Contribution of Renewable Cooling to the Renewable Energy Target of the EU

Policy Report

On behalf of NL Agency of the Netherlands

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0 Executive Summary

Renewable cooling technologies do not play a major role in the climate protection discussion in the European Union today. At the same time the cooling demand is expected to increase significantly in the coming decades. Renewable cooling technologies could contribute to the EU renewable energy target if an appropriate political framework for a further spread of the technologies is created.

This renewable cooling policy report intends to support the dissemination of renewable cooling technologies. It provides an overview of the situation, technologies and potential for cooling from renewable sources and identifies key areas in which further investigation is required. The report shows that there is a great need for the creation of a political framework supporting the market diffusion of renewable cooling technologies.

Firstly the question of a commonly accepted definition on renewable cooling is being addressed. Secondly renewable cooling technologies are described and the today's role of cooling in European statistics and policies is analysed. In the next step existing studies are evaluated to compare the expected development of the cooling demand in Europe to the market potential of renewable cooling. At the end of the paper a long-term vision for renewable cooling is described and first steps towards a European roadmap for renewable cooling are given.

Definition

So far there is no overall accepted definition for renewable cooling. According to ETPRHC, 2011, *cooling* can be defined as the decrease in temperature of indoor air for thermal comfort and for providing the necessary thermal environment for technical processes or activities being carried out.

The following definition for *renewable cooling* has been developed in this report:

Cooling technologies should be considered renewable if they comply with the following requirements:

(a) The (main) energy source used must be renewable according to the definition provided by the RES Directive;

(b) The cooling demand to be covered must be useful cooling demand (in general this applies to any form of space cooling but would exclude cooling down waste heat, e.g. of power plants or other industrial processes that generally could be used for other technical applications);

(c) The technology must meet pre-defined minimum efficiency standards (e.g. minimum seasonal performance factors in the case of heat pumps operating in reverse mode), similar to the performance requirements in the RES Directive for heat pumps.

Applications driven by renewable electricity are not considered renewable due to efficiency reasons (they will not reach the pre-defined minimum efficiency standards) and due to statis-

tical reasons (renewable electricity should always be statistically counted towards renewable electricity).

Next to the definition also a commonly accepted terminology for renewable cooling technologies would help to simplify the political debate between Member States.

Technologies and their today's contribution to cover the cooling demand

There is a variety of renewable cooling technologies ready for the market. They can be classified in direct cooling, indirect cooling and cooling with renewable heat.

Direct cooling applications are technologies that use substances that already have the required low temperature needed for cooling, such as snow, sea, deep lake, and ground water. The availability of these substances is restricted to certain geographical locations and climatic conditions. Therefore these applications are only suitable for parts of Europe. These can be northern European countries or higher mountainous regions for snow cooling, some coastal regions for sea water cooling, regions with appropriate water bodies for deep lake and river cooling, and regions with appropriate geological formations of the underground for ground water cooling. Direct cooling can also include the storage of the cooling substances (e.g. waterstorage in aquifers or waterstorage as snow). The technologies are ready for the market and there are already pilot applications. Hybrid applications of direct cooling and absorption cooling can be a suitable economically and technically solution with high efficiency.

For *indirect cooling* an electricity or water input is needed to lower the temperature. It can be executed with heat-pumps running in the reversible cycle. Another indirect cooling technology is evaporative cooling. This technology is restricted to certain climatic conditions as well, and there also are examples for successful working applications. However, according to the definition of renewable cooling described above, both indirect cooling technologies are only considered renewable if they meet certain minimum efficiency requirements (that can be met if the source for the heat pump has a temperature below the requested temperature).

The third kind of renewable cooling technologies is *cooling with renewable heat*. These can be absorption, adsorption, and desiccant and evaporative cooling systems. The required thermal energy can be provided by different sources, but solar energy delivered by solar thermal systems is expected to be the most important source in the future. This technology is most suitable for southern European regions with high solar radiation and high cooling demand. Other energy sources can be combined heat and power plants burning biomass or geothermal heat. These technologies are restricted to available biomass and suitable geothermal conditions. Some applications are already available on the market, but generally there is still a high need for research and development.

None of the described technologies has been implemented widely yet. This is partly due to still necessary technology development, but also technologies that are already economical are not being implemented to a greater extend. It is necessary to identify the hurdles for their market penetration and to set incentives in order to accelerate their market diffusion.

Cooling in European statistics and policies

Today data on the use of renewable cooling are not collected in the European Union and the Member States. However, the knowledge of data on cooling in general and renewable cooling in particular and its contribution towards the European climate protection targets is essential for the acknowledgement of renewable cooling in the European and national political frameworks. Without statistical data renewable cooling cannot contribute to the renewable energy target of the RES-Directive. This influences the renewable energy policies, which do not deliver incentives to use renewable cooling technologies today. Existing policies usually focus on the support of renewable heating. Statistics for renewable cooling could mainly be collected the same way as those for renewable heating, and would need only little additional work.

Development of cooling demand and renewable cooling potential in Europe

The cooling demand in Europe is expected to increase significantly in the next decades. This increase is expected due to global warming, more heat-emitting electric appliances inside the buildings, a partly glass-dominated architecture, and a rising aspiration for comfort. The service sector is expected to have the larger share of the growing cooling demand. The regional growth of the cooling demand is strongly influenced by the geographical position of the countries.

According to ETPRHC, 2011, the main growth of the cooling demand will take place until 2020. According to them it will treble between 2007 and 2020, from about 230 TWh/a in 2007 to almost 700 TWh/a in 2020. In 2050 the cooling demand will reach 733 TWh/a. Weis & Biermayr, 2009, calculated a more steadily increase of the cooling demand for five European reference countries (Austria, Poland, Germany, Spain, and Denmark). According to their study the demand will grow from 33.6 TWh/a in 2005 to about 55.3 TWh/a in 2020 and 106 TWh/a in 2050 in these five countries. Both studies agree on the triplication of the cooling demand until 2050 compared to 2005, 2007 respectively.

Technically it should be possible to provide 100% of the cooling demand by renewable cooling applications by 2050. Hurdles and limiting factors for the contribution can be unsuitable geographical and climatic conditions, the lack of political awareness and human resources, the missing availability of marketable key components and low prices for fossil fuels and electricity.

Assuming that at least 50% of the cooling demand could be covered by renewable energy applications by 2050, at least about 370 TWh/a (based on the cooling demand calculated by ETPRHC, 2011) should be provided by renewable energies. Weis and Biermayr, 2009, and ESTTP, 2011, agree that (at least) 50% of the cooling demand could be met by solar thermal applications alone.

First steps towards a European roadmap for renewable cooling

The development of a roadmap for renewable cooling could help to accelerate the dissemination of the technologies. The following box provides a long term vision on the use of renewable cooling technologies. The bottlenecks to be overcome to reach this vision are described and the first steps on the way to the roadmap are outlined.

Long-term vision

- In 2050 at least 50% of the total cooling demand should be covered by cooling technologies based on renewables according to the definition under chapter 0; policies should be implemented which aim to increase this share to up to 100%.
- Different renewable cooling technologies will have penetrated in different European regions to a different extent. While in Northern European countries direct cooling technologies will be spread widely, in southern European countries solar thermal applications will dominate the market for renewable cooling technologies.
- District Cooling Systems will become a common technology to cover the cooling demand especially in the business sector.

Bottlenecks to be overcome	**First steps towards a European Roadmap up to 2020**
Definition • Lack of a general accepted definition for renewable cooling.	• Launching a process to set up a definition; inclusion of definition in legal norms (e.g. RES Directive).
Statistics and target accounting • In many Member States and on the EU level a lack of broad reflection of renewable cooling in energy statistics; • For many renewable cooling technologies a lack of methodology for calculating renewable output; • For that reason lack of methodology to properly account renewable cooling towards the renewable targets set by the RES Directive.	• Developing a robust methodology for including renewable cooling in energy statistics; • National and European statistical officers should start to develop a disaggregated data body on the amount of energy used for cooling and for renewable cooling; • Revision of the Renewables Directive by explicitly acknowledging renewable cooling as technology that can be counted towards the target.
Monitoring	

• Lack of routines to monitor the renewable cooling generation from different technologies.	• Common Member State approach to develop respective monitoring routines.
Information • Insufficient knowledge about the potential of single renewable cooling technologies in different geographical regions.	• Broadening and disseminating the knowledge base about the potential of different renewable cooling technologies in different geographical regions.
Policies • Lack of appropriate policies aiming at accelerating the development and market diffusion of renewable cooling technologies.	• On the Member State level the adoption of appropriate policies to support different renewable cooling technologies according to their specific needs, taking into account different stages of market maturity;
Technologies • For specific applications (e.g. single family houses) there is still a lack of appropriate technologies.	• Cooling industry must further improve the efficiency of their renewable cooling technologies and provide technical solutions for all different applications; • Cooling industry should set up an organizational structure to promote renewable cooling.

1 Introduction

The expansion of renewable energy plays a central role within the framework of the EU climate protection policy. The interest in the sector heating and cooling did significantly increase over the last decades.

The Directive on the promotion of the use of energy from renewable sources (RES Directive 2009/28/EC) sets up binding targets for the contribution of renewable energy sources to the EU's final energy demand in 2020. Member States are obliged to determine indicative sector-specific renewable targets for electricity, heating and cooling, and transport. Within the renewable heating and cooling sector, a lot of new information on renewable heating has been produced and new technologies and applications have been developed. The statistics for renewable heating had been poor, but a methodology to set up a renewable heating statistic has been implemented.

Compared to renewable heating the acknowledgement about renewable cooling is still poor. The cooling sector is regarded together with the heating sector; however, specific data on renewable cooling is scarcely collected today and in the monitoring of the directive, cooling is not taken into account. Therefore renewable cooling does not contribute towards the targets for renewable energy. One of the reasons for disregarding the cooling sector is the lack of information. In this report we will give an overview of technologies for renewable cooling, the current status and the perspective of this sector. Renewable cooling could also contribute towards the renewable energy targets, but needs to be developed and acknowledged as renewable energy technology.

First of all a generally recognised definition of what “renewable cooling” covers is lacking. Likewise a common terminology about cooling and renewable cooling technologies that is accepted by European legislators is needed. Regarding the technologies, there are a broad range of promising cooling technologies besides solar thermal applications which are already ready for the market but have not yet been implemented on a large scale. Therefore a political framework in the European Union for the promotion of renewable cooling technologies is lacking, as is a strategy about the potential contribution of renewable cooling to the fulfilment of the European climate targets.

This paper firstly suggests a potential definition of renewable cooling. In a second step the status of different renewable cooling technologies is described. After that it summarizes and evaluates existing studies on the expected development of the total cooling demand with a special focus on the renewable cooling potential. In a final step the paper drafts first steps for a roadmap that aims at improving the policy framework for renewable cooling in order to allow this sector to be given the weight according to its potential to contribute to the renewable targets. Possibilities of political actions will be shown.

NL Agency from the Netherlands has initiated the discussion about renewable cooling after the project Therra on the definition of renewable heat. It was noticed that renewable cooling was still missing. A group of organizations has proposed a project in the Intelligent Energy Europe program, but the proposal was not funded. With the help of the information gathered for the project proposal and funding from the Dutch government it was possible to request the Öko-Institute to write this report.

2 Definition

Cooling can be defined as the decrease in temperature of indoor air for thermal comfort (residential buildings, offices, etc.) and the process of providing the necessary thermal environment for an activity being carried out (hospitals, laboratories, data centres, certain manufacturing, etc.)[1]. "Cooling demand" therefore is the demand for energy to keep the temperature in certain areas below a defined maximum limit for the purposes described above.

Further decreasing the air temperature in enclosed spaces below human or technological standards for thermal comfort (e.g. for storing or freezing food), is defined as (industrial) refrigeration (compare ETPRHC, 2011). Both temperature ranges can partly be provided by the same technologies. Statistically the energy consumption of the different purposes cannot always be separated.

There is currently no generally accepted definition for renewable cooling. Answering the question of what constitutes renewable cooling is necessary before the role that renewable cooling could play with regard to the renewable targets set by the RES Directive can be defined. A possible definition for renewable cooling is as follows:

Cooling applications qualify as renewable cooling if they comply with the following requirements:

(a) The (main) energy source used must be renewable according to the definition provided by the RES Directive (see below);

(b) The cooling demand to be covered must be useful cooling demand (in general this applies to any form of space cooling but would exclude cooling down waste heat, e.g. of power plants or other industrial processes that generally could be used for other technical applications[2]);

(c) The technology must meet pre-defined minimum efficiency standards (e.g. minimum seasonal performance factors in the case of heat pumps operating in reverse mode), similar to the performance requirements in the RES Directive for heat pumps[3].

Generally, passive cooling strategies could also be considered renewable cooling. However, like the treatment of passive solar heating, passive cooling is not currently directly reflected in the energy statistics.

Renewable electricity as operating power for a cooling application (e.g. air-conditioning operating with renewable electricity) is excluded for statistical and efficiency reasons. Statistically renewable electricity should always be counted towards the renewable electricity target. In the case of heat pumps operating in the cooling mode, this would mean that the operating power – provided it is renewable electricity – would be counted towards the renewable elec-

[1] There is no definition for cooling defined and/or accepted by the European legislator.

[2] For example (waste) heat from a server room, that needs to be cooled down year round, could be used for heating offices in winter. Another example is the use from industrial (waste) heat that could be directed in other industrial processes that also require process heat (with, for example, a lower temperature).

[3] For instance this would exclude inefficient heat pumps operating in reverse mode.

tricity target whereas the ambient cold (that is used as heating sink) would be counted as renewable cooling. The special treatment of renewable electricity driven cooling systems also holds true for (partly) non grid-connected systems (e.g. an air-conditioner operated by a PV panel that is not connected to the grid). For these kinds of combined systems where a non-grid-connected renewable installation runs an application (e.g. a PV driven refrigerator) a general solution needs to be found for how they should be treated statistically. Within the definition of end-use of the RES-Directive, this would count as electricity from PV.

Renewable energy sources are defined according to the RES-Directive (2009/28/EC). The following renewable energy sources are relevant for cooling applications:

(a) "aerothermal energy": energy stored (in the form of heat) in the ambient air;

(b) “geothermal energy": energy stored (in the form of heat) beneath the surface of solid earth;

(c) "hydrothermal energy": energy stored (in the form of heat) in surface water.

(d) energy from ‘biomass’: “biomass” is defined as the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste;

(e) solar energy.

Efficiency of air conditioners and air-source heat pumps

Air conditioners and air-to-water-heat pumps running in the cooling cycle work according to the same physical principle. Therefore both technologies can reach about the same efficiency. For thermodynamic reasons air-to-water heat pumps and air conditioners are less efficient than water- and ground-source heat pumps running in the cooling cycle. For that reason air conditioners and air-to-water-heat pumps will not reach the pre-defined minimum efficiency standards mentioned before. That is another reason why they will not be considered renewable cooling technologies.

3 Renewable cooling technologies

In the different studies and papers on renewable cooling up to now there is not yet a sufficient and consistent classification system for cooling technologies using renewable energy sources. At the moment the vast majority of publications about renewable cooling technologies are about heat driven technologies. Usually other technologies are only rarely addressed, disregarding the fact that there is a range of mature technologies with a significant market (and climate protection) potential. The following classification system defines three kinds of technologies for renewable cooling. These are:

(a) Systems using substances that already have the required low temperatures (including storage of substances) (e.g. snow, sea water, ground water) and do not need additional technical devices like chillers or heat pumps → **direct cooling;**

(b) Systems that need electricity or water input to lower the temperature (e.g. active cooling by heat pumps, evaporative cooling) → **indirect cooling;** and

(c) Systems converting heat from renewable energy sources (solar thermal, biomass, geothermal) into cold with chillers (e.g. absorption cooling) → **cooling with renewable heat.**

In all cases in which a cooling demand occurs, priority should be given to possible passive cooling measures (e.g. in the building structure or building management) before considering the installation of an active cooling technology. An overview of passive cooling strategies is provided in chapter 3.3.

District cooling

District cooling systems work similar to district heating systems: a pipe network distributing chilled water connects the respective customers with a cooling production. District cooling systems are usually more efficient than technologies for single buildings or single rooms , although there is energy loss in the distribution. The cooling can be produced by different technologies, which can be direct cooling technologies using natural local resources such as snow and cold water, the use of surplus heat (ab- or adsorption cooling), and electric chillers. Large electric chillers for cooling networks are significantly more efficient than small chillers. Different technologies can also be combined. If the source of the cooling is renewable, also the delivered cold to the end user is renewable.

According to EUROHEAT&POWER, 2010, in Europe up to 50 million tons of CO_2 could be saved, if district cooling were expanded to cover 25% of the European cooling market. The today's share is estimated between 1% and 2%[4]. Today district cooling systems are quite common in Scandinavia, but also in Austria, Spain, France and many more countries. In 2009 a district cooling capacity of about 1,755 MW_{th} had been installed in the EU[5].

Source: EUROHEAT&POWER, 2010

4 Johannes Jungbauer, EUROHEAT&POWER, per Email, 22.03.2012.

5 www.euroheat.org/Statistics-69.aspx, 14.03.2012.

3.1 Direct cooling

Direct cooling is, as mentioned above, provided by substances that already have the necessary low temperature and do not need additional equipment like chillers or heat pumps. Energy input is still needed for the operation of heat exchangers and the circulation of the cooling medium but is lower than for conventional air-conditioning systems or absorption/adsorption cooling systems. Cold water, snow and ice are usually used as sources for direct cooling.

The availability of most of these sources depends on the geographical location, the geological formation of the underground and the climatic conditions. For instance snow cooling is only an option in the northern EU Member States or in mountainous regions with reliable snowfall. Cold water cooling is dependent on the availability of deep lakes, a shore line, ground water deposits or suitable aquifers. At the same time there are usually legal regulations for public water bodies concerning the withdrawal of cold and the re-injection of warm water. Most of these technologies can, depending on availability, be used on different scales from single buildings to larger commercial complexes and district cooling.

Some of direct cooling systems work with seasonal storage of cold water or snow. This is true for snow cooling and aquifer cooling.

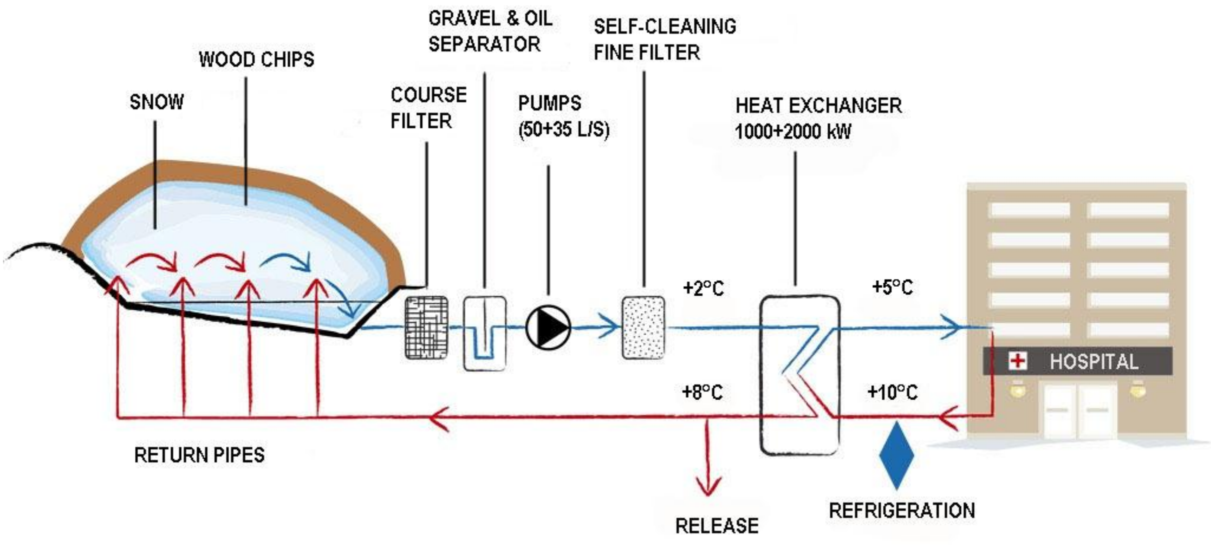
Snow / ice cooling

Snow cooling systems work with the seasonal storage of snow. During summer the cold of the snow can be used by heat exchangers. The snow can be stored in underground bunkers or in above ground holes being insulated. If the snow melts in summer, the run-off water with temperatures just above freezing temperature will be led through a heat exchanger and can be used for cooling. The warmer water is routed back to the snow bank to be chilled again. Ice cooling uses the same principle.

A well-known example from Sweden at the hospital in the city of Sundsvall shows the applicability of snow storage systems. This system is already operating since 1999. The snow is stored in a sealed pond structure covered with a layer of woodchips for insulation. The cold is extracted by direct contact of the circulating water with the snow (Figure 1). Up to 93% of the annual cooling load of the hospital can be covered by this system (Skogsberg 2005).

There are some more examples in Japan and North America, but it is not clear whether snow cooling is a widely used technology in Scandinavia or elsewhere in the European Union. As mentioned before snow cooling is suitable mainly for regions with much and reliable snow fall. In these areas the potentials are probably enormous.

Figure 1 District snow cooling system at Sundsvall Hospital in Sweden



Source: http://advantage-environment.com/byggnader/stored-snow-for-summer-cooling/

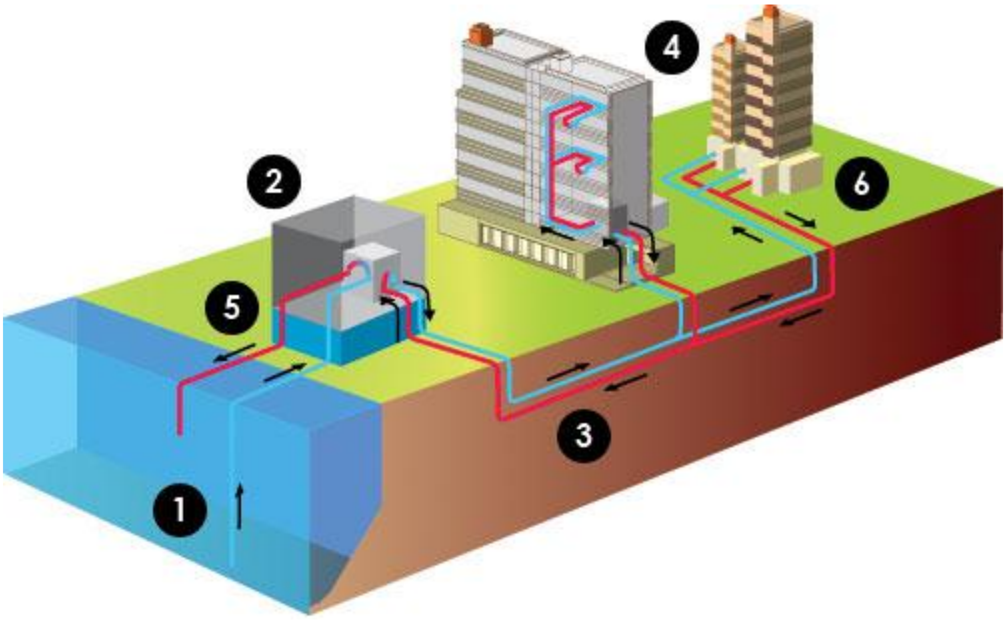
District cooling systems using hydrothermal energy from seawater, deep lakes, rivers

Seawater, deep lake and river cooling follow the same principle as snow cooling. The cold source is sea or lake water that must have temperatures between 4°C and 7°C. The cold water is pumped up and cools the district cooling network via a heat exchanger. The warmed-up sea water is led back to the sea or lake. The advantages of this technology are low exploitation costs and short payback periods. The CO_2 emissions can be reduced by 90% compared to electric air conditioning.[6]

This application is limited to regions with suitable water sources. These can be regions with hot summers and steep coastline. The climatic conditions in most European regions will not provide water with suitable temperatures during summer. Therefore the potential of this technology might be restricted; however considerable potentials might exist in hybrid systems combining seawater, deep lake or river cooling with other (renewable) cooling technologies.

6 www.greenvis.nl/english/stadskoude-swac.php; 06.02.2012

Figure 2 Sea water district cooling system



1-Deep water intake, 2-Heat exchanger building, 3-Chill water loop, 4-Serviced buildings, 5-Seawater discharge, 6-Air conditioning

Source: http://www.otecorporation.com/seawater_district_cooling.html (*10.02.2012)*

An example of a working seawater district cooling system is the district cooling in the city of Helsinki. The seawater cooling system works between November and May, when the sea's temperature is below 8°C. During summer the cold is provided by an absorption cooling cycle based on the heat of the CHP-district-heating system (heat that otherwise would not be used during summer). 60% of the used energy of the described district cooling system is renewable.[7] Other sea water cooling systems are installed in Stockholm, Honolulu and in the United Arab Emirates. An example of deep lake cooling comes from the Netherlands: for a district cooling system in Amsterdam cold bottom water from the manmade Lake Neiuwe Meer is used. The temperature at a depth of 30m is about 5-6°C. When the lake water is too warm, electric chillers are used to provide the cold for the district cooling system.[8]

Aquifer / Groundwater cooling and aquifer thermal energy storage

Aquifer or groundwater[9] *cooling* is also possible as direct cooling without using heat pumps. Cold groundwater is delivered by a suction well, led through a heat exchanger and re-

7 www.helen.fi/energy/kj_tuotanto.html; 06.02.2012

8 http://www.iea-dhc.org/download/Showcases_District_Cooling_Amsterdam.pdf; 10.02.2012.

9 The terms "aquifer cooling" and "groundwater cooling" are used synonymously in different European countries.

injected through an injection well. A cooling-pipe system leads the cold water to fan convectors which cool down the temperature in single rooms.[10]

An example of groundwater cooling is a hotel in the city of Freiburg in Germany where cold water is pumped up at a temperature of 12°C and re-injected back into the ground at a maximum of 16°C.

Aquifer storage actually works like aquifer / groundwater cooling. The big difference is that suitable aquifers are used for (seasonal) storage[11] of cold water in the underground. Cold water is injected in suitable ground water aquifers during winter to store the winter cold. During summer this cold water can be used for cooling. Seasonal storage in aquifers for space cooling is usually used in combination with space heating.

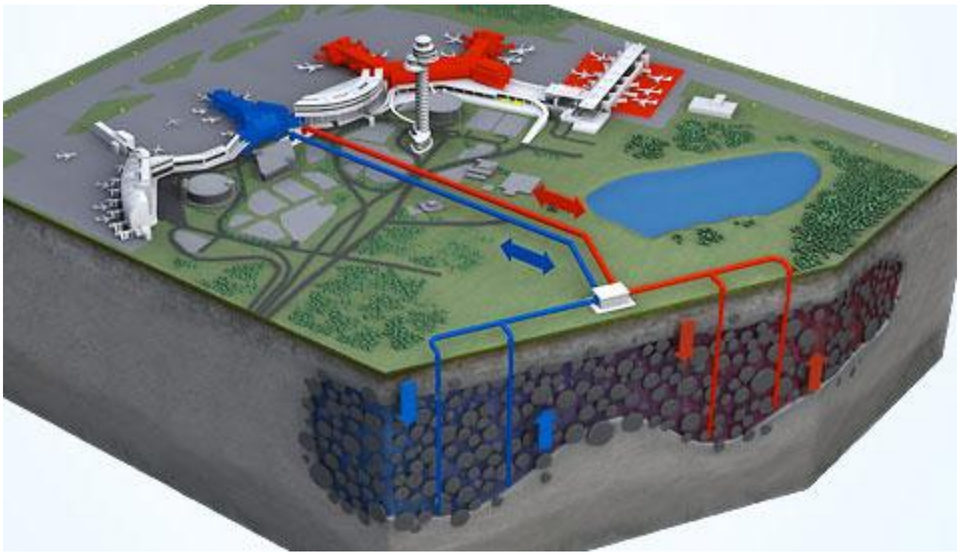
The world's largest energy storage system for space cooling and heating is located at the Stockholm Arlanda Airport (Figure 3). The German federal state parliament building ("Reichstag") is another example of aquifer utilization. An aquifer positioned at a depth of about 50 meters is used as a seasonal cold storage. During winter water is cooled down by ambient air in so-called cooling towers to a temperature of 5°C. This water is injected to the aquifer. During summer the water can be pumped up at a temperature of 6°C and can be used for cooling the building (Boeing, 1998). In Germany around 70% of the surface is suitable for energy storage in aquifers. Assumed that 2000 aquifer storage installations with a capacity of 5-10 GWh each would be erected, the total storage capacity would be more than 10 TWh p.a. (FVEE, 2011). In the Netherlands the potential of aquifer storage and aquifer cooling is also very high. According to Snijders (without year) around 2,000 systems[12] are in operation in Europe.

10 http://www.um.baden-wuerttemberg.de/servlet/is/55619/; 06.02.2012.

11 There is no common definition for *aquifer storage*, which can be seasonal or short time storage.

12 Snijders distinguishes in "aquifer thermal energy storage systems" and "borehole thermal energy storage systems"

Figure 3 Energy storage and space heating and cooling with Aquifers



Source: http://www.arlanda.se/en/Information-about/Environmental/Reducing-carbon-dioxide-emissions/Energy/The-aquifer/ 10.02.2012

Free / Passive and active cooling with heat pumps[13]

Another system for ground water cooling is free or passive cooling with (reversible) heat pumps. Ground coupled heat pumps that are used for heating in winter can also be used for cooling in summer. For free / passive cooling the cold liquid that is circulating in the collector loops will be pumped via a heat exchanger through the (floor) heating tubes and lower the indoor temperature. The cooling potential of this technology is restricted since the temperature of the cooling liquid must be above the dew point in order to prevent the forming of condensate which might damage the building. This means that depending on floor humidity and temperature, the temperature of the cooling liquid must not be too low otherwise the cooling effect is limited. Therefore this technology is not suitable in regions with hot summers. The advantages of this technology are the low investment costs (if the heat pump is also used for heating purposes) and the low amount of additional energy input (e.g. electricity to run the pumps).

It is rather complex to use a heat pump for passive cooling in existing homes or buildings. The heating system must be adapted for the cooling process. At least, there must be added an electronic control unit to switch between heating and cooling cycle.

The cooling application can be more easily integrated in new build buildings. Integrating vapour barriers to the floor heating loops might help to prevent depending on the dew point,

13 According to stakeholders of the heat pump industry the two different heat pump-cooling cycles are called *passive* and *active cooling (with heat pumps)*. In some European countries the term "free cooling" for passive cooling with heat pumps is also common. *Passive cooling with heat pumps* may not be confused with *passive cooling strategies,* described below, at the end of chapter 3.

If passive cooling with heat pumps is not sufficient, heat pumps can also be used for active cooling. In active cooling systems the available cold will be transferred to the indoor air via fan convectors. These systems do not depend on the dew point. Therefore lower temperatures and higher cold capacities can be realised; however, the heat distribution system cannot be used for cooling and additional investment costs for distributing the cold occur. There is additionally use of electricity for the fan convectors.

Active cooling could be done with brine-to-water (e.g. ground coupled) heat pumps and water-to-water (e.g. surface-water) heat pumps, the latter provided there are suitable surface water sources.

3.2 Indirect cooling

Indirect cooling with reversible heat-pumps

Reversible heat pumps cannot only increase the temperature of the used medium in the heating cycle, but can also run a cooling cycle. In the cooling cycle the temperature of the medium is decreased by the compressor, so it can be used for cooling. Actually heat pumps running in the cooling cycle work the same way as conventional air conditioners. Similar to active cooling via heat pumps (see above) the cold is distributed via fan convectors.

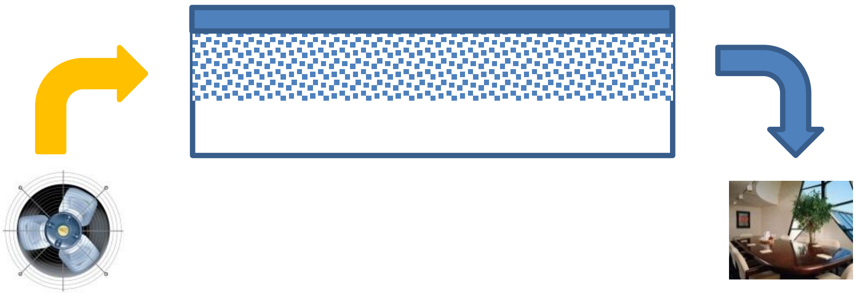
Reversible heat-pumps need more input energy than direct or passive cooling systems with heat pumps. In principle all different types of heat pumps could be used irrespective of the thermal source (air, water, ground).

According to the definition developed in chapter 2 only those reversible heat-pumps running in the cooling cycle should be considered renewable cooling that meet certain minimum efficiency requirements. That means that the temperature of the source must be lower than the required temperature.

Evaporative cooling

If water evaporates it lowers the temperature of the surrounding air. This fact is used to cool buildings with evaporative cooling. Hot dry outside air will be ventilated into the evaporative cooler. Inside there is a water source, the water evaporates and colder wet air is ventilated inside the building. More advanced devices use the humid airstream to cool down another airstream which is not moist itself. There are also known as indirect evaporative coolers or two-stage-coolers. These kinds of devices are less efficient, though. There are several more varieties of indirect-evaporative coolers. The advantages of evaporative coolers are that they are much more efficient than electric air-conditioners. The disadvantages are that they need water (and chemicals for water treatment) and that single-stage-coolers provide humid air which might be uncomfortable (AFSG, 2009).

Figure 4 Principle of a single-stage direct evaporative cooler



An example of passive downdraught evaporative cooling (PDEC) is the application in the central atrium space within the New Stock Exchange in Malta. It demonstrates the viability of a wider application of this technology in Southern Europe, both to new buildings and in refurbishment projects. The PDEC-application meets approximately 25% of the cooling demand; the residual load is met by chilled water cooling coils. The system reduces the need for conventional air conditioning considerably. The building was completed in 2001.[14]

Evaporative cooling is only considered renewable cooling if it meets the definition in chapter 2. Additionally the origin of the used water must be observed. Especially single-stage-coolers use much water. The energy needed for water treatment must be included in the energy efficiency calculation[15].

3.3 Cooling with heat from renewable energy sources

Contrary to the direct and indirect cooling systems described above, absorption, adsorption, desiccant and evaporative cooling (DEC) systems are using heat to produce cold. The required thermal energy can be provided by different sources. In the future the most important renewable energy source for cooling with heat is expected to be solar energy delivered by solar thermal systems. Other sources are heat from combined heat and power plants (CHP) burning biomass and geothermal heat. The main processes to convert heat into cold can be divided into closed and open cooling cycles.

3.3.1 Closed cooling cycles

Absorption and adsorption devices are both considered to belong to the closed heat driven cooling cycles as the process is confined in a closed system. Both chiller types deliver cold water as the product of the process. The output temperature of the water determines the range for application – while temperatures between 15 and 20 degrees Celsius are enough

14 http://www.managenergy.net/resources/96.

15 Basically evaporative cooling is comparable to direct cooling technologies such as snow cooling, which also work with water that is temporarily withdrawn from the water cycle. In contrast to snow cooling and hydrothermal direct cooling technologies the water usually must be treated before using it for evaporative cooling.

for panel cooling systems like underfloor or wall cooling, temperatures between 6 and 9 degrees Celsius are needed for systems that also provide air dehumidification (FSV, 2006).

Absorption chillers are the most common thermally operating devices and are usually working with a refrigerant-sorbent combination of water and lithium bromide or water and ammonia. While the first is usually used with output temperatures above 4°C for space cooling, the latter can also be used at temperatures below 0°C. Absorption chillers exist in the capacity range of a few kW to multi-MW and can therefore be used for a wide variety of purposes from cooling a single building to large industry-scale freezing purposes. Large-scale absorption chillers today can only economically compete with vapor compression chillers if they operate with electricity in areas with an unstable power supply. Today they are often operating with waste process heat (ESTTP, 2011).

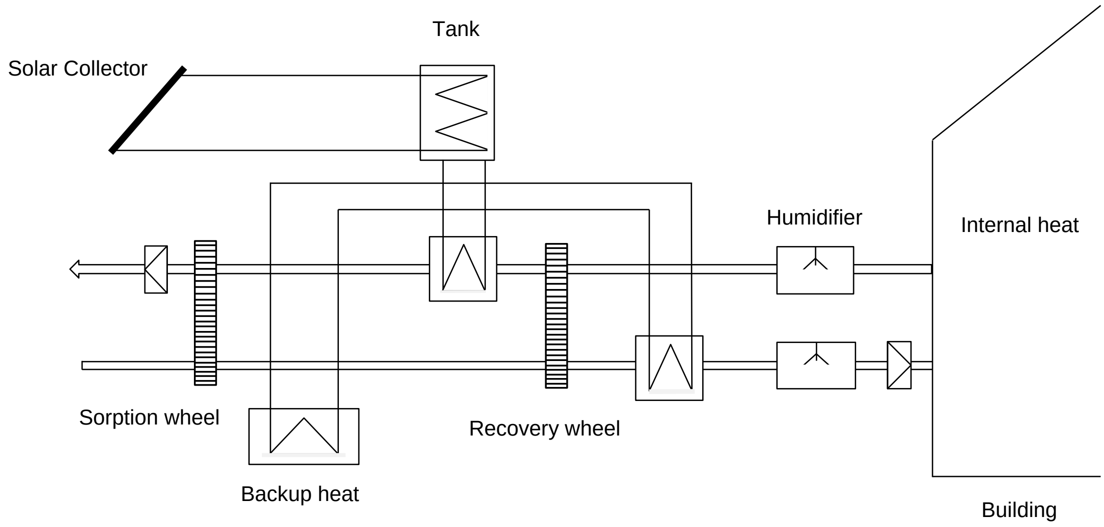
Adsorption chillers use different refrigerant-sorbent combinations like silica gel and water. They have some characteristics that make them promising for thermally driven cooling cycle applications, for example they can reach higher power densities (Henning, 2004).

Closed cooling cycle technologies, especially absorption chillers, are known and used already for some decades even though they are still at an earlier development stage than conventional vapour compression chillers and there is still room for improvement. At the same time, the combination with renewable energies is still in its infancy. Future research and development (R&D) could help to bring down the comparably high system costs, and more knowledge about the systems themselves and the possibility of combination with renewable energies is needed. The European Solar Thermal Technology Platform (ESTTP) laid out a strategic research agenda in which three points were assumed to be most important: (a) increase the co-efficient of performance (COP) values, (b) build more compact chillers, (c) enable chillers to cope with lower input temperatures (for a more detailed research plan see ESTTP, 2011).

3.3.2 Open cooling cycles

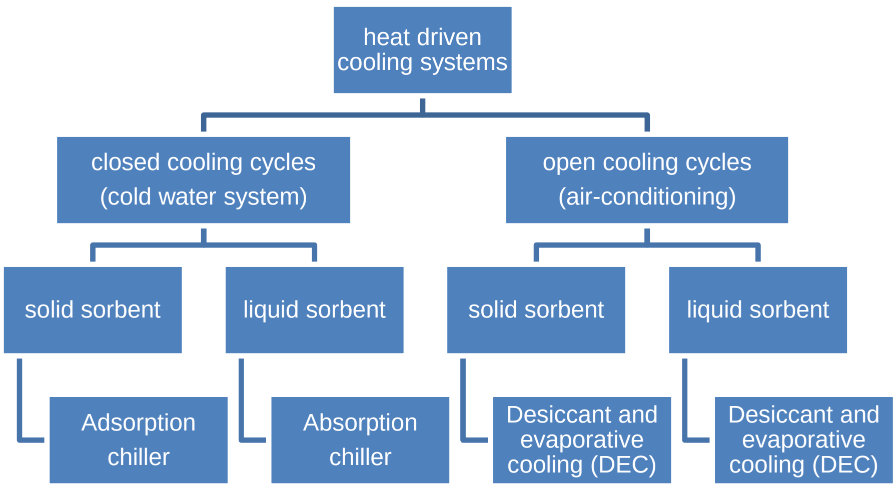
Desiccant and evaporative cooling (DEC) systems are called open cooling cycles as the refrigerant water is in direct contact with the atmosphere. The main goal is to provide filtered and fresh air in buildings, i.e. air dehumidification and lowering the temperature in a hygienic manner. The system consists of a dehumidification unit which usually is a desiccant wheel and standard air-conditioning parts like air handling and heat recovery units as well as heat exchangers and humidifiers. From an energetic point of view it is advisable to limit the device’s capacity on the needed volume flow rate for fresh air. Depending on climate zone and the cooling loads this could entail that the required air temperatures are not met under all weather conditions and a combination with e.g. an absorption chiller could be necessary. (ESTTP, 2011)

Figure 5 Desiccant and evaporative cooling system based on solar heat



Source: http://www.raee.org/climatisationsolaire/gb/pop/pop_or/ineti.htm; 10.02.2012

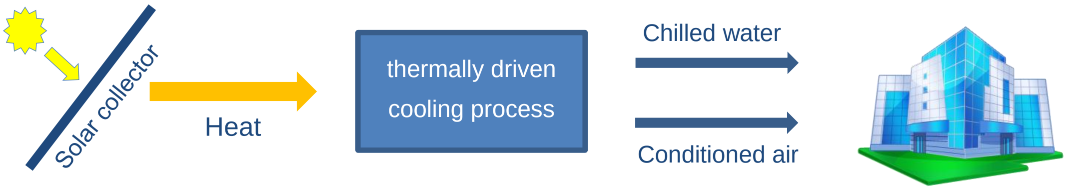
Figure 6 Overview of heat driven cooling systems



3.3.3 Solar thermal technologies

Solar thermal panels, usually roof mounted, can provide the heat that is needed to run closed and open cooling cycles. Solar thermal cooling systems are also very attractive because the cooling demand of some applications, such as residential buildings and offices, coincides with high solar irradiation. Another advantage of solar thermal systems is the scalability of the installations between a few kW and several MW. Also the possibility for triple-use of the heat for cooling in summer, for heating in winter and for year round domestic hot water production makes this technology more attractive.

Figure 7 Diagram showing a solar cooling system



The technical feasibility of solar cooling systems has been proven in many projects. But there is still a great need for research and development. Important fields of research are: (a) Material research in the field of absorbance, (b) Further development of small thermal cooling systems, (c) Development of electric/thermal hybrid systems, and (d) Research on system technology for system concepts, design, controls, maintenance, and equipment management (FVEE, 2008). A crucial aim is to bring about an increased cost-performance. There is a significant potential for reducing costs and increasing performance, also through further research and development, and economies of scale in manufacturing with higher production numbers (ESTTP, 2011).

Solar collectors producing heat for cooling systems can also be integrated in heating and domestic hot water cycles. This increases the productivity of the investment. In the last 5-8 years applications in the small capacity range, below 100 kW and in particular below 20 kW down to 4.5 kW, have been developed. These small water chillers with a capacity of few kW for single family houses came on the market only very recently. Large systems for centralized air-conditioning applications in large buildings can reach the size of several MW capacity (ibid). Spain, Germany and Austria have the most mature solar thermal markets with installations for a wide array of applications: hot water, space heating, district heating, and cooling (Weiss and Mauthner, 2011).

In industrial scale projects most solar thermal cooling applications have been installed within the scope of support and pilot project programs up to now. Only recently a few new systems have entered operation in Southern European countries which have the highest potential due to high irradiation. A stronger market penetration has been hindered by higher system prices in comparison to conventional compression chillers. With increasing electricity prices and more model systems being installed the market entry barriers seem to gradually become smaller (ESTTP, 2011).

3.3.4 Cooling with biomass

Heat from combined heat and power plants (CHP) that burn biomass can also be used as a heat source for thermally driven chillers. Biomass CHP plants are today mainly producing heat for space heating in winter and hot water supply. During summer there is usually residual heat that cannot be used. Combining the CHP with a thermally driven cooling process will increase the biomass conversion efficiency. The CHP plants could achieve a higher number of annual full-load hours as the heat can be used for more purposes. But also in this field there is much need for research and development, especially with the following priorities: combined heat and power and cooling systems (tri-generation), hybrid cooling solutions of biomass-CHP in combination with other renewable cooling technologies and energy efficiency enhancement of district heating and cooling systems (Mertens, 2011).

Still it is not expected that renewable cooling by biomass will play a major role in this context in the future. The biomass potential is restricted and there are competing utilisation pathways (such as utilisation of biomass as raw material for products). In addition it has to be considered that all three sectors, electricity, heating and cooling, transport, are competing for the limited resource. For that reason biomass potentials available for multiplying the number of combined heat & power & cooling applications based on biomass might be limited.

3.3.5 Geothermal technologies

Geothermal heat with temperatures above 60/70°C from great depth can also be used for district heating and cooling applications. These hydro-geothermal systems can provide the necessary temperature to run district heating systems and also to run thermally driven chillers for district cooling systems. District heating and cooling may also be supplied from residual heat left over after the production of electricity from a high-enthalpy geothermal heat source.

To date there are few projects known where this technology is applied. The potential for geothermal heating and cooling is high in certain European regions (e.g. the upper Rhine valley), but so far there a numerous reasons why this technology has not been implemented widely. Among the reasons are that deep drilling is rather expensive and risky in economic and technical terms. The Geothermal Panel of the European Technology Platform for Renewable Heating and Cooling (ETPRHC) sees a potential of around 50 TWh p.a. up to 2020 and 350 to 700 TWh p.a. up to 2030 for heating and cooling, mainly in new district heating and cooling networks. (ETPRHC, 2009)

Table 1 Overview of renewable cooling technologies

Technology	**application**	cooling	refrigaration	**application size**	district cooling	single family home cooling	large commercial building	**restrictions**	geographic/climatic restriction	restricted cooling load
Direct cooling										
Snow/Ice Cooling		x			x		x		x	
Seawater Cooling		x			x		x		x	
Deep Lake Cooling		x			x		x		x	
Groundwater Cooling		x			x		x		x	
Free / Passive Cooling with Heat Pumps		x				x	x		x	x
Aquifer Cooling		x			x		x		x	
Indirect Cooling										
Indirect Cooling with reversible Heat Pumps		x				x	x		x	
Evaporative Cooling		x			?	x	x		x	x
Cooling with heat from Renewable Energy Sources										
Absorption Chiller-one stage		x			f	f	x			
Absorption Chiller-two stage		x	x		f	f	x			
Adsorption Chiller		x			f	f	x			

f= future development

Passive cooling strategies

Passive cooling strategies aim at the prevention or reduction of cooling loads by considering the building structures and management. Heat inside buildings originates from solar irradiation on the building that infiltrates or transfers to the inside through the building envelope (roof, walls, windows), from electric appliances and the inhabitants. Heat reduction strategies have to take the climatic conditions into account as, for instance, passive night-time ventilation systems are only reasonable if a drop in temperatures can be expected at night.

The best option to implement passive cooling into the temperature and comfort management of buildings is in the planning stage of construction or refurbishment. A focus should be laid on avoiding heat gains in the first place. This can be achieved through a large number of technologies and architectural measures. Two relatively easy and low cost options (if considered before construction) are shading devices and reflective roofs. Shading can be achieved for instance by awnings or vegetation like trees in front of windows. After construction shading can also be improved, e.g. by using shutters or draperies. Parker et al. (2002) compared six different roof systems and concluded that reflective roofs can have a significant influence on cooling demand. The energy savings linked to cooling accumulated up to 24% for the best system in comparison to the reference.

If heat gains are still too high for a comfortable working or living environment or cannot be avoided, strategies for heat reduction are needed. Brown (1997) identified four main strategies:

(a) Natural ventilation: Open windows or doors allow air exchange with the outside, especially when they are open on opposite sides of the building.

(b) High thermal mass: A loop of absorption of heat during the day by material inside the building and the release of heat during the night allows additional heat reductions.

(c) High thermal mass with night ventilation: The same concept as in number 2 with additional night-time ventilation allows cold outside air to cool the thermal mass and exchange warm inside with cold outside air.

(d) Evaporative cooling: The evaporation of water decreases air temperature. In warm countries that was traditionally accomplished by water fountains in the inner courtyard of the building. Also roof ponds or evaporative coolers running on electricity use this effect.

4 Today's contribution of renewable cooling to cover the cooling demand

There is little information and especially few figures about the contribution of renewable cooling applications to cover the today's cooling demand. The available data is summarized in this chapter.

There are few more examples for direct cooling than the ones described above. Skogsberg, 2005, mentions some snow cooling projects in Japan, Canada and the USA. Further examples for snow cooling in Europe are not published, but they probably exist. District cooling systems using hydrothermal energy are in operation in Helsinki and Gothenburg; there are probably some more examples. Usually these systems are combined with absorption cooling applications. According to Froning, 2008, about 9 PJ/year of cold have been provided by about 100 district cooling systems in Europe. Most of them are in France, Sweden, Germany, and Italy. However, not many of these applications are using renewable sources.

Groundwater cooling and aquifer thermal energy storage are spread widely in the Netherlands. Around 1.6 PJ of cold have been extracted from geothermal energy in 2010[16] (Statistics Netherlands, 2012). By 2007 690,000 ground source heat pumps had been installed in the eight European countries with the largest heat pump market[17] (EHPA, 2008). These heat pumps can theoretically be used for cooling (compare chapter 3). However, how many of these heat pumps are already being used for cooling or how many are installed together with heating systems that are suited to cooling is not known.

For reversible heat pump systems it should be possible to estimate the contribution for cooling from the contribution for heating. To do this the ratio between heating and cooling demand for different building types in different climatic regions must be known. It should be possible to develop a methodology to estimate the contribution for cooling, if the share of heat pumps that are reversible and are used for both, heating and cooling, is known.

Heat-pumps used for cooling in southern European countries usually are air-to-water heat-pumps, which are not considered renewable cooling according to the definition in chapter 2. In Germany, cooling with ground coupled heat-pumps is not yet wide spread, there are no figures known, respectively.

Around 250 solar air-conditioning systems were installed in Europe by 2007, with an exponential increase of activity in 2009 and 2010 (ESTTP, 2011). The systems in operation range from small units for single-family houses to large units for factory buildings. There have been 525 solar cooling applications installed in Europe in 2010 and 600 worldwide (Weiss/Mauthner, 2012), and by the end of 2011 there could have already been around 750 solar cooling systems installed worldwide (Mugnier/Jakob, 2012).

[16] This number might include cold extracted by absorption cycles from geothermal heat.

[17] Austria, Estonia, Finland, France, Germany, Norway, Sweden, Switzerland.

5 (Renewable) cooling in European statistics and policies

Regarding the heating and cooling sector, today statistics and policies focus on the heating part of the market. Providing industrial process and space heating with renewable energy sources is an essential component of multiple national and European strategies for achieving the climate protection targets. The potential for the reduction of greenhouse gas emissions by substituting fossil fuels by renewable energy sources for providing space heating and domestic hot water supply is a focus of policy and addressed by a variety of instruments and policies. Data on the contribution of renewable heat to cover the heat demand are collected Europe-wide.

On the other side renewable cooling technologies do not play a major role in the climate protection discussion. This is despite the fact that the cooling demand is expected to increase sharply in the next decades in the EU (compare chapter 6). Figures about the cooling demand are not collected in all Member States, and data about the contribution of renewable cooling technologies to cover the cooling demand are not collected today, either (compare chapter 4).

The RES-Directive defines a 20% final energy related target for the overall share of energy from renewable sources. The overall target was translated into individual targets for each Member State. Member State governments were obliged to break down their overall renewable target to indicative sector-specific targets and trajectories. Besides electricity and transport heating and cooling constitute one joint sector. However, neither the template for the National Renewable Energy Action Plans nor for the future biannual reports asks for separate data for renewable cooling, figures on heating and cooling need only to be reported together.

One of the assessment bases for setting the renewable energy targets for the Member States was the data collected via the joint annual questionnaire on renewables and waste and the annual electricity and heat questionnaire, both by EUROSTAT[18]. The questionnaire on renewables and waste was created in 1999 basing on the statistical development since the early nineties and modified in 2000 – 2004 (Roubanis, 2009). The Energy Statistics Regulation (EC) No 1099/2008[19] calls for further development of renewable energy statistics, to improve the quality of the energy statistics in order to make available additional, pertinent, detailed statistics on each renewable energy source.

The existing questionnaires do not collect data on energy consumption used for cooling. With electric air conditioners dominating the cooling technology market today, the energy use for cooling is hidden in the overall electricity consumption of buildings. Some country-specific studies and statistics contain data on the share of end energy use required for air conditioning.

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[18] e.g. Eurostat, IEA, UNECE (2011): Electricity and heat annual questionnaire 2010 and historical revisions.

[19] The EU Regulation (EC) No 1099/2008 on energy statistics establishes a common framework for the production of energy statistics in the European Community. It applies to statistical data concerning energy products and their aggregates.

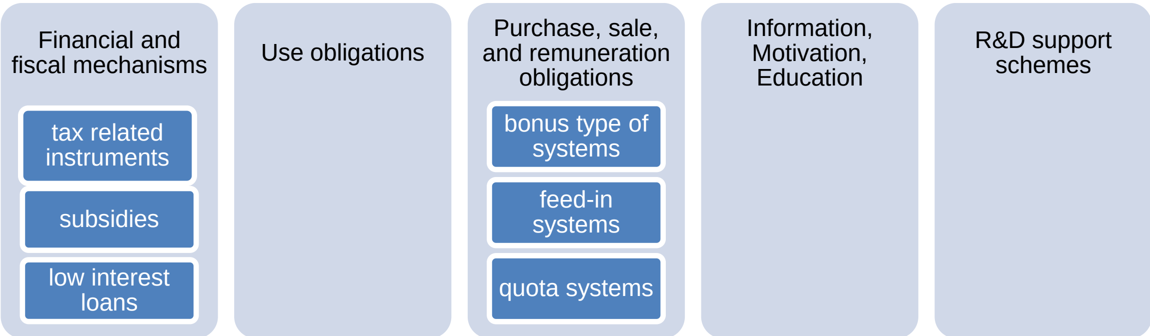
- According to AGEB (2011) the amount of energy used for air conditioning in the industrial and service sector in Germany was 7.4 TWh in 2010; 6.86 TWh was covered by electricity[20], corresponding to approx. 1.4% of the total electricity consumption in Germany in the respective year. For refrigeration another 14.03 TWh has been used in 2010, 13.9 TWh covered by electricity. Together this corresponds to 4.0% of the overall electricity consumption in Germany.
- Pennartz, A.M.G. & van den Bovenkamp, M.V. (2011) estimate that cooling and refrigeration amounts for approx. 13% of the overall electricity consumption in the Netherlands.

There is little information about the number of renewable cooling applications in Europe (compare chapter 4).

The collection of data about the contribution of renewable cooling is necessary, if renewable cooling should be able to contribute to the European and national renewable energy targets. To collect these data an appropriate statistical method in accordance with the RES-Directive is needed[21].

Since figures on the energy consumption for cooling and especially of renewable cooling are not collected systematically, at least those renewable cooling technologies that are not covered by the electricity or heating statistics currently do not contribute to the renewable targets defined by the RES-Directive. At the level of the Member States this leads to lacking incentives to improve the support framework for the respective technologies. Apart from the broad range of different technological, economical and informative barriers this is an additional hurdle against a faster market introduction and diffusion of renewable cooling technologies.

Figure 8 Support mechanisms for renewable heat and cooling in the MS



Source: Author's own illustration based on Bürger et al. (2011)

20 The remaining share was covered by natural gas.

21 If the conversion of heat into cold is located at the end user, the input of renewable energy into the system is counted as renewable energy according to the RES-directive. E.g. for a solar cooling system at a house or office (where the cold is not sold to others), the RES-directive counts as renewable heat the heat produced by the solar collectors. For a system that burns wood to create heat and then use the heat in an absorption cycle, The RES-directive will account the energy content of the wood as final renewable energy use.

Existing Member States' renewables policies reflect this fact. In most Member States current renewable support schemes addressing the heating and cooling sector focus on renewable heating. The most commonly RES-H/C support mechanisms for the promotion of renewable heat and cold are financial and fiscal instruments and use obligations (Figure 8). In the following some examples for RES-H/C-support schemes with sample Member States applying these schemes are given. This overview is based on Raimundo, 2011:

Feed-in tariff for heat: for solid biomass power plants (Austria)

Investment subsidies: usually paid for solar thermal applications, (geothermal) heat pumps, CHP and/or biomass-applications (Belgium-Flanders and Wallonia, Austria, Italy, Germany, Luxemburg, Sweden). In Germany solar thermal applications for cooling are eligible.

Tax exemptions: solar heating and biomass applications are exempted from CO_2 and/or energy tax (Denmark).

Tax incentives: tax credits granted for expenses caused by deploying renewable energy, changing the heating system (Finland); deduction of part of the investment costs of solar thermal systems from the tax bill spread over 10 years (Italy).

Use obligations: building owners are obliged to source a minimum amount of their H/C energy demand through RES (Germany: different renewable heating options are possible; Spain, Portugal and Italy: solar thermal obligations).

Bonus type of system: operators of renewable heating devices receive a legally fixed bonus payment for each kWh produced (UK, restricted to large scale appliances)

The above list shows that cooling support policies are not widespread in the EU. Some cooling technologies such as solar thermal cooling or heat pumps that are used for heating and cooling might be eligible in some Member States, though. In the German programme for investment subsidies for renewable heat/cold (Marktanreizprogramm) in 2010 64% of the requests aimed at solar thermal applications (Langniß et al. 2011). Solar collectors can generally be used for space heating, domestic hot water production and air conditioning, but will usually be only used for heating and hot water supply today.

6 Development of cooling demand in Europe and renewable cooling potential

There are only a few studies providing data about the status and the possible development of the cooling demand in the European Union. Usually *cooling* or *space cooling* is defined to cover the energy demand for decreasing the temperature of indoor air for thermal comfort or for providing a suitable temperature for technical installations, e.g. IT-technology (compare chapter 2). However, in some of the quoted studies it is not completely clear how *cooling* is defined.

The cooling demand mainly depends on climatic conditions (on a global but also regional and urban scale) and additional factors such as (a) the architectural and structural design of a building, (b) the design and operation strategy of the cooling supply installations, (c) the amount of internal thermal loads caused by technical equipment and human beings, and (d) the social behaviour of the building users such as working hours and vacation periods (Ecoheatcool, 2006a).

6.1 Market potential of space cooling in Europe

Within the IEE-project Ecoheatcool[22] which ran from 2005 to 2006 a simplified analysis of the cooling demand in Europe has been conducted based on the above-mentioned factors. The methods and results are described briefly in the following.

First of all the climatic factors such as temperature, wind, solar radiation and air humidity of different European regions were analysed and a "European cooling index" was calculated. It is assumed that starting from 29°C outdoor temperature an indoor temperature of 7 K below the outdoor temperature has to be maintained. In this very simplified analysis differences in the social behaviour, the internal heat loads and the building structures were not taken into account. The average space cooling demand should be proportional to this index.

The second step was to investigate the specific cooling demand (SCD). According to Ecoheatcool, 2006a, the SCD can vary by the factor 3 between different types of (commercial) buildings with identical outer conditions. This is due to the structure and the comfort standard of the building. Even larger spreads are possible. In countries in the northern part of Europe office buildings are usually dimensioned for a specific cooling load of 30-60 W/m², annual operation hours are in a range between 1,100 and 1,300 full load hours. In the southern part of Europe the specific cooling load for office buildings is about 20% higher than in the northern part and cooling systems operate about 50% longer. For residential buildings the specific cooling load is about 20 to 30% lower than in commercial buildings and the running time is about 50% lower. This is due to a lower internal heat load and to the fact that the residents are often not at home during the day (DEA, 2005, in Ecoheatcool, 2006a).

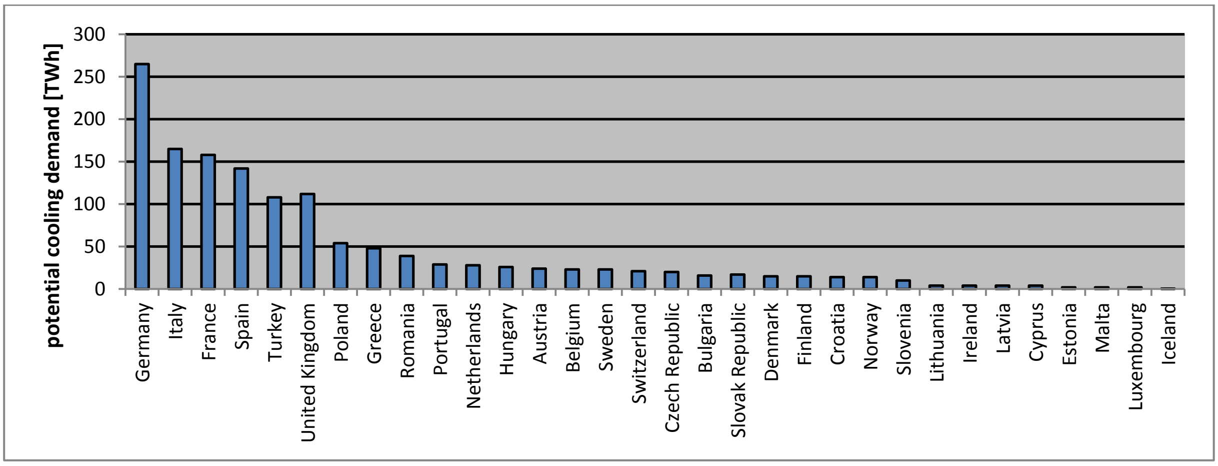
The next important figure used to calculate the potential cooling demand is the total floor space of residential and commercial buildings in Europe. Data for residential buildings are mainly available in national statistics. In 2003 the Europe-wide average residential floor area

[22] www.euroheat.org/ecoheatcool.

per capita was 36.5 m², resulting in a total floor area of approx. 20.9 billion m². Accurate data on useful floor space in the service sector are not available for each European country, which is why the missing data had to be estimated, leading to an estimated total service sector area of approx. 7.0 billion m² (corresponding to an overall average of 12.2 m² per capita).

Figure 9 shows the results of the estimation of the cooling market potential in Europe for the current climatic conditions. The calculation was carried out by using the parameters described above (specific cooling demand, cooling index and building areas). Based on those, Ecoheatcool, 2006a, estimated the total cooling market potential for European buildings to almost 1,400 TWh/a. 41% derives from the service sector and 59% from the residential sector.

Figure 9 Total potential cooling demand of European countries



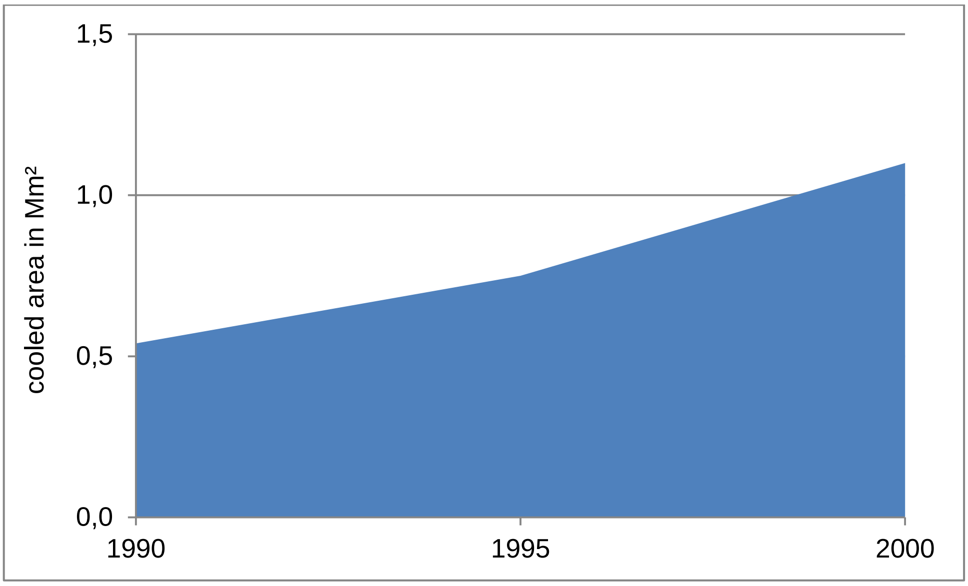
Source: Ecoheatcool, 2006a

The estimated potential cooling demand can be compared with actual statistical data. The German energy balance for the final energy use by sectors contains a sum for the consumption of electricity for “climate cold” (which is air-conditioning) of 24.7 PJ/a in 2010 (6.86 TWh/a) in the industry and service sector (AGEB, 2011). This is less than 3% of the calculated 260 to 270 TWh potential cooling demand in Germany in Figure 9. The data for energy consumption in the UK (EC, 2011) shows a similar picture: the energy consumption for cooling *and ventilation* in the service sector in 2009 was 8.67 TWh/a, less than a tenth of the 120 TWh/a specified above. This shows that there is a major gap between the current active cooling supply and the estimated market potential. This gap will still be huge when it is considered that there are no data for air-conditioning in households and that the available data might not be complete. So it is very likely that the given numbers for the market potential are widely overestimated. They might still be interpreted as the upper limit of the market size in Europe, if 100% of all useful space was air-conditioned.

6.2 Status and development of cooling demand in Europe

From 1990 onwards there is a sharp increase of the cooled area in Europe. Figure 10 shows the development of air-conditioned space from 1990 to 2000 in the EU15-countries. Between 1990 and 2000 the cooled area has more than doubled, from 540 million m² of surface area to about 1,100 million m². The technologies used were mainly smaller AC systems (<12 kW).

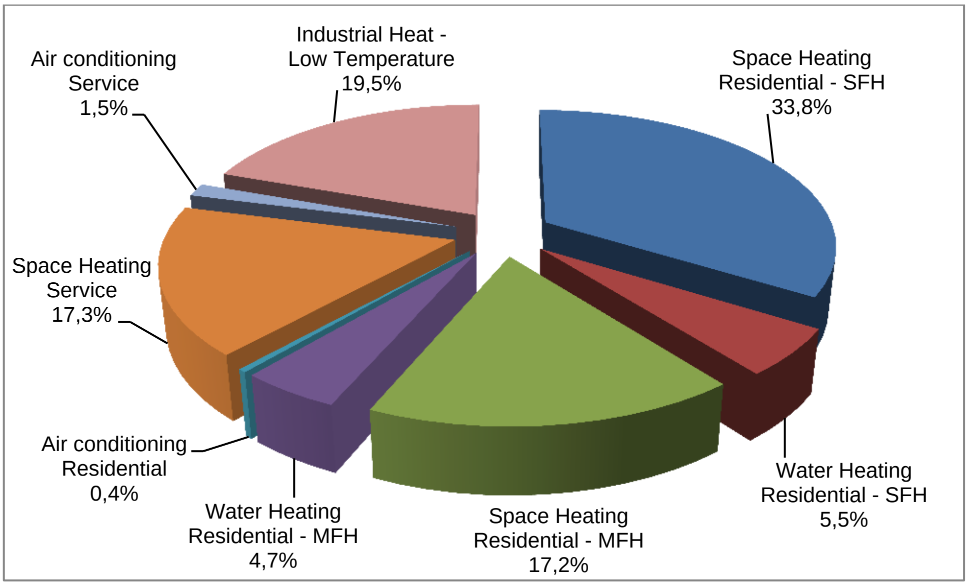
Figure 10 Development of the cooled area in EU15 from 1990 to 2000



Source: Adnet, 2003, cited in Summerheat, 2009

Weiss and Biermayr, 2009, calculated a share of 1.9% for space cooling of the total final energy consumption for heating and air conditioning in 2006 in the EU-27. This is equivalent to approx. 88 TWh p.a.

Figure 11 Final energy consumption for heating and cooling in EU 27 in 2006, total 4,640 TWh pa



Source: Weiss and Biermayr, 2009

The cooling demand in the European Union is expected to grow strongly in the next decades. This growth is expected for a multitude of reasons, including more hot days in summer due to global warming, more heat-emitting electric appliances inside the buildings, a partly glass-dominated architecture for commercial buildings, and a rising aspiration for comfort. It should also be noted that the cooling demand is strongly influenced by the geographical location of the countries.

In the following sections the results of two studies which provide estimates on the development of the cooling demand in Europe will be summarized. These studies are (a) the “Common Vision for the renewable heating and cooling sector in Europe” by the European technology platform renewable heating and cooling (ETPRHC), 2011, and (b) the report “Potential of Solar Thermal in Europe” prepared by Weiss and Biermayr, 2009, together with the European Solar Thermal Industry Federation (ESTIF) within the FP6-framework.

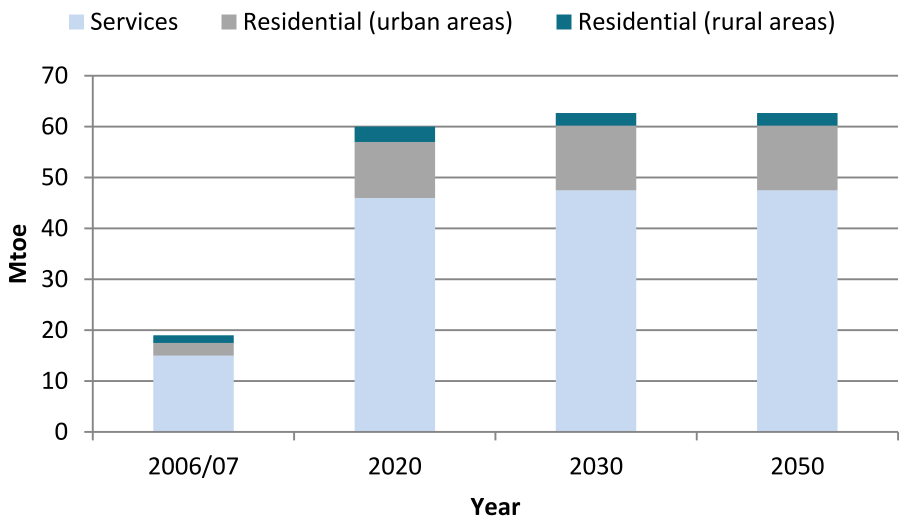
Figure 12 illustrates the expected development of the cooling demand as calculated by ETPRHC, 2011. According to this study the cooling demand will treble between 2007 and 2020 in the EU, from just under 20 Mtoe in 2006 (232.6 TWh/a) to 60 Mtoe (697.8 TWh/a) in 2020 and to about 63 Mtoe (732.7 TWh/a) in 2050.

The authors of the study present the following key assumptions for their results:

- 80% of the cooling demand for residential uses is in high- and medium-density areas (73% for heating);

- the increasing cooling demand – reflected by the fact that the amount of useful floor area that is cooled and/or air conditioned has increased in the past few years – will continue for at least the next ten years which will result in an expected very steep increase in cooling demand by 2020. From 2007 to 2020 a 82% increase of cooling demand in the residential sector and a 60% increase in the service sector is expected;
- in 2020 a saturation rate of 60% for the service sector and 40% for the residential sector will be reached. Any further expansion will be due to an increase in occupied overall floor space, climate change, additional technical installations, building standards (having an impact in the opposite way) and social behaviour. On this basis, following the strong growth from now up to 2020, only a very slow increase in cooling demand is expected from 2020 to 2030 (6%), and from 2030 to 2050 (1%).

Figure 12 Expected evolution of cooling demand in the EU



Source: ETPRHC (2011)

Weiss and Biermayr, 2009, developed scenarios regarding the development of energy consumption for air conditioning (as opposed to the cooling demand) for five European countries (Austria, Germany, Denmark, Spain and Poland). They calculated an increase of cooling demand in the different countries between 270% and 980% until 2050. Table 2 shows the results for the calculation of the expected development of the energy consumption (electricity) for air conditioning. It is based on a bottom-up model and considers the current diffusion rates for different cooling technologies as well as the influence of higher cooling demand due to increasing cooling degree days from global warming. Table 3 and Source: Weiss and Biermayr, 2009

Table 4 show the expected development of energy consumption for air conditioning for the residential and the service sector separately. It is shown that the service sector is expected to have the larger share of the growing cooling demand. Weiss and Biermayr (2009) do not provide data for the industrial sector.

Table 2 Estimated development of energy consumption for air conditioning in five European reference countries

Country	**Total energy consumption for air conditioning** (in TWh)			
	2005	2020	2030	2050
Austria	0,55	0,75	1,34	1,86
Germany	4,01	7,41	13,97	19,08
Denmark	0,12	0,26	0,73	1,18
Spain	28,33	44,9	61,82	77,92
Poland	0,58	2,00	4,06	5,71

Source: Weiss and Biermayr, 2009

Table 3 Estimated energy consumption for air conditioning in the residential sector in five European reference countries

Austria Energy consumption for air conditioning (TWh)			
2005	2020	2030	2050
0,15	0,26	0,57	0,83
Germany Energy consumption for air conditioning (TWh)			
2005	2020	2030	2050
0,88	1,63	3,34	5,22
Denmark Energy consumption for air conditioning (TWh)			
2005	2020	2030	2050
0,03	0,06	0,21	0,53
Spain Energy consumption for air conditioning (TWh)			
2005	2020	2030	2050
6,23	10,8	15,84	19,95
Poland Energy consumption for air conditioning (TWh)			
2005	2020	2030	2050
0,14	0,78	1,66	2,36

Source: Weiss and Biermayr, 2009

Table 4 Estimated energy consumption for air conditioning in the service sector in five European reference countries

Austria: Energy consumption for air conditioning (TWh_e)			
2005	2020	2030	2050
0,40	0,49	0,77	1,03
Germany: Energy consumption for air conditioning (TWh_e)			
2005	2020	2030	2050
3,13	5,78	10,63	13,86
Denmark: Energy consumption for air conditioning (TWh_e)			
2005	2020	2030	2050
0,09	0,2	0,52	0,65
Spain: Energy consumption for air conditioning (TWh_e)			
2005	2020	2030	2050
22,1	34,1	45,98	57,97
Poland: Energy consumption for air conditioning (TWh_e)			
2005	2020	2030	2050
0,44	1,22	2,40	3,35

Source: Weiss and Biermayr, 2009

The numbers in Table 2 can be compared to the data of the latest German energy statistics. It shows that these numbers do not match: 6.86 TWh electricity used for air conditioning in 2010 (AGEB, 2011) face 4.01 TWh in 2005 and a calculated 7.41 TWh energy consumption for air conditioning in 2020 according to Weiss and Biermayr, 2009. So it is possible and probable that Weiss and Biermayr underestimated the increase of the cooling demand in their paper.

But the two studies about the development of the cooling demand in Europe still show data of the same order of magnitude. While ETPRHC, 2011, quantify the cooling demand by 2050 with 733 TWh p.a., Weiss and Biermayr, 2009, quantify it with 106 TWh p.a. for the five reference countries.

6.3 Renewable cooling potential

Generally there is a variety of technologies and renewable energy sources (as chapter 3 shows) that can provide a large amount of the cooling demand. Technically it should be possible to provide 100% of the cooling demand by renewable cooling technologies by 2050. Assuming that at least 50% of the cooling demand can be covered by renewable cooling by 2050, at least 366 TWh pa can be provided by renewable cooling technologies by 2050, based on the total cooling demand calculated by ETPRHC, 2011 (Figure 12).

Limiting factors for the installation of renewable cooling systems are unsuitable geographical, geological and climatic conditions. Limiting factors can also be the lack of human resources, a lack of political awareness and also low prices for fossil fuels and electricity (Weiss and Biermayr, 2009). Another limiting factor might be the availability of marketable key components. In this case research and development efforts will probably provide solutions in the future. For solar thermal cooling applications another limiting factor is the availability of space for the installation of collectors.

Weiss and Biermayr consider about 60% of the roof area and 20% of the façade area in Europe architecturally suitable for solar technologies. This area can be used to install photo voltaic, solar thermal or solar cooling appliances. The authors of the cited study assume that 50% of the available area will be used for solar thermal technologies. They calculated three different scenarios for the solar thermal contribution to the heat demand for some European reference countries and for the EU27: the Business-as-usual Scenario (BAU), the Advanced Market Deployment Scenario (AMD) and the Full Research and Development and Policy Scenario (RDP).

In Table 5 the results of the RDP-scenario are reproduced, showing the maximum market share of solar thermal appliances up to 2050. In this scenario the authors implement a significant reduction of the heat demand of up to -30% by 2050 on average. A high R&D rate and full political support by appropriate mechanisms push the market diffusion of solar thermal applications. According to this scenario almost 50% of the low temperature heat demand (including the cooling demand) within the European Union can be provided by solar thermal applications by 2050. Transferring these results to the cooling sector would mean that that half of the cooling demand could be met by solar energy. This would need a specific collector area of 8 m² per inhabitant and a total collector area of 3,880 million m².

Even more ambitious data has been provided by the European Solar Thermal Technology Platform (ESTTP). According to them, solar thermal technologies will cover more than 50% of the heating and cooling demand in refurbished buildings in the long term. In new buildings even 100% of the heating and cooling needs shall be covered by solar technologies by 2050 (ESTTP, 2011). From today’s point of view the latter seems to be very ambitious, since huge heat storage facilities would be needed. According to ETPRHC, 2011, 5% of the cooling demand from the service and the residential sectors will be covered by thermally-driven cooling systems in 2020. In 2030 renewable heating and cooling technologies could already supply more than 50% of the heat used in Europe.

Table 5 Solar thermal contribution to the low temperature heat demand of selected European countries and EU27 according to the Full R&D and policy scenario

		Austria	Denmark	Germany	Poland	Spain	EU27
Solar yield							
2006	TWh pa	0.97	0.13	3.0	0.05	0.58	8.5
2020	TWh pa	9.9	1.1	43.4	2,7	11.8	155
2030	TWh pa	16.5	4.8	1158	27	71.1	582
2050	TWh pa	23.3	15.2	231.5	67.4	142.1	1,552
Solar fraction of total low temperature heat demand							
2006	%	0.9	0.2	0.3	0.02	0.22	0.2
2020	%	10	2	5	1	5	3.6
2030	%	19	9	15	13	29	15
2050	%	40	32	34	38	63	47

Source: Weiss and Biermayr, 2009

7 Conclusion and first steps for a roadmap

7.1 Conclusion

The results conducted in the scope of this study can give a significant input to the discussion about the contribution of renewable cooling to the renewable energy targets of the European Union. It is shown that first of all it is necessary to create a common definition about what is considered renewable cooling. In the report there is provided a proposal for a definition for renewable cooling that it is line with the definitions in the RES-Directive. This proposal can be the basis for a further discussion of a common definition. Additionally it is necessary to define a common terminology about different technologies to facilitate the discussion between Member States.

In this paper it was also shown that a large variety of renewable cooling technologies are ready for the market. Some of them are reasonably established in some countries, but many have not yet been implemented widely. Therefore it needs to be discovered what hurdles restrict their more extensive use. To find out the reasons why technologies that are already economical are not being implemented to a greater extent can provide important information about how to support the spread of these technologies.

The described direct cooling systems are mostly restricted to Northern European or Central European regions, which are not expected to have the highest cooling demand in Europe today and in the future. But also in these regions there is a potential for these technologies that definitely should be used. Hybrid applications of direct cooling technologies and absorption cooling technologies might also have great potentials in other European regions that should be developed.

In the next step the study showed that statistics for renewable cooling are hardly existent. With the same efforts that are now directed towards improving the renewable heating statistics, statistics for renewable cooling can also be available in a few years. Some data can be found already. The report also shows that since the current contribution of renewable cooling is not taken into account in international statistics, renewable cooling cannot contribute to the targets of the renewable energy directive. It seems to be necessary to develop a general understanding about the impact of cooling on European climate protection efforts and of the potential contribution of renewable cooling technologies to lower this impact.

There seems to be a broad consensus that the cooling demand requires a growing fraction of European energy use in the upcoming decades, which corresponds to an increasing climate impact if - as today - cooling is mainly produced from fossil-fuelled electricity generation. However, renewable cooling could contribute significantly to the growing cooling demand. Existing studies about future cooling demand mostly focus on specific technologies (e.g. solar cooling), which leads to a somewhat unbalanced picture of the whole technology portfolio and related potentials.

Although renewable cooling is still not too important, it can give a significant contribution to the renewable energy targets in the future. According to estimations in this paper renewable cooling could cover between 50% and 100% of the growing cooling demand in 2050. If the right political conditions are provided, this share can be close to 100%. The inclusion of accurate and disaggregated data on cooling in general and specifically on renewable cooling in European energy statistics is an essential step towards greater acknowledgement in the European and national political frameworks, such as the RES-Directive and national support frameworks. Without knowledge about the contribution of cooling to the overall greenhouse gas emission there will be no efforts to reduce these emissions.

The overview in this paper shows that there is a great need for the creation of a sound political framework aiming at an accelerated market diffusion of existing well-developed renewable cooling technologies. For technologies that are close to market maturity, the way for smooth market introduction needs to be paved. It will be helpful to set incentives in order to accelerate its market diffusion. Many of the technologies will not need high level support.

As there are no special policies addressing renewable cooling technologies, there are consequently no incentives to use them. The same applies to renewable energy targets: since there are no sector-specific disaggregated cooling targets for renewables, and due to the lack of a methodology to count many of the renewable cooling technology options as contributing to meeting the heating and cooling targets, there is little political will to incentivize them. The few funding instruments existing already are concentrating on solar air conditioning, while direct cooling technologies are not being supported. Furthermore R&D activities, also by the industry, need to be strengthened in order to be able to exploit the whole spectrum of different technology options.

A roadmap for renewable cooling could help to accelerate the market diffusion of renewable cooling technologies. The most important steps leading towards the roadmap would be to establish a definition for renewable cooling, to develop a methodology for calculating cooling from the different technologies in European energy statistics and start to collect data for this purpose in each Member State.

Apart from the more data-related elements the strengthening of efforts to develop a coherent and coordinated policy framework that addresses the needs of the heterogeneous renewable cooling technologies used on different scales would help to increase the share of renewable cooling. The policy framework should extensively take into account the diverse spectrum of different barriers comprising financial hurdles, but also legal or administrative barriers, psychosocial aspects such as attitudes, preferences, fears as well as information and motivation deficits.

In conclusion, for the development of the market for renewable cooling and the contribution to the EU renewable energy directive, the following steps will be needed:

- Acknowledge renewable cooling as a technology for the RES-directive
- Develop the statistics to monitor the contribution of renewable cooling towards the EU renewable energy targets
- Further development of the technologies, by the industry and R&D institutes
- Development of the market by the industry
- Establishment of incentives by the national governments could help to accelerate the market growth.

With these steps the contribution of renewable cooling could grow significantly.

7.2 First steps for a renewable cooling roadmap

The following box provides a long-term vision on the use of renewable cooling technologies within the European Union. Below that the bottlenecks to be overcome to reach this vision are described and first steps that could be taken to create a European Roadmap for the supporting of renewable cooling technologies are outlined.

Long-term vision

- In 2050 at least 50% of the total cooling demand should be covered by cooling technologies based on renewables according to the definition under chapter 2; policies should be implemented which aim to increase this share to up to 100%.
- Different renewable cooling technologies will have penetrated in different European regions to a different extent. While in Northern European countries direct cooling technologies will be spread widely, in southern European countries solar thermal applications will dominate the market for renewable cooling technologies.
- District Cooling Systems will become a common technology to cover the cooling demand especially in the business sector.

Bottlenecks to be overcome	**First steps towards a European roadmap up to 2020**
Definition • Lack of a general accepted definition for renewable cooling.	• Launching a process to set up a definition; inclusion of definition in legal norms (e.g. RES Directive).
Statistics and target accounting • In many Member States and on the EU level a lack of broad reflection of renewable cooling in energy statistics; • For many renewable cooling technologies a lack of methodology for calculating renewable output; • For that reason lack of methodology to properly account renewable cooling towards the renewable targets set by the RES Directive.	• Developing a robust methodology for including renewable cooling in energy statistics; • National and European statistical officers chould start to develop a disaggregated data body on the amount of energy used for cooling and for renewable cooling; • Revision of the Renewables Directive by explicitly acknowledging renewable cooling as technology that can be counted towards the target.
Monitoring • Lack of routines to monitor the re-	• Common Member State approach

newable cooling generation from different technologies.	to develop respective monitoring routines.
Information • Insufficient knowledge about the potential of single renewable cooling technologies in different geographical regions.	• Broadening and disseminating the knowledge base about the potential of different renewable cooling technologies in different geographical regions.
Policies • Lack of appropriate policies aiming at accelerating the development and market diffusion of renewable cooling technologies.	• On the Member State level the adoption of appropriate policies to support different renewable cooling technologies according to their specific needs, taking into account different stages of market maturity;
Technologies • For specific applications (e.g. single family houses) there is still a lack of appropriate technologies.	• Cooling industry must further improve the efficiency of their renewable cooling technologies and provide technical solutions for all different applications; • Cooling industry should set up an organizational structure to promote renewable cooling.

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