EBC

Energy in Buildings and Communities Programme

IEA EBC ANNEX 75

WORK IN PROGRESS: November 2018

Technology Overview

Subtask A – Work Package A1

Summary

The objective of Work Package A1 is the identification of existing and emerging technology options (both envelope and systems and at both building and urban scale). The document reports on work developed through collection of technologies with the potential to be included in the methodology for the participants of the research project.

Work in Progress consists of a series of documents presenting on-going work being developed in the context of the Annex 75 research project.

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Contents

Building envelope

Low emissivity windows

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Description	Low-E (low-emissivity) glass minimizes the amount heat exchanged by radiation. Low-E glass windows have a microscopically thin coating that is transparent and reflects heat.
Main characteristics	Envelope
Power range	N/A
Technology interdependencies	Synergies with district heating and cooling systems
Advantages and disadvantages	High performance reducing heat losses. Lower cost than triple glazing windows.
References	

Triple glazing windows

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Description

Triple glazing windows present three sheets of glass to provide improved sound and thermal insulation in comparison and double-glazing.

Figure 1 - Triple Glazing Windows

Main characteristics

Envelope (U values 0.5-1 W/m^2 K)

Power range

N/A

Technology interdependencies

Synergies with district heating and cooling systems

Advantages and disadvantages

High performance reducing heat losses (U=0.8-1.1 W/m^2.K). Higher cost (in Spain, it could be around 180 €/m^2) than other solutions, such as double glazing windows (around 110€/ m^2) or even Low-e windows (around 150€/ m^2).

References

Quadruple glazed windows

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Description

Quadruple glazed windows is a relatively novel development. The solution uses very thin thermally treated glass for the two internal panes, and thereby the weight of the quadruple glazed windows is approximately the same as for triple glazed windows. Light transmission is approximately 75 % and solar energy transmission above 50 %. The U-value of the glazing is typically around 0.3 W/m^{2}K and total window U-value of around 0.5 W/m^{2}K depending on the frame.

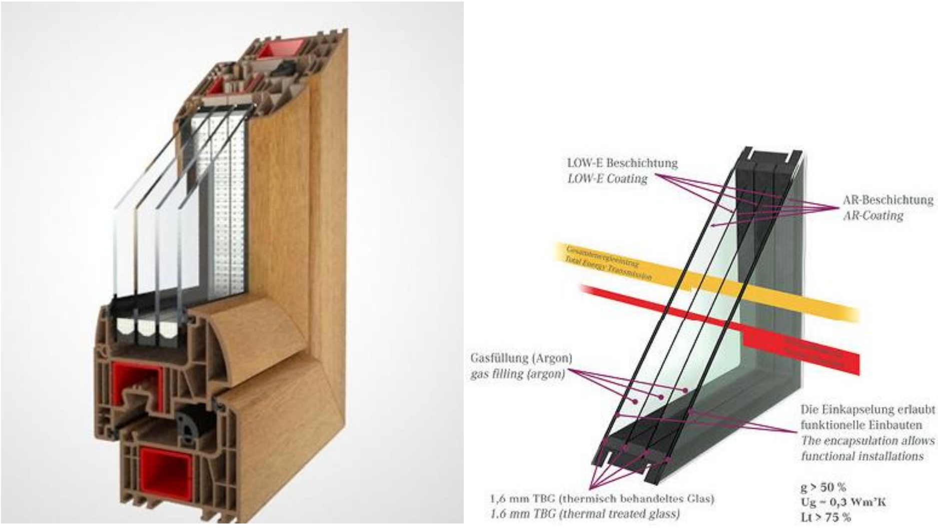

Figure 2 - Examples of quadruple glazed windows (Source: fenster-Jancic.at left and glaswelt.de right).

Main characteristics	Glazing system (façade or roof)
Power range	N/A
Technology interdependencies	Possible synergy in reducing the overall heat loss from the building to a level where downscaling of the heating system is possible.
Advantages and disadvantages	The solution will probably be most relevant to use in climates dominated by heating as opposed to climates dominated by cooling.
References	[1]https://www.glaswelt.de/Archiv/Newsletter-Archiv/article-688757-112170/4-fach-iso-amortisiert-sich-.html

External Thermal Insulation Composite System I

Fabio Peron, fperon@iuav.it, Italy ; Piercarlo Romagnoni, pierca@iuav.it, Italy

Description	The CGFP - Concrete Glulam Framed Panel is a prefabricated composite wall made of a reinforced concrete slab and a glulam frame.

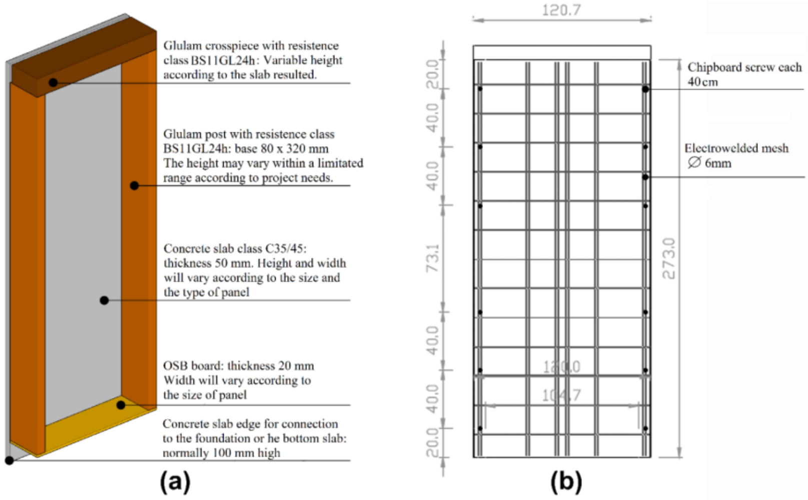

Figure 3 - CGFP (Concrete Glulam Framed Panel) standard configuration (a) and electrowelded mesh (b) (Source:Boscato, 2018)

Main characteristics	Envelope
Power range	N/A
Technology interdependencies	Synergies with district heating and cooling systems
Advantages and disadvantages	The CGFP panel shows a good thermal performance, a low environmental impact respect to similar construction systems and promising structural behaviour. The CGFP panel presents a low level of impacts in term of environmental assessment and embodied energy
References	https://doi.org/10.1016/j.jobe.2018.05.027

Modular Façade Panels

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Description	Modular Façade Panels are prefabricated composite systems ready to be applied in existing buildings external walls. They are generally composed of a layered structure with a cladding surface and insulation material. The system allows for integration of complementary technologies such as monitoring devices and use of 3D printing and scanning.

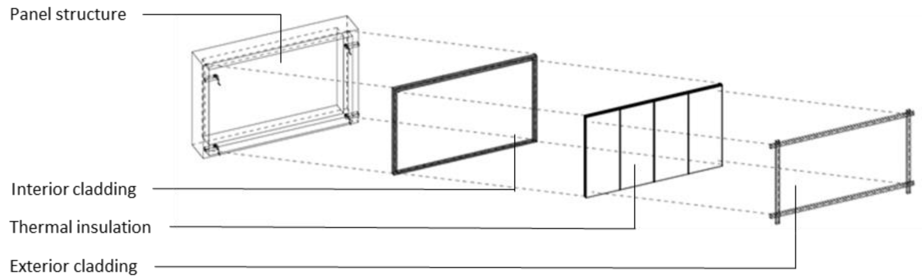

Figure 4. Schematic of a generic modular panel assembly (Source: adapted from www.more-connect.eu/)

Main characteristics	Envelope
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Synergies with district heating and cooling systems
Advantages and disadvantages	Reduced time of application with minimal disturbance of occupants. Potential economies of scale when applied in groups of buildings.
References	http://repositorium.sdum.uminho.pt/handle/1822/43170

Ventilated façade

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Description	A ventilated façade is a construction method whereby a physical separation is created between the outside of the façade and the internal wall of the building. This separation creates an open cavity allowing the exchange of the air contained between the wall and the outer cladding. The cavity can provide a range of thermal, acoustic, aesthetic and functional advantages.

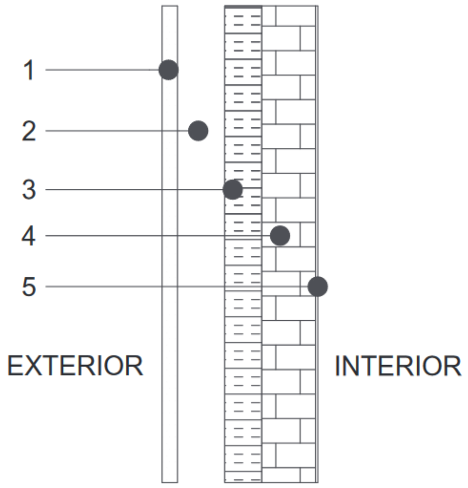

Figure 5. Schematic section of a ventilated façade (Source:figure obtained from Diarce, G. et al. (2013) *Ventilated active façade with PCM.* Applied Energy, 109, 530-537)

Main characteristics	Envelope
Power range	N/A
Technology interdependencies	Synergies with district heating and cooling systems
Advantages and disadvantages	Good performance both for reducing heating and cooling demand. Ventilated air cavity allows reducing solar gains during summer. Potential economies of scale when implemented in groups of buildings. Higher cost than other solutions, such as ETICS.
References	Ibañez-Puy, M. et al (2017). *Opaque Ventilated Façades: Thermal and energy performance review*. Renewable and Sustainable Energy Reviews, 79, 180-191. https://doi.org/10.1016/j.rser.2017.05.059

External Thermal Insulation Composite System II

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Description	ETICS is the general denomination for external wall insulation systems consisting of several components, including the insulation material (commonly EPS or mineral wool), mechanical fixings, a mesh layer and a top-coat render and finish.

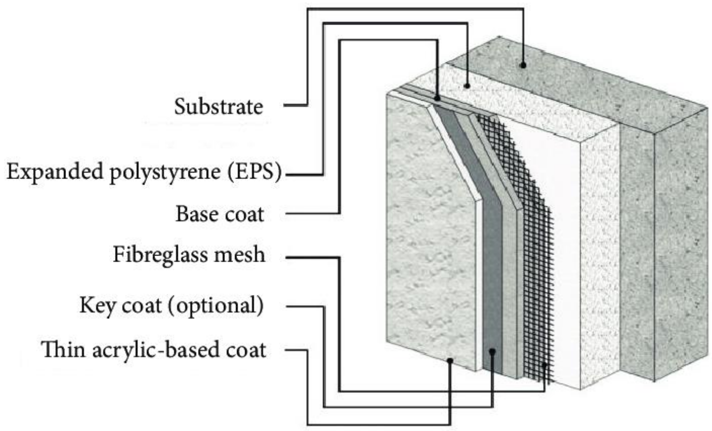

Figure 6. Schematic of the composition of the system (Source: VP Freitas (2002))

Main characteristics	Envelope
Power range	N/A
Technology interdependencies	Synergies with district heating and cooling systems
Advantages and disadvantages	Low cost and ease of application. Potential economies of scale when implemented in groups of buildings.
References	https://www.hindawi.com/journals/amse/2014/650752/

Pre-fabricated insulated façade elements with integrated ventilation and solar PV

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Description	Prefabricated façade elements to improve building envelope. In addition, the elements include ventilation ducts for balanced ventilation with heat recovery and solar PV panels for local electricity production. Prefabricated elements reduce installation time at the construction site and allows the residents to stay on living in their apartments during the construction period. First pilot currently under installation in Norway. The concept could potentially include other technologies such as piping for waterborne heating and/or cooling

Figure 7 - Photograph from pilot construction site 2018.06.06

Main characteristics	Improvement of building energy performance
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Includes renewable energy technology (solar PV) and ventilation ducts. Integration with air handling unit.
Advantages and disadvantages	Prefabrication allows for industrial production and potentially reduce costs and installation time, but requires more detailed planning and design
References	http://4rineu.eu/2018/03/02/update-from-oslo/

Building systems

Building Automation System (BAS)

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Description	Building Automation generally refers to the data acquisition and control system used to command main functions of buildings or groups of buildings such as heating, cooling and ventilation. In conjunction with energy management systems or a building automation system (BAS), allows for optimized tuning of energy functions and real time adaptation to environmental conditions, maximizing the use of renewables in a building or group of buildings. It also allows for continued optimizations during the operation phase.
Main characteristics	Building energy management systems
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Synergies with PV and Thermal Solar systems, as well as district heating and cooling systems
Advantages and disadvantages	High initial cost
References	https://www.sciencedirect.com/science/article/pii/S221067071730135X

Energy management and monitoring systems (EMS)

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Description	Energy monitoring and/or management systems (EMS) are tools that are provided to increase awareness and to provide system control. EMS are expected to lead to the adoption of energy-saving measures and energy flexibility at the district level. If the system only provides insights we speak of a Energy Monitoring System. If the system allows control, we identify it as Energy Management System. For residences these systems are also identified as Home Energy Monitoring Systems (HEMS).

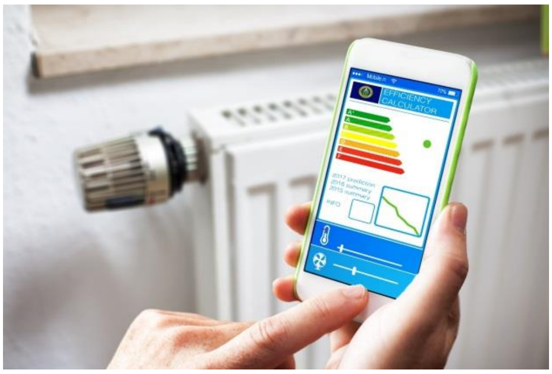

Figure 8 - Example of an IT-applications related to a HEMS (Source: Triple-A).

Main characteristics	The use of EMS is not new and can be related to the rollout of smart meters and energy bookkeeping systems as a precondition to give energy users feedback about actual energy consumption and to encourage users to lower their consumption. An EMS includes tracing energy consumption and the eventual energy the buildings themselves produce, use and/or deliver back to the grid via renewable energy sources like PV-panels.
Power range	N/A
Technology interdependencies	(H)EMS are being developed to act interdependent with other technologies such as smart meters, ICT, HVAC control systems and (household) equipment. They are critical component to achieve energy flexible buildings.
Advantages and disadvantages	EMS are being adopted mainly is non-residential buildings. It remains a challenge to diffuse HEMS in residential areas.
References	Meijer, F., Straub, A., Mlecnik, E., 2018, Impact of Home Energy Monitoring and Management Systems (HEMS), Triple-A: Stimulating the Adoption of low-carbon technologies by homeowners through increased Awareness and easy Access, D2.1.1. Report on impact of HEMS, http://www.triple-a-interreg.eu/project-reports IEA EBC Annex 67 Energy Flexible Buildings, http://annex67.org/

Energy system – Production

Low-temperature thermal grids/Smart thermal grids

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Description

Local district heating/cooling solutions in combination with small and large heat pumps is based on a local district heating network for e.g. a group of buildings or a small district that has a significantly lower temperature than the regular district heating network. The local network is connected to the "global" one, and can draw energy from this whenever needed.

The local network supplies water at a temperature of e.g. 20 °C (compared to the 70 °C of a typical district heating network)…

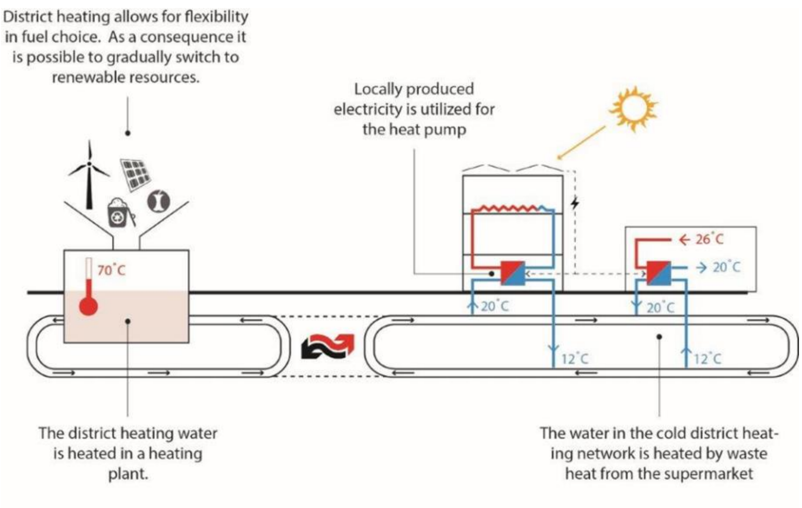

Figure 9 - Schematic of the interconnection between local and global district heating system.

Main characteristics	Distribution system at district level
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Synergies with heat pumps, renewable energy – PV and solar thermal, storage systems and district heating and cooling systems
Advantages and disadvantages	May be difficult to install and run in practice
References	https://www.degruyter.com/downloadpdf/j/sbeef.ahead-of-print/sbeef-2016-0030/sbeef-2016-0030.pdf

Cogeneration with Organic Rankine Cycle

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Description

Organic Rankine cycle technologies are increasingly of interest for cost-effective sustainable energy generation. Popular applications include cogeneration from biomass and electricity generation from geothermal reservoirs and concentrating solar power installations, as well as waste heat recovery from gas turbines, internal combustion engines and medium- and low-temperature industrial processes. There are hundreds of ORC power systems already in operation and the market is growing at a fast pace.

The Rankine Cycle is a thermodynamic cycle that converts heat into work. The heat is supplied to a closed loop, which typically uses water as working fluid. The Rankine Cycle based on water provides approximately 85% of worldwide electricity production. Organic Rankine Cycle (ORC) is basically a cycle with a steam turbine that uses a high molecular mass organic fluid instead of water.

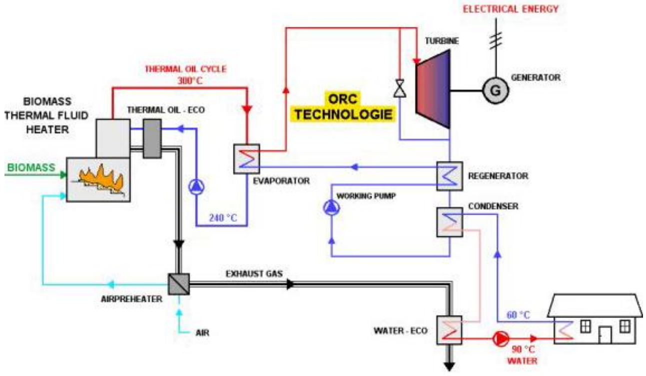

Figure 10 - Schematic representation of biomass cogeneration with ORC technology..

Main characteristics	Production of heat and electric power
Power range	From few kW to MW of electric power
Technology interdependencies	Synergies with solar thermal, absorption cooling, storage systems and district heating and cooling systems
Advantages and disadvantages	Maintenance can be problematic even if it is a mature technology.
References	http://dx.doi.org/10.1016/j.rser.2013.01.028

Cogeneration with Internal Combustion Engines

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Description

The cogeneration using internal combustion engines operate mainly according to the Otto cycle and the Diesel cycle. Being the heat source "internal" to the machine, the choice of fuels is exclusively "high-quality" fuels, which are petrol, natural gas or biofuel for the Otto engine and diesel and bio-diesel for the Diesel engine. The crankshaft connected to an alternator produces electricity and at the same time heat recovery can be realized in four points:

- from the exhaust fumes: at the exit from the engine these can also have 400-500 ° C and can be cooled to about 200 ° C. It is possible to recover between 30% and 35% of the heat supplied to the engine.
- from cooling water it is possible to recover 25% of the heat supplied to the engine and the recovery thermal level is around 85-90 ° C;
- from lubricating oil, overall it is possible to recover 4-7% of the heat supplied to the engine and the recovery thermal level is around 85-90 ° C;
- from the air: if there is a supercharging system a part of the heat can also be recovered from the combustion air injection device;

In order for the efficiency of the motor to remain high, it is preferable to operate in continuous mode, satisfying the maximum demand for electrical production and disposing of excess heat. To satisfy the thermal demand peaks, the system must be integrated with auxiliary boilers and systems accumulation.

With these systems it is also possible to cover a wide range of power between 1 kW and 20 MW. In the last ten years some engines have been proposed on the market of very small size suitable for domestic cogeneration (1-5 kWe). For micro-cogeneration units, small automotive engines have successfully been used.

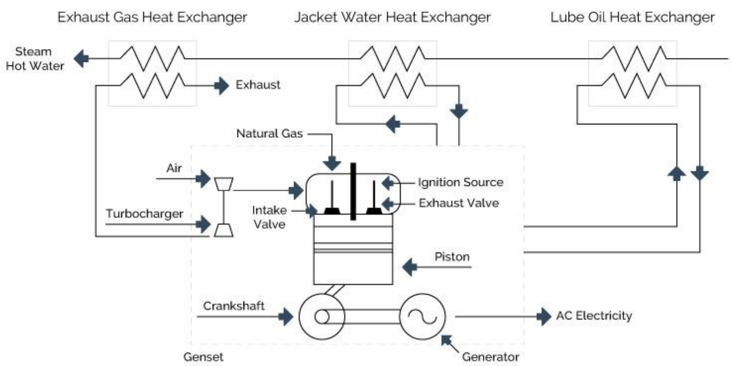

Figure 11 - Schematic representation of internal combustion engine cogeneration system.

Main characteristics

Production of heat and electric power

Power range

From few kW to MW of electric power

Technology interdependencies	Synergies with absorption cooling, storage systems and district heating and cooling systems
Advantages and disadvantages	• great flexibility and reliability obtained by transferring the experience accumulated in the propulsion • modularity, realized by varying the number of cylinders according to the power to be supplied • high electrical yields, from 20-25% of the machines from a few tens of kW to 40% and more for the different engines hundreds of kW • easy start-up and reliability of the ignition system, together with the speed of set-up. • high maintenance costs for large-scale installations • rather high emissions of all the major macro-pollutants of regulatory interest • In the field of renewable fuels there are a multiplicity of applications: bio-gas, ethanol, bio-diesel, vegetable oils, oils deriving from processes industrial processing of organic substances, oils from animal fats, used cooking oils, etc.
References	https://doi.org/10.1080/15435075.2014.962032

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Absorption cooling

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Description

An absorption refrigerator uses a heat source (e.g., solar energy, a fossil-fueled flame, waste heat from factories, or district heating systems) to provide cooling. Usually it is used where waste heat is available or where heat is derived from solar collectors. Connected to a cogeneration system can recover energy during the cooling period. Rather than a mechanical compressor like the ones used in compression refrigeration systems, absorption chillers operate on the basis of a so-called thermal compressor. Two widespread absorption cycles currently in use are the lithium bromide (LiBr) cycle and the ammonia-water (NH3H20) cycle. In the former, water acts as the refrigerant and LiBr as the absorbent. In the latter, the ammoniawater solution is the refrigerant and water is the absorbent. The LiBr cycle tends to be more common.

COP's of absorption chillers are low. Single effect LiBr machines offer COP's of 0.65 ~ 0.7 and double-effect chillers can achieve COP's of about 1.2. The temperature of the heat source is the most important factor in the thermal efficiency of an absorption chiller. The higher the temperature of the heat source, the better the COP

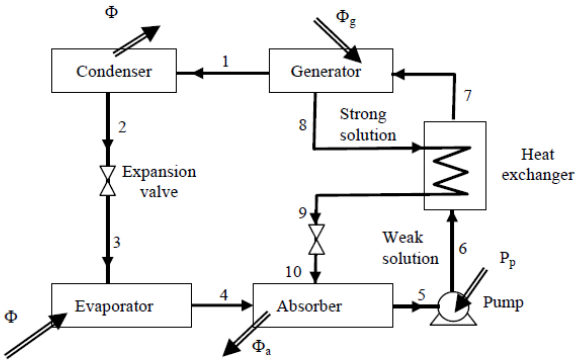

Figure 12 - Schematic representation of adsorption cooling technology..

Main characteristics

Cooling power

Power range

From few kW to MW

Technology interdependencies

Synergies with solar thermal, storage systems, cogeneration plants and district heating and cooling systems

Advantages and disadvantages

The advantages of absorption cooling machines are low electrical power requirements, fewer moving parts, limited noise, and the use of low Global Warming Potential (GWP) refrigerants. Disadvantages include a high rate of heat rejection, limited unit selection and support, large physical size and weight, and toxicity of ammonia absorbent. Maintenance can be problematic even if it is a mature technology.

References

http://dx.doi.org/10.1.1.473.8896

Geothermal heat pumps – local district heating

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Description	In Sweden 80 % of the multi-family buildings are connected to district heating. The average Swedish district heating in based on to 50.7% on recycled energy and 40 % on renewable energy. The fossil energy source covers only about 7% on the district heating energy. An alternative solution is to convert from centralized district heating to geothermal heat pumps, which means extracting heat from the ground and raising the temperature with heat pumps. This is done for a group of buildings or individual buildings. The reason is usually to reduce energy costs. If the used electricity is from renewable sources, then the heating is completely based of renewable sources. The heat pumps are usually designed not to cover all heating on cold days. The peak load is then covered by district heating or electricity.
Main characteristics	Distribution system at district level
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Synergies with heat pumps, renewable energy – PV, storage systems and district heating and cooling systems
Advantages and disadvantages	May be difficult to install and run in practice
References	

Solar Thermal Systems

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Description	Solar Thermal Systems refer to systems harnessing solar energy for generating thermal energy used in buildings for space heating and Domestic Hot water (DHW). In the light of new requirements for decarbonization of the built environment, solar thermal systems and photovoltaic systems compete for space in building roofs. In this context, in comparison with single building application, implementation of these systems in a group of buildings can be beneficial to take advantage of the scale effect, even if a district heating system is not available.
Main characteristics	Renewable energy system
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Synergies with district heating and cooling systems, as well as with building energy management systems
Advantages and disadvantages	Established technology
References	https://www.sciencedirect.com/science/article/pii/S0360544217307363 https://ieeexplore.ieee.org/abstract/document/7914744

Photovoltaics system

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Description	Photovoltaics systems refer to systems harnessing solar energy for generating electricity. In the light of new requirements for decarbonization of the built environment, solar thermal systems and photovoltaic systems compete for space in building roofs. In this context, in comparison with single building application, implementation of these systems in a group of buildings can be beneficial to take advantage of the scale effect, even if a district heating system is not available.
Main characteristics	Renewable energy system
Power range	N/A (requires more detailed specifications)
Technology interdependencies	Synergies with district heating and cooling systems, as well as with building energy management systems
Advantages and disadvantages	High initial cost
References	https://www.sciencedirect.com/science/article/pii/S1040619012000589 https://ieeexplore.ieee.org/abstract/document/7914744

Photovoltaic thermal hybrid solar collectors (PVT)

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Description	PVT collector is a solar energy device that uses PV as a thermal absorber and produces both electrical and thermal energy. A wide variety of PVT module configurations exist. Several previous market surveys have been published and include a classification. The attention for PVT systems and the number of suppliers is steadily growing. On the one hand PVT collectors are used in the well-known fields of application of solar thermal energy such as domestic hot water heating and domestic hot water heating with heating support. However, non-covered liquid-cooled PVT collectors are also used in heat pump systems where their low-temperature heat is primarily used at the source side of the heat pump. In particular, mention should be made of the use for the regeneration of geothermal probes.

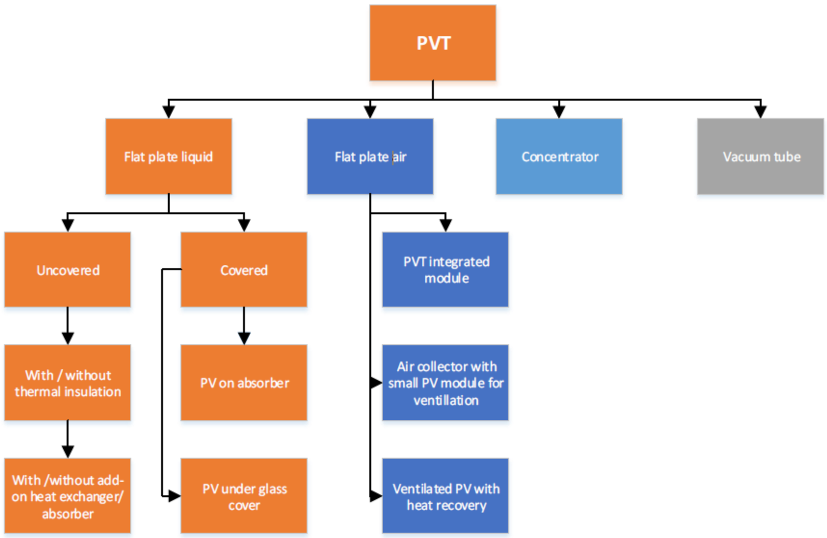

Figure 13 - PVT Module Classification (Source: https://www.seac.cc/wp-content/uploads/2018/01/SEAC_PVTinSHaPeBenchmark_final.pdf)

Main characteristics	renewable heat and electricity generation
Technology interdependencies	similar to sole solar thermal and photovoltaic installations
Advantages and disadvantages	Advantages: Compactness and yields, good combination of PVT with heat pump disadvantages: Complexity of system design and installation, difficulties in optimization, low economic profitability and high investment costs
References	https://www.seac.cc/wp-content/uploads/2018/01/SEAC_PVTinSHaPeBenchmark_final.pdf

PEM (Proton Exchange Membrane) fuel cells

Description

Fuel cells are electrochemical devices that convert fuel into electricity and heat. Generally, the conversion efficiency from fuel to electricity is high in a fuel cell and the technology is scalable without loss of efficiency. The proton exchange membrane (PEM) fuel cell consists of a cathode and an anode made of graphite and a proton conducting polymer as the electrolyte as shown in Figure 1 [1]. Low temperature PEM fuel cells operate at temperatures below 100 °C (typically around 80 °C) since the membrane must be saturated by water.

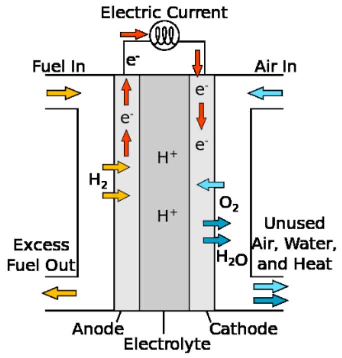

Figure 14 - Diagram of a PEM-FC (Source: [2]).

Today, the larger power and heat generating units FC-CHP are typically arranged for integration in conjunction with industrial processes where hydrogen is a waste gas from the industrial processes e.g. production of chloric gas. In many of the early units, only the electricity as output is used. In the future, the hydrogen used for the fuel cell may be produced from electrolysis based on fossil free electricity. Additionally, the potential of the LT-PEM fuel cell for transport purposes and within the area of mCHP installations has been estimated to be significant [1].

The technology has good part load and transient properties. The regulation of PEM systems can be designed to achieve close to 0% nominal load without significant loss of efficiency. Furthermore, the start-up time of the technology is short and the fuel cells can start and operate at room temperature and has no problems with frequent thermal cycling (start/stop). Response time from cold start during hard frost is very short down to a few seconds.

Figure 15 - A 50 kW LT-PEMFC CHP hydrogen unit from Dantherm Power.

Main characteristics	PEM fuel cells can usually work as both a fuel cell and a water electrolysis cell, i.e. converting hydrogen into electricity and heat in one process and converting water and electricity into hydrogen in the reverse process. This means that the fuel cell can store excess electricity as hydrogen when production from e.g. wind turbines is high and use this hydrogen as fuel when production is low.
Power range	The larger FC-CHP units are typically around 20 to 1,000 kW of electrical power.
Technology interdependencies	Combining PEM-FC with electricity based on renewable energy sources like wind-turbines or photovoltaics means that it is possible to store excess production as hydrogen which can be used as fuel in the PEM-FC at a time where there is a shortage of electricity production. Stored hydrogen could also be used for transportation purposes in e.g. cars. The fuel cells produce both electricity and heat and in order to obtain maximum efficiency the heat should be utilized as well, e.g. by heat pumps connected to a district heating system.
Advantages and disadvantages	The main advantages include: • The PEM-FC utilizes the scalability of the fuel cell technology to produce electricity locally with efficiencies equal to or higher than for conventional power plants. • Larger FC-CHP units in the grid can support the grid companies in balancing the grid. • The grid balancing property of the PEM-FC contributes to reduced additional investments in infrastructure e.g. cables. • Hydrogen produced from excess electricity based on renewable sources can be stored in hydrogen storages and utilised in the PEM-FC in situations, where wind turbines, solar PV and other renewable technologies are not available. The main disadvantages include: • Relatively high production costs today due to expensive materials (platinum). • The lifetime of the current technology needs to be improved.

Data for analyses	The maximum theoretical efficiency is 83 % at 298 K. The practical efficiency of PEM fuel cells are in the range of 50–60 %.
Energy performance	The generating capacity for one unit is 0.05 MWe (2015) and 0.10 MWe (2020). The electricity efficiency is approximately 45%.
Financial data: investment, operation and maintenance	The investment costs are projected to decrease from 1.9 to 1.5 M€/MW by 2020, 0.7 M€/MW in 2030 and 0.6 M€/MW by 2050 according to the projection of the IEA Technology Roadmap - Hydrogen and Fuel Cells, 2015. O&M costs are 95,000 €/MW/year and expected to drop to 65,000, 55,000 and 40,000 by 2020, 2030 and 2050 respectively. The typical generation capacity is expected to increase from around 0.1 MW in 2020 to approximately 2 MW in 2050, while the electrical efficiency is expected to increase to 50%.
Environmental issues	If the hydrogen is produced from fossil free electricity, the operation of the LT-PEM-FC is carbon neutral. Exhaust gas does not contain NO_x and SO_2.
Development potential	The fuel cell technology has shown high electrical efficiency above the efficiencies of competing power generation technologies. However, the fuel cell technology still needs to be matured on issues like lifetime and cost reduction. It is expected that the Danish fuel cell technology will mature to a commercial level within this decade.
References	[1] Partnerskabet for brint og brændselsceller, Fuel Cell Technologies, http://www.brintbranchen.dk/, visited 18.10.2018. [2] Wikipedia, Proton exchange membrane fuel cell, https://en.wikipedia.org/wiki/Proton_exchange_membrane_fuel_cell, visited 18.10.2018.

Energy system - Storage

Solar district heating

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Description	Large-scale solar panel arrays connected to an insulated water basin. During summer, the solar panels heat the water in the basin to approximately 90 °C and during winter, the stored energy supplies the district heating. Systems will have additional heat generating capacity to ensure that all of the consumers' heating needs are met, when there is insufficient sunshine.

Figure 16 - Toftlund District Heating. 27,000 m^2 solar panels and 70,000 m^3 water. The facility will cover approximately 45 % of the total heating needs of the 1,033 individual customers.

Main characteristics	Solar collectors combined with a large water storage basin.
Power range	N/A
Technology interdependencies	If solar heat is used in combination with combined heat and power production (CHP), the flexibility value of the storage for electricity production in a system dominated by wind power could be included.
Advantages and disadvantages	The solution is relevant in climates dominated by heating with a seasonal variation in sunshine levels and temperatures.
References	"Solar Water Heating Project Analysis", RETScreen International (www.retscreen.net), 2004.

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Flow batteries

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Description	A flow battery is a type of rechargeable battery where rechargeability is provided by chemical components dissolved in liquids contained within the system and most commonly separated by a membrane. This technology is akin to both a fuel cell and a battery - where liquid energy sources are tapped to create electricity and are able to be recharged within the same system. Different classes of flow cells (batteries) have been developed, including redox, hybrid and membrane-less. The fundamental difference between conventional batteries and flow cells is that energy is stored as the electrode material in conventional batteries but as the electrolyte in flow cells. There are different types of flow batteries, i.e.: Redox, Iron-Chromium, Vanadium Redox and Zinc-Bromine based.
Main characteristics	Allows for long term storage without losses
Power range	The size can be varied by changing the size of the storage tanks for the electrolyte. For one producer in Denmark storage capacities may vary from 25 to 500 kWh. Nominal charge/discharge power may vary from 5 to 100 kW.
Technology interdependencies	Synergies with heat pumps, renewable energy systems: PV and wind.
Advantages and disadvantages	The flow battery is a very green/sustainable solution compared to for example a solid state battery. Another is that the power and energy ratings are independent of each other and each may be optimized separately for a specific application. Third is a long life-time (>20) years and more than 10.000 cycles. Fourth: One of the advantages of flow batteries is that they can be almost instantly recharged by replacing the electrolyte liquid, while simultaneously recovering the spent material for re-energization
References	http://energystorage.org/energy-storage/storage-technology-comparisons/flow-batteries

Solid state batteries

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Description	On its most basic level, a battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell contains a positive terminal, or cathode, and a negative terminal, or anode. Electrolytes allow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work. Advances in technology and materials have greatly increased the reliability and output of modern battery systems, and economies of scale have dramatically reduced the associated cost. Continued innovation has created new technologies like electrochemical capacitors that can be charged and discharged simultaneously and instantly, and provide an almost unlimited operational lifespan. The most well – known type of solid-state battery is the Li-ion type – often used in electric cars. Other types are Ni-Cd - and Sodium-Sulfor (NaS) batteries. The latter has been used extensively in Japan.
Main characteristics	Relatively high power in and out: Suitable for short-term – up to 6 hours - peak – shaving / electrical storage.
Power range	The size may vary from energy-type batteries of a few kilowatt-hours in residential systems with rooftop photovoltaic arrays to multi-megawatt containerized batteries for the provision of grid ancillary services.
Technology interdependencies	Synergies with heat pumps, renewable energy systems: PV and wind.
Advantages and disadvantages	The Li-ion is a rather simple construction, which is easy to install in the electrical network.
References	http://energystorage.org/energy-storage/storage-technology-comparisons/solid-state-batteries

Thermal storage

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Description

The general principles for storing heat are sensible heat storage, latent heat storage, sorptive heat storage and chemical heat storage. Sorptive and chemical heat storage technologies are called thermochemical energy storage.

- Sensible heat storage depends on the heat capacity of the material. Examples for sensible heat stores are storage tanks, borehole thermal energy stores or aquifers. The enthalpy-temperature curve is linear.
- Latent thermal heat stores use the phenomenon that there is a temperature range at which the material changes its phase. This is coupled to a large increase (or vice versa decrease) in enthalpy (e.g.melting, evaporation, crystallisation). The materials used for latent thermal heat stores are water, organic and inorganic phase change materials.
- Thermochemical heat storage uses the principle of physical adhesion and absorption enthalpy or chemical reaction enthalpy.

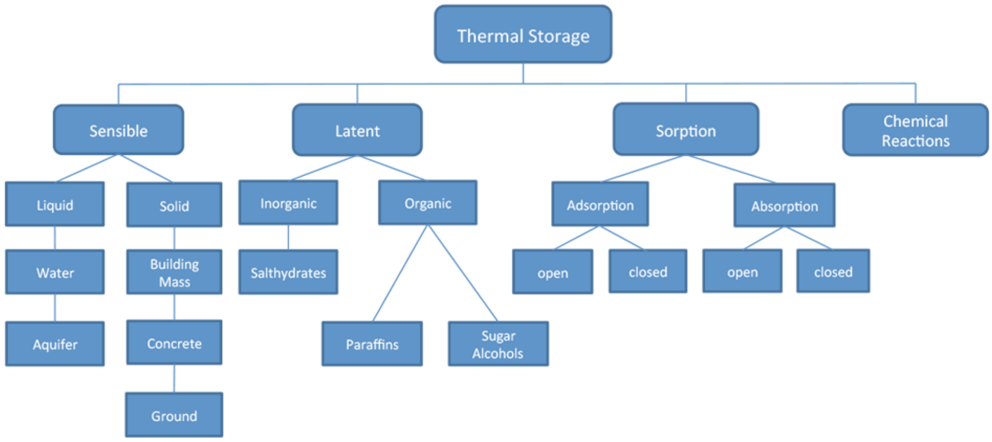

Figure 17 - Principal storage technologies

Main characteristics

heat storage at building (and in future at district level)

Technology interdependencies

combination with local solar thermal collectors would be beneficial, depending on the application low temperature source for evaporation and condensation of water vapor

Advantages and disadvantages

disadvantages: low experience regarding the use of PCM and TCM thermal storages, high investment costs (energy storage material)
advantages: higher energy storage density (goal 6 times higher than water) leading to more compact storage systems (smaller size)
no sensible heat losses during storage time (applicable for seasonal heat storage)

References

http://comtes-storage.eu/; http://www.createproject.eu/; http://www.scores-project.eu/; http://tes4set.at/de/

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Thermal Energy Storage System

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Description	Thermal energy storage systems (TES), using phase change material (PCM) in building walls, has become a very interesting topic for buildings designers. As latent heat storage media, phase change materials (PCMs) are a series of functional materials taking advantage of high energy storage density in a narrow temperature interval

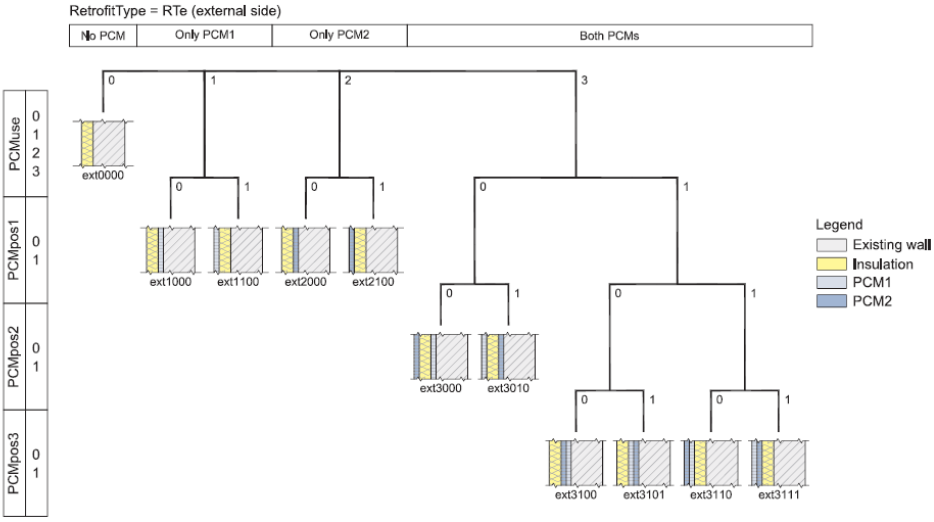

Figure 18 – Wall configurations for retrofitting on the external side.

Main characteristics	Envelope
Power range	N/A
Technology interdependencies	Synergies with district heating and cooling systems
Advantages and disadvantages	The optimal positioning of the PCM must be evaluated according to some variables, among which the period in which it prefers to reduce the energy consumption, the orientation of the walls. It must be noted that the practical engineering application on PCM walls is few, and researches show that the application of PCM walls is not proceed independently, but combined with other media or devices so as to strengthen the application effect.
References	https://doi.org/10.1016/j.egypro.2015.02.118 https://doi.org/10.1016/j.egypro.2015.11.846 https://doi.org/10.1016/j.apenergy.2017.11.081

Component activation

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Description	For using the thermal mass of the buildings the activation elements must be integrated into the building components themselves (e.g. in the foundation or intermediate ceilings between floors), so therefore they can only be easily applied to newly constructed buildings with reasonable effort. For existing buildings therefore a lot more effort is required to implement storage elements into these buildings which can be a burden to the occupants (milling of activating elements into the floors and ceilings). A simple way to thermally activate large masses in existing buildings and thus to generate heat storage energy is by means of a liquid or electrically driven activation level (principle "external wall heating") from the outside via the building facade. First calculations have shown that facades with a U-value larger than 1 W/m²K are very well suited to this approach. A logical prerequisite for functioning is insulation of the existing façade. This means that practically all non-refurbished buildings come into play for thermal activation of the existing walls. In doing so, the heat requirements can be reduced and thermal storage can be activated at a very low cost.
Main characteristics	heat storage at building and district level; heat dissipation in buildings
Technology interdependencies	thermal renovation (insulation) of building envelope is necessary combination with local solar technologies (solar-thermal, PVT, PV) and other local renewable energy sources brings additional benefits
Advantages and disadvantages	A core advantage is that the entire heat distribution for room heating, with the exception of temperature sensitive rooms such as the bathroom can be controlled via the external activation level, which can also be used for cooling if necessary. The disadvantage is probably the degree of novelty and in further consequence the low experience of using component activation in refurbished buildings.
References	https://tinyurl.com/component-activation

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