DOMESTIC ENERGY USAGE TOWARDS FUTURE INTELLIGENT ENERGY EFFICIENCY

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Opinnäytetyössäni tutkin ja perehdyin omakotitalon energiatehokkuuteen ja sen optimointiin. Tavoitteena oli kartoittaa nelihenkisen perheen energiankulutus. Perheeseen kuuluu kolme aikuista ja yksi lapsi. Havaintojeni perusteella ehdotin muutoksia ja investointeja energiankulutukseen mukavuudesta tinkimättä.

Opinnäytetyö rajautuu olennaisesti elektroniikkaan, aurinkolämmitykseen, aurinkosähköön ja automatisointiin. Opinnäytetyössä ei oteta huomioon talon rakenteeseen liittyviä konsepteja kuten eristystä ja tulisijan vaikutusta. Talo on rakennettu vuonna 1984 ja suurin osa kodinkoneista ja elektroniikasta on n. 10–40 vuotta vanhaa. Jotta opinnäytetyö olisi kohtuullinen en etsinyt jokaiselle elektroniselle laitteelle korviketta, mutta siihen suuntaa antavaa ideologiaa. Talossa on suora sähkölämmitys, johon ehdotin lisäyksenä ilmalämpöpumppua. Valaistus oli sekoitus halogeeni, LED, kaasupurkaus ja loistelamppuja. Kaikki edellä mainitut muutettiin LED- lampuiksi. Kiinteistön tontilla on paljon tilaa, joten 6 kW aurinkopaneelijärjestelmä oli helppo sijoittaa pihapiiriin. Suurin energian kulutus tuli 300 litran vedenlämmittimestä. Veden lämmittämiseen asennettiin 3,5 kW aurinkokeräimet. Ulkona on 47000 litran uima-allas ja 1800 litran poreallas, joiden lämmitys ja suodatusjärjestelmät toimivat manuaalisesti / suodatinpumpun tuntisäädön kautta energiatehottomasti. Tähän ratkaisuksi löytyi Arduinoon perustuva järjestelmä. Perhe oli investoinut Google Assistenttiin, joka ohjaa sähkölämmitystä, sisä- ja ulkovalaistusta automaatiolla Wi-Fi-kytkimen avulla. Järjestelmää voi ohjata PC:llä, älylaitteella tai puheohjauksella. Viimeisimmät kodinkoneet, jotka vaihdettiin, olivat vanha keittiön liesi ja jääkaappi, joilla on energiatehokkaammat luokitukset. Analyysi, suunnittelu ja budjetti osoittivat asukkaille selvästi, että energiatehokkuusremontti oli kannattava ja tulevien vuosien säästöt tulevat olemaan merkittäviä.

Avainsanat Energia, optimointi, automatisointi.

Sivut 30 sivua.

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Electrical and Automation Engineering | Abstract
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Subject Domestic energy usage towards future intelligent energy efficiency
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In my thesis, I studied the energy efficiency of a residential building and its optimization. The target was to map out the energy consumption of the household a family consisting of three adults and a child in, a single-family detached home. This thesis' findings suggest adjustments to the current energy consumption and investments to optimize the energy consumption without sacrificing household comforts.

The thesis is essentially focused on, solar electricity, solar heating and automatization. This thesis will not considerations from the perspective of energy optimization, the house structure, insulation, or fireplace.

The house under investigation was built in 1984 and most of the electronics in use are between 10 to 40 years old. To keep this thesis within reasonable scope, recommendations were not made for replacements for each electronic device in use. The house has direct electrical heating, with which I suggested an air source heat pump as an addition. The lighting was a mix of halogen, LED, gas-discharge, and fluorescent lights. All of the lights were changed to LEDs.

The property has a lot of room, so placing a 6kW solar power plant was simple. The largest energy consumption came from the 300-liter water heater. Solar collectors of 3,5kW power were installed to heat water. The outside has a 47000-liter pool and a 1800-liter hot tub. Heating and filtration work manually, with filtration pump with hour cycle. I automated the filtration pump on site for daily usage with a system based on Arduino Uno.

The family had purchased a google assistant utilizing automation to control indoor and outdoor lighting and electrical heating using a Wi-Fi switch control. The system can be controlled through PC, mobile devices and voice control. The last device or voice control that were replaced were the old kitchen stove and the fridge which were replaced with more energy efficient models.

The analysis, planning and budget clearly showed to the residents that energy efficiency rehaul was a necessity. The potential monetary value of future savings are notable.

Keywords Energy efficiency, optimization, automation.
Pages 30 pages.

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Figures, tables and equations

1 Introduction

Detached houses have various different variables that effect the energy needs and consumption. In my thesis, energy efficiency has not been a priority in the house under analysis, either at the time of its building or during the decades that have followed. That was not a major concern at that point in time. Generally, single-family houses have been made more efficient with thermal insulation over time. On the other hand, energy is consumed on other electrical devices, such as heaters. Thermal insulation regulations have been published since 1975 in the Finnish the building regulations collection. The regulations were set to motion by the Ministry of the Environment. The previous regulations were set on different construction parts as the heat transfer coefficient factor (k), which you wouldn't be allowed to surpass. The regulations were intended for the walls, floors, roof and the windows. Since the year 2003, the heat transfer coefficient factor symbol has been U. There has clearly been no more detailed monitoring of the energy consumption of detached houses. Monitoring has been the responsibility of private entities and data collection or access to information has been difficult. It has been difficult to estimate the exact energy efficiency value, when it is not necessarily known how the structure has been implemented.

The latest requirements belong to section D3 of the collection Energy efficiency of buildings. The collection deals with energy efficiency much more widely than the previous ones, which that stipulated only the thermal insulation of building parts. Energy calculations should be left to professionals, who also know the different terms. Also, what is new in the regulations is the review of the building's total energy consumption. In the calculation of the total energy consumption (E-number), certain coefficients assigned to different forms of energy are used. Depending on the purpose of use, different building types are assigned a maximum that the E number must not exceed. For example, the coefficient for district heating is 0.7 and for electricity 1.7. The coefficient of electricity is significantly higher than that of other forms of energy. Therefore, the E-number of a building heated with electricity easily rises much higher than others, so the energy consumption must be kept to a minimum.

The new regulations have considered, for example, the energy consumption of the ventilation system and hot water heating. Energy efficiency requirements will be tightened further in the next few years. In terms of construction in Europe, the European Commission's goals include that nearly all construction should come close to "zero-energy construction". As usual, Finland wants to be the leading country in implementing energy efficiency.

As I mentioned above, I will limit the energy efficiency improvement of the project I described in my thesis into two groups: heat energy production and energy use.

Improving energy efficiency often requires permits to implement solutions, but these permits are typically limited to small modifications of single-family homes and common energy production devices. Examples of licensed processes include connecting a solar panel system to the electricity grid, signing a contract for the sale of electricity, and installing an air heat pump.

2 Background study

2.1 Solar electrical energy

Solar power is the method of converting energy from sunlight into electricity. Solar energy can be collected by capturing radiant light and heat from the sun. This energy can be utilized in various ways using a vast array of technologies, one of which is photovoltaic cells in solar panels.

Solar electricity is a renewable source of energy and requires an initial investment. The investment can be expensive depending on the size of the system, and if it has added extras, such as battery packs. Typical investment on a standard sized solar power system ranges from 5,900 to 10,000€ for 12 to 18 solar panels according to Väre (2023). This typically can generate 4200 to 6300 kWh/y in Finland.

The investment starts to pay itself back when it’s installed and connected to the grid.

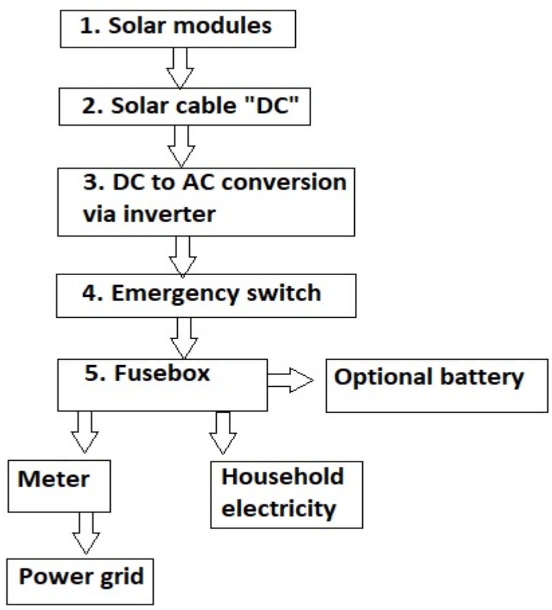
2.1.1 Operating principles

Photovoltaics (PV) is the process of converting sunlight into electrical energy. A single PV device is called a cell. This cell is tiny in size is able to produce one to two watts of electricity. These cells are connected to a larger chain to form modules. These modules are connected to form arrays. Arrays can then be connected to the grid to complete a PV system. The PV systems are easily modified into small or larger systems depending on the demand.

There are many components that go into the PV system. These start from the mounting structures on the actual surface where the solar panels are installed. Usually this is the roof but can apply to wall and ground installations. This makes the solar plants adaptable into various situations and places. Other components include AC to DC inverters. These also can be customized into one central unit or multiple microinverters that optimize the individual panels. This gives the system the capacity to generate the maximum energy even in the situations with part of the solar system is covered, such as in cases of snow, shade or debris. Together, these components form the PV system.

The operation of the system is straightforward. The solar modules trap sunlight and use it to convert it into electrical energy. This electrical energy that is captured is in form of direct current (DC). DC electricity is then converted to AC using an inverter or transformer. The AC electricity is then connected to the house grid or alternatively stored in battery packs for later consumption. An electrical meter is used to indicate the amount of electricity that is consumed. If the electricity is greater than the consumption, the extra energy is sold back to the electric grid as seen on the flow chart, Figure 1.

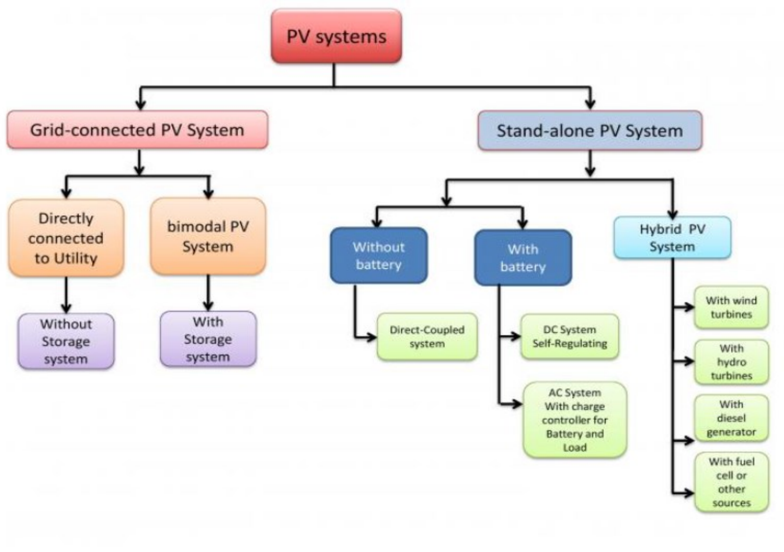
Figure 1. Solar electricity flow chart



2.1.2 PV sizing principles

The sizing is a key component in PV design. The size of the PV system is determined by the requirements of the function. The two standard PV systems are grid-connected and stand-alone type PV systems. Grid-connected system can also be with and without energy storage, battery packs as seen on Figure 2. (PennState, 2020)

Figure 2. PV system types (PennState, 2020)



Stand-Alone system is a system with storage capabilities. In this system, the battery packs act in a way like a bank account. The PV array generates energy (income) and this energy is stored in the battery packs (deposits) and consumption of electrical loads (withdrawals). Sizing for a Stand-Alone system balance between supply and demand. The PV system is required to provide enough energy to meet the load of the system, and, in worst case scenarios, system losses.

Grid-connected system is a PV system without storage capabilities. In this system it is imperative to determine the maximum array output power. Select one or multiple inverters whose combined rating aligns with 80-90% of the array's power output. Estimation of the energy produced takes the local climate into account.

2.1.3 PV sizing tools

Software can be used to optimize the sizing for a PV system. There are tools available online for this specific task. PVGIS measures the power that can be harnessed by analyzing the sunlight annually in a specific region.

2.1.4 Environmental and construction aspects of PV systems

Solar electricity systems are generally considered a green and environmentally friendly option for electricity. The effects on the environment are harmful in the process of making solar panels. These effects cause land, water and air pollution. The hazardous material ends up in the environment, according to the EPA (EPA, 2022).

Construction permits in Finland are depended on the type of building the system is installed in.

2.1.5 PV system installation and orientation

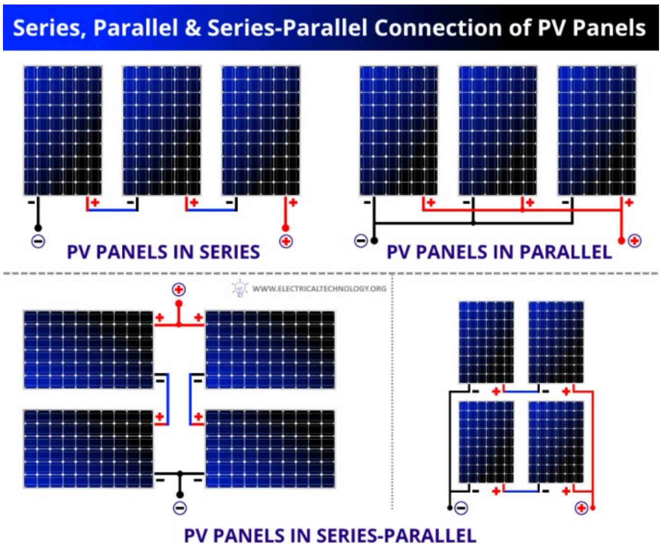
After the sizing is completed on the solar power plant, the planning phase starts. This phase consists of establish safety protocol, scaffolding, ropes, harnesses and personal protective equipment. Following the safety protocol is installation of the roof mounting. This supports the rails that the solar panels are installed on as seen in Figure 3.

Figure 3. Roof mounting and rails for solar panel installation

The rails need to be at an 18 to 36 degrees angle to achieve maximum yield. The solar panels are bolted to the rails with specially designed mounting components to ensure the panels stay attached. After the panels are installed on the rails the DC cabling is made. The panels are connected to each other commonly with MC4 connectors. The DC cabling is then attached to the inverter. It is best to place the inverter in a dry, cool and sheltered location. The inverter also has the capacity to have battery packs attached to it.

In the PV system the panels can be installed in series or parallels as seen on figure 4.

Figure 4. Series, parallel & series parallel connection of PV panels (Electrical technology, 2020)



The PV system in series has the solar panels attached to each other and then connected to the inverter. This type of system has the voltage of each panel add to the total voltage and has the effect of keeping the current regulated. The downside of this type of system is that, if there is a single covered or shaded panel in this type of system, the entire connection is crippled and will not produce electricity. (All about circuits, n.d.)

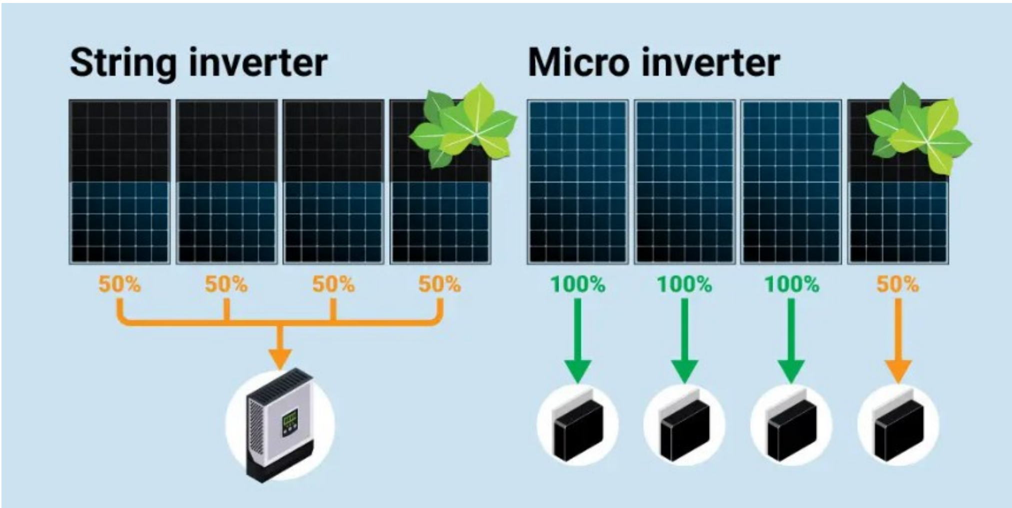
A system in which parallel installation method is used, the positive terminals are connected in a string and the same is done to the negative terminals. In this system, the current increases but the voltage stays the same. The voltage remains the same as on a single panel. The upside is the, opposite to the serial connected system, that if a single panel is covered it wouldn't affect the rest of the system. (All about circuits, n.d.)

The orientation of the system is essential. In the norther hemisphere solar, panels need to be facing true south, and in the southern hemisphere in reverse, true north. Pointing the panels facing southwest makes it able to produce more electricity when the sun is setting. The general rule for the angle of the solar panel is the latitude of the geographic location where the PV system is located according to Energy Education. (Energy education, n.d.)

2.1.6 Inverter for solar power

The inverter converts the electricity, DC produced by the solar panels, into more easily consumable AC for the household. Different inverters have various capabilities and uses. Figure 5 we can see an example between micro inverters and string inverter.

Figure 5. The difference between String inverter and Micro inverters (Solarreviews, 2023)



String inverters are the most common inverters for residential use. For a string of solar panels there is one inverter.

Microinverters are compact inverters that are directly connected to the solar panel. There are various versions of these inverters as well. The DC cable is connected directly to the microinverter. There are one or two panels per one microinverter. These then optimize each panel to produce the maximum output from each individual panel and convert it to AC. This AC electricity is then connected to the household for consumption.

Central inverters are best suited for systems that require several hundred kilowatts. Usually, central inverters are not used in residential houses.

Battery inverters are suitable for the case of battery and solar panels are required to be run through different inverters.

Hybrid inverter enables the battery to be connected to the solar system. It enables the battery packs through DC coupling and manages the charging and discharging for the battery packs. (Svarc, 2021)

2.1.7 Charging controller

A charge controller is a regulator that prevents the battery from being overcharged. This is done by regulating the voltage and current. There are diverse types of charging controllers for different purposes and uses.

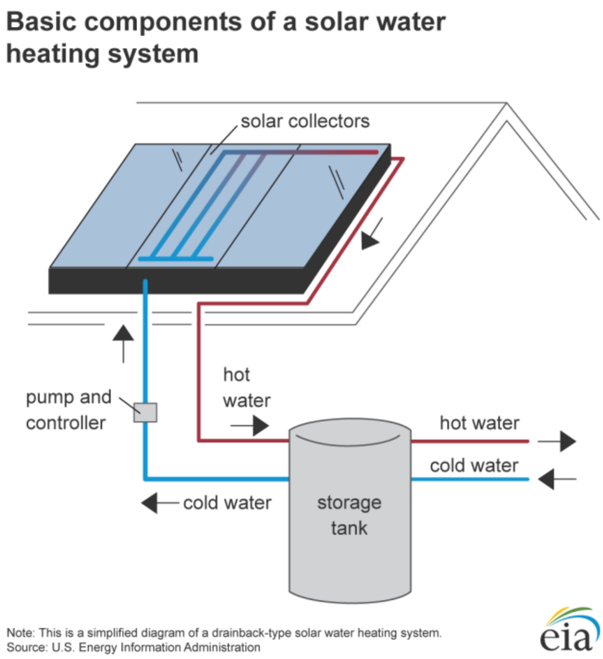
2.2 Solar thermal energy

Thermal Solar Energy is the method of harvesting the Sun's thermal energy. The energy harvested can be used for residential, industry and commercial purposes. These thermal energy harvesting methods can be classified in three distinct categories, low, medium and high temperature collectors.

2.2.1 Operating principles

Thermal Solar Energy or TSE technology gathers and produces heat using the sun's radiation. Water is heated and used for consumption. This happens by solar collectors gathering sunlight which heats up a heat-transfer fluid. The heated fluid is then used to heat up water in a tank of water which has a cold-water supply. The heated water is then consumed for many purposes, (Solar365, n.d.) One of them being residential purposes as seen on Figure 6.

Figure 6. Basic components of a solar water heating system (eia, 2022)



2.2.2 Solar thermal sizing principles

The amount of heated water required is dependent on the amount of water that is consumed. The amount of heated water consumed depends on the number of people using it and the amount that they are using.

- Low temperature collectors are generally used for heat ventilation air or for swimming pools.
- Medium temperature collectors are usually flat plates. These generally are used for water heating and air heating for residential and commercial consumption.
- High temperature collectors are mirrors or lenses that concentrate sunlight to generate heat. The temperature is 300 degrees Celsius / 20 bar for industrial use minimum.

2.2.3 TSE sizing tools

Tools for thermal solar energy assessment are easily available online for free. These include, but are not limited to, software tools based on excel type energy projection analysis. The software can calculate the optimal direction and insolation of the sun for the collectors. The software takes into account the shade and surrounding buildings and trees for the area. (Mcscertified, 2019).

All of the software that is necessary can be found online for residential, commercial and industrial uses.

There is also software to analyze the efficiency, yield, storage tank volume, collector area and many other metrics.

2.2.4 Environmental and construction aspects of TSE systems

In Finland there are no construction permits required for the construction of the system unless it has a significant impact on the environment. These can range from protected buildings or installations that affect other properties. Protected buildings have restrictions that require a special permission for the plant.

Other environmental impacts are, for example, a farm that uses high temperature collectors. These produce a bright glare that might have an impact on the neighboring properties.

2.2.5 TSE system installation and orientation

The Thermal Solar Systems can be installed on the roof, the wall or on the ground. The way to optimize the installation is to keep in mind the orientation of the collectors, the location and other outside factors that may vary in each installation.

Wall, ground and roof mounts have their dedicated versions and should be adjusted accordingly taking, into account the angle and direction to provide optimal performance from the system. The connections and overall inspection should be done by certified personnel.

The optimal orientation of the collectors is south, away from obscuring objects and shade. Windy areas are nonoptimal for this type of energy gathering. The collectors should be fairly close to the heat storage due to loss of heat. This happens between the phase of collecting the heat and storing it. The angle that is optimal in Finland is 45° according to Jäspi (2017).

2.3 Air source heat pump system

2.3.1 ASHP operating principles

ASHP or Air source heat pumps are the most commonly used heat pumps. The inside and outside unit work together to pump air. The two types of ASHP are heating and heating or cooling which utilizes a reversing valve.

The air source heat pump systems take advantage of the air outside in heating mode. In cooling it uses the outside air as a heat sink. As seen on figure 7 and figure 8. The process that is used is vapor-compression refrigeration in which the refrigerant substance undergoes phase changes. (Mindset, 2018)

Figure 7. The air source heat pump heating mode (Mindset, 2018)

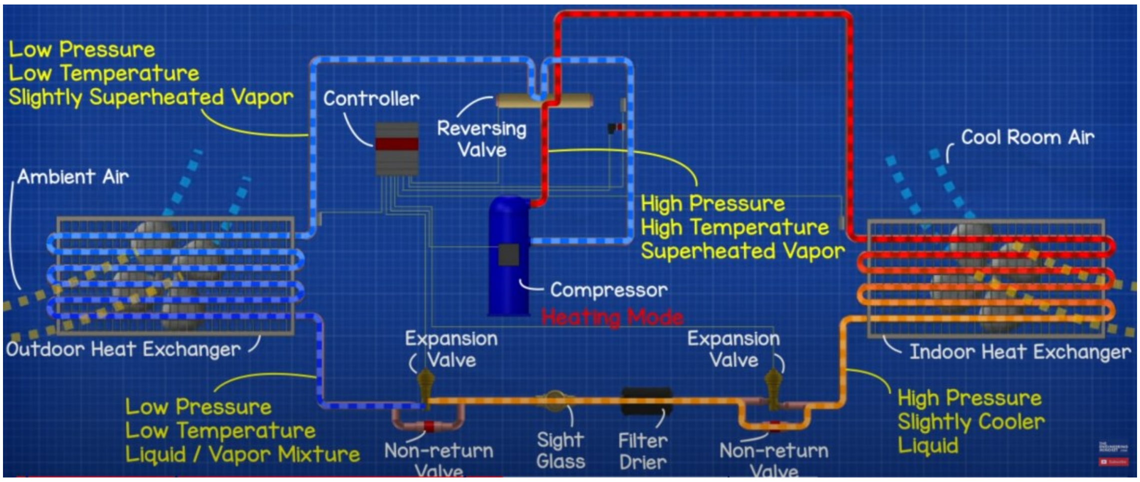
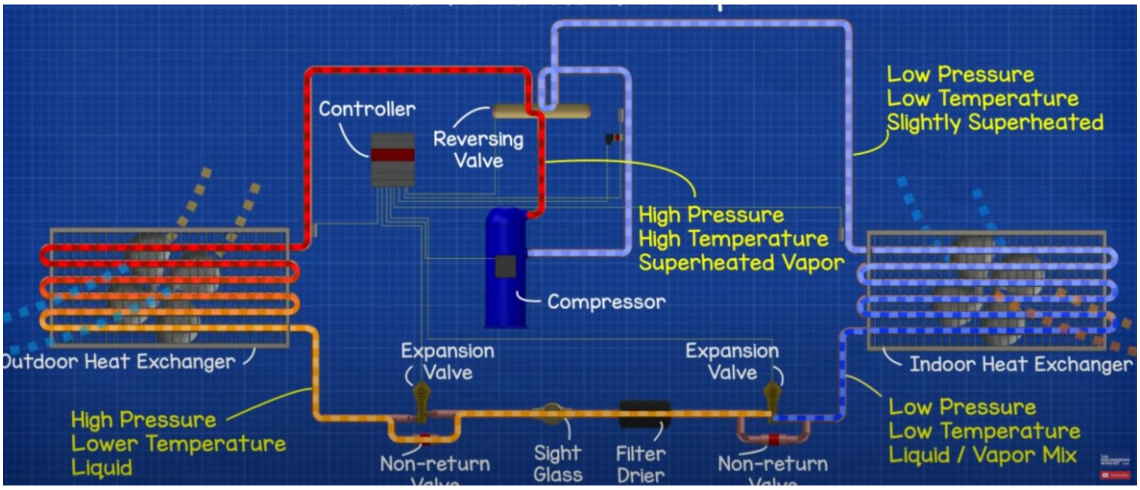


Figure 8. The air source heat pump cooling mode (Mindset, 2018)



2.3.2 ASHP sizing principles

The general principle is that the greater the area or the house, the more heating or cooling is required. The insulation also plays a key role in the buildings air temperature. As an example, a residential building with decent insulation the size of 100 m^2 may require a system with the capability to produce 5kW to effectively cool or heat the building. The range is larger for buildings with bigger area, the range 10kW in 200 m^2 houses according to (IMS Heat Pumps, 2019).

2.3.3 Environmental and construction aspects of ASHP systems

Climate change has been the hot topic issue in the recent decade. This is relevant in air conditioning due to the environmental impact of the chemicals used in heating and cooling. The refrigerant substances halocarbons (CFC's) and hydro halocarbons (HCFC's) have been shown to have negative consequences on the ozone. The refrigerants deplete the ozone and thus have impact on the climate change. (Aura Gas Limited, 2022)

Compared to the other different types of heat pumps such as ground source heat pump (GSHP) ASHP can be close to half the price of GSHP. The GSHP can range anywhere from

15,000 to 25,000 euros according to TEACHEAT (n.d.), which can be compared to the ASHP which is 2,000 – 3,000 euros according to LämpöYkkönen (LämpöYkkönen, n.d.).

Water source heat pumps (WSHP) are priced between 8,000 to 20,000 euros according to LämpöYkkönen.

The efficiency between the ground source and air source heat pumps are dictated by the “source” temperature. Therefor the efficiency fluctuates between the two when the temperature changes. The WSHP is comparable to GSHP according to (Benjamin Greening, 2012).

Air source heat pumps have the greatest energy loss thus the least efficient and having the most impact on the environment according to Greening & Azapagic (2012).

2.3.4 Installation and connection of the ASHP systems

The installation process for the air source heat pumps includes the two units, indoor and outdoor one. The composing access points inside the building, the piping connection between the indoor and outdoor units and the electrical connections.

2.3.5 ASHP and automation

Air source heat pumps have the ability to be automated with modern systems. The device has the ability to monitor the outside temperature which adjusts the flow temperature. The process optimizes the efficiency of the heat pump, thus lessening the impact on the environment. The modern heat pumps come with touch screen technology to make it more convenient for the user.

2.4 Lighting

Optimizing the lighting is essential when considering energy saving methods. Conventional light bulbs or incandescent light use a vast amount of energy more compared to the modern LED bulbs. The energy saving is more than 75% when using LED lights. The difference when using low power levels is even greater. Bright LED lights use 11 to 12 watts of power but creates an output comparable to a 50W incandescent light. According to (Arcadia, 2020). On Figure 9, we can see the difference between the different light technologies.

Figure 9. Incandescent, CFL, and LED comparison (Arcadia, 2020)

Using LED lighting, we can also have smart controls for the user. Some modern LED lights have the ability to be integrated to a smart home system thus being controlled by the existing google home assistant with voice controls. We can also have the option to add LED strips that are RGB colored. Mood lighting, dimmer, less eye straining colors for nighttime and indirect lighting to make it aesthetically pleasing, as seen on Figure 10.

Figure 10. Mood lighting LED light strip

2.5 Automation

Google home assistant allows the user to control smart devices that are connected to the same network. The user is able to send commands to the device using a PC, smart device such as a phone or tablet or using voice commands (Google Assistant, n.d.).

One such command can be “hey google turn on living room light” the google home assistant device then sends a command and the smart light which has previously been connected to the same network turn on.

Using this we can time lights outside and inside to save energy. Controlling the lights so that when the sun rises or sets, we can have the lights turn on or off. The sun doesn’t rise or set at the same time each day thus the device updates the time when lights are being used. Such as in turn lights on after sunset +30 minutes. This will turn the lights on 30 minutes after the sun has set, and adjust it daily to match the time when the Sun actually sets. We can see an example of this in Figure 11.

Figure 11. IKEA Trådfri Home smart 1 app timer

On this app, the user is able to set the turn on lights and turn off lights time. In this example, the lights turn on 15 minutes after the sun has set. The turn off time is set to 23:00 at night, which being the time the user does not want to have the lights on. This then repeats from the selected dates. Then the user is able to determine which devices are connected to this timer for the user's convenience.

2.6 Hot tub

Arduino is an easy-to-use hardware and software solution to control devices. The boards are able to read inputs such as light, finger on a button, or even a social media message, which can be turned into an output that has various uses according to (ARDUINO.CC, n.d.). Arduino boards are inexpensive and can be a simple solution for a small automation project such as controlling a hot tub heating and water devices.

3 Energy consumption

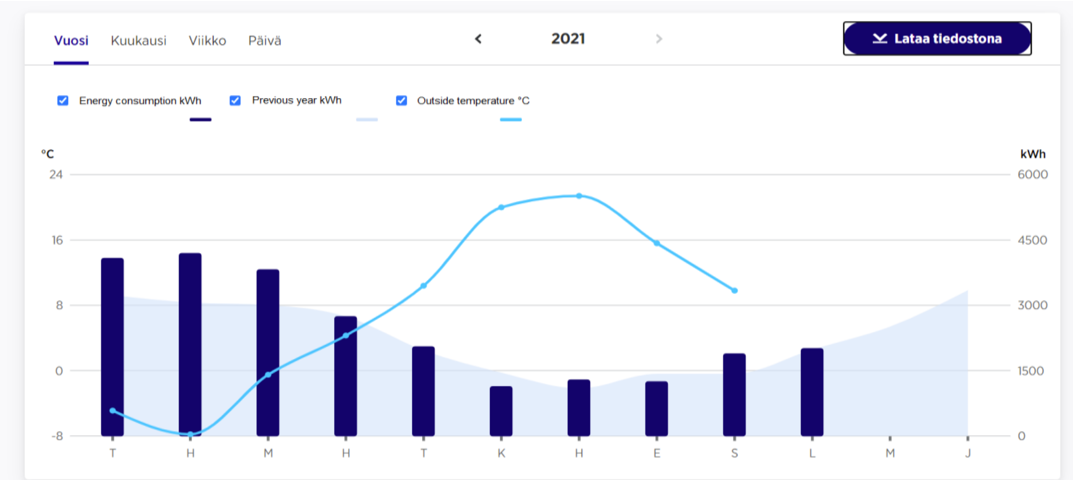
3.1 Examining the current energy consumption

The air source heat pump is used to keep the house warm during the winter months. This is paired with a wood burning stove that assists the ASHP. The residential building previously had fully electric heated radiators but has been modernized by removing radiators from common areas and replacing them with ASHP. The bedrooms are heated with radiators which use electricity. During the summer months the ASHP provides AC in cooling mode.

The air source heat pump used is the Mitsubishi SRK25ZJX-S. The capacity for cooling, 2,5 – 2,9kW and heating of 3,2 – 4,2kW.

The energy consumption during the winter months is higher due to the constant heating required. Especially during the colder winter months, the energy demand is high. This is evident when looking at the statistics gathered from the house’s owner. In figure 12, we can see the correlation between the temperature and energy consumption. After analyzing the statistics from the year 2021, we can clearly see that during colder months the energy consumption is higher due to nonstop heating. As the temperature rises, we can see the correlation of energy consumption lowering. During the summer months, as we reach the threshold of temperature versus energy consumption, we see a shift that switches from warmer the less energy consumption to back to energy consumption rising due to air conditioning cooling. The ideal temperature for a house is between 20 to 22 degrees Celsius. in the chart, we clearly see that energy consumption starts to pick up again after we go beyond the ideal upper limit of 22 degrees Celsius.

Figure 12. Energy consumption correlates with temperature

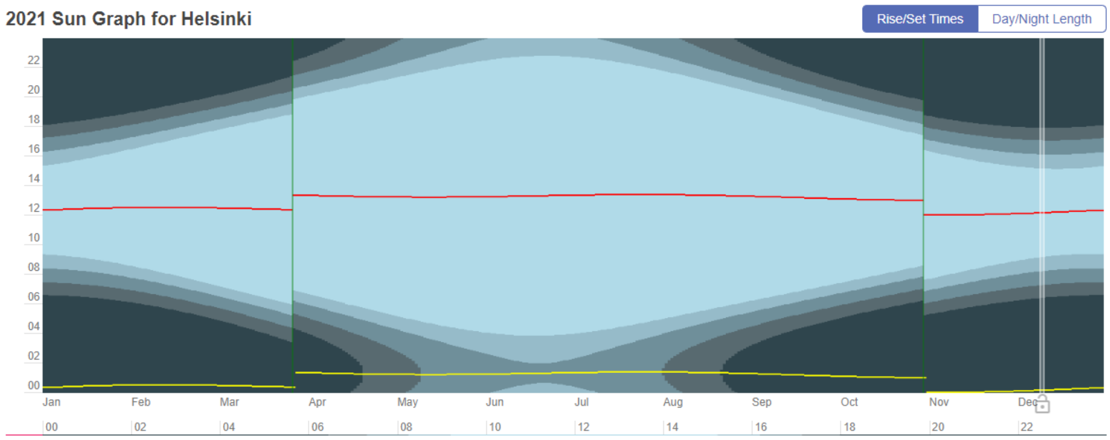


Analyzing the previous year marked on the chart with the lighter color blue we can determine that the temperature during the winter months has been warmer due to the energy consumption having been lower than the year 2021. During the summer months the summer must have been warmer, thus the need to have been using more energy to cool the residential house.

We can also determine from the chart that during the winter months solar energy power plant work less efficiently due to the lack of visible sunlight and short days where the Sun isn’t visible. Thus, energy consumption is higher due to nonstop heating required, because of the lower temperatures outside, and the correlation with energy not being produced due the darkness of the Finnish winter seasons. During the summer months the solar energy power plant is at its most efficient. We can determine this when examining the chart and keeping in mind the effects of solar electrical energy. We can observe that energy consumption is amplified during different seasons, particularly in summer when we receive more energy from the abundant sunlight. The effect being that during the summer months we use less energy from cooling the residential building when the solar energy power plant is more efficient.

We can look at the Sun graph data gathered to prove that sunlight availability in Finland winter versus summertime is drastically different, as seen in figure 13. There is a difference between summer and other seasons in terms of sunlight availability. During summer, we have 18 hours of daylight between 4:00 and 22:00, according to time and date. (Timeanddate, 2021). This difference is exceptionally greater than compared to the winter when the sun is at its lowest, available for six hours from 09:00 to 15:00. The solar power plant also accumulates snow on top of the solar modules, so the effects of the sunlight gathered is hindered to an even lesser extent.

Figure 13. 2021 Sun graph for Helsinki (Timeanddate, 2021)



3.2 Energy comparison

Energy production using a PV system has been installed in the target building. The Solar panels that produce 5.7 kW worth of power and have an inverter that is rated at 6 kW.

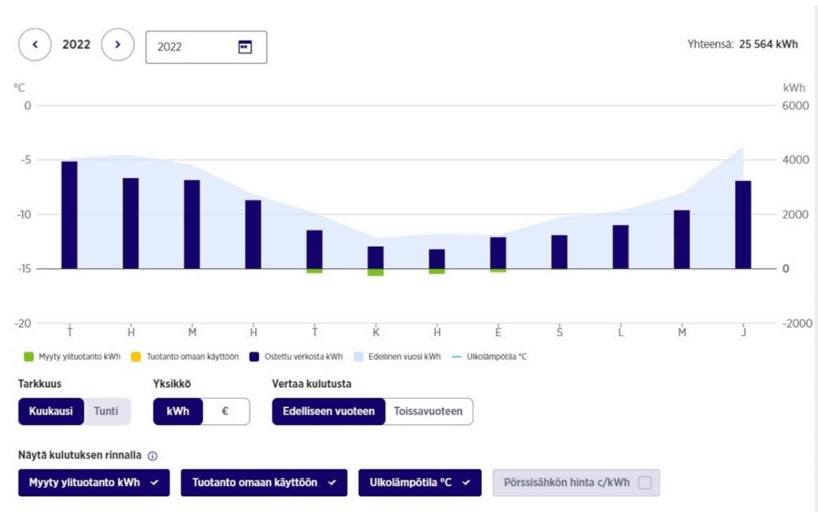
4 Collected data

The data collection has taken place between 2021 and the first quarter of 2023. During this time, we've been optimizing the energy efficiency of the house and collected data along the way with the homeowner.

4.1 Examining the collected data

Energy consumption from the year 2022, from January through to December, totaled 25,564kWh. In Figure 14 we can see each month's consumption in kWh, and how different seasons play a part on the expenditure of energy. During the summer season we see the effects of solar power play a part in energy consumption. The temperatures were high during July and August, so the AC unit was running full power around the clock.

Figure 14. 2023 energy consumption chart of the target building



The months between April and September varied in terms of energy usage, had a significant drop compared to last year's consumption. In Figure 15, we can see the energy sold to the grid, bought from the electric company and the previous year's consumption.

Figure 15. 2022 energy consumption chart spring to fall

The chart above shows the amount of energy purchased from the electric company in dark blue. Above that in green we can see the amount of energy sold to the grid. This is due to the solar power plant producing power during the daytime, when there is sunlight available to be harvested. During the peak times of solar energy production, we can determine from the chart that the production of electricity surpasses the consumption. This is then sold to the grid as the demand is not as high as production. The amount purchased from the grid then is reflected when there is no energy production, in times such as:

- Early in the morning when the sunlight cannot be utilized.
- There is heavy blockage of the solar system such as clouds.
- Late at night when the sun has set, sunlight cannot reach the panels.
- During the night, when energy is used and it is dark outside.

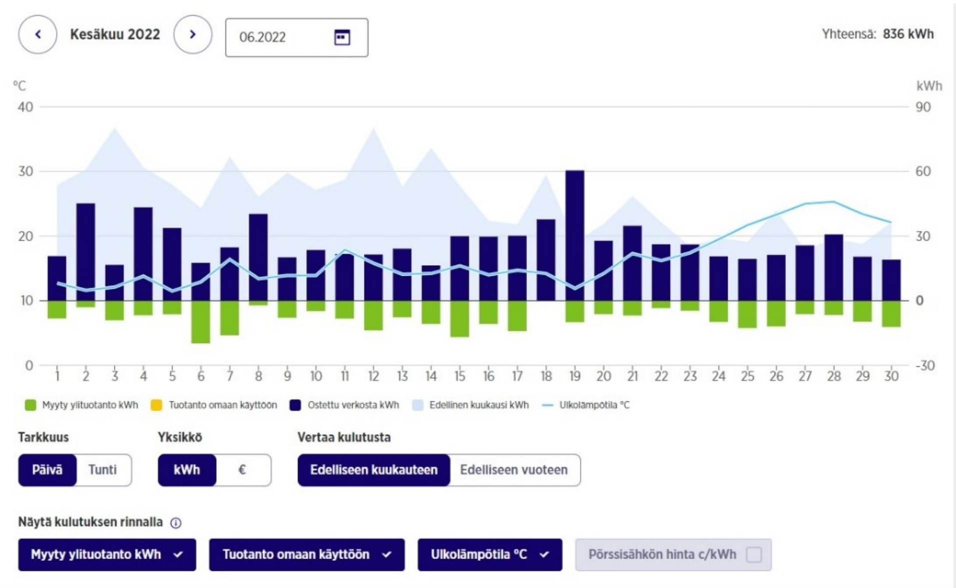
We can clearly determine that the solar energy powerplant we installed is verifiably working. The chart shows when comparing the years 2021 and 2022 we can see a monumental difference in energy purchased from the electric company. This gap changes during the different months, but this is due to the variables changing. These are the differences in weather, temperature and the optimization of energy consuming devices.

4.2 Solar electricity production

The electricity production, as seen in Figure 15, changes between the months and peaks during the summer months at 273,62kWh when it is sold. The production is largely due to the Sun providing optimal light when collecting solar electrical energy.

In Figure 16 we can see the variance of energy produced, the temperature, amount of energy produced and the date of the month.

Figure 16. 2022 June energy chart



The temperature fluctuations seem to have an erratic effect on the production vs consumption relationship.

5 Energy efficiency benefits

5.1 Target building

The target building for this thesis is a 1984 wooden detached house located in Akaa, Finland. The area for this building 176 m^2. The residential building has six rooms with a kitchen and sauna that uses hybrid wooden and electrical heating. The residential building also has an attached heated garage. The house has three adults and a child living in the building. The property has a detached building, which includes a two-room guest house and a studio.

The energy was a direct electricity for heating, an air source heat pump for HVAC needs and a water accumulator for water heating.

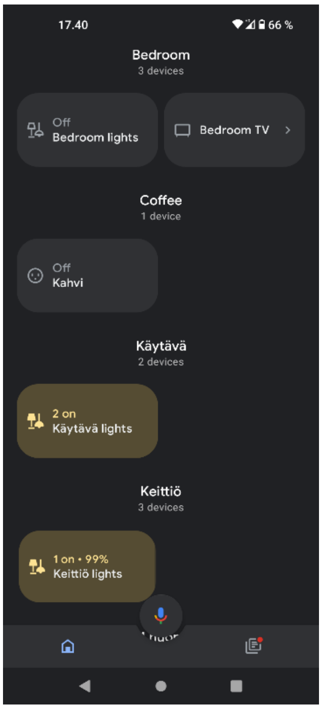
The house residents utilize google home to control smart lighting. This is currently only used in a few lighting devices and hasn't been fully utilized to control all lighting.

The advantage of using smart home systems, such as google home app, as seen in Figure 17, connected to a smart home system, is the ease of controlling all the devices connected to it. This is mainly a convenience factor.

Configure your smart home system to turn on your coffee maker when you turn off your alarm clock, as well as to turn on specific lights at a dimmed brightness and in an easy-to-view color. Movement sensors that turn on a light in a room when the said room is entered and when no movement is detected turn off the lights. The utility of a smart home system enables the users the convenience and the energy savings.

Timing the devices to turn on and off at set times is convenient, but also plays a role in energy savings. The ability to control electrical devices with a smartphone from a different city is advantageous and practical.

Figure 17. Google Home app connected to a smart home system



5.2 Benefits of energy efficiency

The results of the energy efficiency project will be shown in the future, as the consumption and the amount of electricity purchased from the electric company is decreased. The slope down is shown in relationship with the improvements done upgrading the house, such as changing the stove to a modern energy efficient one, a modern refrigerator and freezer along with other home appliances. A lot of improvements have been made, but adjustments and further energy efficient solutions in the future need to be met with analysis and potential adoption.

5.3 Maximizing energy efficiency additions

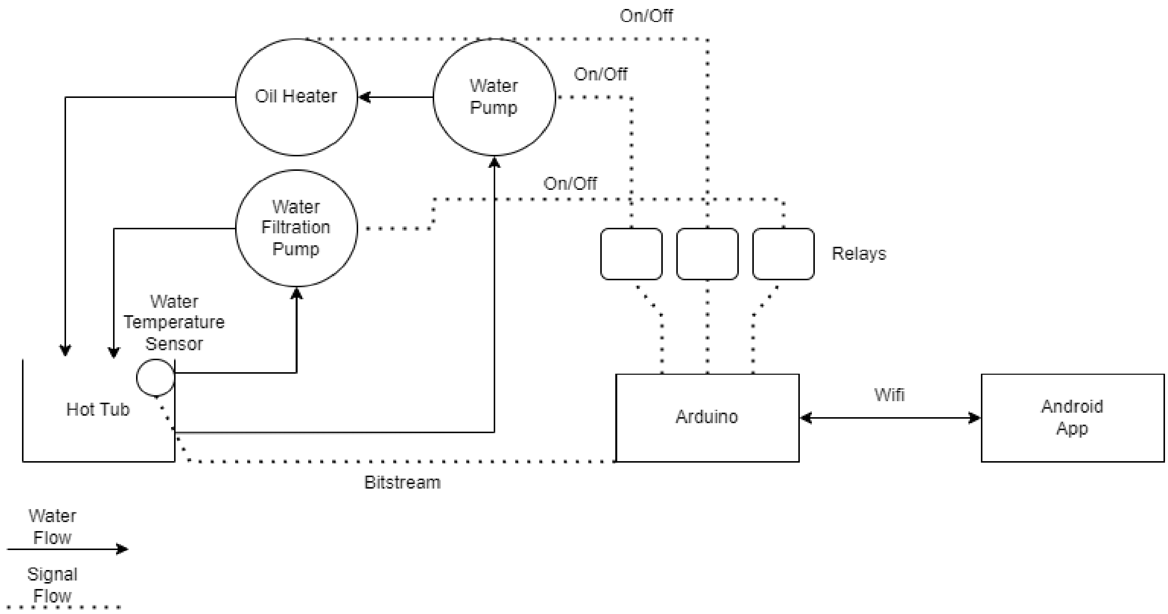
We wanted to make a "DIY" or do-it-yourself type solution to the hot tub that is always ready. The plan was to have the oil heater to heat the water, save water and time by not having to refill the hot tub with each use. The decision was made to use an old oil heater that was designed for a house, which has its own thermostat to control the water exiting from the heater. We used a sand filtration water pump, which was designed for pools and chemicals to keep the hot tub water clean and full of water. This way, we were able to solve the heating and water, in addition to keeping it clean.

There were some issues that arose quickly. The oil heater was too powerful for the small amount of water which was in the hot tub. This is good in a way that the water can be heated quickly, but the downside was that it was hard to control the temperature of the water in the hot tub. If the heater was kept on constantly the water would become too hot. During the winter, the pipes would freeze if the system wasn't running daily. The decision was then made to create a DIY automated hot tub heating system.

Arduino control relays were used that would switch electrical sockets on and off for three devices in the system. These devices were: filtration pump, oil heater and water pump to circulate water through the heater. We connected a temperature sensor to the Arduino to check the true temperature in the hot tub. An Android app was used to send commands to Switch pumps on and off, measure temperature and launch different modes of the system, for example a winter mode.

The Arduino was coded using the basic Arduino programming language, and the software creates a TCP server that runs on the Arduino, and sends and receives html commands via WIFI, in our case, inside the home network. The Arduino reads the bitstream from the temperature sensor and sends the decoded temperature in Celsius to the TCP server, which can be read with the Android app. The Arduino can receive commands from the TCP client (Android app) which includes: The water pump, oil heater, filter pump, winter mode and heat mode. Based on the command, the Arduino will give a relay a command to switch on or off via digital pins on the Arduino. The pumps are controlled with the relays and the different modes have been coded to the Arduino software. They have to be manually launched with the Android app. The structure of the hardware is shown in Figure 18.

Figure 18. The structure of the hardware in the system

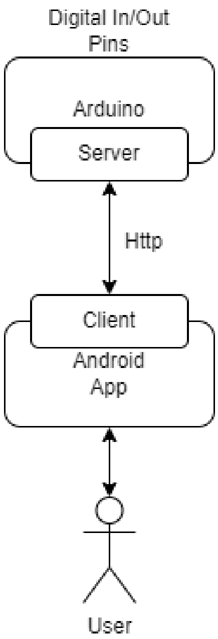


The heat mode is automated to monitor the hot tub water temperature. The heater and water pump are turned on until the water is at 37 degrees Celsius after which it turns the heater off. The oil heater preserves a large amount of heat energy as a result it keeps heating the water if the circulating pump is on. The circulating pump is kept on until the water reaches 38 degrees Celsius after which it is switched off. The heater and the pump will start the process again after the temperature of the water drops to 36 degrees Celsius. This is a simple control system, but it works as intended and the results were excellent.

In winter mode the system is on all, the time, except when the hot tub is in use the system is switched to heat mode. The winter mode works in the way that the system runs the heater and all pumps for one hour every six hours. This is used so that the pipes don't freeze.

The filter pump has its own built-in timer so that it runs continuously for four hours every day. When the hot tub is used in heat mode, the filter pump is on all the time. The Figure 19 flow chart below shows the process of the system.

Figure 19. Flow map of the system



The Android app home screen is shown in Figure 20. The app runs on a wall mounted tablet, which is placed inside for the convenience of the residents. From the app, where it can be monitored. The temperature of the water and with buttons choose the different modes or manually control separate pumps. The GUI, or Graphical User Interface shows either a red light next to the button, if the device is off, or a green light if the device is on.

Figure 20. The home screen of the Android app

6 Energy efficiency conclusion

During the energy efficiency project, we've seen a dramatic decrease in consumption and rise in electricity production. These were achieved by changing the heating systems with energy efficient air source heat pumps and removing the old electric radiators. Solar collectors heat water that can be consumed in a much more energy efficient way.

The lighting was modernized with LED energy efficient lighting, automating said lights with Google assistant and making mood lightings that can be changed by the users.

The hot tub was automated with Arduino and an Android app to control the pumps and heaters. This was a major upgrade to the previous system and has been a significant quality of life and energy-cost-saving method.

A Solar energy power plant was installed and creates electricity that can easily exceed the demand and sell the excess to the grid during the spring and summer months. The investment has truly made a difference in energy consumption according to the residents.

7 Conclusion

In conclusion, I wanted to find diverse ways in which the house owner would be able to adapt new methods in energy optimization. The project started several years before the start of this thesis, so the opportunity to enhance the project with research and findings from the thesis to truly optimize energy efficiency in the single-family house.

I was able to make a difference with researching and coming up with new methods and actually implementing them in real life while monitoring the results by analyzing data. The data collection was an important aspect of this thesis.

Being able to automate the family's home with smart lighting and control the hot tub with ease through a smart device were great bonuses that enhanced the quality of daily living.

The research showed that with simple steps we were able to have a significant effect on energy savings. This has required investments, ranging from smaller purchases, such as cheap LED lighting, to the more expensive investments, such as the solar electricity power plant that is now planted on the resident’s backyard. In this project, there were several larger devices that were carefully examined and scrutinized before implementation.

Although a lot of implementations were manufactured while researching, the energy efficiency project is ongoing. The project’s progression is a steady upward slope in energy savings.

When looking for ways to cut costs by using energy-efficient devices and methods, it is important to weigh the pros and cons of each option. Ask yourself whether a particular method is suitable for your specific case and whether it would work well in your situation. Additionally, consider the costs and potential benefits of each option before making a decision.

Conducting this research and applying it to real-world scenarios has significantly improved my ability to analyze and implement new ideas. If the project had only resulted in theoretical energy savings, it would have been vastly different. However, seeing the actual results in action was a brilliant experience.

The feedback from the homeowners has been positive, so I consider this project to have been effective and successful.

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