FREED

Funding Resources for Innovation in Energy Enterprise Development

Innovation Review Report

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Western Development Commission

Northern Periphery and Arctic Programme 2014–2020

EUROPEAN UNION

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About FREED

FREED (Funding Resources for Innovation in Energy Enterprise Development) is a three year project funded under Interreg's Northern Periphery and Arctic Programme.

The Project will provide SME's in the programme area with the support network required to introduce and develop energy innovations which would otherwise be unavailable to them.

FREED's five step process will:

- Carry out a needs analysis of the types of energy innovations required in the partner region
- Initiate a tender process to generate the necessary technology innovations
- Partner R&D institutions with SME's from the region
- Develop business plans to assist the SME's in delivering the innovation in the region
- Provide a financing service that utilises private investment funds to aid the development of the innovations

The project, which is led by the University of Oulu in Finland, is a collaborative partnership involving private investment firms, R&D institutions, colleges of education and public bodies from Scotland, Northern Ireland, Norway, The United Kingdom, Germany and Ireland.

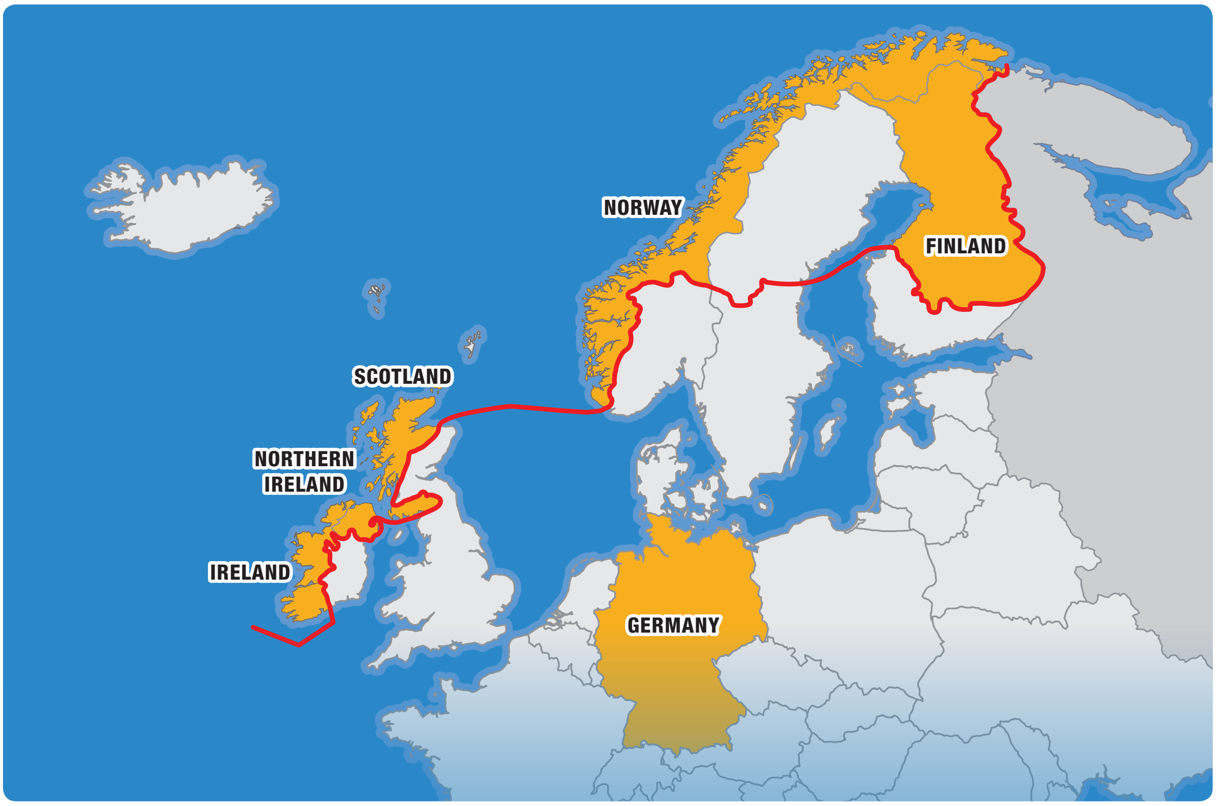
1 Introduction

Overview

Using the innovations listed in WP3 Activity 3.3 and 3.4, the technology breakthroughs in the energy sectors that are leading development elsewhere will be reviewed. This will be a global review to establish how technology is trending in the different energy sectors, insofar as it relates to the needs and priorities for the NPA region defined in 3.3. and 3.2.

Purpose of report

This report presents a summary of the different technological breakthroughs that can have a positive effect on energy use in the public sector. End use in the public sector has been reviewed as well as the distribution to the energy users. Future trends in the technology development are also laid out.



NPA programme area and participating countries in the Freed project.

Work Package 3: Innovation Scanning

According to a 2016 megatrends report by Sitra (Finnish Innovation Fund), there are three prevailing megatrends at the moment affecting the world. They are the radical technological change, globalism and breaking the link between the growth of the economy and use of resources and energy. Globalism can make it more difficult for SMEs in rural regions to compete on the global scale. The radical technological change including digitalization and emerging energy technologies can play a key role in breaking the link between economic growth and resource use. For example the Sitra report states that the price of solar energy is projected to decrease by 40% by 2020, which can lead to a more rapid adaptation of solar energy production. These new innovative technologies can also be adapted in buildings.

In Howells (2005) it is described that the word innovation often is wrongly used interchangeably with inventions. The article states that innovation can be seen as a process where an original idea, or invention, is refined, its feasibility is analysed in each step and it is finally adopted in an innovative way. This view is shared in Denning (2004) as it stated that innovation is the adoption of new practices and invention is simply the creation of something new. Where inventing requires only attention to technology, innovating also requires attention on other people, what they value or will be able to adopt. In OECD/Eurostat (2005) innovation is described as having different possible forms. Innovation can be the implementation of a new or improved product, a new marketing method or a new organizational method in the business practice of a company. Product and process innovations are further defined as being technological innovations.

According to Noailly (2012) technological innovation can be a key factor in reducing the energy use of buildings. Noailly (2012) and Johnstone et al. (2010) both argue that environmental policy is an important force pushing energy efficient and renewable energy innovation forward. R&D funding is also mentioned as an important factor.

The United Nations Environment Programme releases a yearly report on renewable energy investments. From the report released in 2016, it can be seen that the investments into renewable energy sources are growing. Notable is that the year 2016 was the first year when investments in developing countries surpassed the investments in developed countries. The report stated that the most funded renewable energy research was solar panel research (4,5 billion $), wind power research (1,8 billion $) and biofuel research (1,6 billion $).

The global energy requirement of buildings may double or even triple as we approach the year 2050. According to Lucon et al. (2014), the final energy use can stay the same to today's levels or even decrease if best practice methods and technologies are widely adopted. It adds that recent technological advancements, know-how and behavioural changes can reduce the energy demand of new buildings to a tenth of the standard use and a two to four time reduction can be achieved in existing buildings. The report also states that all the reductions can be achieved cost-effectively and at times even at negative costs. The following innovation review will uncover the area of energy innovations related to public buildings. The technologies included in the review can be seen in Table 1.

Table 1. Some of the important energy technologies reviewed in this report.

Area	Technology
Energy Production	Photovoltaic (PV) electricity, fuel cells, CHP
Energy Storage	*Electricity:* Flow batteries, flywheels, lithium based batteries, supercapacitors *Heat:* Phase change materials, thermochemical storage, latent heat storage
Energy Distribution	Smart energy networks
Heating and Cooling	Advanced heat pumps, solar thermal
Building Structure Approaches	Smart windows, new insulation materials, heat recovery systems, LEDs, solar lighting, building automation, nanomaterials

2

Innovations in Energy Production

Photovoltaic systems

Solar photovoltaic (PV) systems are the most used solar electricity systems in use. They have many advantages as they have no moving parts, use light as fuel, operate at a near ambient temperature and can be easily scaled to any size without a change in efficiency. The system itself consists of multiple solar cell containing PV modules, combiner boxes, inverters, transformers, mounting racks, wiring and enclosures. If the system is connected to a grid, the low-voltage direct current is transformed into high-voltage alternating current by combiners, inverters and transformers. The operation of the system is based on sunlight illuminating the module. Photons with a high enough energy will be absorbed by the cell and their energy will be transferred to an electron and its positive counterpart. A panel normally consists of many 15cm cells, that produce around 4 – 5 watts in peak illumination (Wp) conditions. Peak illumination conditions are used in rating the different electricity production of solar panels and the test conditions are 1000 W/m2 of illumination, an air mass of 1,5 and a standard temperature of 25 °C. (MIT Energy Initiative 2015 chapter 2)

Different solar cell technologies are divided into wafer-based or thin film technologies, according to their light absorbing material. At the moment most commercial photovoltaic cells are made from wafer based single-crystalline silicon (sc-Si) or multi-crystalline silicon (mc-Si) cells. Silicon modules offer maximum light conversion efficiencies of over 20% but in commercial panels the efficiency is commonly around 15%. They are reliable, non-toxic and efficient but their main weakness is weak light absorption which results in thick absorption layers and more use of resources. Gallium arsenide (GaAs) is a compound that is approaching commercial markets. It has strong absorption, has a bandgap that fits well to the solar spectrum and has very low non-radiative energy-loss. GaAs cells have reached efficiencies of 28,8% in lab conditions and 24,1% in modules. A lack of cost-effective production and sufficient film quality are still holding the technology back. (MIT Energy Initiative 2015 chapter 2)

Thin film solar cells are produced by additive fabrication. It may reduce the amount of used materials and lifecycle GHG emissions. Most commercial thin film technologies are based on cadmium telluride (CdTe), copper indium gallium diselenide (CIGS) and hydrogenated amorphous silicon (a-Si:H). These materials absorb light very efficiently, which results in a thinner absorption layer and a lighter final product. Most thin film technologies still suffer from many issues such as low efficiency that inhibit their large scale use and need further research and development (R&D). Around 10% of the solar cells produced in the world are thin film cells. Nanomaterial based cells are also possible for PV installations in the future, but are still under development. Figure 1 illustrates the structure of the most common commercial wafer and thin film cells. (MIT Energy Initiative 2015 chapter 2)

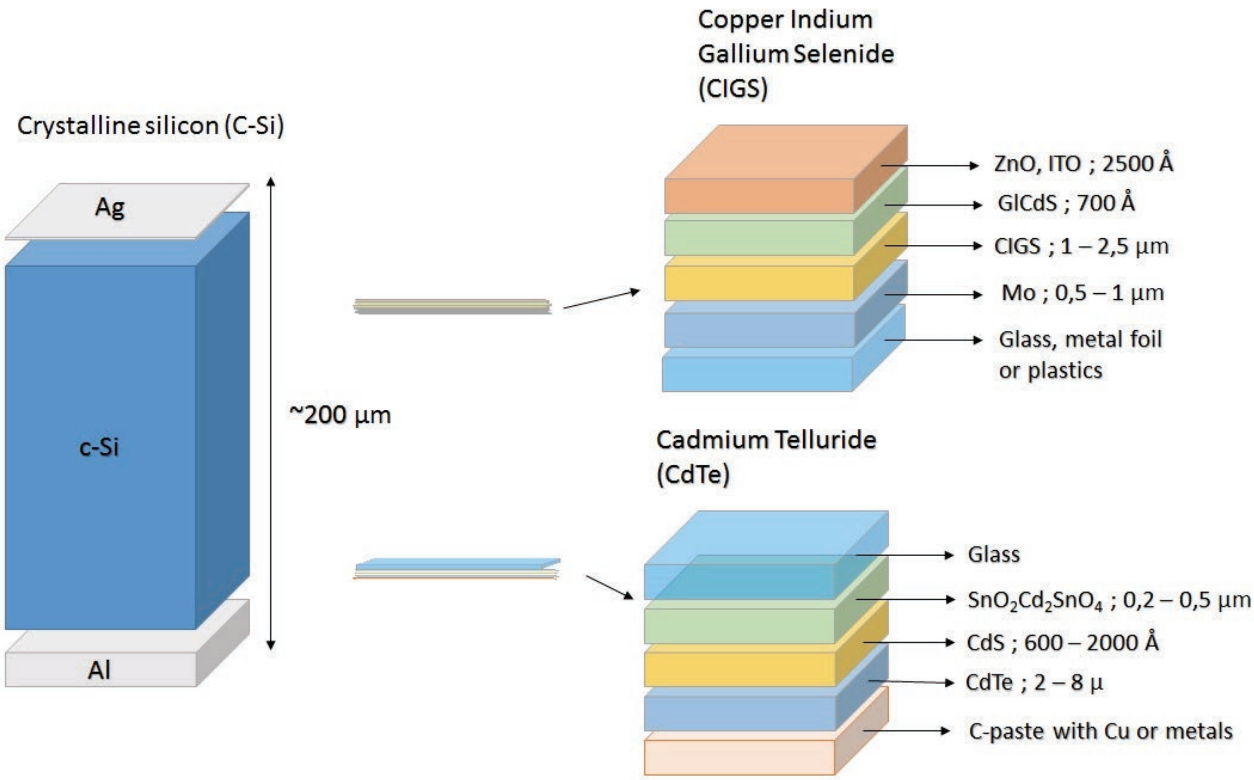


Figure 1. Common commercial PV cell technologies. ***(Based on a figure from MIT Energy Initiative 2015 chapter 2)***

Photovoltaic electricity generation systems can be integrated into the built environment to better utilize the space. Especially for flat roofs, photovoltaic (PV) systems can be easily installed onto a building structure. Roofs are increasingly becoming locations for distributed PV systems and the MIT Energy Initiative report on the future of solar energy (2015) states that these distributed PV systems can produce large shares of energy in the future. They are installed on rack mount systems and placed on the roof. They offer electricity but also offer shading that can be an important asset especially in hot climates. It is important to take into account that PV systems are not installed on roofs that have a shorter lifetime than the PV system itself. Flat roofs generally need reroofing every 15 to 25 years. (IEA 2013b)

A new approach is building integrated PV systems where a cheaper less efficient PV cells are used to form the roof surface. The intention in this approach is to install the system on most of the roof area. The installation is easier and it can lead to a more cost-effective PV system. The system does have a down side in hot climates as the roof integrated PV cells transfer the solar heat efficiently into the building. The PV cells also reach higher temperatures which lead to lower efficiency. (IEA 2013)

Micro-CHP

In Europe, distributed heat is widely generated by boilers. In 2013, 8,6 million oil and gas boilers were sold in the European market. Most are sold to the residential sector and around 7% are sold to the tertiary sector. Heat pumps and pellet boilers were sold in 0,55 million units total. Micro-CHP offers possibilities to replace inefficient oil and gas boilers to produce heat and electricity. It is estimated in CODE2 (2014) that primary energy savings of 540 PJ per year can be saved by replacing residential and tertiary conventional boilers with micro-CHP systems. This is the equivalent of 1,1% of the total primary energy use in Europe in 2010. The report estimates that growth in micro-CHP systems will begin around 2020 and 3 million micro-CHP systems will be installed annually in Europe in 2030. The biggest obstacles in micro-CHP adoption are stated to be reaching a cost competitive product. Large production amounts will make this possible but political will is needed for the market transformation. (CODE2 2014) Political change in the EU is already happening as for example in Germany a new incentive program was started in 2016. The program subsidizes the replacement of old inefficient boilers with efficient heating technology such as fuel cells. The program also includes awareness campaigns. (Build Up 2016)

In micro-CHP fuel is converted to electricity and heat in a distributed energy network at the end-user level. Micro-CHP can be achieved with three technologies:

- Internal combustion
  - Gas engine
  - Gas turbine
- External combustion
  - Stirling
  - ORC (organic rankine cycle)
  - Steam engine
- Fuel cells
  - SOFC (solid oxide fuel cell)
  - PEM FC (proton exchange membrane fuel cell)

Micro-CHP systems can range from 5 KW residential systems up to 1 MW systems. Depending on the technology, different shares of electricity and heat are generated. Solid oxide fuel cells offer the greatest electricity production efficiency. Stirling engines can offer the greatest overall efficiency of close to 100%. The average efficiency of micro-CHP is 90% (40% electricity and 50% heat). (CODE2 2014)

3 Innovations in Energy Storage

Renewable energy production is growing every year as we are aiming to reduce our CO_2 emissions. Yang et al. (2011) states that the problem with renewable energy is that the production varies greatly depending on the time of the day.

This makes it necessary to produce new innovative energy storage technologies that can store the energy produced at overcapacity to be used at times of low production. According to MIT Energy Initiative 2015 appendix C, energy storage systems can offer other benefits to buildings such as offering backup power in case of a blackout. In the appendix, requirements of different energy storage technologies relating to buildings are described (Table 2).

Table 2. The characteristics of energy storage for different energy services relating to buildings. (Based on a table from MIT Energy Initiative 2015 appendix C)

Service	Size (MW)	Duration of discharge	Amount of cycles	Time of response	Output energy
Variable supply resource integration	1 - 400	1 min - 1 h	0,5 - 2 /d	< 15 min	electricity, thermal
Waste heat utilisation	1 - 10	1 - 24 h	1 - 20 /d	< 10 min	electricity
Storage for CHP	1 - 5	min - h	1 - 10/d	< 15 min	electricity
Demand shifting and peak reduction	0,001 - 1	min - h	1 - 29 /d	< 15 min	electricity, thermal
Off-grid storage	0,001 - 0,01	3 - 5 h	0,75 - 1,5 /d	< 1 h	electricity, thermal

From table 2 it can be seen that different energy services require storage solutions with different characteristics. This leads to a wide range of specific storage options that suit certain needs. In an IEA (2014) report, key energy storage solutions are assessed and divided by their stage of development, risk and storage type. The solutions mentioned in the report can be seen listed in table 3. The report also states that currently there is around 140 gigawatts of large-scale energy storage in use worldwide. Most of this capacity comprises of pumped storage hydropower technologies (99%). Other technologies, such as battery, compressed air storage, flywheels and hydrogen storage form the other one percent.

Table 3. Key energy storage technologies, which are in use or in development. (Based on a figure from IEA 2014b)

Technology	Electricity or Thermal Storage	Capital Requirements x Technology Risk
Commercial Technologies		
Pumped Storage Hydropower (PSH)	Electricity	Low
Pit Storage	Thermal	Low
Cold Water Storage	Thermal	Low
Underground Thermal Energy Storage (UTES)	Thermal	Medium
Residential Hot Water Heaters with Storage	Thermal	Medium
Demonstration and Deployment		
Compressed Air Storage (CAES)	Electricity	Medium
Sodium-sulphur (NaS) Batteries	Electricity	Medium
Ice Storage	Thermal	Medium
Flywheel (low)	Electricity	Medium
Molten Salt	Thermal	High
Lithium-based Batteries	Electricity	High
Research and Development		
Flow Batteries	Electricity	High
Flywheel (High Speed)	Electricity	High
Supercapacitor	Electricity	High
Superconducting Magnet Energy Storage	Electricity	Medium
Adiabatic CAES	Electricity	Medium
Hydrogen	Electricity	Medium
Synthetic Natural Gas	Electricity	Medium
Thermochemical Storage	Thermal	Low

The technologies are listed in table 3 according to their development stage. It can be seen that technologies that have been in use for some time and are most useful to public buildings are pit storage (district heating), cold water storage, UTES and residential hot water heaters with storage. Technologies that are being adapted are distributed batteries and ice storage. Technologies that still need further development are flow batteries, supercapacitors, superconducting magnet energy storage, hydrogen storage and thermochemical storage.

Electricity storage

Electrical energy can be stored directly as electrical charges in capacitors or via conversion into kinetic energy, potential energy or chemical energy (Yang et al. 2011). Flow batteries, superconducting magnet energy storage, supercapacitors and other advanced batteries are mentioned in IEA (2014) as being promising technologies at early development. Batteries are especially useful in distributed energy storage. They are efficient and scalable. (IEA 2014)

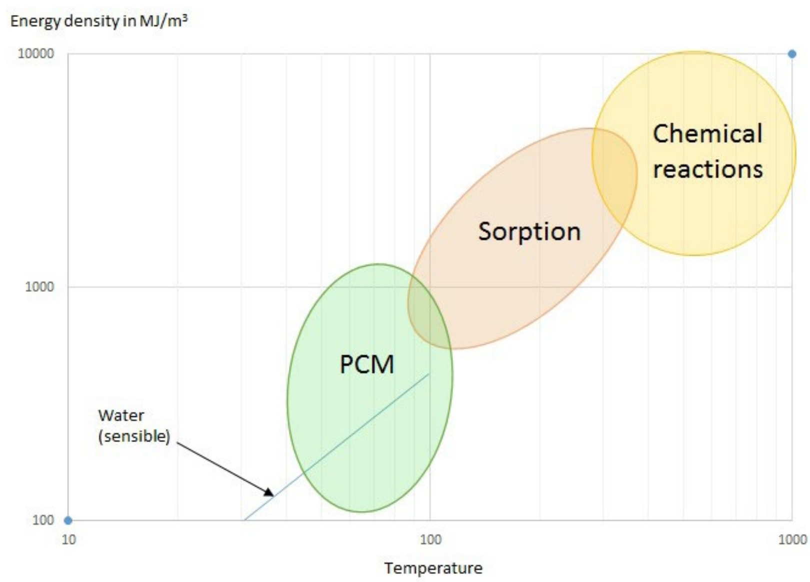
There is rapid change happening in battery development and their market at the moment. According to the United Nations Environment Programme report (2016), due to the growth of the electric vehicle market, battery storage prices have fallen from 1000 $/kWh to 350 $/kWh since 2010. The report states that batteries could be used in the electricity grid to even out electricity generation changes and they could act as local storage for small scale renewable production. It is stated though, that the price at the moment is still too high for many large scale projects. Distributed batteries could act as both long term and short term storage. (IEA 2014)

Yang et al. (2011) goes more in depth about the future possibilities of chemical energy storage in batteries. Especially four technologies of batteries are more closely examined; redox flow batteries, Na-beta alumina membrane batteries, unique Li-ion chemistries, and lead-carbon combination technologies. These battery types may in the future fit to the economic and technological requirements for storing small scale distributed electricity production of renewables. Advanced battery technology needs further improvements and the cost of the batteries has to drop for them to be economically viable. There are many companies globally entering the markets with new battery products.

Heat storage

Effectively storing heat could be especially beneficial for co-generation systems, renewable powered heating systems and end-users. Applying efficient heat storage to buildings could reduce a buildings energy consumption but also help in matching energy supply and demand. If a building can store heat effectively, the indoor temperature differences caused by outdoor temperature fluctuations are minimized. This minimizes the use of heating and cooling. Heat can be stored short term for daily temperature fluctuations or as seasonal storage for seasonal fluctuations (Sibbit et al. 2012, Soares et al. 2013). Heat storage is often applied as sensible heat storage where energy is stored in temperature differences in materials. In more advanced technologies heat can be also stored as latent heat in phase change materials (PCMs) or thermochemically in thermochemical heat storage (THS) (Figure 2).

Figure 2. Different heat storage methods and their comparison. (Based on a figure from Aydin et al. 2015)



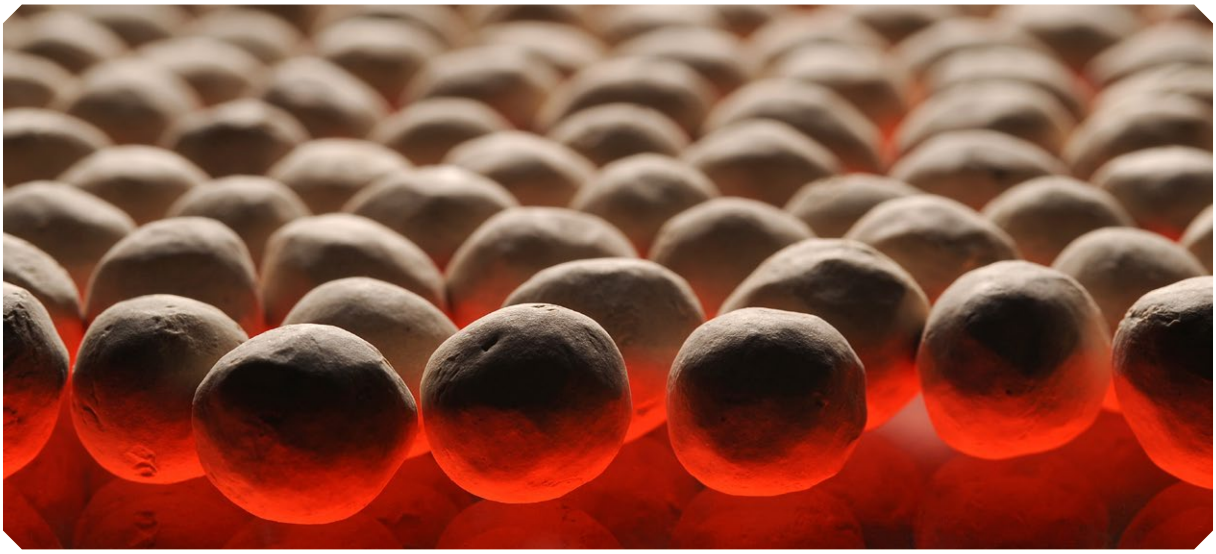


Figure 2 illustrates the energy densities and system temperature ranges for various different heat storage techniques. Most PCMs function in temperatures from 40 to 110 degrees and have maximum energy densities of around 1000 MJ/m^3. Sorption materials (e.g. zeolite and silica gel) function in higher temperatures and have higher energy densities. Two way chemical reactions offer the highest potential for heat storage with energy densities up to 10000 MJ/m^3.

In PCMs the energy is stored as latent heat and released in the forming and breaking of chemical bonds. The material phase change in thermal storage can happen between solid–solid, solid–liquid, solid–gas and liquid–gas phases. It is said in Sharma (2009) that solid-liquid transitions are most favorable as the volume change is small and the latent heat is stored effectively. There are three different PCM types, organic paraffin and non-paraffin materials, inorganic salt hydrates and metallics. Compared to the organic compounds, the inorganic compounds have around double the volumetric latent heat storage capacity. Sharma (2009) describes that PCMs release and absorb heat at their phase change temperature and that they can they can store 5 – 14 times more heat per volume than most common sensible heat storage methods.

Soares et al. (2013) states that an effective way of utilizing PCMs in buildings is by incorporating them in the structure in walls, windows, ceilings or floors. The PCMs themselves are usually embedded in supporting materials. Phase change materials can be in the future even incorporated into construction cements as is shown in Zhang et al. (2013). Soares et al. (2013) describes shape-stabilized-PCMs, which have been studied by many authors. In them the PCM is dispersed in a supporting material and together they form a stable composite material with PCM properties.

Thermochemical storage materials have even higher energy storage densities than PCMs, reaching up to ten times the storage density of PCMs. They also have the possibility to store energy for long periods of time with low heat losses. Heat is generated in THS materials by sorption (thermochemical) or chemical reactions, which are both reversible. In sorption, heat is used to remove a sorbate (gas) from a sorbent (matrix). Chemical systems are based on reversible reactions of chemicals. Because of the useful properties of THS materials, they are widely researched for practical utilization. (Aydin et al. 2015)

Sorption systems generally are more suitable for low temperature applications and during storage the heat loss is minimal. This leads to the possibility to for example store solar energy in the summer for winter use. During the summer time the system could also be used for cooling. A wide range of materials are researched for THS use and some examples are $CaCl2 \cdot H2O$, zeolite, vermiculate, activated carbon and silica gel. THS systems still need development on many areas to be commercially viable and need further development on reactor design, materials, humidification processes and regeneration processes. (Aydin et al. 2015)

4 Innovations in Energy Distribution

When energy production and control systems are integrated to end users, the operation of the whole grid inherently changes. Energy flows in the distribution systems can be stabilized and electricity must flow both ways (Farhangi 2010). It can be perceived that smart buildings and grids are thus cross-linked and affect each other.

Smart grids

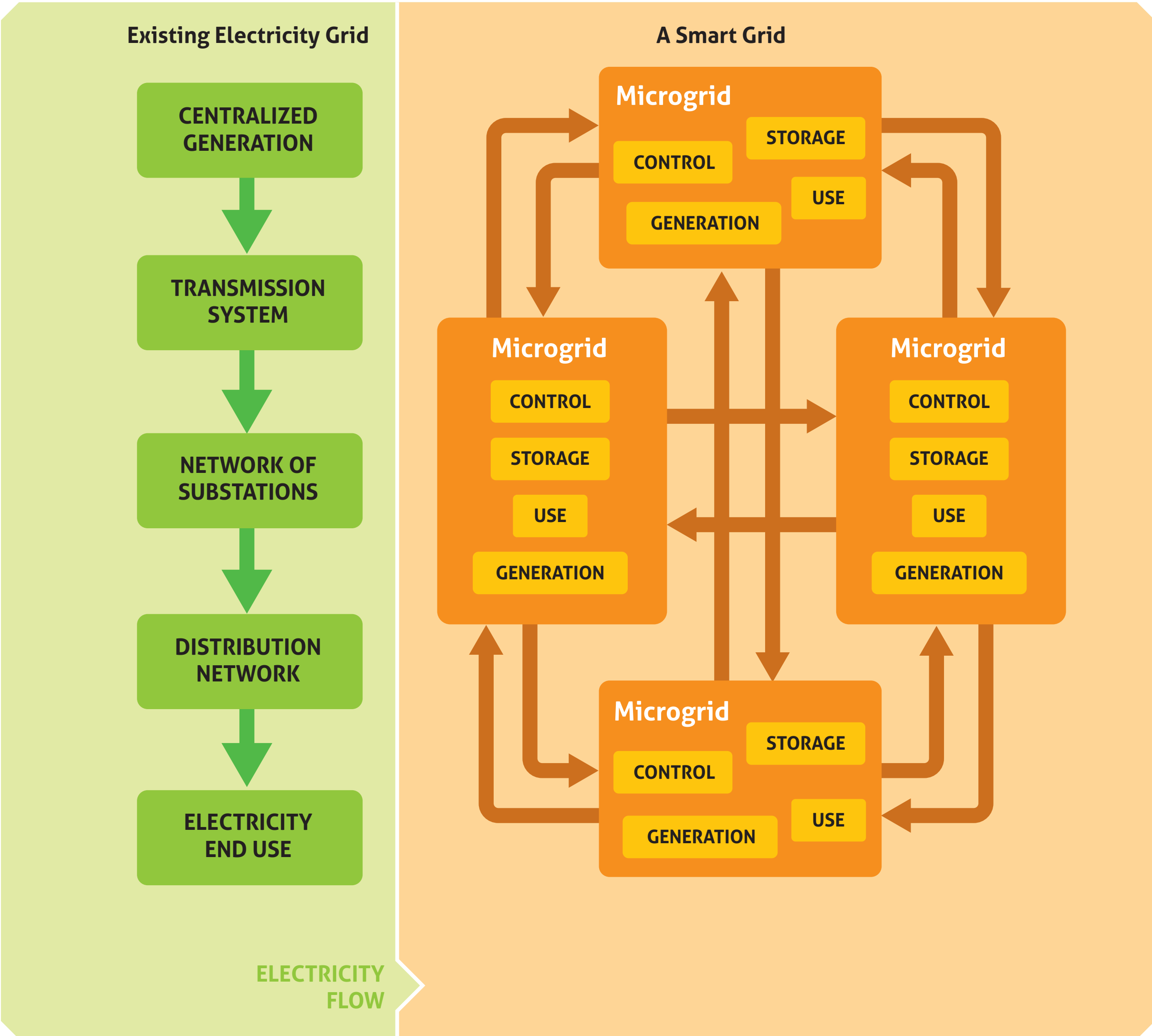
There are multiple issues with the electricity grid that need to be addressed. For one it is built to be one directional and makes distributed electricity production problematic. It is also inefficient as about 8% of the transferred electricity is lost in transmission lines and 20% of the capacity exist to only meet the peak demand. In addition the hierarchical asset topology leads to domino effect failures. A new type of electricity grid, called a smart grid, is emerging to address these mentioned issues. (Farhangi 2010)

According to Louis et al. 2016, smart grids represent the future for the electricity sector and their adoption aims to reduce the energy use and environmental impacts of the society. The paper states that a smart grid integrates multidisciplinary aspects and ideas such as a communication field, the internet of things, power engineering, control system engineering and environmental engineering. The grid structure is changed in a smart grid as is the flow of information. The basic concept difference is that information and electricity in a smart grid flow in two ways and the grid is more autonomous to respond to changes. While a traditional electricity grid consists of a hierarchical system topology, a smart grid consists of multiple micro grids that all can produce, use and store energy. This makes the electricity supply more reliable and shortens the distance from supply to demand. Information and energy is transferred within and between different micro grids. The structural differences between the existing grid and a smart grid can be seen in figure 3. (Farhangi 2010)

As it can be seen from Figure 3, the networked structure of a smart grid differs greatly from the structure of a traditional electricity grid. Information and electricity in a smart grid flows in two ways in a digital system. Each micro grid is a self-sustaining system. The grid also has self-healing and self-monitoring properties, which enable it to be more adaptive. (Farhangi 2010)

A big advantage in smart grids comes from the possibility of minimizing inefficient energy production for peak energy use by using energy storage and demand control and forecasting. In Persson (2014) utilizing smart grid technologies for district heating was described. According to the report, demand peaks in district heating often cause the heating companies to temporarily operate additional heat sources. These temporary heat sources can be inefficient and expensive and therefore their use should be minimized. Persson (2014) describes a Swedish company called "Noda",

Figure 3. The structural difference of the existing electricity grid and a smart grid. (Based on a figure from Farhangi 2010)



which has developed a smart district heating system to minimize heating peaks. The system measures factors such as temperatures, pressure levels and mass flows and takes into account weather forecasts. The system automation uses this data to manage the demand by prioritizing heating needs, preheating the buildings before forecasted peak hours or by postponing the heating of certain buildings. Accumulator tanks can also be used which can be filled during low demand and utilized in high demand.

In Lund et al. (2014) electricity grids, district heating and transport are included under the same concept of a smart energy system. In this concept separate smart grids for electricity, heat and gas are combined to utilize synergies between them, which leads to a better overall performance. The integration allows for more optimization on production and demand shifts as well as storage options. To make this possible, the information must flow between the different smart grid infrastructures. Lund et al. (2014) presents a list of studies which say that although district heating systems act an important role in smart energy systems and renewable energy utilization, they need to be changed into intelligent low-temperature district heating networks that are combined with low-energy buildings. This grid concept is defined as 4th Generation District Heating (Figure 4). The lower temperature allows the adoption of distributed heating units, better utilization of waste heat, and use of renewable energy sources.

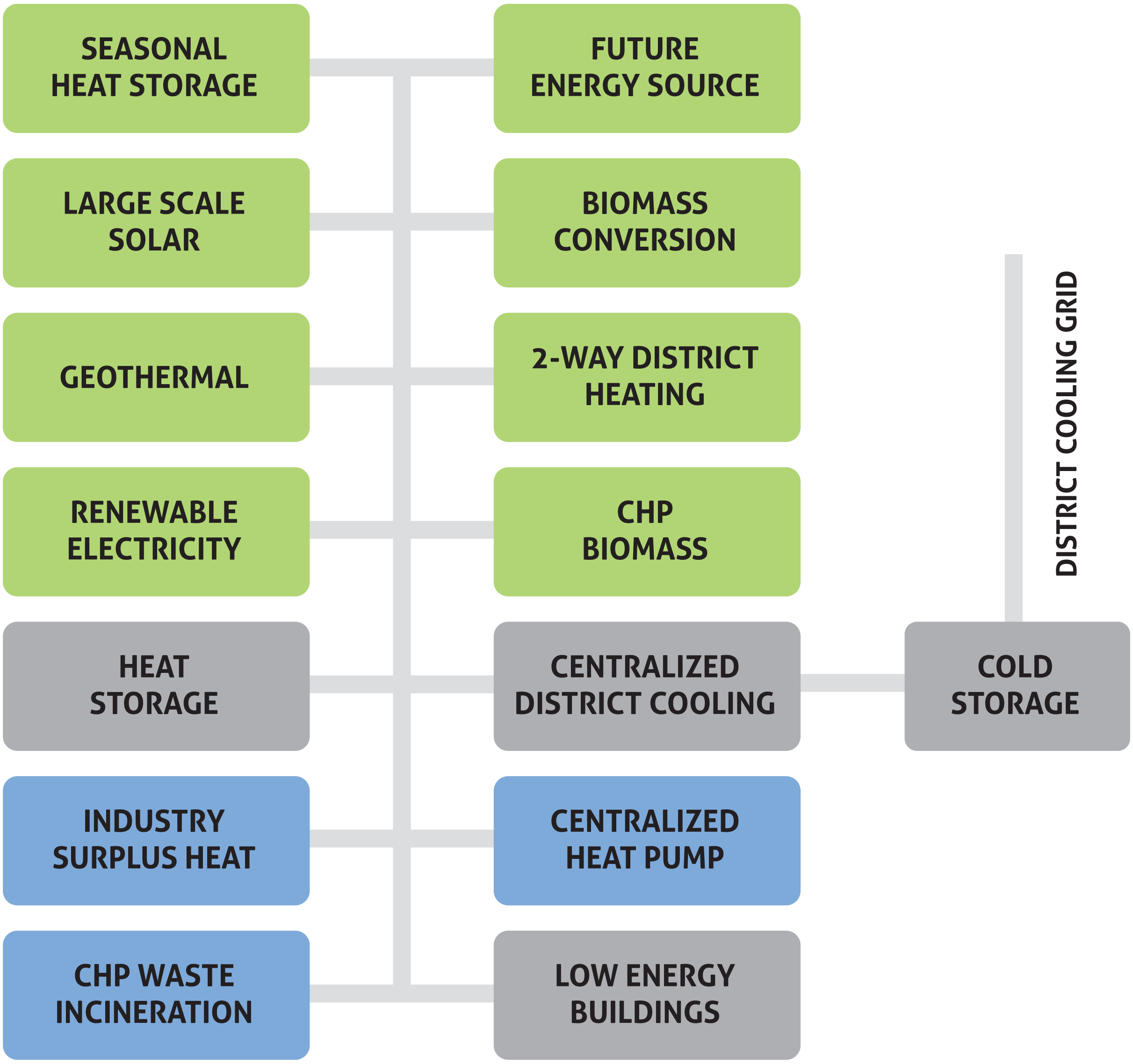


Figure 4. The concept of a 4th Generation District Heating grid. (Based on a figure from Lund et al. 2014)

Smart buildings

When electrical grids shift towards smart grids, buildings are fitted with new technological features that map and control the energy use. A key concept in smart buildings is demand side management (DSM) (Costanzo 2012). The main point in DSM is, that by being able to affect the demand in smart buildings real-time, loads could be forecasted and consumption could be scheduled which would enable shaving off electricity use peaks. Energy management systems can be used to control the electricity consumption, smart metering can be installed to enable overviewing the energy use and smart electricity plugs can be installed to remotely control appliances. The energy saved by the control devices does not necessarily negate the manufacturing and end-use energy used to make and dismantle them (Louis et al. 2015a). It was found out by Louis et al. (2015b) that fitting a house with smart plugs may actually increase the total amount of energy used and CO_2 emissions released during the lifetime of the smart plugs. Therefore smart systems in buildings do not necessarily always decrease the lifecycle energy use and consideration should be used when adopting them. (Louis et al. 2015b)

5 Innovations in Heating and Cooling

Space and water heating account for about 50% of the buildings sector energy needs.

Space cooling on the other hand accounts for only about 4%, but has grown steadily over the past decade.Therefore remarkable reductions in energy use can be done by utilizing innovations in these areas.

New HVAC approaches can be adopted or heat transfer between the building and the outer environment can be minimized. In 2010 most, 65%, of the global space and water heating was generated by fossil fuels. In the following parts, technologies are reviewed, that may have a positive impact to energy efficient buildings in the future. Three technologies are listed in IEA (2013) as being the most important for heating and cooling improvements in the future:

- Advanced heat pumps
- Solar thermal technologies
- Co-generation systems (fuel cells and micro CHP) and distributed energy systems

Heat Pumps

Heat pumps account in some IEA scenarios to over half of reduced future CO_2 emissions from buildings. Heat pumps can provide buildings with space heating, cooling and hot water. All of these three services can be provided by one integrated unit. Heat pumps are already a mature technology that transfer thermal energy from a source to a target space using a vapor compression cycle. The same process can be applied for cooling. Traditionally heat pumps use an electric motor to drive the cycle but there are now also thermally driven heat pumps and coolers on the market. These heat pumps can use low grade heat, such as solar thermal, to drive the vapor compression cycle. They bring the possibility to use heat sources, such as solar thermal or district heat, for cooling during the summer months when heating is not needed. Traditional heat pumps can reach use efficiencies greater than 250% and thermal heat pumps often reach efficiencies of 70 – 120%. Still heat pumps have not reached theoretical limits of performance and improvements can be made. (IEA 2013, IEA 2011)

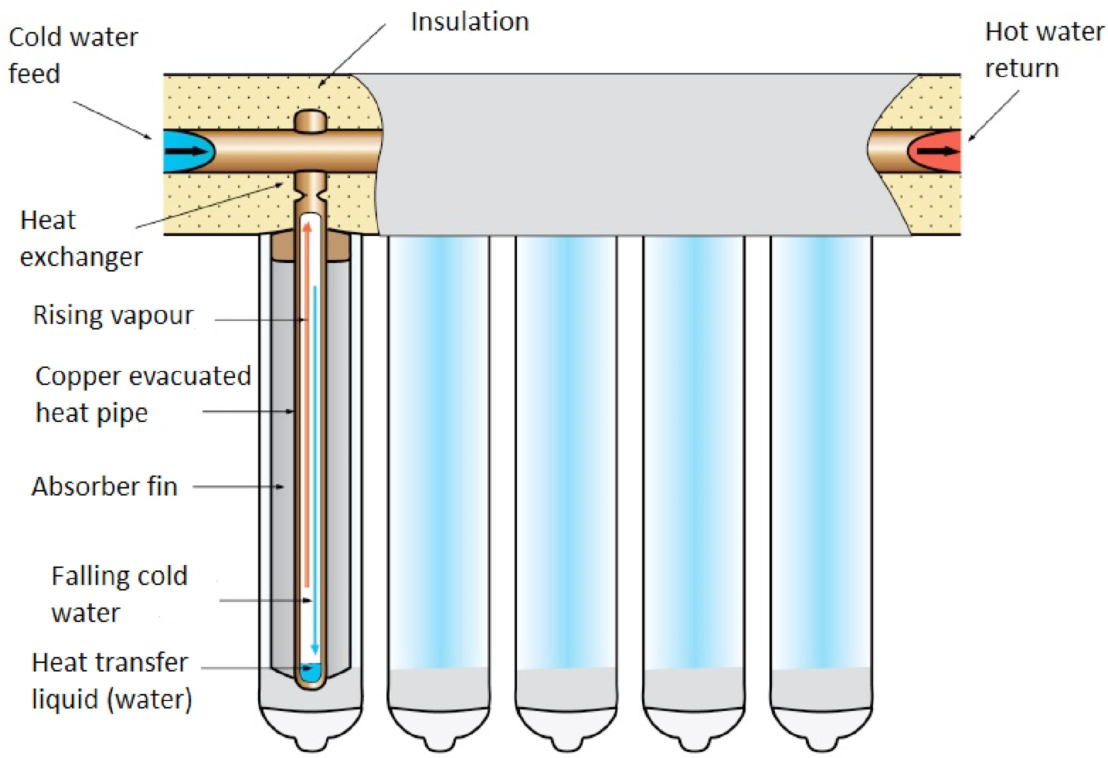


Figure 5. One type of solar thermal evacuated tube collector. (Sustainability Victoria 2009)

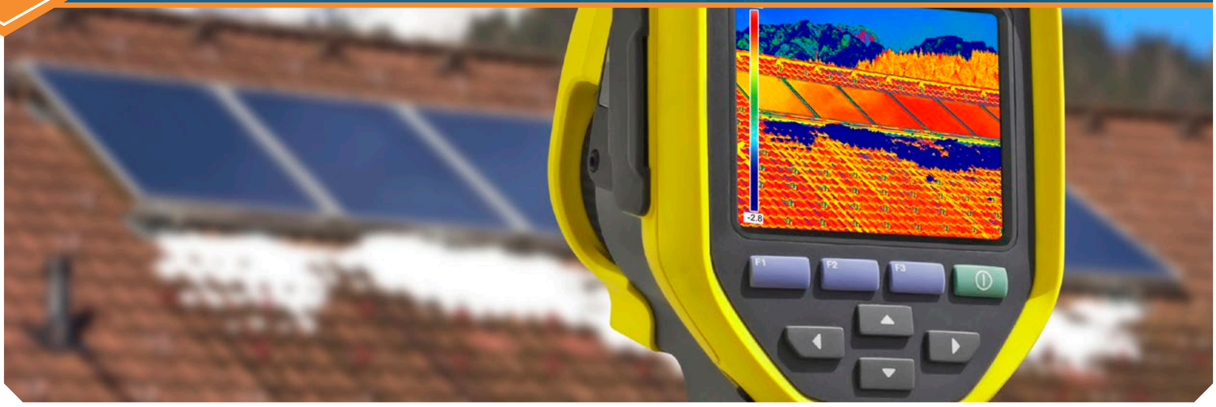
Solar Thermal

Solar heating and cooling includes a range of technologies that can be active or passive. In active solar thermal (AST) technologies the systems collect the radiation of the sun to heat a working fluid of a heat exchanger or they can heat directly water that is used. The hot water that is created by AST systems can be used for space heating, domestic hot water or cooling in thermal absorption cooling systems. Even large thermal load in buildings can be supplied by AST systems. China is leading the market in the adaptation of solar thermal collectors as in 2010 81,4% of collectors were sold in China. (IEA 2013)

There are two types of collectors at the moment, glazed and unglazed. Glazed collectors retain the heat that is gained from the absorbing components. Unglazed collectors collect the heat in polymers or metals and are useful only during the day when heat is supplied. In cold areas mainly glazed collectors are useful. Generally two types of collectors are used in buildings, flat plate collectors and evacuated tube collectors. Evacuated-tube collectors (Figure 5.) are especially used in cold climates. They come in different types but all offer vacuum insulation for the absorbing system from the cold environment and reduce heat loss. (IEA 2013)

Solar thermal systems can be coupled with other heating systems such as heat pumps to cover for the heating demand that is not provided by the solar system. Thermal storage systems can also be added to store the solar heat for times when there is no sunlight available. According to IEA (2013) it can be done at an acceptable cost and is useful in climates with prolonged periods of low light. Solar thermal systems can also be used to provide district heat. They can provide heat to the district heating system on a seasonal timeline in cold climates. Seasonal storage applications, such as underground pits, thermochemical storage or boreholes, can be added to provide district heat around the year. For example Denmark has taken a determined stance and heats large areas by solar thermal powered district heating (Solar District Heating 2016). (IEA 2013)

6 Innovative Building Envelope Approaches



The building envelope is essentially the separating element between the indoor and outdoor environments. It can consist of various components such as walls, the roof, the building foundation, insulation, thermal mass, shading structures etc. The building envelope should aid in controlling the indoor environment conditions and minimize energy use. (Jelle 2011)

Windows

Heat transfer through windows accounts for about 5 to 10% of the total energy demand of buildings in the OECD countries. They provide multiple functions and the challenge in an energy sense is to optimize their heat flow depending on the outside conditions. (IEA 2013) During cold weather the window should retain the heat and let in as much solar radiation as possible and in hot conditions it should be able to keep the heat out (Long & Ye 2014, Figure 6). (Jelle et al. 2012)

Figure 6 shows the behavior of an ideal window. In hot conditions outside thermal radiation is blocked as is infrared radiation. Only visible light enters the inside space and thermal radiation can pass through the window to the outside environment.

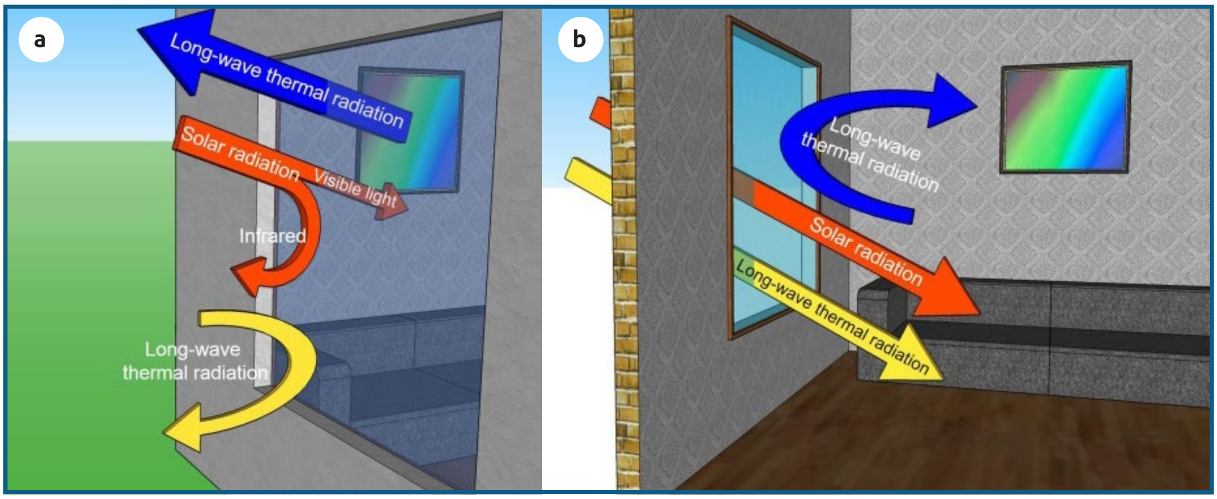


Figure 6. The behaviour of an ideal window in hot conditions (a) and in cold conditions (b). (Long & Ye 2014)

Table 4. Recent advances in energy saving window technologies. (IEA 2013, Jelle et al. 2012, (Long & Ye 2014))

Technology	Advanced Products in the Market	In Development
Low thermal conductivity	Vacuum glazing, aerogel filled frames, advanced low-e coatings	Multilayer vacuum glazing, advanced aerogels
Variable solar radiation glazing	Smart windows (thermochromic, photochromic, electrochromic)	Smart windows with vacuum glazing
Additional window properties	Solar cell glazing, self-cleaning glazing, phase change material incorporated windows	Multifunctional windows incorporating several technologies

In cold conditions all outside radiation is let through and thermal radiation is reflected back inside.

There are different technologies used with the aim of reaching ideal window conditions. In general, these window technologies can be divided into low thermal conductivity and solar radiation control technologies. In addition to those properties the windows can also have additional functions. (Jelle et al. 2012) (Table 4.)

Table 4 contains recent window technologies that aim to achieve low heat conductivity, solar radiation control and add additional functions. Market viable approaches that aim to achieve low thermal conductivity are advanced low emissivity coatings (low-e), vacuum glazing and aerogels. Incoming solar radiation can be controlled with smart windows and additional functions can be added with solar cell glazing and self-cleaning properties. Future products can advanced the properties of existing technologies or incorporate multiple different technologies in the same product. The main important technologies will be described in more detail next.

Low emissivity coatings are aimed at blocking infrared and ultraviolet radiation from passing through the glass. They are typically metal oxides or dielectric-metal-dielectric layers. Advanced low-e coating succeed in blocking most of unwanted radiation but development is still needed in reducing visible light reflection. In northern climates solar energy reflection can be unwanted and low-e coatings counterproductive. (Jelle et al. 2012)

At the moment vacuum glazed windows have the same heat conduction as multilayer glazed windows. Vacuum glazed windows are though much thinner than multilayer glazed windows. There is also research done that predicts that vacuum glazed windows could reach much lower heat conduction values by incorporating a multilayer structure. Low-e coatings can also be adapted to vacuum glazed windows to further improve their characteristics. Current issues with vacuum glazing are thermal expansion issues and leaking edge seals. (Jelle et al. 2012)

Aerogels are open celled mesoporous solids that are extremely light and their volume is typically 90-99,8% air. A wide range of material such as silica, alumina, carbon and polymers can be used to manufacture them. Products with aerogel glazing have been in the market since 2006 and the design consists of polycarbonate panels filled with an aerogel. The aerogel product weighs a fifth of an equivalent glass panel and has an impact strength 200 times larger. These attributes combined with their high light diffusion make them perfect for skylights in buildings and other locations where a glare effect is unwanted. Advanced aerogels, such as evacuated aerogels, have also been shown to reach very low heat conduction values. (Sadineni 2011, Jelle et al. 2012)

Smart windows incorporate switchable reflective glazing, which is a technology that allows adjusting the window tint to cool buildings with a large solar gain. Low DC voltage (electrochromics), temperature adjustment (thermochromics), hydrogen (gasochromics) or light guiding elements

(photochromics) can be used to change the light reflection of the surface. There are companies in the market that incorporate the technology in new windows and Jelle et al. (2012) mentions a Swedish company that incorporates an electrochromic surface on existing windows. (Sadineni 2011, Jelle et al. 2012)

Solar electricity can be produced on window surfaces by spraying a coating of silicon nanoparticles on the glass surface. The coating also inhibits the light from entering the building. Therefore more solar electricity production causes less natural inside light. The heat conduction values of solar cell glazing resemble those of smart windows. (Jelle et al. 2012)

Insulation

Insulation is one of the most important factors in energy use in buildings as it is found in walls, floors, roofs and foundations. The goal of insulation is to minimize the heat flow from the inner environment by conduction, convection and radiation (Sadineni 2011). Decisions on the insulation type should be done based on the insulation efficiency, fire and safety standards and material and labor costs. Insulation materials used in buildings today include stone fiber, glass fiber, expanded polystyrene (EPS), extruded polystyrene (XPS) and polyurethane boards/spray. Old buildings with bad insulation can be re-cladded with new insulation to improve their performance or insulation foam can be sprayed into the wall cavities. (IEA 2013)

Recent developments in insulation are aerogels such as nano-structured silica aerogels, vacuum insulated panels (VIPs) and phase change materials (PCMs). They offer far better insulation levels than the traditional options but are still hindered by high material costs and needs for further development. (IEA 2013) VIPs are evacuated porous materials that are foil-encapsulated. The main issue with them is maintaining the vacuum within time. Fumed silica has been proven to function well as a core material. VIPs have a very low thermal conductivity which can be five to 10 times lower compared to traditional insulation materials (Jelle 2011). PCMs can be used in large scale heat storage but also as insulation material that store and absorb heat. There are already products in the market (Phase Change Energy Solutions). In buildings they stabilize temperature changes and decrease the need for heating and cooling. (Sadineni 2011)

Nanotechnology can be applied in insulation materials and in the future they may become economically viable. In insulation materials, the goal of nanotechnology is to change the pore size of the insulation material into the nano scale. These materials are called nano insulation materials (NIMs) and the pore size is between 0,1 to 100 nm. In pristine conditions, NIMs can result in even lower thermal conductivities than VIPs. NIMs apply the Knudsen effect to reaching low thermal conductivities and thus don't need vacuum conditions. This results in a longer lifetime than VIPs. The Knudsen effect is based on conditions where the mean free path of the gas molecules is larger than the diameter of the pore, which results the gas molecules inside the pore hitting the pore wall instead of other gas molecules. (Jelle 2011)

Passive Solar Heating

Passive solar heating aims to provide thermal comfort by capturing solar energy into the structure. Especially in cold climates buildings should be designed to utilize sunlight. Passive solar heat gain in Europe is considerable and according to Voss & Wittwer (2013) it accounts for about 10 – 15% of the total heat demand. Even though solar heat gain accounts for a large portion of renewable energy in total, it is not included for example in EUROSTAT heat statistics as solar energy. Voss & Wittwer (2013) mention the reason for this is that energy statistics only consider what is on the supply side. As passive gains only reduce the actual demand, they are not included in the statistics. Stevanovic (2013) states that in the EU strategy of NZEBs, passive solar heat gain can play an integral part in reducing the demand of active systems providing renewable energy. In France passive solar utilization has already been adopted in the national building code (IEA 2013).

The possibilities for passive solar can be best tested and modified in the conceptual design phase of the building. When all structural and environmental attributes are added into a simulated model of a building, the passive solar gain of the design can be calculated. Changes can be made to the design and using optimization methods the best options can be found. Complex simulations are necessary as passive solar takes into account the building orientation and form, the insulation of the walls, roofs and floors, the ratio of window area to wall area, glazing type of windows, shading etc. (Stevanovic 2013)

There are many ways to maximize passive solar heat gain. Window placing can be planned to harness as much of the suns energy during the day as possible. Advanced window glazing technologies make it possible to make windows larger without affecting the heat loss. Thermal mass structures can be combined with sunlight harnessing. The structures will slowly warm up during the day and release their heat in the evening. (IEA 2013)

Solar Lighting

In optical daylighting natural light is collected and delivered into a building to provide for lighting needs. There are different approaches in how the sunlight is collected and distributed such as mirror sun lighting systems, light pipe systems and parabolic mirrors or Fresnel lenses combined with fiber optic cables (Kim 2010, Muhs 2001, Shin 2014). Light pipe systems are static and don't react to the suns location as where parabolic mirror and Fresnel systems typically need to rotate following the sun. The infrared spectrum is also separated

in parabolic mirror and Fresnel systems. The spectrum of natural light provided by daylighting systems is considerably wider than light produced by most lamps and is said to be more enjoyable for building occupants (Muhs 2001, Shin 2014). The advantage of daylighting systems is based on the fact that they avoid transforming the light first into electricity and then back into light in the lamp when compared to using solar panels to generate electricity. Collection losses and conversion losses are avoided. Losses in daylighting systems are formed in the transportation of light into the desired location. The transport losses grow as the light is moved further down the building which makes these lighting options best suited for low buildings. (Muhs 2010, Kim 2010)

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Notes:

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Funding Resources for Innovation in Energy Enterprise Development

Finland

University of Oulu

Eva Pongrácz eva.pongracz@oulu.fi

Niko Hänninen niko.hanninen@oulu.fi

Northern Ireland

South West College (SWC)

John Harrison john.harrison@swc.ac.uk

Jill Cush jill.cush@swc.ac.uk

Republic of Ireland

Western Development Commission (WDC)

Mary Keaveney marykeaveney@wdc.ie

Limerick Institute of Technology (LIT)

Padraic Cullen padraic.cullen@lit.ie

Derek Blackweir derek.blackweir@lit.ie

Norway

Narvik Science Park (NSP)

Fred R. Johansen fred@fpn.no

Scotland

Green Angel Syndicate (GAS)

Nick Lyth nicklyth@gasgat.com

Steve Taylor steve@ideeas.net

Germany

European Institution of Innovation (EIFI)

Chris Ashe c.ashe@eifi.eu

Benjamin Daumiller b.daumiller@eifi.eu

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