0 |
| 11 | 19889.0 | 0.0 | 0.0 | 0.0 | 1738.0 |
| 12 | 24097.0 | 0.0 | 0.0 | 0.0 | 1840.0 |
| Total | 150735.5 | 0.0 | 0.0 | 0.0 | 21321.0 |