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D2.4

Catalogue of innovative energy saving technologies.

This project has received funding from the European Union`s Horizon 2020 research and innovation programme under grant agreement No 785147.

Document history

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0 Publishable Summary

This catalogue describes examples of innovative energy saving technologies, which can be used in housing associations in combination with more traditional energy retrofitting measures.

The innovative technologies are primarily in the field of local CO2 neutral, energy supply of buildings in housing associations, heating supply as well of supply of electricity.

The catalogue provides information about the specific technology, its integration in the building system, the energy saving potential and investment need.

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1 Electricity Production

1.1 Solar Cells

1.1.1 Theory.

Solar cells are an electrical device used to convert sunlight into electricity. When sun rays strike the solar cells, both current and voltage gets produced, causing the generation of electric power.

In general, a solar cell has two light-absorbing layers, called the emitter and the base, consisting of semi-conducting material such as Silicon.

The top layer is the emitter, or n-type layer, and is negatively charged due to excess electrons i.e. the majority carrier being electrons. This is caused by doping the layer with e.g. phosphorous.

The bottom layer is the base, or p-type layer, and is positively charged, due to missing electrons i.e. the majority carrier being holes, caused by doping the layer with e.g. boron.

On top of the emitter, front contacts are placed and in between the contacts the emitter is coated with an antireflection coating.

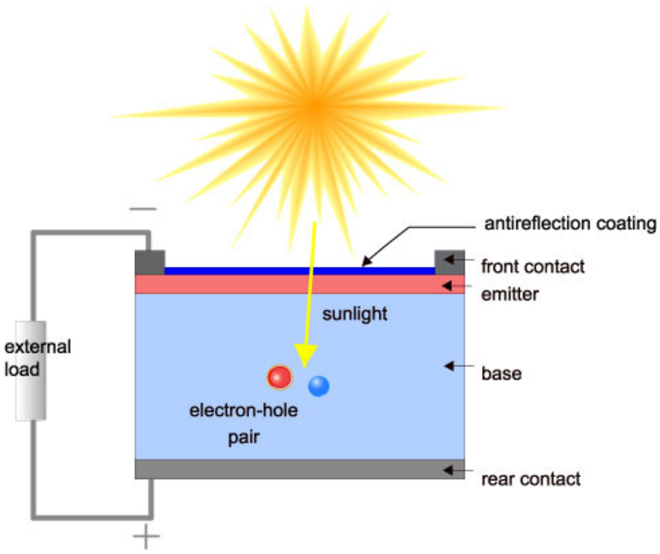

Figure 1 Cross section of a solar cell[1].

Sunrays consists of photons, i.e. energy in the form of electromagnetic radiation from the sun. When these rays strike a solar cell, the energy of the photons cause electrons to reach a higher energy state. When an electron reaches a higher energy state, it leaves a hole behind, and hence an electron-hole pair has been created.

For the solar cell to generate power, it generates a voltage as well as a current. This is carried out by exploiting a process called the photovoltaic effect.

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When two different materials are put together, an electric field is established at the junction, due to the separation of charges.

If connecting an external circuit with a variable to the solar cell, it becomes possible to manage the current and the voltage across the cell, yielding the opportunity to maximize the power output.

1.1.2 Mono-crystalline Cells

Mono-crystalline solar cells, also known as single-crystalline solar cells, are easily recognizable by their color. They are made from high purity silicon, causing the cells to have a uniform dark (black) color.

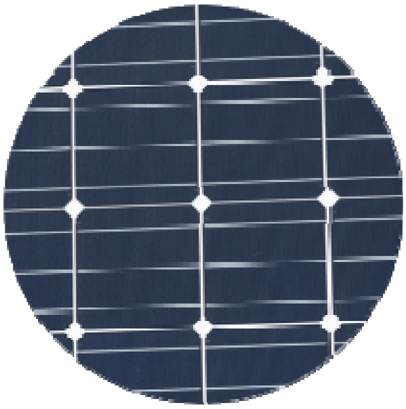

Figure 2 Mono-crystalline solar cell.

The main difference between mono- and poly-crystalline solar cells is the way the silicon wafers are produced. For mono-crystalline wafers, high-grade silicon is melted at a high temperature. Then, a small mono-crystalline silicon ingot is lowered into the melted silicon and slowly pulled up while rotating. This yields a bigger mono-crystalline ingot, which can then be further processed. Due to cells being square, the round ingot gets cut into a square, before being cut into wafers for the actual cell. Cutting off sides of the ingot leaves a lot of high-purity silicon waste. To minimize the waste, mono-crystalline cells usually have round corners.

The efficiency of the mono-crystalline solar cell is around 13-17%[2].

Advantages and disadvantages of mono-crystalline solar cells include:

<u>Advantages:</u>

- Mono-crystalline cells have the higher efficiency compared to poly-crystalline cells and thin-film cells.
- Aesthetically, this type of cells tends to be the nicest and most suitable for building-integration.
- Most space-efficient due to high efficiency.

<u>Disadvantages:</u>

2. http://solcelleforening.dk/fakta/solcelletyper/

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- Processing the round ingots, by cutting off 4 sides to yield a square, leaves a great amount of waste.
- More expensive, due to higher manufacturing costs, compared to poly-crystalline solar cells.

1.1.3 Poly-crystalline Cells

Poly-crystalline solar cells, also known as multi-crystalline solar cells, are recognized by usually having a brighter blue color, compared to mono-crystalline cells, and having a mottled look. Just as mono-crystalline cells, this type of cells is made of silicon.

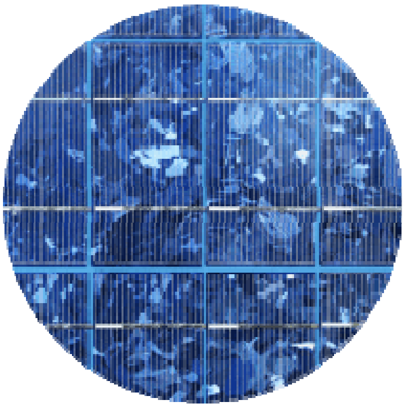

Figure 3 Poly-crystalline solar cell[3].

The manufacturing process of poly-crystalline cells are easier compared to for mono-crystalline cells. To produce the square ingots for the wafers, silicon is melted in a form and cooled down gradually from the bottom. By doing this, the silicon slowly crystallizes, yielding the characteristic mottled look of the poly-crystalline cell. After cooling down, the block is cut into square ingots and wafers afterwards.

The efficiency of the poly-crystalline solar cell is around 12-14%[4].

Advantages and disadvantages of poly-crystalline solar cells include:

Advantages:

- Manufacturing process is easier and hence cheaper.
- No wasted silicon from the wafer manufacturing process.

Disadvantages:

- Not as aesthetically pleasing compared to mono-crystalline and thin-film cells.
- Due to a lower efficiency, compared to mono-crystalline cells, the solar array tends to become bigger.

Solar cell panels can also be manufactured in **other surface colors:** White, green, red.

[3] https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels
[4] http://solcelleforening.dk/fakta/solcelletyper/

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1.1.4 Thin-film cells

2nd generation solar cells include thin-film cells. The color of the cells is homogeneous and is usually black or dark brown. As opposed to mono- and poly-crystalline cells, thin-film cells do not have a crystalline structure. The light-absorbent of the cell varies depending on the type of thin-film cell. Different types of thin-film cells with various absorbent material.

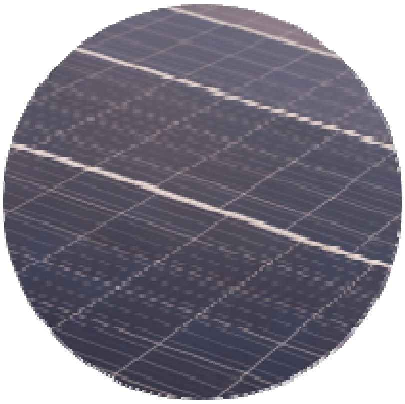

Figure 2 Thin-film solar cells[5].

This type of solar cells is made by deposing the photovoltaic material onto a substrate, e.g. thin film. Another possibility is by enclosing the photovoltaic material between two sheets of flexible plastic, which opens new opportunities for innovative use.

Thin-film solar cells are compelling due to the low use of photovoltaic materials. This, together with the fact that the manufacturing process is simple, makes thin-film cells cheap to produce and make the technology suited for large scale purposes. Another compelling argument for thin-film cells, and probably one of the most important, is the fact that this type of solar cells have the least impact on the environment, compared to other types of cells.

The efficiency of thin-film cells varies from 6-10%[6].

Advantages and disadvantages of thin-film solar cells include:

Advantages:

- Manufacturing process is simple, and the use of photovoltaic material is low. Hence, making this type of cell the most cost efficient.
- Least impact on the environment.
- New possibilities of implementation, due to the opportunity for cells to be flexible or transparent.

Disadvantages:

[5] https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels
[6] http://solcelleforening.dk/fakta/solcelletyper/

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- Low efficiency compared to crystalline solar cells.
- Thin-film cells tend to degrade faster compared to crystalline cells causing a shorter lifetime.

1.2 Solar Roof

Figure 3 Ennogie solar

A solar roof is where common roofing, such as concrete roof tiles, are substituted by a new type of tiles with integrated solar cells. There are almost no boundaries to whom might use this type of roofing. The solar cells integrated in the roof are thin-film cells. The solar cell panels are based on tempered glass with no frames. The panels have a homogenous black color that is suitable for most building types.

The base of mounting the solar roof is similar to the mounting of traditional roof types, i.e. the solar roof can be mounted on a fixed underlay or a traditional roofing underlay. Before mounting the solar panels/tiles, an inverter drawer must be installed at the bottom of the roof surface, due to the solar roofs use of micro inverters. By using micro inverters, the solar roof increases the operational safety and reduces effects from shading. If it is not possible to cover the full roof area, due to the design of the roof, adapter module has been developed. This module is not a solar cell, but the design is similar, and it gives the opportunity to modify the module as desired.

At average, a solar roof from the Danish company Ennogie produces around 70-100 W per m^2, corresponding to about 60-90 kWh per m^2 per year. Cases show that this output usually is enough to cover about 70% of a household's electricity consumption, and if adding a battery to the system the solution could result in a 100% self-sufficient household.

1.3 Solar windows.

If an energy retrofitting project includes new windows, it is possible to integrate solar thin films in the window/glass.

The solar thin films are transparent, and daylight will still enter the rooms, and it will still be possible to look through the windows.

1.4 Energy savings from solar cells.

The energy output from solar cells varies between 100 kWh/m2 to 150 kWh/m2 electricity per year depending on the type of cells (thin film to mono-crystalline) and depending on the placement of the cells.

The solar cells are normally connected to the public electrical grid, unless the building has its own battery storage for the solar system.

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If the solar cells are connected to the grid, it is important to optimize the size of the solar cells according to the variation of the electricity consumption in the building.

It is not feasible to export the surplus produced solar electricity to the grid in periods, where the electricity consumption in the building is lower than the production of solar electricity.

A thumb rule is, that the area of the solar cells is dimensioned, that 80 % of the produced solar electricity can be absorbed hour-by-hour in the building.

1.5 Investment in solar cells systems.

A solar cells system installed on a building will typically cost 250 Euro per m2 cells including inverter and electrical installations and excl. VAT. This price is for solar panels mounted on roofs.

If the solar panels are integrated in the roof or in the facade, the investment will typically be 25% higher, because typically it will mean more construction work and a new underlay to the roof.

These investment prices are typical in combination with energy retrofitting of buildings. Solar systems for new buildings will be cheaper, because it is cheaper to integrate solar panels in new buildings.

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2 Small Wind Turbines

An alternative to solar cells can be small wind turbines placed close to the buildings.

However it is often very difficult to get approval from the authorities to install a wind turbine in

the local neighborhood.

There are normally 3 strict requirements to be met for approval of small wind turbines.

The first requirement is distance from the buildings. A small wind turbine needs to be installed maximum 30 meters from the building in city areas.

The second requirement is regulation of noice, which is extremely difficult to meet in city areas.

The third requirement is shadows from wind turbines. Here it is also very difficult to meet these requirements in local neighborhoods.

Therefore the recommendation is not to plan small (or big) wind turbines in neighborhoods in urban areas, but only outside cities.

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3 Storage

If generating energy, one important aspect is to consider adding a storage opportunity for the system. The reason for this must be found in the settlement rules for power production. Almost all solar plants in Denmark are destined to settle the generated energy on an hourly basis or momentarily basis. Either way, it is very important to design the electricity production for the demand as exact at possible. The reason behind this is electricity price. If producing more electricity than demanded, the excess electricity must be sold and delivered to the public electricity network. When sold, the settlement price is the actual market price at the moment of the sale and is determined by Nord Pool. This settlement price tends to be much lower compared to the settlement price when buying electricity, and hence it becomes economically profitable to use as much of the generated power in house.

This is where a storage system comes into play. If considering having a solar cell system, the majority of the electricity is produced during the day, when one does not have the opportunity to use it all. Hence, this would not be profitable economically. But if having a storage system, it would be possible to store the produced electricity and use it in the evening, or during the night, when the demand is on it highest, and the solar cell system is not producing energy. Therefore, by designing a system giving the opportunity to use the produced energy when it is needed, one will achieve the most profitable economy of the system.

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4 Batteries

A battery is a device able to convert chemically bonded energy into electrical energy. Usually, a battery consists of 2 materials, physically separated by a chemically permeable membrane, which are then immersed in an electrolyte. The two materials act as positive and negative electrodes respectively. The negative electrode is called the anode, and the positive electrode is called the cathode.

When applying either a load or a charge to the electrodes, a chemical reaction called redox takes place. Redox is short for reduction-oxidation reaction and is a double reaction, where one of the reactions releases electrons (oxidation) and the other reaction gains electrons (reduction).

When the redox reaction occurs, the battery either charges or discharges, depending on whether a supply or a load is connected.

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5 Batteries for buildings.

Electricity storage is a key technology in effective utilization of renewable energy sources like solar and wind power. Local electricity storage opens the possibility to take advantage of fluctuating electricity price. An increasing demand of batteries from many sectors have led to continuous development in battery technology. In the following, three technologies are reviewed with a focus on application in housing associations. The following table presents the three technologies, their installation cost and the amount of cycles they expect to perform.

Battery Type	**Installed Cost Range**	**Service Life Range**
Vanadium redox flow battery	Euro 285 to 945 per kWh	12,000 – 14,000
Lithium-ion (lithium iron phosphate)	Euro 180 to 760 per kWh	1,000 – 10,000
Flooded lead-acid battery	Euro 95 to 425 per kWh	250 – 2,500

https://solarbay.com.au/vanadium-batteries-commercial-use-pros-cons/

5.1 Redox flow

Redox flow batteries differ from other battery technologies, as it is made of two tanks filled with electrolyte-fluids, a membrane and an engine/pump. A set of two tanks is called a stack and consists of a cathode-tank containing positive electrolytes and an anode-tank containing negative electrolytes. By adding and removing energy, protons moving from one side to another leaves one tank with a greater positive charge than the other.

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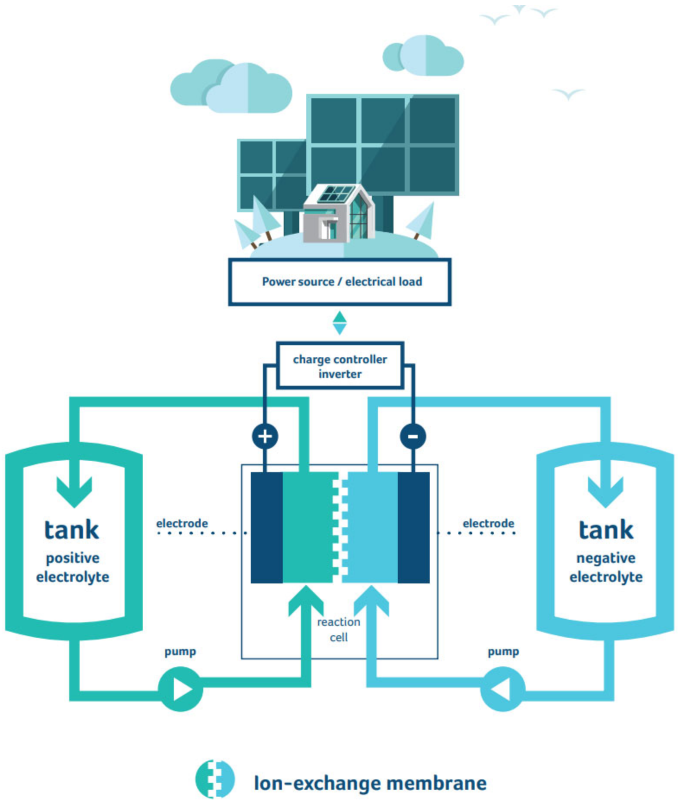

Figure 4 - Diagram of a redox flow battery[7]

The size of the tanks determines the battery capacity, and the power output needed determines the number and size of the stack cells. The volume of the tanks is relatively high compared to solid batteries: The space requirement is according to Visblue[8] 50 m^3/MWh. UniEnergy Technologies has in promotional material suggested, that an installation with 240 MWh storage capacity would occupy a land area of 4000 m2 [6]. This corresponds to a land use of 16.7 m2/MWh, which is a very low space requirement for a redox flow battery but still 2-3 times more than Lithium-ion and led-acid batteries.[9] The system can be tailored to meet specific needs of the housing association. The battery is easy to upgrade, if the housing association's electricity pattern or energy needs change, as it is built for disassembly.
The environmental impact of the redox flow battery is good, as the liquid can be reused or recycled. Furthermore, the battery is non-flammable, as most of the liquid solution is water. During extended periods of high demand redox flow batteries can respond effectively, but they may be unable sudden demand peaks[10]. Redox flow batteries are not slow; in fact they are among the fastest technologies, just not as fast as the lithium-ion.

The lifespan of redox flow batteries is long compared to other battery technologies. The membrane must be replaced after approx. 20 years or 20,000 cycles, but the fluids can be reused. A redox flow battery is not affected by depth of discharge. Operating temperature in the range between -10 °C and 40 °C. The long service life comes with a higher upfront cost compared to other types of

[7] https://visblue.com/assets/6413_visblue_profilbrochure_eng_final2_hi.pdf
[8] https://visblue.com/staff.html
[9] https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_energy_storage.pdf p. 144
[10] https://solarbay.com.au/vanadium-batteries-commercial-use-pros-cons/

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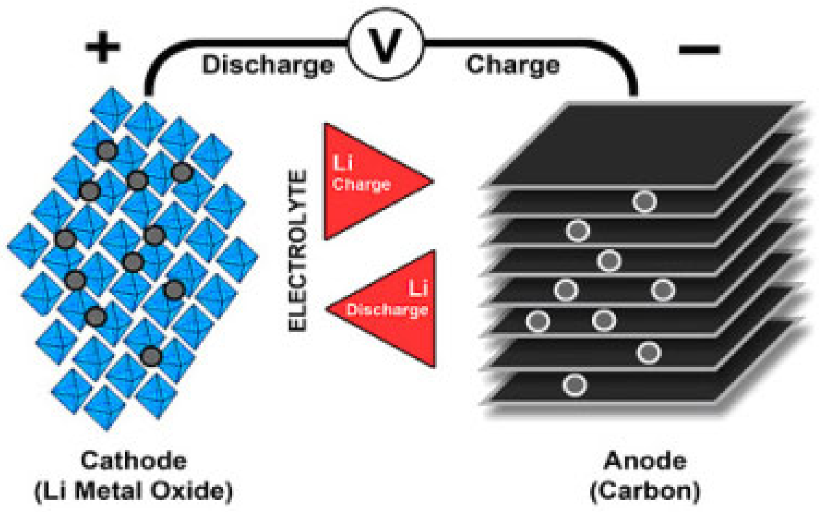
batteries. The price for small battery-packs (5-40 kWh) is approx. 1000 €. Prices for redox flow batteries are decreasing as is also the tendency for Lithium-Ion batteries.

Pros	**Cons**
✓ Environmentally friendly as liquids can be reused or recycled.	✗ The battery is not as compact as the solid batteries – requires more space
✓ Fire-resistant as the energy is stored in a liquid electrolyte, which mainly consists of water.	✗ Unsuitable to rapid changes in power demands
✓ Scalability	✗ High installation cost

5.2 Lithium-Ion

A Lithium-ion battery is made of many smaller batteries called “cells”. The electrical current reaches the cells via conductive surfaces e.g. aluminum on one side and copper on the other. Just as in any other battery, there is a positive and negative side called the cathode (+) and the anode (-). The cathode (or positive electrode) is made of a very pure lithium-metal-oxide. The more uniform its chemical composition, the better the performance and the longer the battery life is.



[11]

Figure 5 - Diagram Lithium-ion battery technology

On the opposite side the anode (or negative electrode) is most often made of graphite, a form of carbon with a layered structure. The battery is filled with transport medium, the electrolyte, so that the lithium-ion carrying the battery’s charge can flow freely. This electrolyte must be extremely pure,

[11] https://batteryuniversity.com/learn/article/lithium_based_batteries

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and as free of water as possible, in order to ensure efficient charging as discharging. To prevent a short circuit, there is a layer between the two electrodes; the separator. To the tiny lithium-ions, the separator is permeable, a property called “micro-porosity”. Although ions pass freely between the electrodes, the separator is an isolator with no electrical conductivity [12].

When the battery is charged, the positively charged lithium-ions are passed from the cathode through the separator into the layered structure of the anode, where they are stored. When the battery discharges, when energy is removed from the cell, the ions travel via the electrolyte from the anode through the separator back to the cathode. The discharge starts when the two electrodes are connected via an external circuit and during this process electrons flow via the external circuit from the negative electrode to the positive[13].

The lithium-ion battery technology has a risk of a thermal runaway, which is a chemical reaction where the battery burns out and suffers permanent damage. It happens if separator does not work as intended.

The price for a lithium-ion battery is currently close to 180 €/kWh but predictions suggest that the price will drop to 90 €/kWh in 2020. The lithium-ion battery is the most compact of the three with space requirements of 5-7,5 m2/MWh.
The round-trip efficiency of the lithium-ion battery is typically around 95%, which means you get 9,5 kWh back if you store 10 kWh.

Pros	**Cons**
✔ Energy density – 3 times less weight and 6 times less volume compared to lead-acid batteries	✘ Fire hazard
✔ Higher voltage – 3-4 V versus ~2 V per cell in lead-acid batteries	✘ More expensive in acquisition than lead-acid batteries
✔ Round-trip efficiency	
✔ Good ability in handling peaks/uneven demands	

5.3 Lead-acid

Lead acid batteries are a tested technology, that has been used in off-grid energy systems for decades. While they have a relatively short life and lower DoD than other battery types, they are also one of the least expensive options currently on the market in the home energy storage sector. For homeowners who want to go off the grid and need to install lots of energy storage and have enough

[12] https://batteryuniversity.com/learn/article/bu_306_battery_separators
[13] https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_energy_storage.pdf

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space, lead acid can be a good option.[14] Lead-acid batteries typically have an efficiency of around 80%.

The ongoing development and decreasing price of the lithium-ion battery technology result in the price-per-cycle of the lithium-ion technology is approaching the lead-acid technology. When that is the reality, lead-acid batteries can only be recommended to costumers unable to accommodate the high investment of a lithium-ion battery pack.

Pros	**Cons**
✔ Installation cost	✘ Space requirements
✔ Well known technology	✘ Round-trip efficiency

[14] https://www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels/

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6 Heating

6.1 Heat pumps

A heat pump is a refrigerant-based device, that transfers the low-temperature thermal energy in the surroundings to the heating system of a house at a higher temperature, e.g. a water-based heating system. Heat pump systems primarily differs by the heat source. Furthermore, heat pumps have possibilities of transferring heat to different heating systems such as water-based and air-based heating systems.

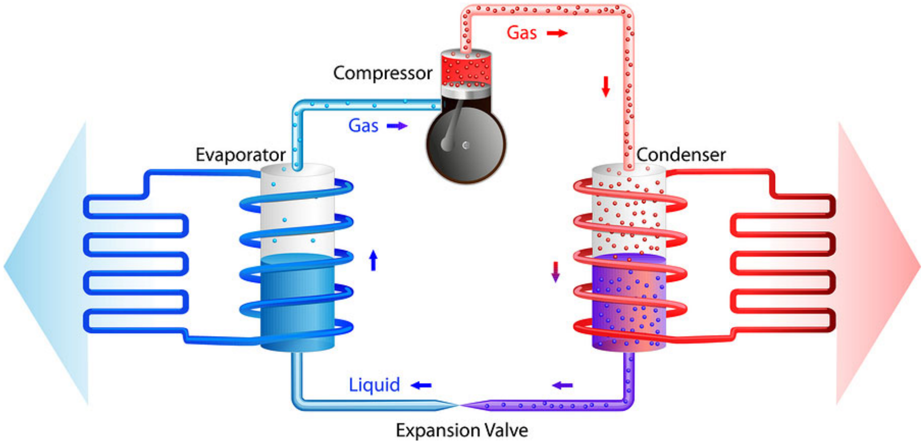

Figure 6 Technical design of a heat pump[15].

A heat pump consists of 4 main components:

- <u>The evaporator:</u> The heat from the heat source is transferred to the refrigerant, at a low pressure, which leads to the refrigerant evaporating (phase changes from a liquid to a gas). Due to the low temperature of the heat source, the refrigerant needs a low boiling point for it to evaporate.
- <u>The compressor:</u> The refrigerant is compressed to a higher pressure and hence the temperature of the refrigerant increases. This is the only component of the heat pump, besides the pumps of the system, which gets energy supplied in the form of electricity.
- <u>The condenser:</u> The high pressure and temperature refrigerant then enters the condenser. Due to the higher pressure of the refrigerant, the boiling point is now higher than before entering the compressor. This is utilized by the refrigerant transferring heat to the external heating system. This leads the refrigerant cooling to the point of saturation, causing it to change phase from gas to liquid. The liquid refrigerant then continues to cool further before entering the next component.
- <u>The expansion valve:</u> The now liquid refrigerant enters the expansion valve in which the pressure is reduced, leading to decreasing the temperature to at point near the evaporation temperature. The refrigerant then returns to the evaporator and the cycle continues.

[15] https://www.aptalaska.com/wp-content/uploads/2017/03/heatpump.bigstock.76690067.png

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If the heat pump contains a reversing valve, it can be used in reversible mode as well. In reverse mode, heat is transferred from inside the house, during the summer, and released to the outside. This mode is what is used in refrigerators, where heat is transferred from inside the refrigerator to the ambient surroundings, usually behind or beneath the refrigerator.

A heat pumps efficiency is identified by its Coefficient of Performance (COP). The COP is the simple indication of the efficiency and is overall a measure of how much energy the heat pump produces in relation to the energy supplied to the heat pump. A more realistic indication of the heat pumps operational efficiency is the Seasonal Coefficient of Performance (SCOP), which is a measure of the heat pumps efficiency throughout a heating- or cooling season.

The efficiency of the heat pump is dependent on the temperature of the heat source (input) and the heat sink (output). By minimizing the temperature gap between the input and output temperature, it is possible to improve the COP of the heat pump.

Therefore, when considering a heat pump system, it is important to evaluate aspects which influences the input- and output temperature.

One aspect could be the type of the heating system, and especially if it is an existing system. Then the heating system should be prepared for low temperature supply flow to minimize the temperature gap and hence increase the COP of the heat pump. Underfloor heating is usually the best fitted heating system for a heat pump due to its low operating temperature at around 30-35 °C. If the heating system consists of radiators, one should make sure that the system is designed with enough surface area to cover the heating demand at a low supply temperature. This includes both new and existing radiator systems. If the surface area is insufficient, the area could be supplemented by installing more radiators or other energy saving measures could be implemented to reach the desired heating demand reductions.

Another aspect is the temperature of the heat source. The higher the temperature of the heat source, the better the COP of the heat pump.

6.1.1 Air to Water Heat Pump Systems

This type of heat pumps is defined by extracting energy from the outside air and transferring the heat to a water-based heating system, i.e. radiators or underfloor heating, hence the name air to water heat pumps.

The heat pump is situated outside, where a fan drags in the outside air into the heat pump. Hence, the outside air is acting as the heat source, causing the refrigerant of the heat pump to evaporate and the heat pump cycle to begin.

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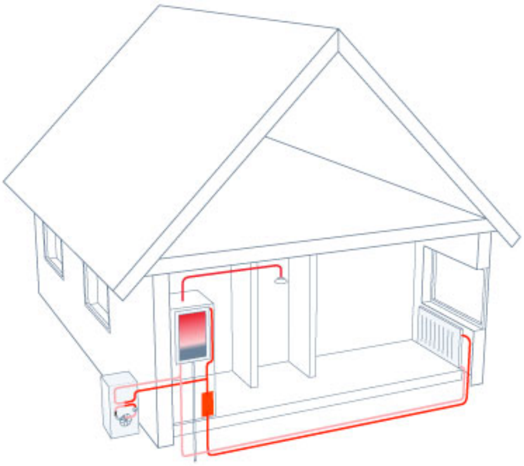

Figure 7 Example illustration of an air to water heat pump system[16].

The heat produced by the heat pump is then transferred into the home. Here it is delivered either to the water-based heating system, via a storage tank, or the domestic hot water storage tank. The hot water storage tank is equipped with a management system, including a domestic hot water priority system, enabling the system to decide whether the heat pump produces heat for the hot water storage tank or for the water-based heating system of the house.

An air to water heat pump is usually designed to cover around 80-85% of the design heat loss. By doing this, the heat pump can cover up to 95-100% of the total heat demand and therefore operate more efficiently, due to better operating conditions. At peak times, when the heat pump is not sufficient, it is usually supplemented by an immersion heater placed in the hot water storage tank.

The temperature of the heat source is very important for the efficiency of the heat pump. As this type of heat pump harvests the energy of the outside air, its COP is highly reliant of the climate. In milder climates it can be highly efficient, but in colder climates, which experiences temperatures below around 0 °C, the heat pumps efficiency is decreasing due to the larger temperature gap between the heat source temperature and the heat sink temperature. Furthermore, the heat pump can be exposed of the risk of freezing. Freezing causes the heat pumps defrost-setting to activate and this leads to a greater energy consumption, hence delivering less energy output i.e. decreasing the overall COP of the heat pump as well. When reaching temperatures below 0 °C, it can be more efficient/profitable to produce heat with e.g. a gas boiler.

The COP for an air to water heat pump is usually around 2,5 to 3, but depending on its operation prerequisites it can reach, and sometimes exceed, a COP of 5.

Overall, an air to water heat pump has advantages and disadvantages, which includes:

[16] https://sparenergi.dk/sites/forbruger.dk/files/img/Illustrationer/varmepumpe_luft-vandvarme.jpg

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Advantages

- This type of heat pump system is cheaper compared to e.g. a ground source heat pump system.
- Installation is easy.
- Does not require much space inside.

Disadvantages

- Can be less effective in colder climates
- Outside part of the system is noisy and can hence be a problem in urban built areas.

A standard air to water heat pump system at 5-10 kW costs from 90.000 DKK incl. VAT[17].

6.1.2 Ground Source Heat Pump Systems

This type of heat pumps is defined by extracting energy from the ground and transferring the heat to a water-based heating system, just like an air to water heat pump system. I.e. the heat source is now the ground. The ground possesses great amounts of heat and has a more consistent temperature if comparing to the fluctuating temperature of the outside air.

As opposed to an air to water heat pump, the ground source heat pump is situated inside the house, along with the domestic hot water storage tank. To harvest the energy, a sealed pipe system is buried in e.g. trenches in the ground (horizontal geothermal system). A horizontal geothermal system usually requires 35-50 m^2 per kW design heat loss[18]. Another possibility is to drill wells, known from geothermal plants but here at a smaller scale, which uses much lesser space (vertical geothermal system). This type of geothermal system would only require around 50x50 cm per well[19].

The pipe-loop is acting as the heat absorber and is connected to the evaporator, causing the refrigerant of the heat pump to evaporate and the heat pump cycle to begin.

[17] Den Lille Blå om Varmepumper, s. 47.
[18] Den Lille Blå om Varmepumper, s. 42.
[19] https://sparenergi.dk/forbruger/varme/varmepumpe/varmepumpetyper#1

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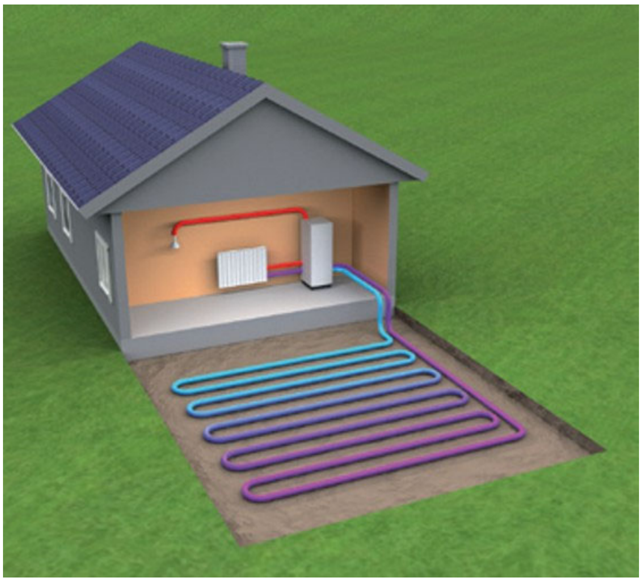

Figure 8 Example illustration o f a ground source heat pump system with a horizontal loop[20].

The heat produced by the heat pump is delivered either to the water-based heating system, via a storage tank, or the domestic hot water storage tank. The hot water storage tank is equipped with a management system, including a domestic hot water priority system, enabling the system to decide whether the heat pump produces heat for the hot water storage tank or for the water-based heating system of the house.

A ground source heat pump is, just like an air to water heat pump, usually designed to cover around 80-85% of the design heat loss. By doing this, the heat pump can cover up to 95-100% of the total heat demand due to better operating conditions. At peak times, if the heat pump is not sufficient, it can be supplemented by e.g. an immersion heater.

By burying geothermal pipes in the ground, either horizontal or vertical, it is possible to harvest energy from an almost consistent temperature. If choosing a horizontal geothermal system, the pipes are buried near or below the frost line, securing a constant temperature above 0 °C and hence having a more reliant COP of the heat pump. Another possibility, yielding better operating conditions, is by choosing vertical geothermal system. This system does not require as much space as the horizontal solution, but instead the wells are drilled to a depth of 120-180 meters, where it is possible to yield a constant temperature of 6-8 °C. Therefore, by choosing a vertical system, it is possible to yield a better COP of the heat pump, due to the temperature not being dependent on the outdoor climate.

The COP for a ground source heat pump is usually 3 and above, but depending on its operation prerequisites it can reach, and sometimes exceed, a COP of 5. I.e. a ground source heat pump has a slightly, but better, COP compared to an air to water heat pump.

[20] http://www.energiamba.dk/files/vedvarende%20energi/v%C3%A6ske%20til%20vand%20varmepumpe.jpg

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Some of the advantages and disadvantages of ground source heat pumps includes:

Advantages

- Not as noisy as air to water heat pumps, due to no fans being present.
- More likely to cover 95-100% of the heat demand, compared to other heat pump types.
- High and more reliant COP.

Disadvantages

- More expensive due to excavation/drilling costs.
- Demands lots of available space for piping.

A standard ground source heat pump system at 5-15 kW costs from 110.000 DKK incl. VAT[21].

6.1.3 Thermal Energy Absorber

If experiencing problems with available space for piping, it is possible to reduce the area needed by up to 40-50% by implementing a thermal energy absorber. The purpose of a thermal energy absorber is to enhance the performance of the ground source heat pump, by transferring energy from the sun, wind and rain, to the ground containing the piping for the ground source heat pump system.

By adding a thermal energy absorber to the ground source heat pump system, the system now has 3 operating modes:

- Mode 1: The system operates as a standard ground source heat pump system, without the use of the thermal energy absorber. Could be the case, if the ambient air temperature is too low compared to the temperature of the brine, which would cause the heat pump brine to cool and hence lower the performance of the heat pump.
- Mode 2: This mode of operation includes the thermal energy absorber. If the temperature conditions are beneficial, i.e. the temperature of the absorber is higher than the temperature at the exit of the heat pump, the temperature difference controller will activate pump 2, causing a subset of the brine to flow through the absorber. This will preheat the brine before reaching the pipe system in the ground. Reaching the ground, the preheated brine will store some of the thermal energy in the ground, which can then be exploited at a more favorable time.
- Mode 3: The heat pump does not operate. This means that the brine is bypassed in the heat pump. The purpose of this mode is to solely transfer and store thermal energy from the absorber in the ground for later use. This could be the situation during the summer, when the demand for heat is less.

[21] Den Lille Blå om Varmepumper, s. 44.

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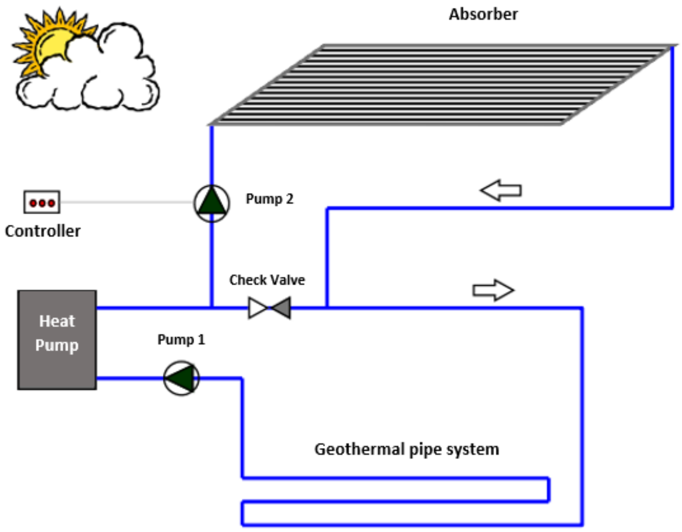

Figure 9 Schematic of a ground source heat pump system Including a thermal energy absorber[22].

A thermal energy absorber is sort of an open solar collector, due to not having any glass coverage layer. It is versatile in terms of installation and can be installed on flat roofs, on soffits, on the ground or even as a fence.

6.1.4 Hybrid Heat Pump Systems

A hybrid heat pump system is a system combining an air to water heat pump and a gas boiler. By doing this, it is possible to exploit the best characteristics of both the heat pump and the boiler, which results in the most efficient system possible.

The structure of the system is almost identical to a traditional air to water heat pump system. The only exception is the presence of the gas boiler, either new or existing, placed inside the household. This boiler solves the need of having e.g. an immersion heater to cover heat load for the domestic hot water, as explained earlier. The boiler gets connected to the heat pump system by a hybrid module, which enables the two technologies to communicate.

[22] https://pdf.solarventi.dk/dk/dk_energifang_15_br.pdf

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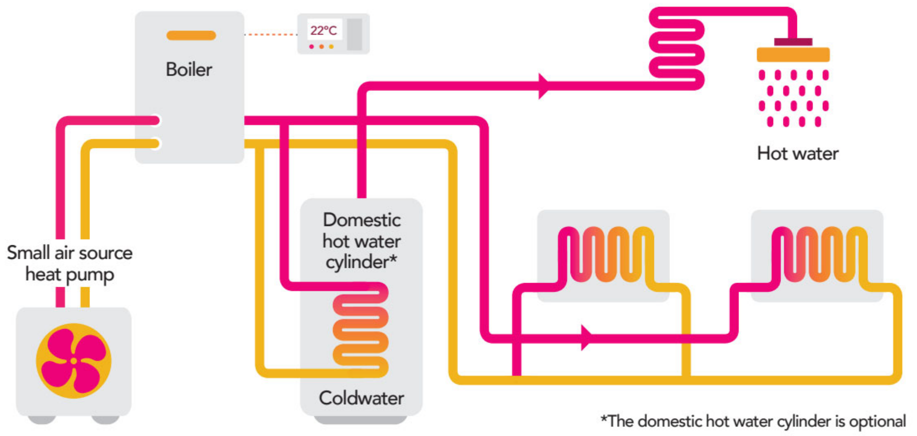

Figure 10 Example illustration of a Hybrid Heat Pump system[23].

The primary heating source of the system is the air to water heat pump. The heat pump delivers in the interval of 50-90% of the heat to the household, leaving the gas boiler to deliver 10-50% of the heat. For an average household, the gas boiler only needs to deliver around 33% of the heat[24].

The operation of the system is usually determined by the outside ambient temperature. The efficiency of a heat pump increases when minimizing the temperature gap between the source and the sink. Hence, if assuming a fixed temperature of the sink, the heat pump becomes more efficient, when the temperature of the source increases. Therefore, by combining the operation of a heat pump and a gas boiler, it is possible to produce heat in a more efficient way. This is due to the gas boiler efficiency almost being independent of the outside ambient temperature, causing the boiler to produce heat, when the temperature becomes too cold for the heat pump to operate at a better efficiency than the boiler.

A hybrid heat pump system consists of 3 different operation modes:

- Mode 1: Only the air to water heat pump operates. This mode is in use when the temperature is sufficiently high, for the heat pump to cover the total heat demand and operate at a high COP value.
- Mode 2: The boiler and the air to water heat pump co-operates. Usually when the temperature reaches a point leading to heat pump not being able to cover the full heat demand.
- Mode 3: Only the gas boiler operates. This mode is used when the temperature drops to a point where the operation of the gas boiler is more efficient compared to the heat pump.

[23] http://www.wdsgreenenergy.co.uk/wp-content/uploads/2017/08/Hybrid-air-source-heat-pump-no-cylinder.png
[24] Hybrid-varmepumper, Lærkevej – konvertering af naturgasopvarmning til varmepumper og hybridvarmepumper, s. 4.

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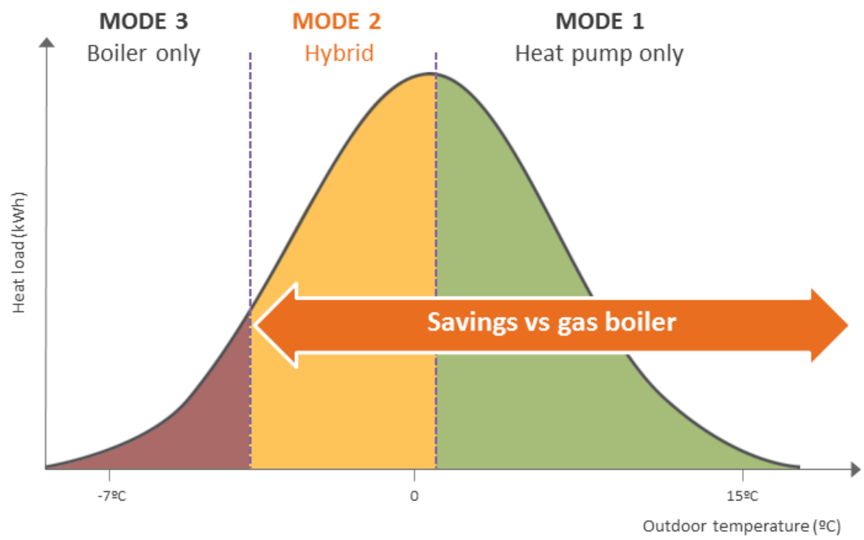

Figure 11 Example illustration of the operation of a hybrid heat pump system[25].

Other opportunities of operation or aspects influencing the management of the operation include:

- Electricity price: If the electricity price is too high, the system can be managed to shut down the heat pump and initiating the gas boiler to cover the heat demand instead.
- Smart grid: The system can be implemented in a smart grid. Here, a Balance Responsible Party, BRP, are managing the heat pump relative to the electricity market. This gives the BRP the opportunity to shut down the heat pump if upregulating of the electricity balance is needed. In this case, the owner of the hybrid heat pump system gets compensated if the heat pump gets centrally shut down by the BRP.

6.1.5 Air-to-air Heat Pump System

It is also possible to install an air-to-air heat pump system, where the water-based heating system in the building is an air-based heating system instead of radiators and underfloor heating.

However air-based heating systems are not very common in Danish houses, primarily because they can be a bit noisy compared to radiators, and because air heating systems often are combined with air-cooling systems, and it is not common with cooling systems in Danish houses.

[25] http://ees-renewables.co.uk/wp-content/uploads/2015/11/ASHP-Chart.png

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7 Hybrid Solar Cell – Solar Heating System

A hybrid solar panel is a combined solar cell and solar collector.

The solar cell produces electricity and the solar collector produces heat.

This combined panel is called a PVT solar panel (PhotoVoltaic-Thermal)

A PVT panel can at the same time produce electricity and heat, the heat can be either hot water or warm air.

The solar cell panel is mounted upon the solar collector, and the heat loss from the upper solar cell panel is recovered by heating the water or the air in the solar collector.

When the solar cell is cooled by the water/air from the collector, the efficiency of the solar cells increase, and the heat loss is reused at the same time. Therefore the total efficiency of the hybrid PVT panel is high.

The PVT panel can be used to preheat cold outside ventilation air circulating through air ducts in the panel, or the panel can have integrated waterpipes to preheat the domestic hot water.

A PVT solar panel looks like a normal solar cell panel, but it is deeper than a normal solar panel, because it contains both a PV panel and a solar collector panel.

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Happi
Infusing our housing association with energy efficiency

8 Solar Heating.

Solar energy is not only for electricity. It is also easy to utilize energy from the sun to supply

domestic hot water production and space heating in buildings.

Most district heating in cities is produced in an (almost) CO_2 neutral way. Therefore it is most relevant to

utilize solar energy for heating in buildings heated with fossil fuels (natural gas, oil, electricity).

Solar energy can be used only for domestic hot water or for a combination of domestic hot water and space heating. Solar is most efficient, if space heating is based on floor heating, because the temperature level is lower in floor heating systems.

A thumb rule is, that we need 4-5 m2 solar collector and a water tank of 200-250 liter to cover the domestic hot water for a family of 3 persons.

If we also want to supply the space heating demand for a family, a solar collector of 10-12 m2 and a water tank of 600 liter is recommended. A thumb rule says, that we need 0,5 m2 solar collector per MWh heating demand for the building.

The payback period for solar heating systems is normally around 12 years.

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