Template for Near Zero-Energy Building Renovation

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ABSTRACT

This project was a part of the Near Zero-Energy Building renovation project of the HAMK`s Research Unit. The topic was the template for Near Zero-Energy Building renovations. The main goal of the project was to design a project template with several steps that need to be followed when planning to renovate a building into an NZEB. The reduction of the energy demand, an upgrade of the existing systems, renewable energy sources and storage technologies, were the main steps toward a Near Zero-Energy Building renovation.

Throughout the thesis report, all the potential phases toward NZEB are discussed and studied, including information on ventilation, heating, lighting systems, building health, renewable systems, and storage technologies. Information was gathered mainly from several websites, articles, and previous study-related projects. Some formulas and information were used from the “Near zero energy building” project part from the Distributed Energy Production Applications module.

In conclusion, a clear and useful template is proposed. It consists of five stages, including basic information on the building, upgrading existing systems, a renewable energy system for electricity, energy storage, and final calculations. Information regarding building`s health such as room temperature average, humidity levels, carbon monoxide, and dioxide limitations, etc., are provided here as well.

Keywords NZEB, renewable energy application, building renovation, healthy building, HVAC

Pages 51 pages including appendices 1 pages

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1 INTRODUCTION

Since the emission of CO2 is increasing rapidly due to the combustion of fossil fuels, the need for using more renewable energy source is increasing as well. Therefore, the aim in European legislation is that by 2020, nZEBs should be a standard for all buildings. Designing new buildings with the nZEBs standard is easier and more effective than renovating the old ones. However, implementing the nZEB standard in either new or old building has been challenging and difficult at the same time. When constructing new buildings with this standard, it means that buildings from scratch are planned based on the requirements of nZEBs. In the other hand, when renovating older buildings, there are changes and adjustments that need to be made in order to fulfil the requirements of the nZEBs standard.

The aim of this thesis is to describe the phases that owners should go through when renovating old buildings in order to adjust with the new standard. It is also to inform about the limitations of several factors that affect the comfort of the building, such as humidity, room temperature, air tightness, carbon monoxide and dioxide, etc.
The first phase consists of collecting basic information about the building, such as energy demand, climate, location, ground type, lights, etc. The second phase includes the upgrade of existing systems and implementation that should be done to reduce energy demand. Then, a PV system is designed and implemented to cover the electricity needs of the building. This phase is then followed by the energy storages phase, which consists of several types of technologies that can be used to store the excess of the energy produced by renewable sources. During summer solar thermal systems may generate heat more than neccessary, therefore the part of the demand that is not being used is saved in any of the energy storage technologies that has been used.

The final stage describes the energy consumption that can be saved by improving the existing systems or implementing new ones, and by using a renewable source to cover the biggest part of the energy consumption in a building. It is assumed that around 60% of the energy consumption is saved with the implementation of the above-mentioned retrofits.

2 THEORY

2.1 Ventilation System

Ventilation is the delivery of fresh outdoor air into an indoor space, and it is used to maintain indoor air quality by removing pollutants, reducing moisture and other gases that have been built up indoors for a certain amount of time. It creates air flow, which improves the thermal comfort and well-being of residents. Ventilation helps to moderate internal temperatures, humidity, and to replenish oxygen inside the building.

Ventilation guidelines are based upon the minimum ventilation rate in order to maintain the indoor air quality in acceptable levels. The ventilation rate procedure recommends the rate at which the air must be distributed into space and influences the health and productivity of residents. The higher the ventilation rate, the more will increase the performance of the people in the building. Figure 1 illustrates the dissatisfaction of people for air quality they perceive after entering a space, based on ventilation rate. The standard for residential ventilation should not be less than 35 l/s and 15 cubic feet per min per person.

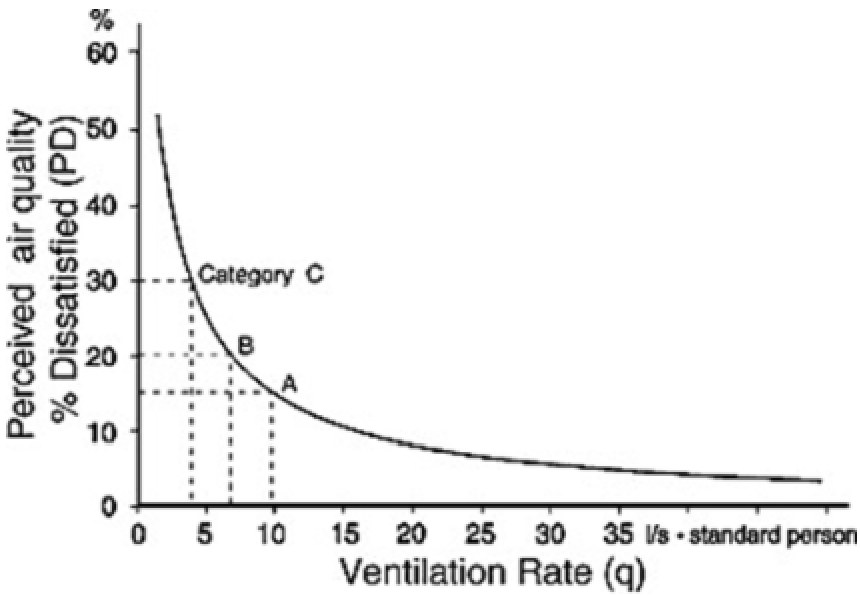

Figure 1. Percentage of people that are dissatisfied by indoor air quality that they perceive (Cubick, 2017)

The provision of outdoor air is categorized as mechanical ventilation and natural ventilation. (Surosh, 2016)

Natural Ventilation

Natural ventilation is the process of air movement inside the building through doors, windows, louvers, etc., and tends to be driven by the pressure difference. The pressure difference occurs due to two factors: the difference between indoor and outdoor air, and by wind velocity, which provides positive pressure on windward façade and negative pressure on leeward. (Adamovsky)

When planning to build adequate natural ventilation, some parameters need to be considered, as follows: (Natural Ventilation - What you need to know)

- The house location
- The house orientation (the wind speed and direction)
- The dimensions and the location of the windows within the house
- The dimensions of the area that needs the ventilation (the bigger the area is, the more air changes per hour)
- The number of residents, their activity and their behavior

Natural ventilation can be categorized as cross ventilation (wind-driven) and stack ventilation (buoyancy-driven).

Cross ventilation is the process where the air enters the building on the high-pressure side and draws out on the low-pressure side, due to pressure differences of the sides of the building as can be seen in Figure 2.

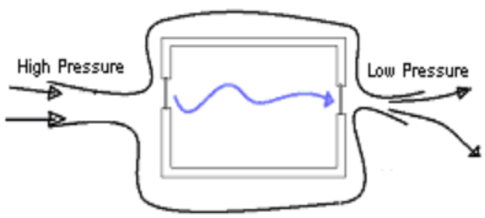

Figure 2. The working principle of the Cross-Ventilation system (Ventilation , n.d.)

Stack ventilation is described as a process where the cooler air is drawn into the building at a low level, is heated by heating systems, occupant, and so on, it becomes more buoyant and ascends through the building to the top, and it is ventilated to the outside as can be seen in Figure 3.

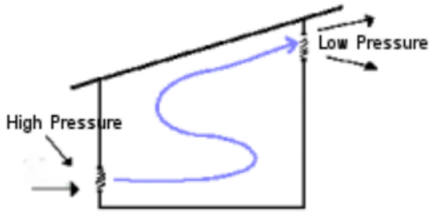

Figure 3. The working principle of the Stack Ventilation system (Ventilation , n.d.)

Natural ventilation is preferred more than the mechanical one, based on it`s low-cost. However, there are circumstances that natural ventilation might not be suitable to be installed, such as poor air quality, noisy environment, building`s location, the density of residents and equipment inside the building, etc.; therefore, mechanical ventilation may be the best solution. (Natural Ventilation of buildings , 2019)

Mechanical Ventilation is also known as forced ventilation, which tends to drive the air flow from outdoor into the building by using ducts and fans. As it was mentioned in the paragraph above, in places where natural ventilation is not possible to be installed, then mechanical ventilation is being used. Mechanical ventilation system comes in different forms, such as a: (Mechanical Ventilation of Buildings, 2019)

- Circulation system or ceiling fans that only circulate the air within the room and are known as artificial ventilation, as there is no introduction of fresh air.
- Pressure system uses inlet fans to draw air inside the building, where the indoor air pressure is greater than the outdoor air.

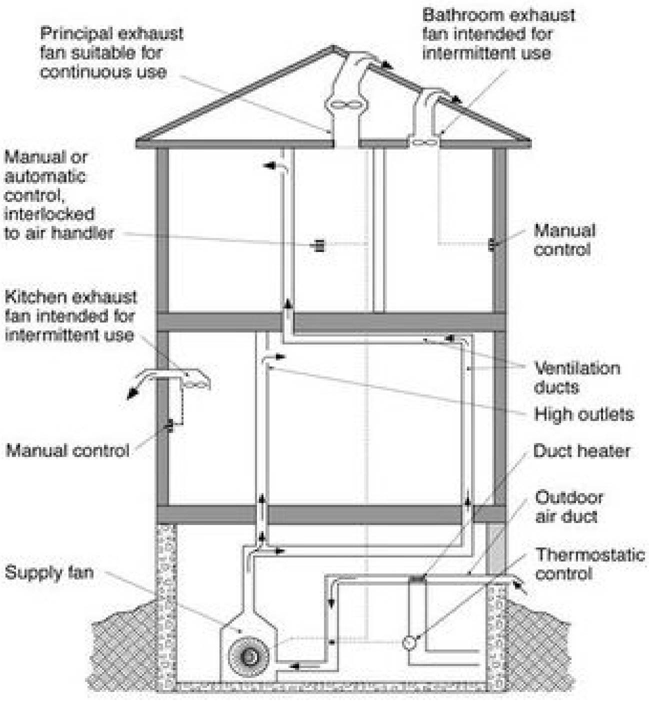

Figure 4. A well-designed pressure system inside the building (Mechanical / Forced Ventilation, n.d.)

- Vacuum system uses exhaust fans to create a lower pressure inside the building then the outside air, ensuring that the stale air is exhaled from the building.

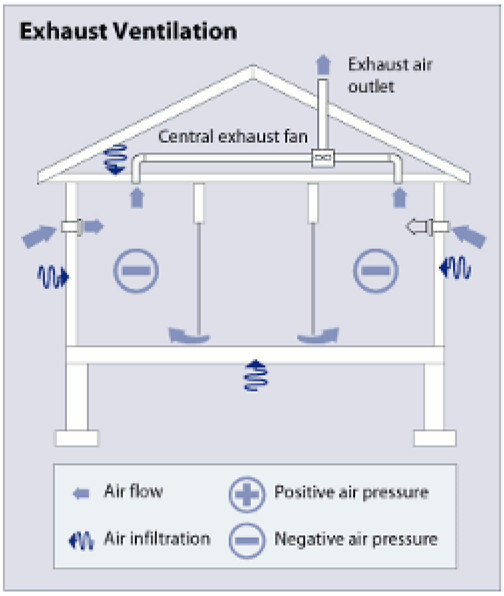

Figure 5. The working principle of an exhaust ventilation system (Supply vs. Exhaust Mechanical Ventilation System , n.d.)

❖ A balanced system is a combination of both inlet and extracts fans, which maintain the internal and external air pressure at the same level. It is so far the most beneficial system, which helps on improving indoor air quality, comfort, health, saving money while consuming less energy.

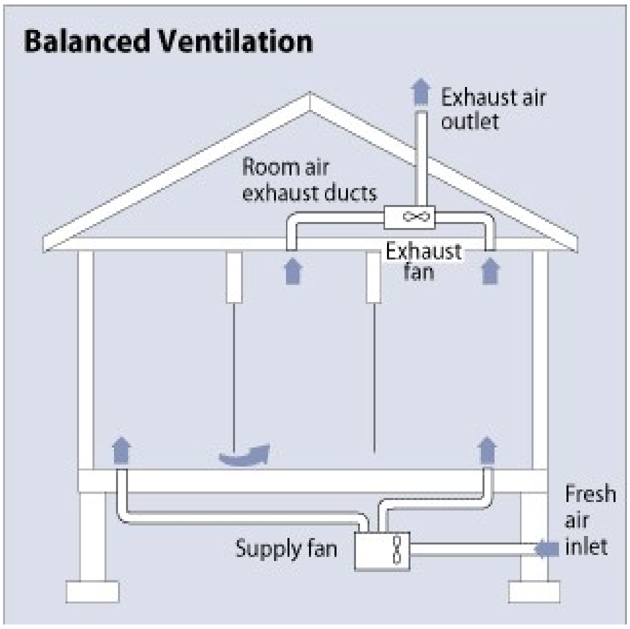

Figure 6. The combination of inlet and outlet fans in a Balanced Ventilation System (Types of Ventilation Systems , n.d.)

❖ Local exhaust systems are small ventilation systems, such as cook hoods, fume cupboards, etc.; used to inhale the heat or contaminated air in local areas.

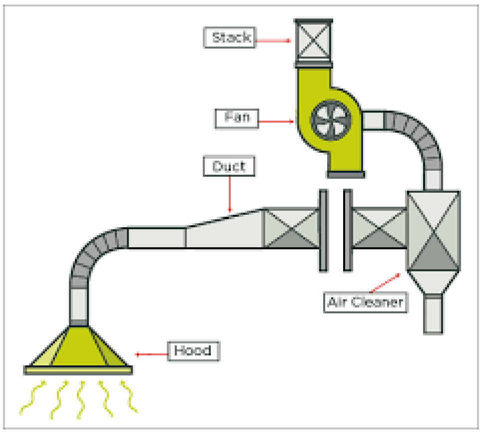

Figure 7. Cook hood as an example of a Local Exhaust Ventilation System, (Local exhaust ventilation - quick guide, n.d.)

Mechanical buildings are mostly designed based on building requirements, and often include more functions than just ventilating the air in the building. In commercial buildings, mechanical ventilation is usually operated by air handling units and can be referred to as HVAC systems, HRV, etc., for which will be discussed in the following paragraphs.

2.1.1 HVAC

HVAC or heating, ventilation, and air conditioning system is used to maintain air quality, temperature, and humidity inside the building. It brings the outside air, filters it, and then distributes around the building. This system is used to create a healthy and comfortable environment for the occupants. HVAC systems differ from one another, depending on the size and space utilization of the building. It consists of control thermostats, which control the thermal loads in each section of the building. One control thermostat serves only one part or zone. While buildings have more than one zone, thus multiple control thermostats are needed to supply each zone with air based on their needs. This system consists of many components, but the main ones are boilers, chillers, and air handling units.

BOILERS

Boilers are an important part of the HVAC System. They consist of propane or natural gas fuels, which are combusted, and the heat released from the burning of fossil fuels is used to heat the water. The hot water goes through the pipes to the radiator units in the building, where air pressure is used to move the heated air through the ducts and into rooms. To transfer the heat around the building is used either hot water or steam. Based on their characteristics, hot water systems are preferable for the buildings. They are more efficient and less susceptible to corrosion than steam systems. Steam water systems are mostly used in places that require a large amount of heat, and these systems need to be maintained a lot more than hot water systems.

CHILLERS

A chiller is also known as an air conditioner. Chillers are another major part of the HVAC system. They are used to cool the air by utilizing heat exchanges and circulating fluids or gases. Chillers are usually located in ground level or in a central plant. Chillers cool the air based on four-factor cycle: compression, condensation, expansion, and evaporation. First, a refrigerant in vapor form is compressed in a compressor; then it is pumped into a condenser where it condenses into a liquid. This liquid is pumped to the evaporation unit. With the help of evaporation coils, the heat is removed from the building and is added to the liquid turning it into vapor again. The vapor is sent back to the compressor, and the process is repeated; therefore, a cooled and fresh air is provided to the building.

AIR HANDLING UNIT

Air handling units draw clean air within the building. Before the air is forced to go through the ducts around the building, the components of the unit take care of cooling or warming the air based on the needs. They can be placed on the basement, roof of floors of the building, and usually, serve a specified area; therefore, more than one unit can be found around the building. Air handling units are classified as smaller AHUs or fan coil units (FCUs), larger AHUs or Makeup air units (MAUs) and roof-top units (RTUs).

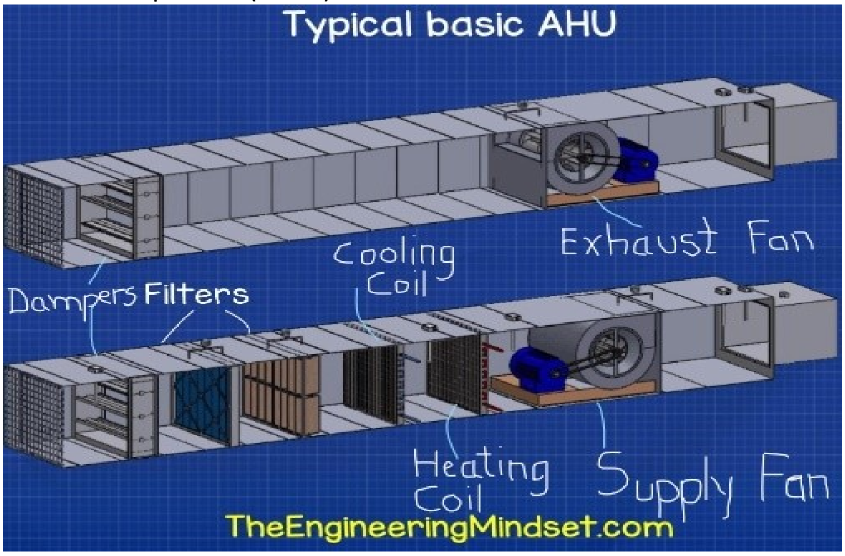

Figure 8. Air-handling Unit and its main components (Evans , Paul, 2018)

A simple model of air handling unit consists of two AHU casings, one responsible for flow air and the other one for return air as can be seen in Figure 8. Both, at the very front on the inlet and outlet, have a grille, so the objects won`t be able to enter the units and cause damages. The AHU casing responsible for bringing fresh air into the building has a damper at the inlet, which consists of multiple metal sheets that can rotate. Those are used to prevent or let the air flow in or out. The dampers are followed then by some filters, which are used to prevent dust from entering the building.

Each bank of filters contains a sensor that measures the dust in the filters and gives warnings when the filters are too dirty. Cooling and heating coils are the following components placed right after filters. These coils contain hot or cold fluids inside and are used to either heat or cool the air based on the setpoint temperature. If the air in the building is below the set point, the heating coil heats the air to increase the temperature. If the air is above the set point, the cooling coil will cool the air until it reaches the setpoint value.

The supply fan is the one responsible for drawing the air from the outside through dampers, filters, coils, and then pushing it into the ductwork that is located around the building. Across the fan is located a pressure sensor which senses if the fan is running. Therefore, if the fan is running, it will generate a pressure difference, which helps in detecting the faults of the equipment. After the air has been filtered, cooled or heated, it goes through ductwork and flows inside the building. There are two types of ductwork, one used to distribute the fresh air around the building and the other one that returns the dirty air back through the other AHU casing outside. The second AHU casing is responsible for extracting dirty air outside. It only consists of a damper and an exhaust fan. The exhaust fan draws the polluted air from the ductwork and through the damper pushes it out. The damper is located at the outlet part of the AHU box, and it closes when the AHU turns off.

Most buildings need to control humidity as well; therefore, a humidifier and a humidity sensor should be located within the AHU casing that enters the fresh air into the building. The humidity sensor measures the air`s moisture, and it has a setpoint based on the design of the building. If the moisture`s value is below the setpoint, the humidifier is used to balance and increase that value by spraying water or steam in the air. (Evans, 2018)

2.1.2 HRV

Lack of air circulation inside buildings can cause moisture and pollutants in a while. That can be easily noticed in walls of the buildings as black spots, and on windows. This is seen as a risk for people`s health, causing allergic reactions and other symptoms. In the above paragraphs, has been talked about pressured ventilation, local exhaust fans, but these separately aren't the best solution to solve the moisture, stale air, and pollutants problem. A combination of these systems can help in refreshing air inside the building and creating a healthy environment. HRV or heat-recovery ventilation has its similarities with the balanced ventilation system. The only difference is that it uses the heat that the outgoing stale air contains to heat up the fresh air inside the building. HRV system consists of two ducts next to each other, one carries the stale air from inside out, and the other one moves the fresh air into the building. Both air flows pass by a heat exchanger, which transfers the heat from stale air that is going outside into the fresh air coming in The process of heat being exchanged from the stale air going outside into the fresh air coming inside is shown in Figure 9; it transfers the heat between the air flows without mixing those. (Klenck, 2000)

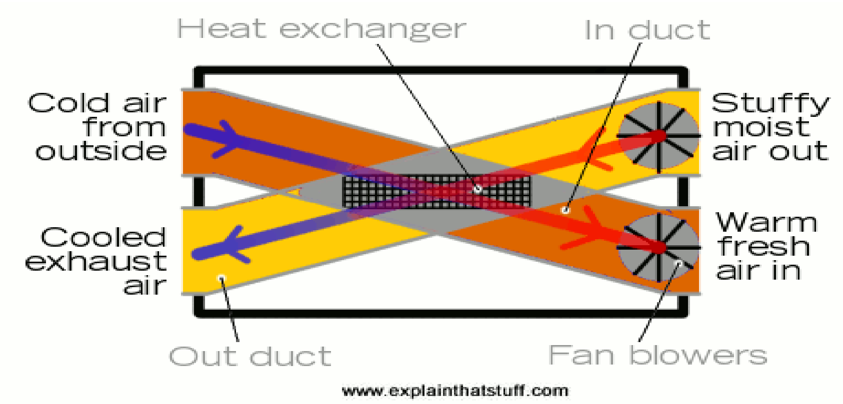

Figure 9. Working principle of a heat exchanger (Woodford C. , 2018)

Heat recovery ventilation helps on warming up the building while keeping it ventilated and on reducing costs. When ventilating the building, a significant amount of the heat is being lost, therefore if these systems are installed 85% of that lost heat can be saved. Although HRV systems can recover heat while ventilating, their installation costs a lot. The money that is being saved is some hundreds of euros, but the cost of installation is thousands of euros, which means that this system cannot pay itself. (Woodford C. , 2018)

2.2 Heating System

The heating system is as important as ventilation; it helps to maintain the temperature levels inside the building. It is often part of the HVAC system, discussed in more details in the HVAC section. The heating system has different energy sources. The most common heating source, especially in Finland is district heating, yet there are other sources such as electricity, gases, oil, renewable sources, etc. The energy generated from any of these sources is transferred into heat by heat generator, then boilers deliver that heat to a heat source, which might be air or water. The generated heat is distributed around the building with the help of distribution systems, such as radiators, convectors, floor or ceiling heating, installed in each room. Based on the way how heat is distributed in the building, there are two different systems: centralized and decentralized systems.

Centralized Heating system

A central heating system is made of a heat source and heat outlets, usually a boiler and radiators. Different heat sources can be considered for the central heating system and based on the source is defined as the boiler type. There are gas boilers, solid fuel-burning boilers, electric boilers, etc. The heating occurs in one place in the building, somewhere in the basement or in a furnace room, and then is spread around the building. Heat is distributed through the ductwork to the radiators around the building by using air-pressure, or through pipes by using either steam or water. Nowadays, hot air pressure is cheaper to use than either hot water or steam. It uses gas or oil to warm up the air and circulate through the ductworks. In the other hand, when using water or steam, is more expensive since pipes require a pipe fitter when installed. However, the centralized heating system is often combined with cooling, which gives it the ability to control airflow, temperature, and humidity around the building. (Understanding Centralized and Decentralized Heating Systems, 2017)

Decentralized heating system

A decentralized heating system is the opposite of a centralized system, uses multiple individual units which control single rooms or locations to distribute heat around the building. Each room`s temperature can be adjusted in a level as is needed, lowering the heating cost of the building. These systems are more practical, economical, and sustainable to use in large areas, high floor buildings, such as hangars, warehouses, etc. They help in reducing CO2 and provide efficient heat within a short amount of time. One fact why this system is more efficient is that it uses radiant heat instead of using air pressure ducts. It eludes the loss of the ducts that air pressure systems provide. Radiant heat doesn’t spread allergens, and it's quite preferable for people with allergies. It is located on the floor, walls, or ceiling of the building. When it’s located on the floor is known as radiant floor heat, and it comes in three different types, such as radiant air floor, electric radiant floor, and hydronic radiant floor. The most cost-effective type is hydronic since it uses pumps to pump the heated water from the boiler to the pattern that is mounted under the floor. Except floor radiant, there are wall`s and ceiling`s radiant as well. They use radiant panels that are usually mounted on the walls and ceilings and can be heated with either electricity or hot water.

Based on the facts above, decentralized heating systems are more cost-efficient and save energy. In Figure 10 there is a comparison between these two systems, and cost reduction for heating. (Radiant Heating, n.d.)

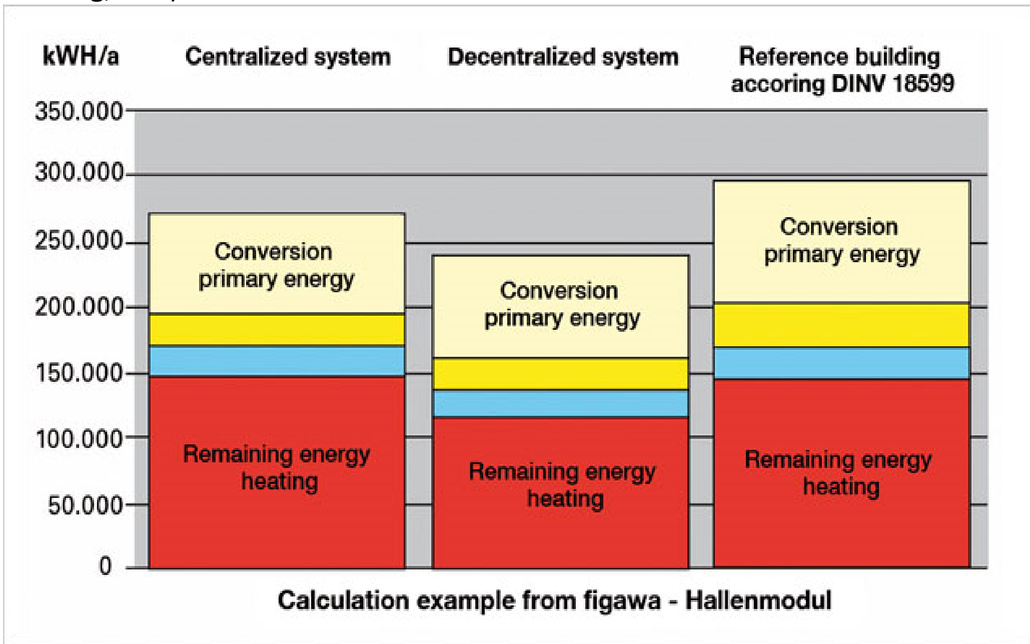

Figure 10. A comparison between centralized and decentralized heating systems (Decentralized Heating, n.d.)

Except for their advantages, these systems also have disadvantages, as can be seen in Tables 1 and 2 which describe these for each system.

Table 1. Advantages and Disadvantages of a Centralized System (The Advantages and Disadvantages of Centralized Heating Systems, 2018)

Centralized System	
Advantages	Disadvantages
Easy to control from one thermostat	CO2 emission
Easy to maintain	Higher operating costs
Comfortable room temp	Lower system efficiency
Aesthetics	More expensive installation

Table 2. Advantages and Disadvantages of a Decentralized System (The Advantages and Disadvantages of Centralized Heating Systems, 2018)

Decentralized System	
Advantages	Disadvantages
Easier and cheap to install	Difficult to maintain
Affordable for large spaces	Aesthetics

Easier individual control	
More efficient	

2.2.1 District Heat

District heating is a system that generates heat in a centralized location and distributes it through insulated underground pipes to buildings. It gives service to more than two or three buildings; it usually covers a block of flats or a particular area. It supplies buildings with heat and hot water as well. The water is returned at the power plant after being used, is reheated and recirculated again through the pipes to buildings. Buildings that are supplied by district heating don't need to have their own heating systems, such as furnaces, boilers, etc. District heating has its individual boilers to heat the water, and it uses fossil fuels or renewable sources to power the boilers.
Nowadays, the use of renewable sources is increasing, and this is happening due to the increased amount of CO2 in the atmosphere. Using district heating as the heat supply for a building brings a lot of benefits, but it has some limitations as well. Benefits of using district heating result on higher efficiency, lower carbon emission, and the opportunity of using renewable fuels. Limitation of using district heating consist of difficulties to retrofit the system, long-term financial commitment, residents who get supplied by district heating are not able to change to another supplier due to the connections of buildings and the system, etc. However, district heating is a suitable and efficient solution if it's planned carefully beforehand, mainly if CHP plants are used. CHP plants generate electricity and use the heat of the engines to heat the buildings. (What is district heating, n.d.)

2.2.2 Electric Heat

Electric heating systems use electricity to power the boilers that generate heat. It's the same as the central heat system that use gas or oil boilers to generate heat and distribute it through pipes to radiators around the building, just that this system uses electricity. Electric heating systems are more efficient comparing to standard central heating systems, are easy to install and maintain.
Although the cost of electricity is more expensive than gas or oil, the installation of gas or oil systems is more costly. However, when using electrical heating systems, there is a storage heater that can be used to store the heat. When electricity price is off-peak during the night, these storage heaters use that electricity to heat up and then use the accumulated heat during the day. Those can be controlled by thermostats, so when the temperature reaches the set point, it turns off the heater (Electric heating systems, n.d.).

2.2.3 Oil & Gas Heat

Gas and oil systems are both classified as 'wet' heating systems; they use a gas-fired boiler and oil-fired boilers to heat the water, which then is distributed through pipes to radiators around the building. The difference between the two systems is the storage tank that oil heating systems need since there is no infrastructure that supplies homes or buildings with oil as it does with gas. They both have their pros and cons as heating systems. Gas is cheaper and requires less maintenance than oil, besides to it oil offers maximum heat, and it's easier to store and use. Even though gas furnaces cost more than oil ones, both systems are expensive to install compared to electric systems (Dyamichvac, 2018).

2.2.4 Types of heating systems

A building is heated by either an air-forced furnace, boilers, heat pumps, electric space heaters, fireplaces, etc. It is important to choose an efficient and affordable system. The most common systems used in commercial buildings are furnaces, boilers and heat pumps which are described in more details in paragraphs below, except for boilers which were described in HVAC systems section above (Types of Heating System , n.d.).

FURNACES

The working principle of furnaces is described as follows: The fuel is mixed with air inside the furnace, which is then burned and warms the air. The air goes from air handler`s furnace through a heat exchanger to the ductwork and then is distributed around the building by air registers or grills. When using a furnace, the system should have a flue pipe as well to vent out the combustion products. In older furnaces, the combustion products vented directly out to the atmosphere, which caused around 30% of fuel energy loss. Nowadays, modern systems use an "inducer" fan to avoid these losses and pull the exhaust gases through the heat exchanger.

As it is mentioned in the heat recovery ventilation chapter, a heat exchanger passes the heat from the stale air that`s going outside to the fresh air that's going inside the building. This helps a lot on reducing heat loss and making the system more efficient. The difference between furnaces and boilers is that furnaces heat air and boilers heat water. In Figure 11 illustrates basic heating systems that use furnaces and boilers. Heating systems use controls to arrange the activity of the components, whether they should be turned on or off. Usually, these systems use only one thermostat, which helps to keep the temperature inside the building at a comfortable level. However, there are systems that use also limit switches, used for safety control.

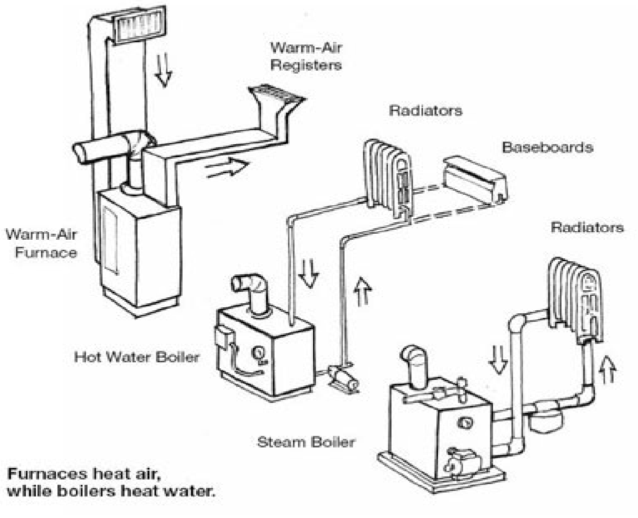

Figure 11. Heating systems that use furnaces and boilers to heat water (Types of Heating Systems , n.d.)

HEAT PUMPS

Heat pumps working principle is similar to air conditioners. During summer they move the heated air from inside to the outside, and during winter they search for heat from the outside air and bring it inside the building using electrical systems. There are two different types of heat pumps: air-source heat pumps, which are more common and ground-source heat pumps. Air-sourced heat pumps are cheaper and easier to install compared to ground-source heat pumps, even though ground-source heat pumps are more efficient and more sustainable. A ground-source heat pumps system is shown in Figure 12. Whilst air-source systems have a simple installation, ground-source heat pumps require more space and a good ground condition to be installed. The heat pumps are buried in the ground horizontally much like a loop, or in vertical boreholes.

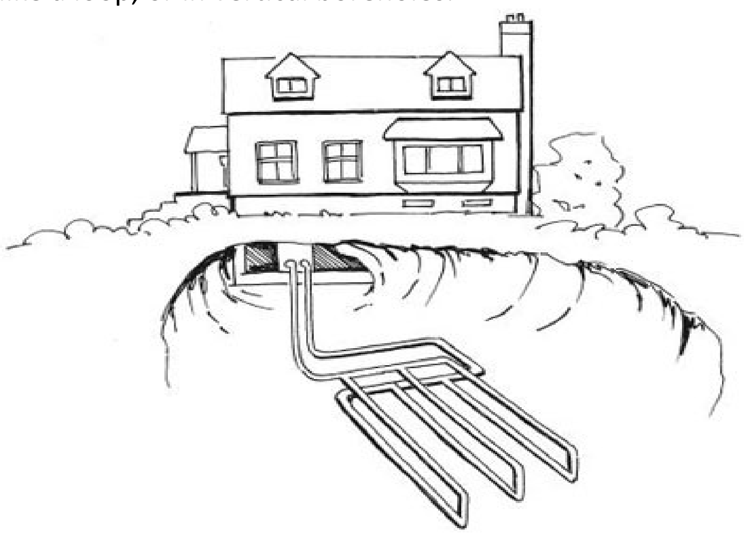

Figure 12. Ground source heat pump design (Types of Heating Systems , n.d.)

Heat pumps use electricity to operate; they basically need it only to run the pump rather than generating heat. The consumed energy is much smaller than the delivered one. Therefore it makes heat pump systems an efficient and reasonable solution among all heating systems types.

2.3 Hybrid Heating System

In order to reduce the usage of fossil fuels, nowadays, the heating industry uses a hybrid heating system. The hybrid heating system known as dual-fuel system combines two heating system, a traditional and a renewable one. Therefore, it usually includes a boiler or furnace and a renewable heating system such as heat pumps to deliver heat into the building. The way how hybrid heating system works depends mostly on weather conditions. Heat pumps are able to collect heat even at very low temperatures, but their highest peak is during summer.
When temperatures are above 2 degrees Celsius, heat pumps collect heat from the ground and heat the building; therefore, there is no need to use traditional systems. When temperatures drop below that value and heat pumps are no longer efficient system will switch to a traditional system which might be boiler or furnace and will continue to produce heat for the building. Whilst heat pumps use electricity only to run the pumps and not to generate heat; it makes them more suitable to use in a hybrid heating system than other renewable sources.
Heat pumps collect heat from the ground, which is renewed naturally, and it has no cost. There are two types of heat pumps: ground source heat pumps and air source heat pumps. Ground source heat pumps extract heat from the ground where the temperature always remains the same, 10-15 degrees Celsius. Even though ground source heat pumps require electricity to run the pump, the energy that they produce is 4 kilowatts of energy for every kilowatt of power that is used.

Air source heat pumps extract heat from the outside air. They can operate in low temperatures at nearly -15 degrees producing enough heat to warm the building. Both air and ground heat pumps will pay themselves back while cutting electricity bills and getting money from the government through Renewable Heat Incentive (RHI) as well.

Solar energy is also one of the biggest sources of renewable energy, but unlike heat pumps, there isn't any hybrid product that combines solar with a traditional boiler. However, they can work beside each other, reducing cost and carbon emissions in the atmosphere (Hybrid Heating System , n.d.).

Since a hybrid heating system is a combination of two technologies, and it gets the best from both, energy efficiency is one of the biggest advantages. Heat pumps efficiency is up to 300%, and the most gas or oil boilers operation efficiency is up to 92%. The main components from two technologies require different maintenance levels. A heat pump requires maintenance every 3-5 years, while a boiler requires annual service that does not cost too much. Boilers operate efficiently for 8 years minimum, and their average lifetime is 10-15 years. When in combination with heat pumps boilers won't be used that much such making their lifetime expand more than 15 years. A hybrid heating system can save buildings 30% to 50% of energy costs and pays itself within three to five years (Hybrid Heating system pros and cons , n.d.).

2.4 **Cooling System**

The cooling system is another important part of the building needed to cool the buildings and maintain the inside temperature to the desired level. It comes as a separated system, but it also comes together with heating and ventilation as an HVAC system. The working principle is described in more details in paragraphs above (see Chillers section at HVAC system). Basically, it uses a compressor cycle to take the heat away from the building. Whilst the refrigerant (a special fluid for the compressor) changes its state from liquid to gas and vice versa; the compressor is either releasing or absorbing heat. There are several types of cooling systems such as air conditioner or chiller, heat pumps, room air conditioner, evaporative coolers, etc.

Air conditioners and heat pumps both use a compressor unit which contains the special fluid called refrigerant, located outside the building and carries heat from one place to another. The only difference between these two systems is that heat pumps can be used during winter as well to provide heat for the building. In Figure 13 shows the working principle of an air conditioner, where the condensing unit is located outside, and the evaporator is located inside. In Figure 14 illustrates the working principle of heat pumps, the difference from the air conditioner is that during winter, the heat pumps transfer the cold air into heat. Therefore the condenser is indoors, and the evaporator is outdoors (Air source heat pumps cold climates (Part III): Outdoor Units, n.d.).

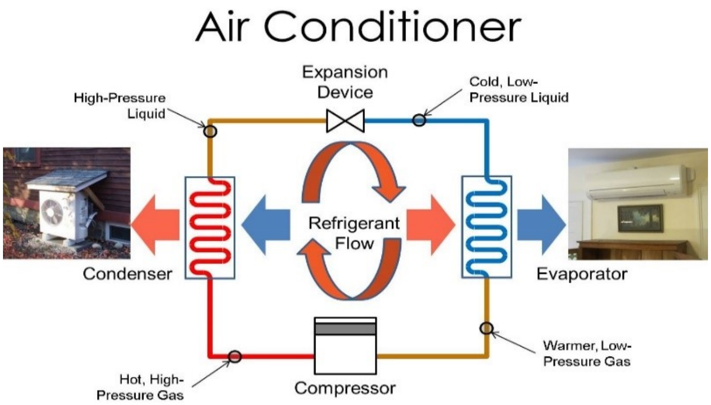

Figure 13. Air conditioner`s working principle as a cooling system (Ait source heat pumps in cold climates (Part III): Outdoor units, n.d.)

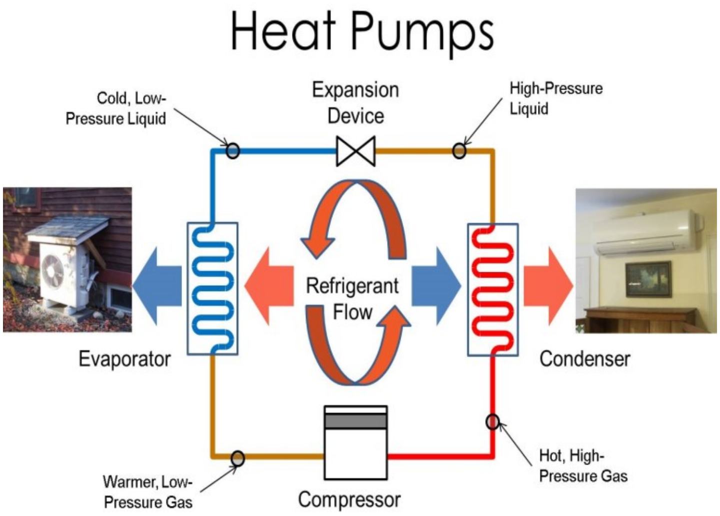

Figure 14. Working principle a heat pump in a cooling system (Air source heat pumps in cold climates (Part III): Outdoor units, n.d.)

Room air conditioners are individual units located in each room with a compressor unit located outside. Comparing to central systems, the cost of individual units is smaller. While evaporative coolers are mostly used in dry areas and differ from vapor compression air conditioners. They use moist pads to pull the air inside the evaporator and can lower the outside air temperature up to 30 degrees. This system is beneficial for dry areas because it adds moisture inside the building and saves up to 75% on cooling costs. However, their disadvantage is that they lose their efficiency when humidity is increased (Cooling Systems, n.d.).

2.5 **Lightning System**

Lighting is one of the main parts of the building, needed to provide occupants visibility while performing their daily work. Based on some calculations, lights take 30 to 40 % of electricity usage and costs in a building. Therefore, lighting control in the building is needed to avoid energy waste and reduce costs. While uncontrolled lightning can cause the temperature of the building increase; cooling is required to cool down that temperature adding extra fees to the bill. However, some strategies can be followed when planning on having a controlled and safe lighting system while reducing costs at the same time. These strategies include scheduling, occupancy sensors, daylight, automation control, etc.

2.5.1 LIGHT BULBS

In the past, all buildings used traditional incandescent bulbs which need a lot of energy to produce enough light. Around 90% of the energy that they use is given off as heat, such as losing power and increasing electricity bills. An easy and cheap way to reduce cost is changing light bulbs in the building using more energy-efficient bulbs instead of traditional incandescent ones. There are three types of light bulbs that help on saving energy and money, such as halogen incandescent bulb, CFL bulbs, and LED bulbs. Their advantages compared to traditional incandescent bulbs are that they use about 25%-80% less energy as seen in Figure 15 and can last 3-25 times longer; therefore, there is no need to change them very often. Even though the initial price of energy-efficient bulbs is higher than the price of traditional ones, their operational cost is lower, which helps in cutting electricity bills.

Figure 15. Comparison between halogen, CF, and LED light bulbs and the amount of energy they save (Lighting Choices to Save You Money, n.d.)

Halogen light bulbs save up to 25% of the energy; they use halogen gas to increase the lifetime, light output and quality. Halogen lights are used in both residential and commercial buildings, in automotive headlamps, work lights, etc. CFL which stands for Compact Fluorescent Light Bulbs use around 75% less energy to produce light comparing to traditional incandescent bulbs. They come in different shapes and sizes, from bulbs that screw into standard lamp sockets to decorative CFL light bulbs and floodlights. CFL bulbs use 1/3 of the energy that traditional incandescent bulbs use and last up to 10 times longer than traditional incandescent bulbs. LED or Light emitting diodes are the most energy-efficient light bulbs which save up to 85% of the energy used by traditional incandescent bulbs to produce light. They are a type of lightning-semiconductors that convert electricity into light and last 15 to 25 times longer than conventional incandescent light bulbs or 8 to 25 time longer than halogen light bulbs. Even though their initial price is higher than the above-mentioned light bulbs, they pay themselves while lasting longer and using less energy to produce light (Lighting Choices to Save You Money, n.d.).

2.5.2 LIGHTING CONTROL SYSTEMS

Nowadays that everything is about saving money and lowering electricity bill, a lighting control system is a must in every building, especially in the commercial ones. In commercial buildings the consumption of electricity is significant, and a big amount of it goes to lighting. Dimmable lights are an excellent solution to help on saving energy, but more intelligent systems are needed, such as smart control systems. There are two types of lighting control system: Analog Lighting Control Systems and Digital Lightning Control Systems (Commercial Lighting Control Systems, n.d.).

ANALOG LIGHTING CONTROL SYSTEMS

Analog lighting control systems use voltage to control the light output. Traditional systems work based on /off switches. When the switch is on, the power comes and turns the light on and vice versa. 0-10V Dimming in a standard Analog lighting control system where the light output varies from a DC voltage signal. The signal goes from 1 V up to 10 V, and each voltage level gives a specified light output. The advantages of this system are that components and fixture cost less, and costs for programming are lower comparing to digital ones since these have limited programming inputs. However, 0-10 V dimming is not addressable, and is not possible to control each light separately. Therefore lights are grouped and controlled in zones. They use a lot of wires, which may increase installation cost and create troubles when it is needed to change zones. Each zone requires a home-run controller, as it is shown in Figure 16.

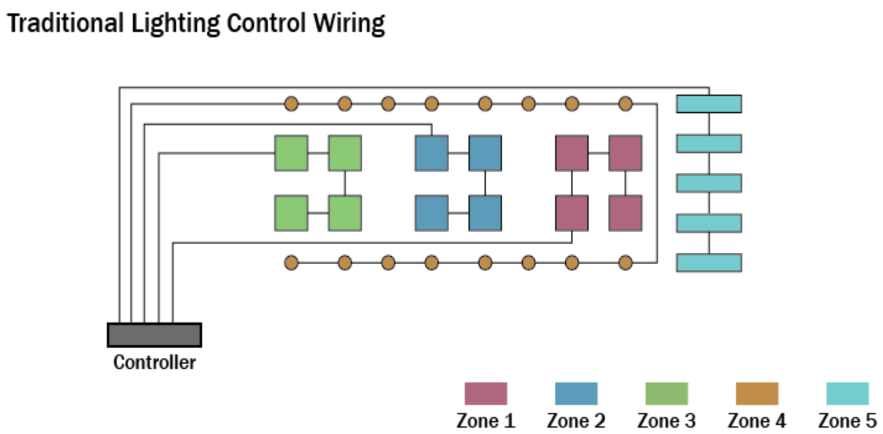

Figure 16. Traditional Lighting Control Wiring (Commercial Lighting Control Systems , n.d.)

DIGITAL LIGHTING CONTROL SYSTEMS

Traditional 0-10 V dimming systems provide simple features on lighting control. Thus complex systems such as digital lighting control systems are more useful. Digital systems send different signals virtually with a combination of binary commands of 0s and 1s. Each light and zone are addressed, fixing and control of zones is made through software, making this system more comfortable to use compared to the 0-10 V dimming. Fixtures can be chained together without regard to zones, as it is shown in Figure 17.

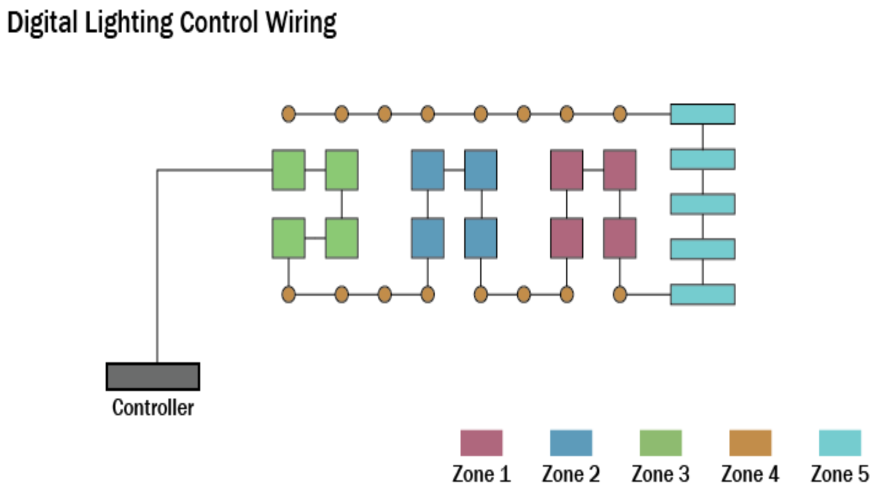

Figure 17. Digital Lighting Control Wiring (Commercial Lighting Control Systems , n.d.)

Digital lighting control systems work based on some protocols, so they can speak and understand the language of binary numbers 0s and 1s. Some of the protocols are DSI, DMX, and DALI.
DSI stands for Digital Signal Interface which communicates over low voltage wires and uses 8-bit protocols to provide dimmable light between 0 and 255 dim levels. It only supports dimming, and the fixtures are not addressable.
DMX short Digital Multiplex or DMX-512 because it allows 512 channels of control in one zone. These are usually used in the entertainment industry where colorful and changing lights are needed, and for LED lighting control as well. Due to its multiple channels, it can adjust color, pan, dimming, etc. It is more flexible than DSI, and its data can be sent wirelessly.

DALI
DALI short for Digital Addressable Lightning Interface, provides a single interface for all light sources and light controllers. DALI is an International Standard lightning control system which enables components from different manufacturers to work together in one control system. The controller of this system is bi-directional; it gives fixtures direction and collects its data, which are then used for monitoring. The name addressable tells that each installation can be controlled and monitored individually, unlike other control systems such as DSI, 0-10 V Dimming, etc. When installing fixtures, CAT5 data cable and RJ-45 connectors are used. One network or a DALI line can control 64 fixtures, but if bridges are used to combine multiple systems, then this number goes up to thousands of fixtures. DALI is an open-source protocol. Therefore other protocols can communicate with it using interpreters.

3 RENEWABLE ENERGY SYSTEM

3.1 Geothermal Energy

Geothermal energy is the heat that comes from the ground. Is one of the most efficient and sustainable energy sources, since the upper part of the Earth`s surface up to 10 feet has a constant temperature between 10 to 16 degrees Celsius? This heat can be delivered into the building using geothermal heat pumps, ductworks, and a heat exchanger. During winter, the heat is moved from heat exchanger to the building, and during summer the process is reversed. Considering the depth of the ground where the energy is collected, there are several geothermal energy sources, see Figure 18. The author will mainly focus on Ground Source Heat Pump and Borehole Thermal Energy Storage in this study.

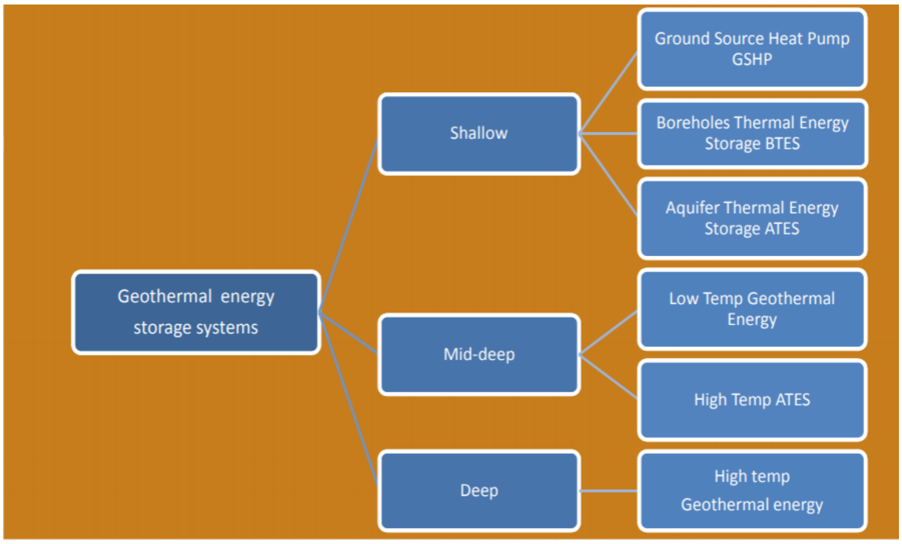

Figure 18. Types of geothermal energy storage systems

3.1.1 Ground source heat pumps

Ground source heat pumps work by collecting heat from the ground and via a heat exchanger and ductworks distribute the heat around the building. No matter what the season is, the temperatures underground go around 10 to 15 degrees Celsius. This system includes three different parts connected together: ground loop, heat pump, and heat distribution systems. The ground loop consists of several horizontal trenches or vertical borehole buried underground. This system takes a large volume of the earth due to its design.
Therefore the size of the system depends on the space available. Vertical boreholes are drilled down on the ground from 15 to 150 meters, depending on the system design, while horizontal trenches go

only two meters down. The fluid that circulates around these pipes is water mixed with antifreeze. The fluid with the absorbed natural heat goes into the heat pump through a heat exchanger. The heat pump then delivers that liquid into ductworks around the building. If needed, the heat pump is able to heat that liquid more by compressing refrigerant gasses which get hot, and that heat is then transferred around the building through heat exchangers.

Heat exchangers are described in more detail in the Heating system section. Heat distribution system or ductworks is the last part of this system; they are used to distribute the heat around the building. Ground source heat pumps operate at low temperature. Therefore, underfloor heating is more preferred than radiators as a heating distribution system. Underfloor heating requires up to 30 degrees to operate while radiators need up to 70 degrees to heat the building. The reason why this system is one of the best so far for heating purposes is because of the efficiency it provides. They generate up to four kilowatts energy more per every kilowatt electricity they use. The power is used by the heat pump, in order to pump the fluid from the underground loop into the building. The system lasts from 10 to 25 years; it all depends on the lifetime of the heat pump (Ground Source Heat Pump System, n.d.)

3.1.2 Borehole Thermal Energy Storage

Borehole Thermal Energy has been used as seasonal heat storage by several renewable systems, mainly by solar ones. It is also known as duct storage which utilizes a heat pump to upgrade the stored heat before using it. It is buried on the ground, and it uses the heat of soil to save energy. The soil is the best source so far to store energy since it doesn’t cost any money and has a functional heat capacity. From the total cost of a BTES system, most of it goes in the heat exchanger which is used to transfer the heat from and to the soil, in boreholes installation and in insulation.

A BTES is more inexpensive than other energy storage when large storage is needed. When planning on installing a BTES, there are some implementation guidelines that should be followed. Soil conditions and water table depth are the most useful information that a design engineer should have. A BTES consists of a large volume of the earth due to the shape and size of boreholes, and the design of the storage. Heat exchangers in a u-tube form are installed into boreholes and connected in series. The hot water for charging flows from the center of the storage to the outer part, and the cold water for discharging flows from the outer part to the center. The distribution of the flow throughout the total storage volume consists of multiple heat exchanger circuits. In Figure 19 shows a layout of a BTES storage and a cross-section of a borehole and u-tube heat exchanger (Sibbitt & McClenahan, 2015).

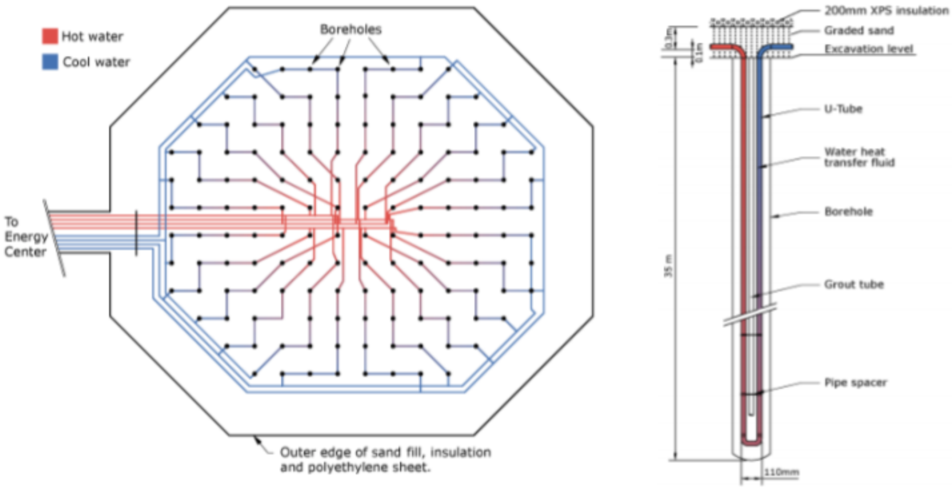

Figure 19. Layout of a BTES storage and cross-section of a typical borehole and u-tube heat exchanger (Sibbitt & McClenahan, 2015)

3.2 Solar Energy

Solar energy is renewable and sustainable energy that comes from the sun. By using solar panels and solar collectors, the energy from the sun is transformed into electricity and heat, thus saving the environment by cutting CO2 emissions and reducing operating costs. When the first solar cell was invented, it could convert only 4% of sunlight to electricity. Nowadays, that value has increased above 20%, also increasing the usage of solar energy worldwide. Using solar energy brings a lot of benefits, such as:

- Reduce costs
- Pays itself
- Avoid rising energy costs
- Property value increased
- Clean environment and lower CO2 emissions
- Sustainability

These are some of the benefits of why everyone should invest in solar systems. Everyday companies are becoming more competitive in developing the most efficient solar systems in the market. Thus far, solar energy is being a suitable replacement for fossil fuels in electricity production (Why go solar, n.d.).

3.2.1 Photovoltaic system

A PV system is used as a replacement of fossil fuels in the electricity market, in order to save the environment and lower electricity bills. Before it has been used only in residential building, but due to its efficiency and sustainability lately it's being used in commercial buildings as well to generate electricity.

3.2.2 Components

PANELS

A solar system consists of solar panels that are made of photovoltaic cells. The solar cells absorb the power from the sun, which is ten times bigger than the energy used on the planet. However, only about 20% of the energy captured by photovoltaic cells is converted into electricity. Solar cells are made of silicon, a semiconductor that is the second most plentiful element on Earth. The PV module consists of two conductive layers with crystalline silicon inside. One of the layers contains extra electrons, and the other one contains positive holes, used to fit in those extra electrons. Electricity is created when electrons and positive holes move around after the sunlight hits the cell. As it is said, one PV module is made of multiple solar cells that generate DC power. This power is then converted to AC through an inverter before being used for home appliances. (Kastrati Anesa, 2018)

INVERTER

An inverter is considered as the head of the solar system; it is used to convert the current from DC to AC so that it can be used from home appliances. Its technology provides multiple functions, from the current conversion to data monitoring, utility control, system design, etc. Designers are trying to design such inverters that are simple and bring down cost without losing their efficiency and features (Zipp, 2013).
There are different types of inverters used in solar systems, listed as follows: (Best grid-connected solar inverters, 2017)

- String Solar Inverters are more common in Australia, Europe, and Asia. The solar system connected to this type of inverters consists of solar panels connected together in series.
- Hybrid Inverters combine two inverters in one, a solar and a battery inverter. As batteries become cheaper, these inverters will replace the solar ones.
- Off-grid inverters work based on powerful batteries and are used to create advanced systems with hybrid grid-connection.
- Micro Inverters are some small inverters mounted in each panel individually. They can operate solely used, especially in complex locations. When comparing to other inverters, micro inverters can be more expensive although they have several advantages over string inverters.

FRONIUS Inverter
The most common used inverter nowadays is ABB inverter. Its unique design has definitely made it the inverter of choice for many residential and commercial building installation. It provides ten years warranty period. Except for its unique design, it also includes an important feature that it the integrated solar DC isolator. When having this feature, there is no need for an external box isolator. The system is monitored using Wifi via the Fronius webpage. It also consists of a smart meter, which shows how much energy has been produced and consumed throughout the day. The possibility to monitor the system using mobile phones in both operating systems, IOS, and Android, is a big advantage.

Figure 20. FORNIUS Inverter (Best grid-connect solar inverters)

ENERGY METER
An energy meter is needed to measure and display data of the panel. This includes monitoring the performance of the panel and its power generation. It usually located at the end of panel arrays before electricity is fed to the grid. Data collected are sent to the central system and visualized. Data consist of energy production throughout the day, temperature in the environment, humidity, etc.

3.2.3 Solar thermal

In comparison with solar electricity or photovoltaic systems, solar thermal energy, it’s not yet developed at a desirable level. It differs from the photovoltaic system since it needs concentrated sunlight to

generate the necessary heat for heating or electricity purposes in the building.
There are two different solar thermal systems: passive and active.
Passive solar thermal systems are static; their efficiency and production depend on the design feature. Active solar thermal systems have moving mechanisms, which circulate the fluids that carry heat.
Based on the temperature, these systems are separated into three categories: low-temperature, medium-temperature, and high temperature.
Low-temperature systems under 100 degree Celsius used mainly for hot water or space heating. Active systems are usually made of flat plate collectors who are mounted on the roof, while passive systems require a unique design of the building in order to capture the heat in the best way possible.
Medium-temperature systems between 100 to 200 °C aren't that commonly used in commercial or residential building since they use a reflector in a unique shape to collect sun rays. They are mainly used in industrial processes.
High-temperature systems provide heat above 250 °C. They concentrate solar energy onto central collectors. The collected heat is used to generate steam, which is then used to turn generator turbines to produce electricity.
The advantage of using solar thermal systems for heating purposes is that it is a clean and renewable energy source; it uses energy from the sun, which costs nothing. They require low maintenance due to their simple technologies and not-moving mechanisms. However, considering the fact that the sun it's not a concentrated source, it will be needed a large area to produce a considerable amount of energy. The location and countries where these systems are implemented play an essential role in energy production since some countries experience shorter summers and long winters, and energy production won't be that satisfying.

SOLAR COLLECTOR

The solar collector is an active solar heating device that has moving mechanisms where the fluid is able to circulate and carry heat. It concentrates and collects the sunlight from the Sun, converting it then into heat. They are mostly mounted on the roof, and their installation varies from the building`s design. As solar collectors need concentrated sunlight, studies on the roof design and on installation`s methods should be made. There are several types of solar collectors, although their working principle and their construction are the same. In general, there is a material that collects and concentrates energy from the Sun and heats the pipes where the fluid flows. Based on the design of the solar collectors, the most commonly used are: Flat Plate Collectors, Evacuated Tube Collectors, Line Focus Collectors, and Point focus collectors (Hanania , Stenhouse, Yyelland, & Donev , Solar Collcetor, 2018).

Flat Plate Collectors

Flat Plate collectors are basically metal boxes which consist of an absorber plate covered with dark-colored glazing on top, and with insulation on the sides and bottom. The absorber plate absorbs the solar irradiation and heats. The heat is then transferred to either water or air that is held between the absorber plate and the glazing. Absorber plates are made out of metal, usually aluminum or copper.

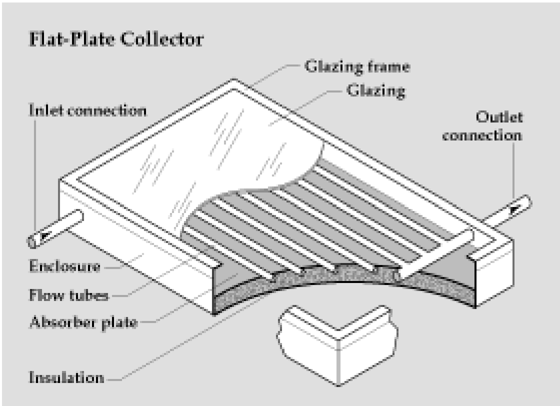

Figure 21. Flat-plate collector (Hanania , Stenhouse , Yyelland , & Donev , Solar Collector , 2018)

Linear Focus collectors

Linear Focus collectors or sometimes known as parabolic toughs consist of rectangular, U-shaped mirrors with a receiver pipe alongside. The mirrors focus the sun rays on the tube (receiver) located on the focus of the mirrors. The collector moves from east to west throughout the day to keep the sunlight focussed on the tube. The operational temperature goes up to 400 degree Celsius. An extensive system of parabolic trough linear focus collectors is the Solar Energy Generating System located in the Mojave Desert in California. There are already nine separated plants in the system SEGS I-IX, and seven last plants III-IX together generate up to 357 MW electricity, making this system one of the largest solar thermal systems in the world. The field of one of the plants is shown in Fig.22 (Solar Thermal Power Plants , 2019).

Figure 22. A power plant of parabolic solar collectors located in the Mojave Desert in California (Solar Thermal Power Plants , 2019)

4 BUILDING AUTOMATION

Upgrading buildings into smart buildings is the main goal of today`s automation industry. Building automation is an automatic centralized system that controls heating, lighting, ventilation, air conditioning, and other systems within a building. This occurs thanks to building automation systems (BAS), otherwise known as Building Management System (BMS). The main function of a Building Automation System is to keep the climate within the set points, lights based on set schedules and monitor performance and failures of devices. Furthermore, it sends warnings if the system is attacked by malicious attackers, providing security and comfortable workspace to occupants. It helps to reduce costs and save energy in the building. An example of how an Integrated Building Automation System looks like is shown in Fig.23. The main level of a BAS consists of computers and servers that store and analyze data while providing users access to this information. In the next level are controlled systems such as lighting, HVAC and security, except zone controllers which take part in the third level. The last level consists of sensors and actuators, which are used to keep a healthy, comfortable, and secure building. Most of the green buildings are designed to accommodate a BAS to conserve energy, air, and water. Moreover, these buildings use as many low-power DC devices as possible, which are accessible to a BAS through the Ethernet connectivity (Basics of Building Automation, n.d.).

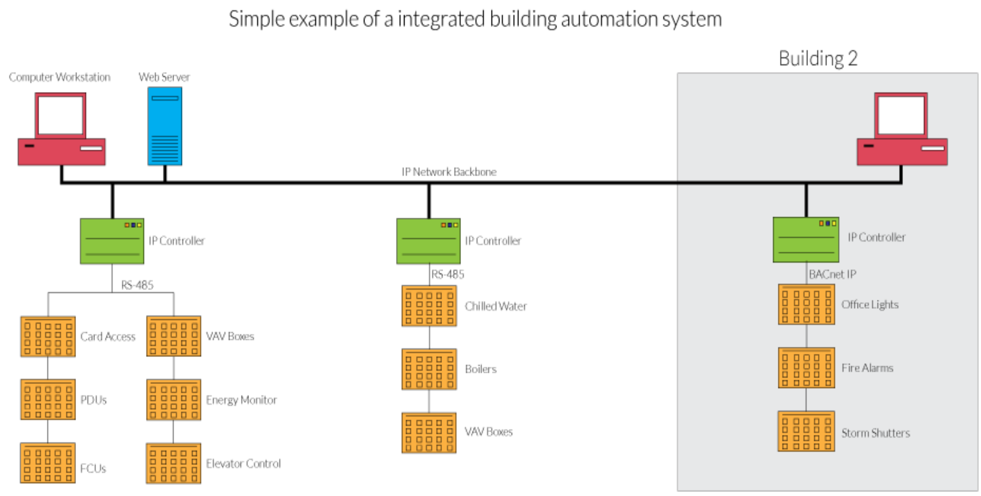

Figure 23. A simple example of an integrated building automation system (Basics of Building Automation , n.d.)

4.1 Buses and protocols

Most buildings use a primary and secondary bus for their automation networks, which are used to connect high-level controllers with lower-level controllers, input/output device, and user interface devices. Protocols such as BACnet, KNX, LonTalk, etc., specify how such devices interoperate. Modern systems use SNMP-based protocols to track events. Simple Network Management Protocol is an Internet Standard protocol used to collect and organize information about devices on IP networks and to change device behavior by modifying that information. Current systems allow users to mix-and-match devices from different manufacturers, due to the interoperability at the application level. Nowadays, systems allow the existing control system to integrate with other well-matched building control systems (Nývlt, Buses, Protocols and Systems for Home and Building Automation, 2011).

BACnet

The most common robust, proven protocol on which commercial and industrial buildings have been historically relying on is BACnet. BACnet is developed from a society called ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). It is a protocol used for building automation purposes, and it differs from other protocols because it is mainly focused on the management and automation level and less on the field level, see Fig.24.

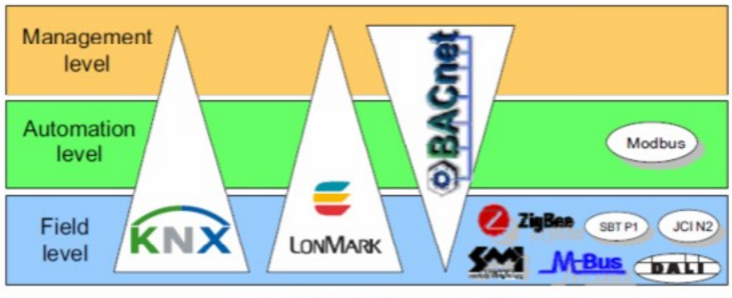

Figure 24. Management, Automation and Field level of several building automation protocols (Nývlt, Buses, Protocols and Systems for Home and Building Automation, 2011)

The management level consists of most operator interface functions, such as communication with controllers, monitoring, centralized energy management functions, statistical analysis, etc. In other words, most of the devices at this level are personal computer workstations. The automation level consists of real-time control functions, and the devices are mostly programmable controllers. The exchange of information between devices over BACnet occurs due to object and service. There exist 49 standard objects in the BACnet, and every unit (Nývlt, Buses, Protocols and Systems for Home and Building Automation, 2009-2011) has at least one object. Objects have common properties such as identifier, name, type, and some individual features depending on the type of object as well. By calling services, these properties can be accessed, read, or written. BACnet except that can take care of traditional tasks in small and medium buildings; it can also perform functions of BMS and complex building systems such as security and fire safety systems, success control systems, elevator control, etc. There exist some disadvantages when using BACnet, one of the biggest problems is that there does not exist a standard configuration tool (such exists in KNX). Therefore each producer must develop its own mechanism. Another disadvantage is that some of the BACnet products were not 100% compliant, bringing the need to establish the BACnet Testing Laboratories (BTL).

KNX

KNX or Konnexbus is one of the most used building automation systems in Europe and other continents as well. KNX is capable of connecting to around 80% of the devices that companies on the market manufacturer. KNX is formed as a union of three older automation systems, which are: EIB Instabus, EHS, and BatiBus. Nowadays, Konnebux consists of five standards:

- ISO/IEC 14543-3
- CSA-ISO/IEC 14543-3 (Canada)
- CENELEC EN 50090 (Europe)

- CEN EN 13321-1 (Europe)
- GB/Z 20965 (China)

KNX is a decentralized system where devices are independent and have their own tasks; they know how and what to send or receive from or to the bus, also have the ability to know how to proceed with the data. There is a KNX association that deals with all conferences, training, meetings, developing and producing software every year, in order to update the system and employers. The product line of KNX consists of actuators, sensors, visualization panels, and gateways. Gateways are used to help the KNX system communicate with other automation systems such as BACnet, EnOcean, DALI, etc. KNX system covers all types of buildings, from small houses to large commercial and industrial buildings as well as airports. Furthermore, it takes under control all main tasks of the building, such as energy management, HVAC control, security and safety control, etc. It uses more than one physical layer:

- Twisted pair wiring
- Power networking 230V
- Wireless KNX-RF
- Infrared
- Ethernet

The twisted pair or TP1 layer is used in a field level to connect basic sensors and actuators, and as a power supply for sensors as well. In the automation level, an Ethernet physical layer is used to connect devices such as gateways, touch-panels, computers, or PLC with the rest of the system. There are two types of addresses that this system uses to communicate with devices: individual and group addresses. Individual addresses are unique for every device and are used for programming, monitoring, and configuration of the device. Whereas group addresses transfer the data and are bundled with net-variables (a shared variable of a specified type). These variables are used to connect variables of the same type which are located in different devices; such are sensors and actuators. The working principle of group addresses is that only one device is allowed to write the data to the group address, yet more than one device is adapted to changes to one group address.

The advantage of using this system is the ease in configuration due to a tool called Engineering Tool Software, which is very easy to learn. When comparing to other building automation systems, this system doesn't need a specific configuration tool for each manufacturer as other standardized systems do. Nevertheless, using this system has its own disadvantages as well. First, the price of the components for small buildings and second, the design of the bus can handle a slight amount of data transfer of a particular type.

4.2 **Sensors**

Sensors are another critical part in a building automation system since they are used to create a comfortable and secure environment while saving energy. Most conventional sensors in the building are temperature, humidity, lighting and HVAC system sensors, air quality, and security sensors. These sensors are used to monitor and measure the physical activity in the building, helping automation system delivers a more natural control of the environment.

Temperature sensors, especially those used for thermostats, play an important role in building automation. They provide feedbacks to heating or cooling systems in order to arrange a comfortable temperature and a proper level of air flow in the building. When heating and cooling in a building is at the perfect level, this is because of the temperature sensor that informs the thermostat about room temperature. In order to collect real data of room temperature and to keep a healthy building, it's essential to place well the temperature sensor. A well-placed sensor is when it is usually placed within the thermostat or connected with wires close to it. Meanwhile, if the sensor is placed in the wrong places, it can cause comfort issues, waste energy, and damage equipment. Some wrong locations to place temperature are listed as follows:

- On the ceiling
- Direct to the sunlight
- Under ceiling fans
- Too close to Heating and Cooling supply ducts
- Over or behind the equipment that releases heat or cold air, such are cooking equipment, refrigerators, etc.

If the hole in the wall where temperature sensor wires are placed is not sealed, the air that comes from the wall and blows to the temperature sensor inflects the values that the sensor collects. However, if the sensor is placed five feet high on a column or interior wall and if the places mentioned above avoided, excellent and accurate report of room temperature is obtained (Oleson, n.d.).

Lightning and HVAC use about 60% of the total energy in the building, therefore a control system would save a lot. Systems nowadays are integrating sensors that measure ambient life and arrange artificial lights based on that. If there is enough natural light, artificial lights are not used or dimmed based on how much light gets into the building from outside. A lighting system such as DALI is, controls and adjusts lights around the building, providing efficiency and saving energy and money.

Other sensors that are used in a building are usually air quality and security sensors such as humidity sensors, smoke detectors, carbon monoxide, and dioxide sensors, etc. (Embedded Revolution , n.d.).

5 HEALTHY BUILDING

Sometimes the term of saving energy might be misinterpreted, especially when saving methods come at that would impinge on the health of the occupants and building. Changing temperatures to very low or very high during a day within the building can cause moisture and health problems to occupants. Keeping a constant room temperature, a proper humidity level, and air quality, is as important as seeking for energy saving methods.

5.1 Room Temperature

People often complain about temperatures in their workplaces, either for being too cold or too hot. Creating a constant temperature would increase their motivation and make them happier. High or low temperatures can cause health problems to the occupants such as heart attacks, heat illness, fatigue, and other issues related to thermal conditions. The standard temperature for a comfortable workplace varies from 20°C to 26°C, depending on the time of the year. Mostly, the temperature should be around 22 degrees; however, what should also be taken into account is that women prefer three degrees warmer than men. Despite regulating temperature and improving thermal comfort, there should be improvements in air conditioning and humidity levels as well (Offices: Temperature and humidity - what are the rules, 2018).

5.2 Humidity

When air enters the building, it generally includes moisture in the water vapor form. Relative humidity measures the amount of moisture that air can hold at the same temperature and pressure. Humidity will cause discomfort, either if it’s too high or too low. If its higher than 60% can cause mold, corrosion, and other problems related to moisture, yet when it’s too small, it leads to an electrical discharge, shrinkage of wood furniture, etc. In order to create comfort, the humidity level should not exceed 60% nor go below 20%, as it is shown in Fig.25.

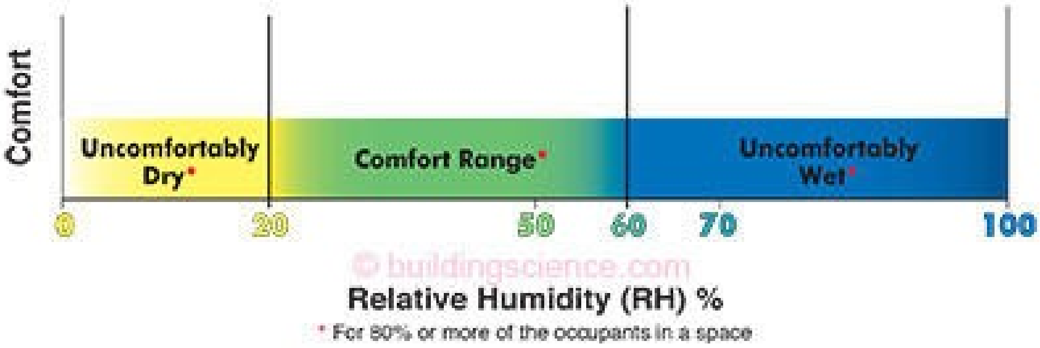

Figure 25. Relative humidity comfort (Lstiburek, RR-0203: Relative Humidity, 2002)

Occupants are not able to sense the humidity level if it is within the of 25% to 60%, yet they are able to detect it if it goes under 25% or above 60%. Keeping the humidity level within this range will reduce health problem and create a comfortable environment inside the building. There have been some discussions about the low limit, whether it should be lower or higher than 25%. If the lower limit is increased, than moisture problems will appear and if it decreases will cause health problems. Therefore, the lower limit so far stays at 25% as the most comfortable one. In terms of health problems, in Fig.26 is shown how humidity levels affect bacteria and other viruses grow in the building (Lstiburek, RR-0203: Relative Humidity, 2002).

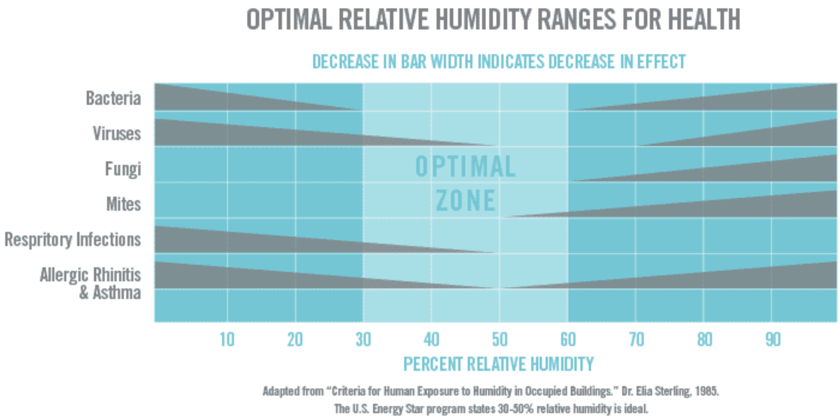

Figure 26. Relative humidity ranges for occupant`s health (How to Eliminate Window Condensation and Stop Mold, n.d.)

5.3 Carbon Monoxide

Carbon monoxide is a poisonous gas with neutral color, generated by the partial burning of fuels, such as natural gas, liquified petroleum, oil, coal, kerosene or wood. Symptoms of CO poisoning include headache, fatigue, dizziness, short breath, and dizziness. In order to prevent getting poisoned by CO, it`s occupants should ensure that appliances are installed in the right way and by professionals, install a CO detector, avoid burning charcoal inside homes, garages or vehicles since charcoal burning is also a source where CO is produced, avoid using gas appliances to heat the building, etc. The higher the CO concentration in air is, the higher the health risks are. The unit of mass of CO in the air is part per million (ppm). When the CO level is below 70 ppm, the symptoms aren't that noticeable. People with heart issues make an exception since their chest pain increases when the concentration is around 70 ppm. If the CO level goes above 70 ppm, then the symptoms are real and inevitable, including headache, fatigue, and nausea. As the

CO level increases around 150 to 200 ppm, a more significant health problem occurs like unconsciousness and disorientation; even death might happen. Therefore, keeping CO as low as possible helps on reducing occupant's health problems and maintaining a comfortable environment inside the building. As it is mentioned above, one way to avoid CO poisoning is the CO detector. CO detector alarms if the CO concentration is in life-threatening levels (Daller, 2017).

5.4 **Carbon dioxide**

Maintaining air quality has become a priority for building engineers since students and employees spend half of the day at work or school. While ventilating and air conditioning the building, occupants never know how much of the incoming air is actually coming from outside and how much is re-circulated. Therefore, they cannot measure the amount of carbon dioxide coming into the building. Measurements of CO2 are used as an indicator to ensure ventilation systems are delivering a healthy and not stale air to occupants. Carbon dioxide is a colorless and poisonous gas, produced from occupants' bodies in the exhaled air and also when fossil fuels are burned. The occupant`s body releases about 35000 to 50000 ppm of CO2. If it wouldn't be for decent ventilation systems, then CO2 would be accumulated and make the building an unsafe place to stay and work. However, there are levels of carbon dioxide that should not be exceeded in order to avoid health problems, listed as follows (Bonino, 2016):

- 250-350 ppm (average outdoor air level)
- 350-1000 ppm (typical level in occupied spaces with good air exchange)
- 1000-2000 ppm (drowsiness and weak air level)
- 2000-5000 ppm (stale air and health problems level, such as headaches, sleepiness, increased heart rate, loss of attention, loss of concentration)
- >5000 ppm (high level of other gases as well)
- >40000 ppm (the harmful level where deprivation of oxygen occurs)

5.5 **Pressure in buildings**

Pressure in buildings is another factor that affects occupants' comfort by causing the airflow into, within and out of the building. These occur due to mechanical ventilation and natural forces such as stack effect and wind. The ideal pressure difference for both residential and commercial building is +0.02 to +0.03 in the water column. To keep positive pressure in buildings, an HRV system or fresh air ducts to the HVAC system should be installed. When supply air flow exceeds the return airflow in the building, it leaves a positively pressurized building.

The amount of air needed to pressurize a building depends on how leaky the building is. Some buildings require only 50 cfm of outside air per 1000 square feet, and some require up to 300 cfm per 1000 square feet. Negative pressure is usually preferred for rooms that contain cleaning or other chemicals, to prevent smell distribute around the building. Wind also creates pressure, on the windward side creates positive pressure and on the downwind side a negative pressure. Tools needed to measure the pressure in the buildings are manometers and tubing or pressure hoses. A digital manometer with a range of 0-in to the 5-in water column and a readable scale of the 0.05-in water column is ideal. Tubes or pressure hoses are needed to connect the manometer. The pressure goes through those tubes to the pressure ports of the manometer, where the pressure of the building is measured. Another method to see if the building is pressurized with positive or negative pressure is cold smoke. A reaction of Titanium Tetrachloride wit moisture creates a cold smoke. To test if the room has positive or negative pressure, leave the door of the room open around one inch or so. Through that opening blow the smoke, if the smoke blows out of the room, then it has positive pressure. If the smoke is pulled back into the room, then it has negative pressure. Pressure throughout a building is not constant; it changes quite often (Falke, 2005).

5.6 Air Tightness

Air tightness expresses the amount of air flow that leaks through the building envelope under a given pressure reference, which is often 50 Pa. The unit of this variable is m3 per hour. Air tightness takes up to 50% of the total heat loss in the building. Poor design and materials can cause air leakage in a building. The values of airtightness vary from building to building. If the building does not have a ventilation system, the amount of airtightness shouldn`t exceed 3.0. If the building has a ventilation system, the value should be less then 1.0, and if the building is a passive house, then the required air leakage should be less than 0.6 (Airtightness requirements, n.d.).
A well-designed airtightness helps on reducing heat costs, improving comfort and health within the building, improving building durability, etc (Crosson, 2017).

6 RESULTS

To achieve a nearly Zero Energy Building, engineers should take into account all concepts, definitions, and rules related to energy efficient and low CO2 emission buildings. This process has different phases, which are discussed in the following paragraphs. Before starting to actually upgrade the system or add renewable systems in the building, the implication is to get to know the necessary information from the building such as electricity and heating consumption, floor plans, etc. In one word, the design and the already used systems of the building need to be studied first. Next step is upgrading the existing systems to achieve more efficiency and avoid wasting energy. The final stage consists of renewable and storage systems integrated together in the building. In order to have an energy efficient building, a relationship between nearly Zero Energy Building and nearly Zero CO2 emission Buildings should be found.

6.1 Template (Project Proposal)

6.1.1 Basic information from the building

As it is mentioned above, to meet the requirements of a nearly Zero-Energy Building first, the necessary information about the building itself needs to be collected. That information includes:

Climate, building geometry, and soil information
Climate plays an important role in the energy production of renewable systems. Therefore, the energy produced by such systems is calculated using weather factors such as irradiation, summer and winter days, wind speed, etc. The warmer the location is, the more energy is generated. Building`s design is important, especially when solar collectors are installed since they need to have a good position in order to concentrate and collect the sunlight. Soil type is used to decide which of the geothermal storages suits the best.

Floor plans of the building
When having the floor plans of the building, is easier to calculate and plan lights, sensors, and Building Automation Systems.

Lights and automation systems used already
All the systems that are being used in the building need to be rechecked in order to see what changes and what improvements can be done. If some of the systems are getting old and losing their efficiency or aren’t that useful when it comes to energy savings, then those should be either replaced or upgraded.

Energy consumption for at least the past year
Monthly or even daily electricity consumption for at least the past one or two years it’s a must. Therefore, it`s known the amount of electricity that is needed to be produced from renewable systems. The system is designed based on the peak value; it means based on the days when

energy consumption values were the highest. If the peak value is too high and the possibilities to build such a system that covers all the consumption are small, a system that approaches that value the most is built. The other part of electricity can be covered by grid or energy storages if there is any.

Heat consumption
The amount of heat consumption is larger during winter and smaller during summer. Therefore, the extra energy that is produced during summer can be stored and used during winter when the renewable system isn't able to provide enough power for the building.

The year and use of the building
In order to do a proper renovation, the year when the building is built, it's required. How often and by how many occupants each part of the building is used, helps on a better arrangement of lightning, heating and ventilation system, and reducing energy demand as well.

U value and building`s insulation
U-value or thermal transmittance is more than needed when it comes to building renovations and energy savings. This value is dependent on the insulation material of the building. The unit of this measurement is W/m2K. The insulation and U-values are related to each other so that the higher the U-value is, the weaker the insulation is. This also affects the heat loss within the building, the higher the U-value, the more heat is lost, and vice versa (Lymath, 2015). Therefore, when renovating the building, there are several U-values that should be considered from engineers:

- U-value of the wall (Facade)
- U-value of roof
- U-value of Windows
- U-value of the insulation material

6.1.2 Upgrading the building

The aim of a building is first to provide a good and healthy working environment to the occupants, to meet the standards of decent indoor air quality. It is not all about saving energy but increasing occupant's productivity while balancing heating and cooling within the building. It is easier to build a new building that meets the requirements of a nearly Zero-Energy Building rather than renovating the old ones to adapt to those conditions. Nearly Zero-Energy building means providing energy to a building which is generated by renewable sources. Therefore, renewable systems are designed to produce electricity, heating, and cooling for a building. As it is discussed in the first phase, before starting to upgrade the already existing system and adding renewable systems into the building, some useful information needs to be considered. One of them is climate, which affects the production of renewable systems, making it impossible to generate enough power only from them. However, before going to the stage of adding renewable energy systems, there are some methods to reduce energy consumption, such as upgrading the building. Upgrading the building means improving and changing old systems that have been used in the building to make them more efficient and lose less energy during their activity. Such systems are Ventilation, Heating, Lightning systems, and Building Automation systems.

Ventilation, Heating, and Cooling system

Ventilation System is usually one of the biggest factors that affect the energy savings in the building. It's so necessary to find a suitable and more efficient system that would contribute to lowering energy demand and maintaining indoor air quality. Thus, there are two ways to reduce energy consumption for ventilation:

- Decrease the ventilation rate
- Recover the heat from ventilation

Reducing energy demand affects the comfortability and healthiness of the building. Therefore, emission sources such as humidity, CO2, pollutants, etc., should be considered as well. Lowering the ventilation rate under the standard limit will cause problems to the building and the occupants.

Thermal heat in low energy building is caused partly by the ventilation. The reduction of heat demand also varies on passive systems; such are thermal insulation, sun protection, airtightness, etc. To make it nZEB the rest of the thermal heat should be generated by renewable sources. The outside air is usually part of renewables when it is brought into the building by heat pumps. Thus, the released air from the then HRV is considered a renewable source. Up to 40% of the ventilation heating losses come from renewable sources, but with HRV, this demand is recovered. Therefore, the usage of HRV systems would help in generating heat and avoid energy losses.

Heat recovery Ventilation is used to reduce energy consumption for cooling as well. The chiller`s capacity and consumption are reduced by using heat recovery (Händel, n.d.).

Lightning system

In order to fulfill the nZEB requirements, changes should be done in the lighting system as well. These changes include:

- Light replacement
- Occupancy Sensors
- Automation System

Changes from traditional light bulbs to LED would save up to 75% or more of the energy that lights use. Occupants usually stay at their workplace or eight to ten hours per day and not always remember to turn off the lights when they leave. Lights of corridors and some part of the building where people don`t spend too much time shouldn`t be on all the time. Therefore, occupancy sensors can be used to control the lighting system and save up to 30% of the energy that is used in those areas.

Automation system

Nowadays, most of the facilities in the building have automation control. It reduces energy consumption by collecting and analyzing the data from those facilities around the building. Ventilation, Heating, cooling, and Lighting Systems use automation control in order to provide comfort and save energy. Several sensors are used in commercial buildings to increase the efficiency of the above-mentioned systems and provide a secure working environment. The range can be from temperature and humidity sensors to security alarms. New buildings usually have the latest versions of BAS while older ones retrofit the most modern BAS equipment into their facilities. The retrofitting in the old buildings indicates a reduction of 13% over five years.

Some of the latest BAS systems that can be implemented into buildings are KNX, BACnet, DALI, all of those described in more details in the second (Lighting System) and third chapter (Building Automation).

6.1.3 Renewable energy systems for electricity

Photovoltaic System

Photovoltaic Systems are worth the investment when it comes to generating electricity. Their price is going down rapidly, making the whole system a lot cheaper than it was many years ago. When designing a PV system, there are some step that should be followed and some conditions that should be taken into account. Such are:

- Irradiation (W/m2) – it determines the power production of a solar system
- Location – the area where the system takes place. It is usually required an open field or roof, without trees or objects that create a shadow around. If panels are under shadow even for a short amount of time during the day, the energy loss is enormous. Therefore, finding the perfect location is very important.
- Components – The selection is usually based on the latest versions of all needed components. PV modules, inverters, energy meters, cables, and mounting arrays are some of the main parts required to build a PV Solar system. Usually, there are companies who sell the system per Watt-peak. That price includes all components and installation cost. The Watt-peak means the installed peak PV power, more clearly the number of panels and their total wattage established.

One method to measure the amount of wattage produced by a certain number of PV modules is this PV calculator shown in Fig.27.

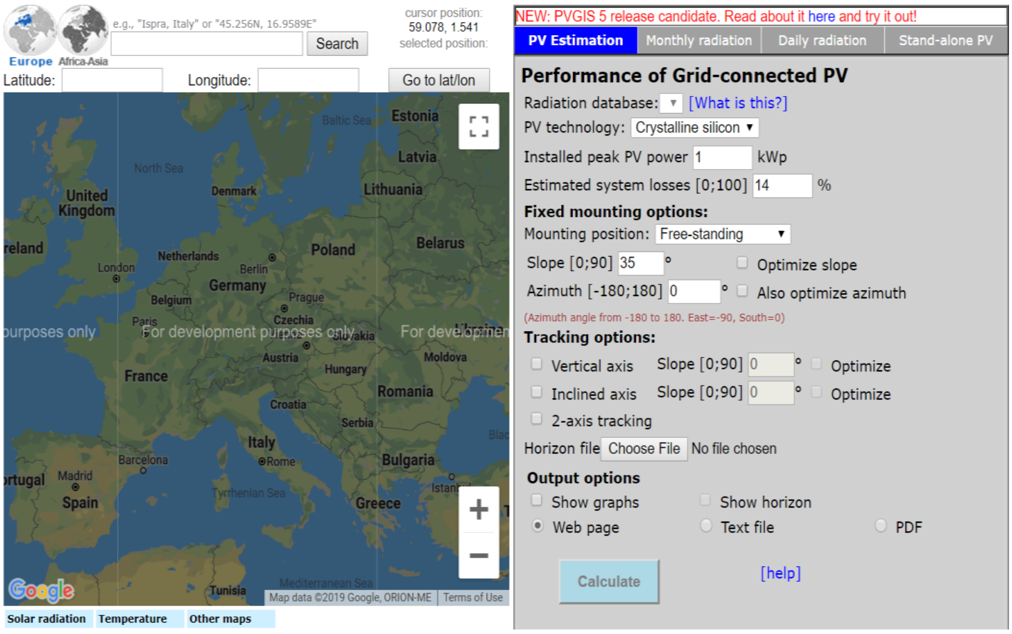

Figure 27. PV calculator (PV Estimation , n.d.)

It calculates the amount of energy generated by the installed peak PV power, taking into account slope, system losses, mounting position, and some other features as seen in the figure. The location is given, and the irradiation value is found from the calculator. There is a case example done in Valkeakoski shown in Fig.28. The case was part of a module project in Autumn 2018. After the required information has been written down in the calculator, it comes up the total energy production generated each month in a given location. The angle of the panel is location-based; thus, it changes depending on weather conditions of that country as well.

PV power estimate information - Google Chrome

Not secure | re.jrc.ec.europa.eu/pvgis/apps4/PVcalc.php

Solar radiation database used: PVGIS-classic

Nominal power of the PV system: 130.6 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 12.4% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 3.1%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 27.0%

Fixed system: inclination=40°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	62.00	1920	0.55	17.0
Feb	211.00	5920	1.95	54.6
Mar	312.00	9680	3.05	94.5
Apr	449.00	13500	4.63	139
May	509.00	15800	5.55	172
Jun	490.00	14700	5.45	163
Jul	489.00	15100	5.49	170
Aug	383.00	11900	4.19	130
Sep	274.00	8210	2.85	85.5
Oct	152.00	4710	1.49	46.1
Nov	60.00	1800	0.56	16.8
Dec	32.30	1000	0.29	9.05
Yearly average	**285**	**8680**	**3.01**	**91.5**
Total for year		**104000**		**1100**

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

Figure 28. The case example of how a PV calculator estimates the energy generated by a certain number of PV modules installed in Valkeakoski (Kastrati , et al., 2018)

- Installation – The process of bringing all components together requires a lot of effort, hard work, and it costs. PV systems can either be the non-tracking or tracking system. Usually, tracking systems are more efficient and produce more power than the non-tracking ones. Their ability to follow the sunlight, makes this system a right solution, especially for countries that suffer from the lack of the sun. They cost a little bit more than the non-tracking system, but the profit is larger too.

- Data monitoring – An energy meter is used to monitor data collected from each panel daily. It usually includes daily power production of each panel, their actual working state, and some extra information such as temperature, humidity, etc. It`s easier to detect if some part of the system breaks down when monitoring the data.

6.1.4 Energy storage

The flaw of renewable energy systems (e.g., solar systems), is that they produce more during summer and less during winter. Therefore, the need to somehow use that excess of energy during wintertime made engineers think of energy storages. Energy storages can be several; they are mostly used for heating and cooling purposes. Geothermal and solar collector system with seasonal energy storages are the two most common storages in both residential and commercial buildings.

Geothermal Storage

When planning to build geothermal storage, these essential steps should be followed:

1. Building`s energy estimation and ground`s geothermal potential
   Estimate the energy demand of the building for the whole year. Before having a final evaluation, a reduction of the energy losses needs to be done. The loss mostly comes from the ventilation system. Ground`s geothermal potential is one of the main factors that play an important role when designing geothermal storage. It determines the type of the geothermal system that should be installed, the number of geothermal loops or wells, the power of the heat pump needed for that system, etc. The balance between building`s energy estimation and the ground`s potential reduces the installation cost and increases the efficiency of the system. After the total energy demand needed is calculated, and the ground`s potential is defined, a suitable geothermal can be chosen.
2. Choose the most suitable geothermal system
   The system is chosen based on the conditions discussed during the previous step.
   Nowadays, a universal geothermal storage system is BTES. It stands for Borehole Thermal Energy Storage, and it consists of boreholes, heat exchangers and heat pump.
   The output of the borehole is calculated based on the formula provided by the professor Osmo Huhtala:

$$Q = \frac{2\pi \times \lambda \times \mathrm{H} \times \Delta\mathrm{T}}{ln\left(\frac{H}{d}\right)}$$

Table 3. Formula notations

Symbol	Meaning
λ	Soil`s thermal activity
H	The active length of the borehole
ΔT	The temperature difference between the borehole and the surrounding soil
d	Borehole`s diameter

The number of boreholes needed to be implemented varies from the building`s peak demand. The formula that estimates the total number of boreholes is:

$$x = \frac{Q_t}{Q} [=] \frac{kW}{kW}$$

Table 4. Formula notations

Symbol	Meaning
Q_t	Building`s peak demand
Q	Borehole`s output
x	The number of boreholes needed

Heat pumps are selected based on the size of the system. If the system is too big, then several heat pumps connected together in series provide a higher thermal production.
The evaluation of the heat pump`s efficiency, the coefficient of performance is used, as defined in the following formula (Kastrati , et al., 2018):

$$COP_{HP,space\ heating} = \frac{Heat\ provided\ to\ heated\ space}{Electricity\ Consumption}$$

$$COP_{HP,space\ cooling} = \frac{Heat\ removed\ from\ cooled\ space}{Electricity\ Consumption}$$

The COP_{HP} of a typical heat pump is around four; that is, the efficiency of the heat pump is up to 400%.

3. Administrative requirements
   A permit is needed when planning to install geothermal systems.
4. Application for a financial grand
   Nowadays, the EU supports and gives grants to all the owners of either residential or commercial buildings, if they install any of the renewable systems.
5. Installation of the geothermal system

The installation is preferred to be done by qualified engineers and experts in order to avoid any mistakes during installation.

6. Maintenance of the system
   The heat pump is known as the heart of the geothermal storage system. Thus, in order to operate efficiently, it needs to be maintained at least every two years.

Solar Collector System with Seasonal Storage

Solar collectors are mainly used for heating purposes. It is known that during summer temperatures are higher, and solar collectors manage to produce more energy than the building needs. Therefore, seasonal storage is used to store the excess of the energy produced.

Solar collectors are an excellent solution to supply hot water to the building. The plan of designing a solar collector system with Seasonal Storage goes through some stages, as follows:

1. Finding the best location where the solar collectors are installed. Since solar collectors need strong sunlight, the location matters, and it affects the efficiency and the production of the system.
2. The type of the solar collector is chosen
3. Irradiation value is found, in order to calculate the output of the collectors. The formula that is used to calculate the output of the collectors is (Kastrati , et al., 2018):

$$Q_{solar} = A_c * H_{T,h} * \eta_{c,h} * (1 - \eta_{loss,h})$$

Table 5. Formula notations

Symbol	Meaning
A_c	Solar aperture area
$H_{T,h}$	Global radiation for the collector
$\eta_{c,h}$	Thermal efficiency
$\eta_{loss,h}$	Loss rate

4. Selection of water storage tanks
5. Borehole storage for solar collectors
6. Heat pump based on the size of the system

6.1.5 Final phase calculations

Each phase of the nZEB renovation helps in reducing energy consumption and costs. Changes and replacements made on the first phase tend to minimize the total cost of around 10-20%. Since this isn’t a real case but only a generalization of how nZEB renovation should be done, the assumption for energy savings is based on the nZEB renovation project for HAMK`s Building Valkeakoski. The second phase consists of the implementation of the designed retrofitting, renewable sources, and energy storages. The energy consumption after this stage measures a 60% reduction.

7 CONCLUSION

In conclusion, this thesis details a near zero energy building template with several stages that should be used by market actors and stakeholders during nZEB renovation projects. Furthermore, it defines the meaning of a healthy building and the factors that induce discomfort to occupants in their working environment.

In the beginning are described the contents of ventilation heating and lighting systems, renewable sources and storage technologies, and Building Automation Systems (BAS) that can be used to build an effective and efficient building. A PV system and Borehole Thermal Energy Storage are described in detail in the second chapter, while sensors and protocols are explained in the third chapter.

Then the factors that affect the comfort and healthiness of the building are studied. Humidity levels inside the building play an extremely important role. The values shouldn’t exceed or fall behind the range that is considered as desirable and healthy, in order to prevent health issues of the occupants or different damages of the building. U-value is another factor that needs to be considered by constructers. It is tightly connected with the insulation of the building and it helps to avoid heat losses. The poorer the insulation is, the higher the U-value will be; therefore, increasing the heat loss and the inefficiency of the building.

The last part details the phases of the template with some explanations per each step that should be followed during nZEB renovations. Climate and ground type are two main topics that affect the efficiency of renewable sources. Energy consumption of the building for the past year helps to detect the gaps and shortcomings in the existing systems, such as ventilation, heating and lighting systems.

Before implementing the PV systems and energy storages, some changes and replacements are made in existing systems in order to decrease the energy demand of the building. A PV calculator is used to estimate the irradiation and the energy production of the installed PV solar system. While a BTES is used to store the excess heat during summer so the building can use it during winter.

Finally, by implementing the designed retrofitting, renovated nZEB can reduce up to 60% of the energy consumption, while reducing CO2 emission and maintaining a healthy building.

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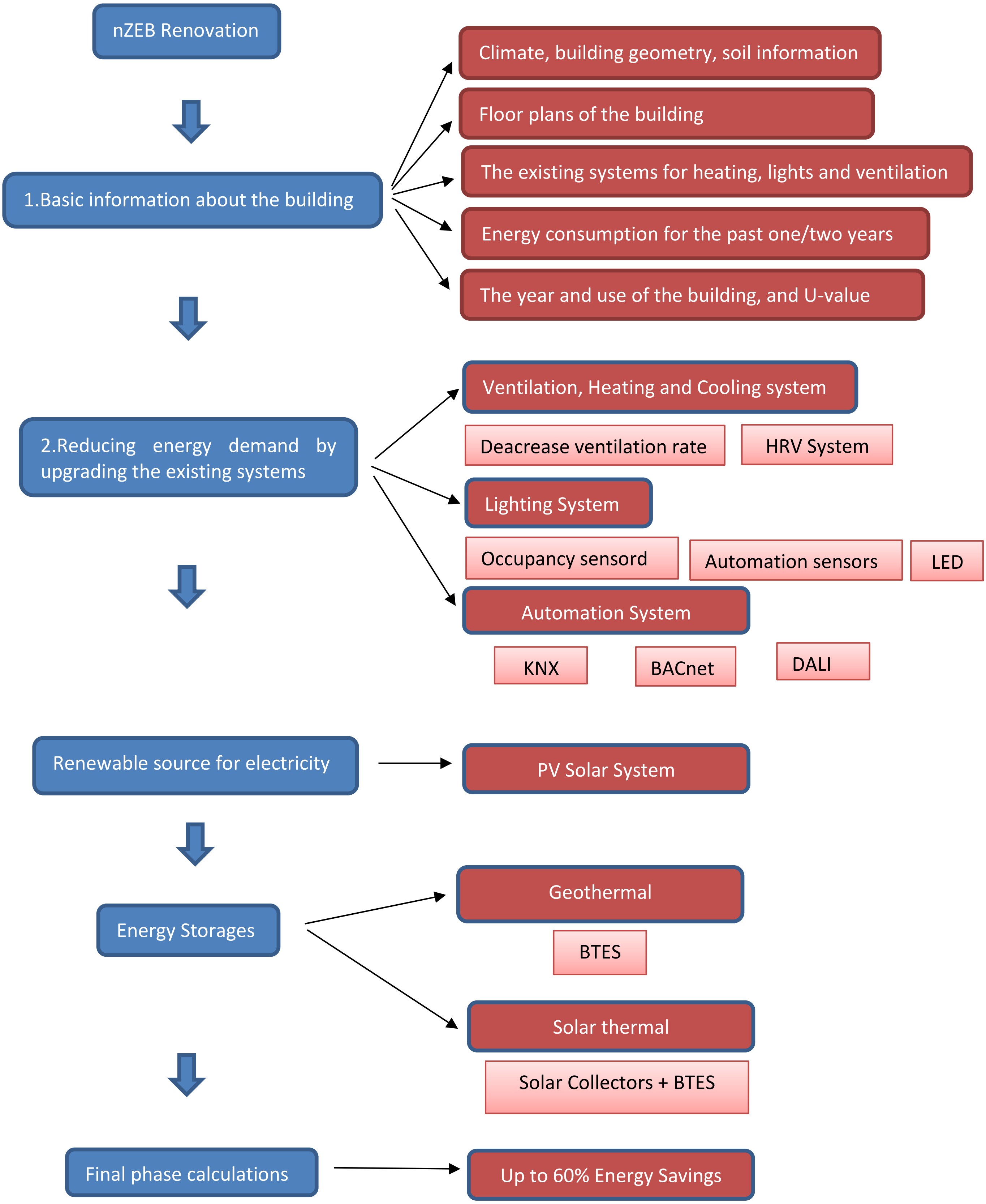
Appendix 1 The template for nearly Zero Energy Buildings Renovation


nZEB Renovation
1.Basic information about the building
Climate, building geometry, soil information
Floor plans of the building
The existing systems for heating, lights and ventilation
Energy consumption for the past one/two years
The year and use of the building, and U-value
2.Reducing energy demand by upgrading the existing systems
Ventilation, Heating and Cooling system
Deacrease ventilation rate
HRV System
Lighting System
Occupancy sensord
Automation sensors
LED
Automation System
KNX
BACnet
DALI
Renewable source for electricity
PV Solar System
Energy Storages
Geothermal
BTES
Solar thermal
Solar Collectors + BTES
Final phase calculations
Up to 60% Energy Savings