Ministry of Foreign Affairs

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

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

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**On behalf of Netherlands Enterprise Agency (RVO.nl)**

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# Executive summary

## Introduction

The global energy demand for cooling is growing rapidly. According to the International Energy Agency, the worldwide installed capacity of air conditioning systems has increased from less than 4 000 GW in 1990 to more than 11 000 GW in 2016 and the energy consumption for space cooling is expected to more than triple until 2050  (IEA 2018). The EU Heating and Cooling strategy projects an increase in cooling demand in the residential sector from 35 TWh in 2015 to 137 TWh in 2050 (Reference scenario) and 78 TWh in 2050 (Energy efficiency scenario) (Jakubcionis and Carlsson 2017).

Currently, the large majority of EU cooling demand is covered by electricity-driven vapour compression air conditioners (Fraunhofer ISI et al. 2016c). Air conditioners use a refrigeration cycle to transport heat from a colder space to a hotter space. As heat would naturally flow in the opposite direction, this requires an external energy input.

Besides vapour compression systems, low-carbon cooling solutions based on natural heat sinks and renewable energies are implemented in EU Member States. Examples include the Helsinki district cooling system, the snow storage cooling system at the hospital in Sundsvall (Sweden), various aquifer cooling systems in the Netherlands and the groundwater cooling system in a hotel in the city of Freiburg (Swedblom et al. 2015; Skogsberg 2005; Späth 2017).

The Renewable Energy Directive (RES-Directive)[1] sets mandatory national targets for the overall share of energy from renewable sources including electricity from renewable energy sources (RES-E), energy from renewable sources for heating and cooling (RES-H&C), and energy from renewable sources in transport (RES-T).

While the RES-Directive outlines the methodology for calculating the renewable energy shares for electricity, heating and transport, it does not offer any indications on how to account for renewable cooling. Due to the lacking methodological guidelines on how to account for renewable cooling, cooling does currently not play a role for target achievement.

Within the ongoing revision of the RES-Directive, the European Council and the EU Parliament propose to empower the Commission to adopt delegated acts in order to supplement the Directive by establishing a methodology for calculating the quantity of renewable energy used for heating and cooling (European Parliament 2018; European Council 2017).

This report collects background information on current and future cooling demand in the EU as well as renewable cooling technologies and discusses possible methodological approaches for calculating renewable cooling in the RES-Directive.

## Cooling demand in the EU – status quo and projections

While information about the energy consumption for cooling is not collected in official EU energy statistics, the current and future cooling demand has been subject to a growing number of studies. The following table provides an overview of the studies that have been analysed in this report.

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[1] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

| Title | Authors | Year | Description |
|---|---|---|---|
| Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) | Fraunhofer Institute for Systems and Innovation Research (ISI) et al. | 2016 | Comprehensive assessment of the heating and cooling sector within the European Union using a bottom-up modelling system. The study comprises end-use energy balances for heating and cooling in 2012; the current state of heating and cooling technologies; scenarios of the heating and cooling demand up until 2030; economic impacts up until 2030; and barriers, best practices and policies. Sector specific information is given for the industrial sector, service sector and residential sector. |
| 2050 Heat Roadmap Europe: Profile of heating and cooling demand in 2015 | Fraunhofer Institute for Systems and Innovation Research (ISI) et al. | 2017 | Update of the study *Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)* with numbers for 2015 based on the existing model. For space cooling, a different approach was used. The space cooling demand was calculated using sales statistics for all vapour compression technologies of the past 24 years. Other cooling technologies are excluded. |
| European space cooling demands | Werner | 2015 | Estimation of the space cooling demand in Europe based on deliveries from twenty district cooling systems in eight European countries. |
| Commission staff working document accompanying the communication on an EU Strategy for Heating and Cooling | European Commission | 2016 | Scenario analysis of heating and cooling by 2030 and 2050 based on PRIMES modelling. The analysis focuses on scenarios developed in the context of the European Commission's proposal for a 2030 climate and energy framework [COM(2014)15] and the Energy Efficiency Review Communication [COM(2014)520]. |
| Status Quo of the Air-Conditioning Market in Europe: Assessment of the Building Stock | Pezzutto, de Felice, Fazeli, Kranzl, Zambotti | 2017 | Assessment of the market for space cooling technology in Europe with focus on electricity-driven air conditioning: quantity of air conditioning units, equivalent full-load hours, installed capacities, seasonal energy efficiency values as well as cooled floor area per air conditioning type and/or sector. The study includes the residential and the service sector in its analysis. |
| Estimation of European Union residential sector space cooling potential | Jakubcionis, Carlsson | 2017 | Estimation of EU space cooling demand potential in the residential sector based on data for space cooling in the USA. The study finds that a significant increase in demand can be expected for residential space cooling. |
| Estimation of European Union service sector space cooling potential | Jakubcionis, Carlsson | 2018 | Estimation of EU space cooling demand potential in service sector based on data on space cooling in the USA. The study finds that no significant increase in cooling demand in service sector buildings of most EU countries can be expected. |

The main findings from the literature analysis are summarized below.

- European energy statistics typically treat heating and cooling in an aggregated way and do not provide any disaggregated data on cooling.
- Heating and Cooling (H/C) account for about half of final energy demand in Europe.
- Space cooling demand is expected to increase considerably in the future.
- Cooling accounts for a relatively low but growing share of the final energy demand for H/C in Europe (2-6%).

- In the service/ tertiary sector, the share of cooling in the final energy demand for H/C is much higher than in the industrial and residential sector (between 9-13% and less than 1% respectively).
- While the energy demand for heating and process cooling is expected to decrease in the future, the space cooling demand is expected to increase significantly. However, in total numbers space cooling continues to account for only a small share of the final energy demand.
- Space cooling is most relevant in southern European countries, where it can account for a substantial share of the final energy demand for heating and cooling.
- So far, the cooling market is dominated by technologies that are powered by electricity.
- The data availability on cooling demand is insufficient. Systematic monitoring and analysis of the cooling sector in Europe is essential for developing policies to reduce the energy use for cooling**.**

## Renewable and low carbon cooling technologies

The report describes various low-carbon cooling technologies and categorizes the different technologies with respect to the required energy inputs (see also Figure 1).

(a) Technologies which make use of existing substances with low temperatures and use the natural flow of heat from a warmer to a cooler object or space → **free cooling systems**

(b) Technologies that require external energy for cooling. These technologies are necessary to transport heat against its natural thermodynamic flow, from a cooler to a warmer space, e.g. if heat from inside a building is supposed to be transported to ambient air which is even warmer. This external energy can be provided by either fossil or renewable sources. The energy input can be in form of:

Electrical energy → **compression cooling systems**

Thermal energy → **Absorption/ adsorption and desiccant and evaporative cooling systems**

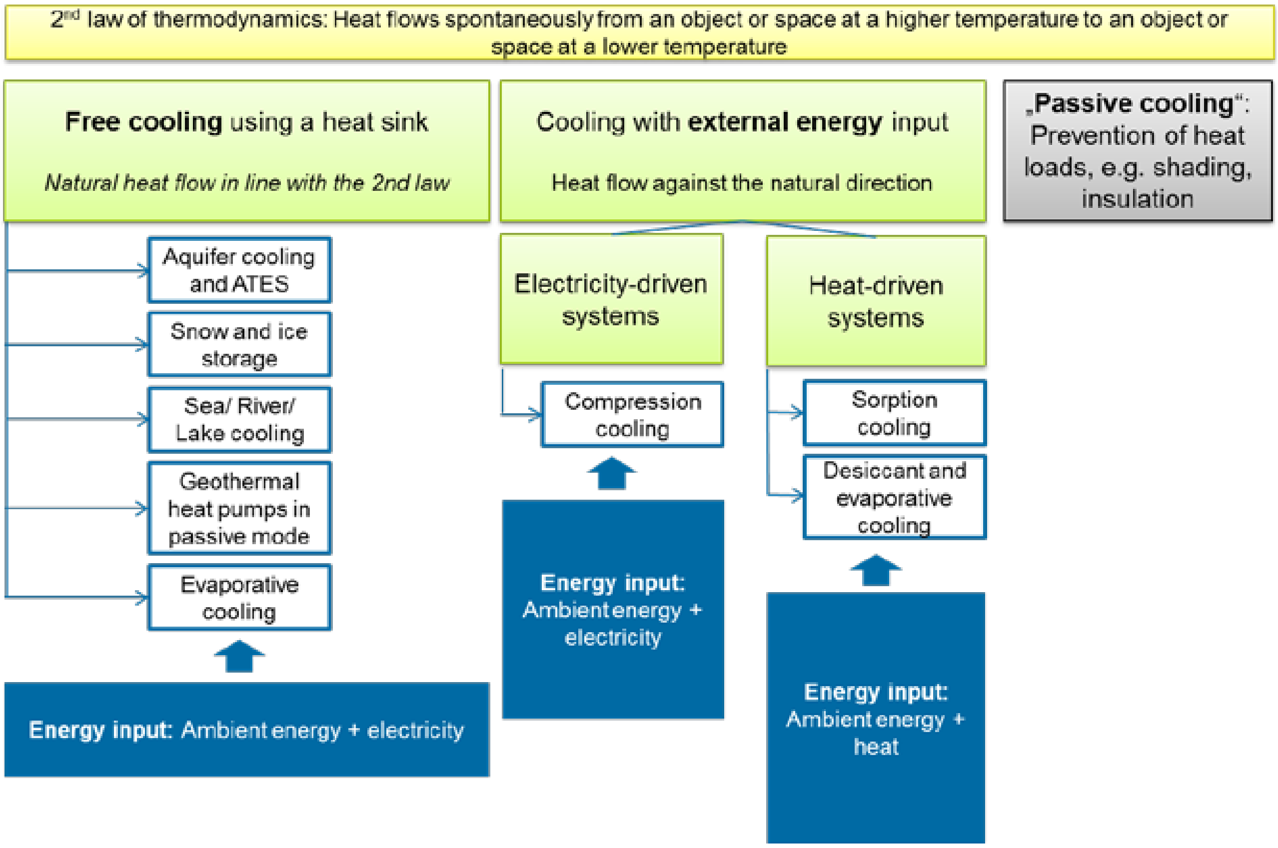

Figure 1: Schematic overview of cooling technologies

### Renewable cooling in the renewable energy directive

The report discusses three options for defining renewable cooling in the Renewable Energy Directive (see Table 1).

Table 1: Overview of discussed options for including cooling in the Renewable Energy Directive

| | Description |
|---|---|
| **Option 1: Minimum requirements on efficiency of the cooling system** | Option 1 proposes to take the same approach as for heat pumps and only count ambient energy for cooling as renewable if the efficiency of the cooling system exceeds a certain threshold. Beside the similarity with the methodology for heat pumps, the advantage of this approach is that only technologies that fulfil minimum sustainability criteria are included. A challenge regarding the approach is that, compared to the approach for heat pumps, the definition of the minimum threshold is less straightforward: For heating, the minimum seasonal performance factor is chosen in such a way that the fossil-fuel input needed for generating the electricity input is lower than the one for providing heating based on the combustion of fossil fuels. For cooling, choosing the minimum efficiency may be more challenging as no such basis exists and the choice has a strong impact on the technologies that are included. A further challenge may be the availability on data, especially for the stock of cooling technologies. As for heat pumps, Member States would be required to estimate the share of devices that meet the efficiency criteria in order to be able to estimate the eligible cooling production. |

| | |
|---|---|
| **Option 2: Minimum requirements on temperature of the heat sink** | Option 2 proposes to only count ambient energy for cooling as renewable if the temperature of the heat sink that is used is below a threshold temperature (e.g. 10° below the temperature of the ambient air). The advantage of this approach is that it favours technologies that use natural heat sinks that do not require electricity-driven cooling cycles. A challenge regarding the approach is that Member States would need to provide estimates of the installed capacity of the cooling systems that meet the requirement. However, as natural heat sinks are mainly used in larger installations and in district cooling systems, this information is typically available (although not collected in current energy statistics). |
| **Option 3: Requirement regarding the type of heat sink** | Option 3 proposes to define the share of ambient energy to be counted as renewable cooling based on the type of heat sink that is used. For example, heat sinks such as the ground, water or snow could be allowed, while excluding the ambient air. Similar to Option 3, an advantage is that typically technologies that use natural heat sinks not requiring electricity-driven cooling cycles would be included. As compared to Option 2, Option 3 may be favourable in terms of reporting, as in Option 2 the temperature level of the heat sink is possibly not known and differs throughout the year. |

## Conclusions

The implementation of policy strategies to address the increasing energy demand for cooling in EU Member States requires reliable data on the energy consumption for cooling. While several recent studies have provided estimates of the current and future cooling demand across the EU Member States, no data on cooling is available in the statistical data provided by Eurostat.

While almost 100% of the current space cooling demand is provided by electricity-driven vapour compression systems connected to the electricity grid, several low-carbon cooling technologies based on renewable sources are available. Such technologies include free cooling technologies using natural heat sinks, electricity-driven systems powered by on-site PV installations and solar-thermal systems that provide cooling using renewable heat.

Although the current RES-Directive refers to renewable heating and cooling, it does not provide a methodology for reporting renewable cooling and Member States have no possibilities to include renewable cooling into their renewable energy contribution. As electricity and heat are reported individually, the main option to include renewable cooling is by considering the ambient energy that is transferred from the space/substance that is cooled to the environment. In order to meaningfully include cooling in the RES-Directive, renewable cooling has to be included in EU energy statistics and a monitoring methodology that limits the additional administrative burden has to be developed.

As basically all cooling technologies are based on the transfer of heat, including all ambient energy transferred in cooling processes would mean that all countries could report near to 100% of their cooling demand as renewable cooling. This would also mean that any cooling demand is always included both in the enumerator and the denominator when calculating the renewable energy shares. This would automatically increase the renewable energy shares thus supporting Member States in achieving their targets towards the RES-Directive.

As for heat pumps, where the methodology outlined in the RES-Directive defines a minimum energy efficiency level, minimum performance requirements may be also introduced to identify the share of ambient energy that may be counted as renewable cooling. This report discusses three options for such requirements: Efficiency, temperature levels and the type of heat sinks. Due to its similarity to the approach for heat pumps, minimum energy efficiency standards seem the most practical option.

The way of defining such performance requirements in the RES-Directive has an impact on the technologies that can be reported as renewable cooling. It is therefore likely that the definition of minimum requirements is subject to controversial debates, particularly between technology suppliers of the various cooling technologies.

If cooling is included in the reporting of the RES-Directive, the targets would need to be adopted In order to maintain the ambition of the Directive. The report shows that including *all* cooling in the RES-Directive would lead to an immediate increase of the renewable energy shares, particularly in countries with high cooling demand. At current levels, the EU renewable energy share would increase by about 6%, while reaching up to 10% for Member States with high cooling demands. This is particularly important as cooling demand is expected to increase, such that the effect becomes more pronounced. At the same time, the figures shown in the report provide an upper limit, while ambitious minimum energy efficiency requirements in the definition of renewable cooling limit the share of cooling demand that classifies as renewable and thus the effect of including renewable cooling on target achievement.

A further challenge when including renewable cooling in the RES-Directive is related to efforts to increase waste heat recovery. As this report shows, industrial process cooling plays a rather prominent role. Energy for cooling waste heat should not be included as renewable cooling, as other options for waste heat recovery are preferable from an environmental perspective.

It is essential to address cooling in EU energy and climate policy in an integrated way, providing a consistent framework with other EU directives addressing cooling technologies such as the Ecodesign Directive, the Energy Performance of Buildings Directive or the F-gas Regulation.

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# 1. Introduction

The global energy demand for cooling is growing rapidly. According to the International Energy Agency, the worldwide installed capacity of air conditioning systems has increased from less than 4 000 GW in 1990 to more than 11 000 GW in 2016 and the energy consumption for space cooling is expected to more than triple until 2050 (IEA 2018). The EU Heating and Cooling strategy projects an increase in cooling demand in the residential sector from 35 TWh in 2015 to 137 TWh in 2050 (Reference scenario) and 78 TWh in 2050 (Energy efficiency scenario) (Jakubcionis and Carlsson 2017).

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The Renewable Energy Directive (RES-Directive)[2] sets mandatory national targets for the overall share of energy from renewable sources including electricity from renewable energy sources (RES-E), energy from renewable sources for heating and cooling (RES-H&C), and energy from renewable sources in transport (RES-T).

While the RES-Directive outlines the methodology for calculating the renewable energy shares for electricity, heating and transport, it does not offer any indications on how to account for renewable cooling. Due to the lacking methodological guidelines on how to account for renewable cooling, cooling does currently not play a role for target achievement.

Within the ongoing revision of the RES-Directive, the European Council and the EU Parliament propose to empower the Commission to adopt delegated acts in order to supplement the Directive by establishing a methodology for calculating the quantity of renewable energy used for heating and cooling (European Parliament 2018; European Council 2017).

This report collects background information on current and future cooling demand in the EU as well as renewable cooling technologies and discusses possible methodological approaches for calculating renewable cooling in the RES-Directive. Chapter 2 provides a detailed analysis of recent studies estimating the current and future cooling demand in the EU member states. Chapter 3 describes the most relevant cooling technologies based on natural heat sinks and renewable energy sources. Chapter 4 suggests possible methodologies to account for renewable cooling in the RES-Directive and discusses the implications for target achievement. Chapter 5 summarizes the main findings and presents our conclusions.

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[2] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

## 2. Cooling demand in the EU – status quo and projections

Cooling demand has been rapidly increasing globally and in the EU. 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 2006).

Information about the energy consumption for cooling is not collected in official EU energy statistics. This section reviews contributions estimating the current and future cooling demand on a Member State level.

### 2.1. Overview of studies on EU cooling demand

The current and future cooling demand has been subject to a growing number of studies, where different methods and assumptions have been applied. One of the most extensive studies including cooling has been carried out for the European Commission by a consortium led by Fraunhofer ISI: "*Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)"*. An update of the study has been provided within the project "Heat roadmap Europe" in 2017 (Fraunhofer ISI et al. 2017). Furthermore, Werner (2015) estimates the space cooling demand for service sector buildings in Europe. The paper is a summary of the results of the EU Stratego project[3] concerning specific and national space cooling demands. Werner (2015) states that many of the published demands are not measured, but instead they are estimated by combining climate data with standard efficiencies for cooling devices. Exceptions are district cooling systems which measure deliveries of cold. Here, supplies are regularly measured in order to create invoices. However, district cooling systems deliver cold[4] mostly to service sector buildings and provide no information about space cooling demands in residential buildings. For the study, Werner (2015) based his calculations on deliveries from twenty district cooling systems in eight European countries in order to estimate the average European space cooling demand for service sector buildings. Further studies which have been analysed for this report include European Commission (2016) and Pezzutto et al. (2017).

An overview of the studies used for the analysis of the European space cooling demand can be found in Table 2.

**Table 2: Overview Studies on Cooling Demand considered for the report**

| Title | Authors | Year | Description |
|---|---|---|---|
| Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) | Fraunhofer Institute for Systems and Innovation Research (ISI) et al. | 2016 | Comprehensive assessment of the heating and cooling sector within the European Union using a bottom-up modelling system. The study comprises end-use energy balances for heating and cooling in 2012; the current state of heating and cooling technologies; scenarios of the heating and cooling demand up until 2030; economic impacts up until 2030; and barriers, best practices and policies. Sector specific information is given for the industrial sector, service sector and residential sector. |

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[3] Stratego. Multi-level actions for enhanced heating & cooling plans. Contract IEE/13/650/SI2.675851. http://stratego-project.eu/.

[4] Werner defines "cold" as heat removal.

| | | | |
|---|---|---|---|
| 2050 Heat Roadmap Europe: Profile of heating and cooling demand in 2015 | Fraunhofer Institute for Systems and Innovation Research (ISI) et al. | 2017 | Update of the study *Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)* with numbers for 2015 based on the existing model. For space cooling, a different approach was used. The space cooling demand was calculated using sales statistics for all vapour compression technologies of the past 24 years. Other cooling technologies are excluded. |
| European space cooling demands | Werner | 2015 | Estimation of the space cooling demand in Europe based on deliveries from twenty district cooling systems in eight European countries. |
| Commission staff working document accompanying the communication on an EU Strategy for Heating and Cooling | European Commission | 2016 | Scenario analysis of heating and cooling by 2030 and 2050 based on PRIMES modelling. The analysis focuses on scenarios developed in the context of the European Commission's proposal for a 2030 climate and energy framework [COM(2014)15] and the Energy Efficiency Review Communication [COM(2014)520]. |
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For this report we first analyse the data compiled in the project "*The Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)"* (Fraunhofer ISI et al. 2016b). We then compare it to results from other studies in order to identify major similarities and differences regarding current and future space cooling demand in Europe.

## 2.2. Cooling demand in the EU today

*Fraunhofer ISI et al. 2016b* use data from the Eurostat final energy balances to calculate the end-use balances for 2012. In cases of incomplete information, additional sector-specific sources and assumptions were used. The study differentiates between the industry, the tertiary and the residential sector.

For calculating the space cooling demand in the industry sector, the specific energy consumption per floor area for cooling (kWh/m$^2$) was used. For the tertiary sector, the main parameters were the specific energy consumption of end use appliances (e.g. heat pumps, air-conditioners, etc.), installed capacities of appliances, utilisation rates of appliances and/or specific data on energy consumption per floor area for cooling (kWh/m$^2$) as well as the demand per employee. For the residential sector, a building physics approach was used, having geometry data and information about the insolation (u-values) of building components as well as installed cooling systems and distribution systems as main input parameters (Fraunhofer ISI et al. 2016b).

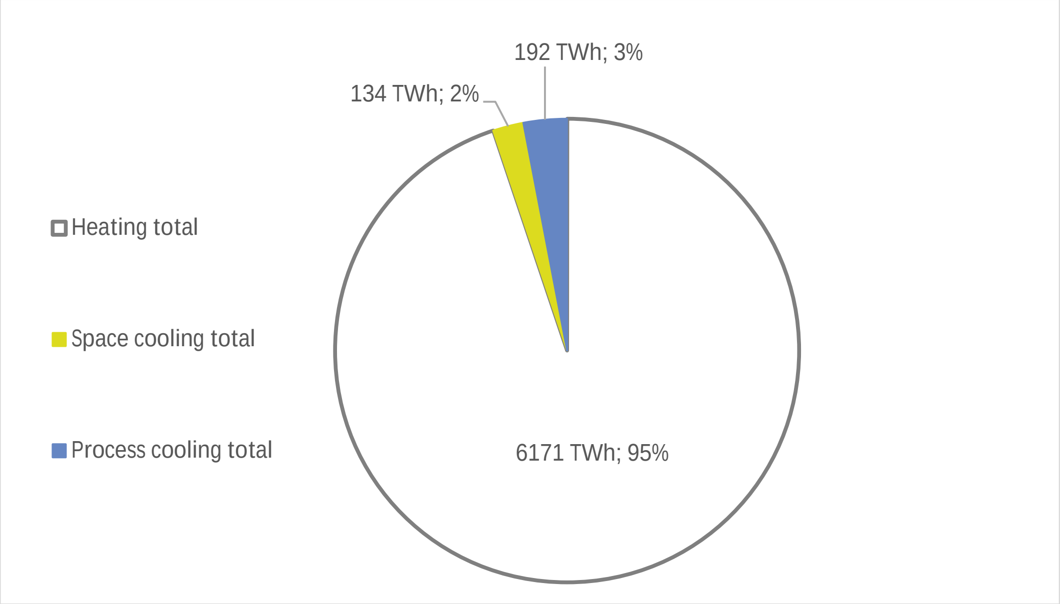
In the update of the study, a different approach was used to calculate the space cooling demand for 2015: Using a bottom-up model based on sales statistics for all vapour compression technologies of the past 24 years, the electricity consumption for space cooling was calculated (Fraunhofer ISI et al. 2017).

The report indicates that empirical data for the space cooling sector is scarce since in most of the EU Member States only little information is available on the cooling supply. Furthermore, estimations on energy consumption are uncertain, because they are mainly based on assumptions regarding the user behavior and (average) performance of appliances. (Fraunhofer ISI et al. 2016b).

Fraunhofer ISI et al. 2017 point out that the actual electricity consumption for space cooling might be higher than calculated due to suboptimal installation, maintenance and usage.

According to Fraunhofer et al. 2016c, the overall final energy demand in 2012 within the EU28 was about 12 800 TWh. Heating and cooling accounted for around 51% of the final energy demand. As illustrated in Figure 2-1, space cooling and process cooling together account for about 5% of the final energy demand for heating and cooling. In total numbers, around 134 TWh of the final energy demand was used for space cooling and around 192 TWh for process cooling[5][6][7].

**Figure 2-1: Share of final energy demand heating and cooling (FED H/C) (CP) 2012**



Source: *Öko-Institut based on Fraunhofer ISI et al. 2016c*

Pezzutto et al. (2017) derive similar results as Fraunhofer et al. 2016c. According to their analysis, the energy consumption for space cooling was 140 TWh in 2014. In contrast to Fraunhofer ISI et al. (2016c), this number excludes space cooling within the industry sector. Pezzutto et al. point out that estimates in other studies partly exceed and partly fall below the above mentioned values, specifically regarding the energy consumption from air conditioning.

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[5] For cooling, near to 100% of final energy demand is provided by electricity

[6] Space cooling refers to cooling in rooms inside of buildings. Process cooling refers to cooling in industrial processes.

[7] Data used in this paragraph is climate-adjusted for the year 2012.

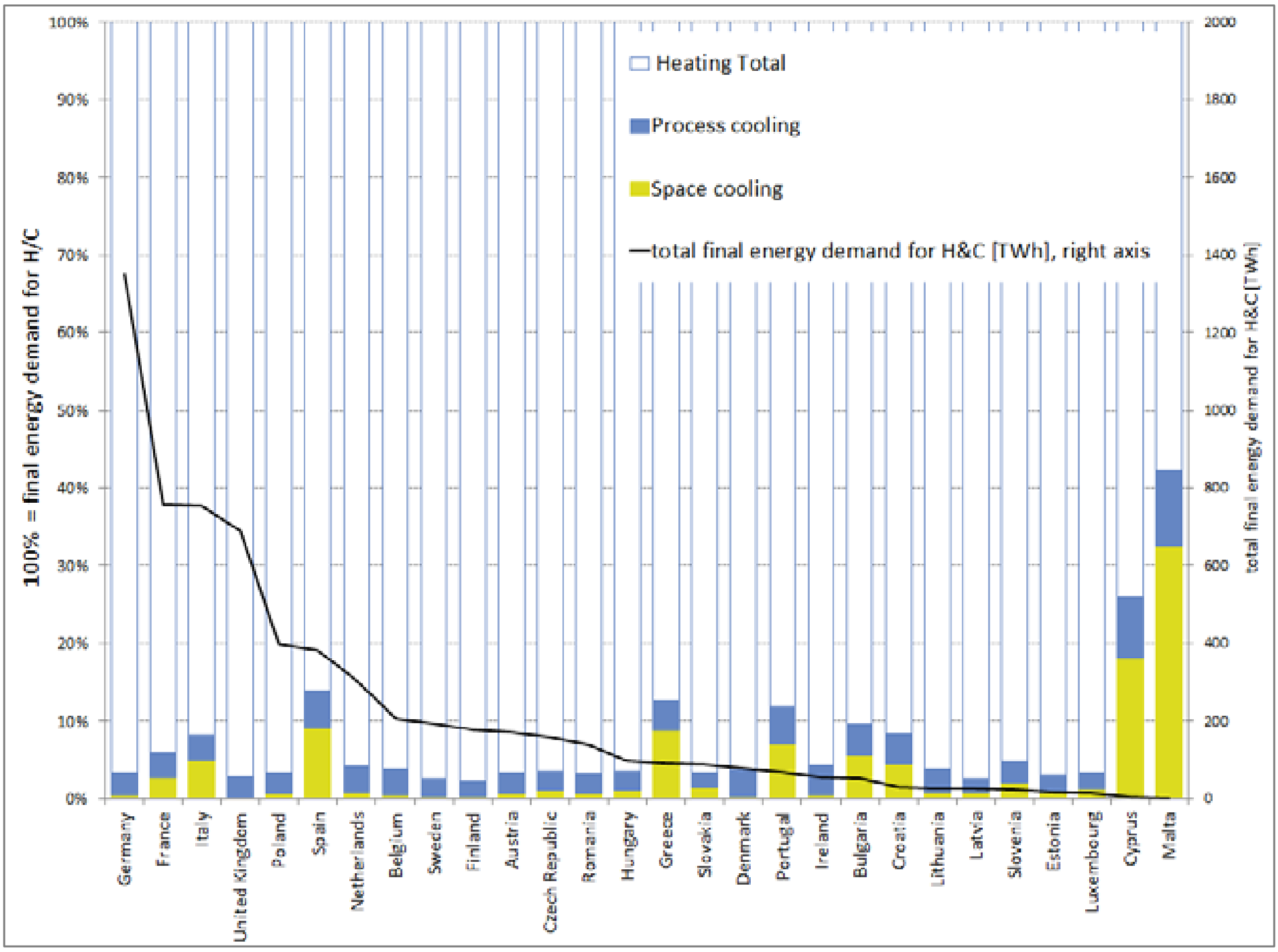
Werner (2015) calculates a space cooling demand of 192 TWh and further refers to different studies estimating the space cooling demand for Europe. While the numbers are slightly different due to different input parameters and different reference years, a common finding is that the service sector accounts for the biggest share of the space cooling demand.

This goes along with the results from Fraunhofer ISI et al. 2016c and 2017: Between the sectors, the importance of space cooling differs. In the residential and the industrial sector, space cooling has a negligible share of less than 1% of the total final energy demand for heating and cooling, while in the service sector, space cooling has a share of 9-10%. With regard to the space cooling demand the sub-sector “wholesale and retail trade” is dominating the service sector, with 58 TWh in total, corresponding to about 57% of the total space cooling demand (Fraunhofer ISI et al. 2016c).

Pezzutto et al. (2017) come to a similar conclusion regarding the importance of space cooling within the different sectors. The service sector has the highest share in energy consumption for space cooling. Looking at only electricity-driven appliances, which are dominating the cooling sector, the study states that air conditioning is responsible for a significant share of electricity consumption in households (about 5%) and even more in the service sector (about 13%). Furthermore, the study identifies “wholesale and retail trade” as the sub-sector with the highest space cooling demand within the service sector. They state that the consumption here is approximately 40 TWh per year (in 2014) (Pezzutto et al. 2017).

On a country level, space cooling is especially high in the Mediterranean countries like Italy, France, Spain, Portugal and Greece. Especially in the two small Member States Malta and Cyprus, the share of space cooling of the total final energy demand for heating and cooling is significantly higher than in the rest of Europe. However, the energy demand in these countries in total numbers is very low (compare Figure 2-2).

Figure 2-2: **Final energy demand for heating and cooling by country in 2012**



Source: *Öko-Institut based on Fraunhofer ISI et al. 2016c*

Werner (2015) uses a similar approach as Fraunhofer ISI et al. (2016c) for calculating the space cooling demand, using floor areas, average specific cooling loads and shares of cooled floor areas. The overall results are similar to the above described data. Significant differences for the space cooling demand only occur within the industry sector. Due to different sources for the input parameters (national statistics, surveys and modelled data), the results for the calculated space cooling demand by Werner (2015) are lower in Italy and Bulgaria and higher in Spain, compared to the Fraunhofer ISI et al. (2016c).

## 2.3. Projected development of cooling demand in the EU

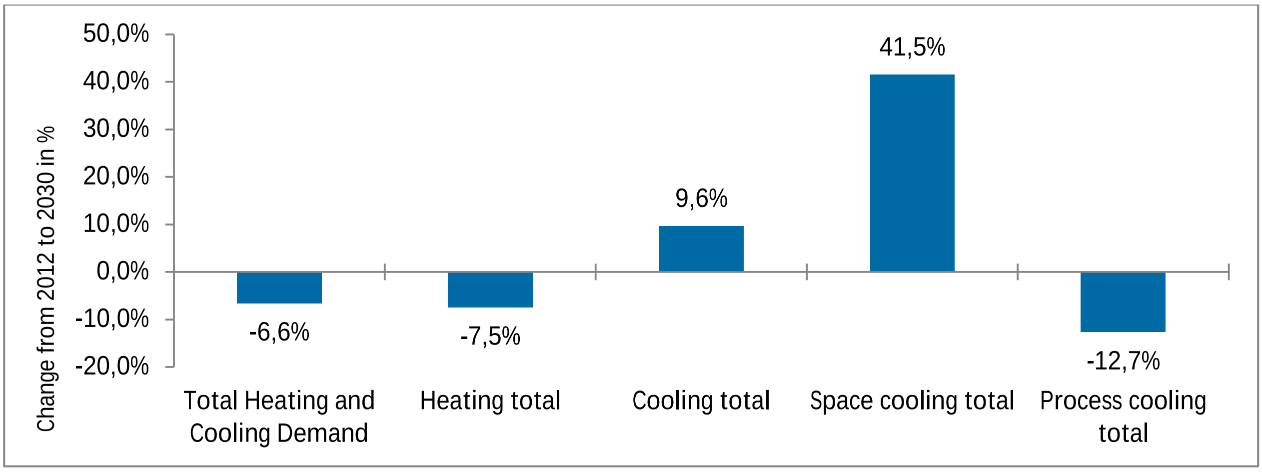
The cooling demand worldwide is expected to increase in the coming decades (Werner 2015; Fraunhofer ISI et al. 2016b; European Commission 2016a; Pezzutto et al. 2017). The most important drivers are changing climate conditions as well as demographic factors like population growth and urbanisation combined with a rising standard of living. Also, changing architecture, e.g. characterised by increasing proportions of glass areas at the building envelope (glass facades) increases the cooling demand in office buildings (Mugnier et al. 2014; Fraunhofer ISI et al. 2016d; International Energy Agency 2018; IEA 2018).

Fraunhofer ISI et al. (2016b) developed three scenarios to calculate and analyse the energy demand for heating and cooling until 2020 and 2030:

1. The ***Current Policy Scenario (CP)*** contains all EU policy legislations related to heating and cooling as well as major national regulations implemented at the end of 2015, assuming that these regulations do not change in the future.
2. The ***Gradual Quota MS scenario (Q0.55)*** assumes the implementation of an obligatory gradual renewable energy quota for heating and cooling suppliers on a Member State level from 2020 onwards. This policy stipulates an annual increase in the share of renewable energy sources for heating and cooling of at least 0.55% between 2020 and 2030. The other policies of the Current Policy Scenario are assumed to continue until 2030. Current subsidies for the installation of technologies as well as fixed feed-in tariffs are assumed to phase out in 2020. There are no follow-up subsidies for renewable heating and cooling.
3. The ***2030 Quota EU scenario (Q27):*** This scenario assumes an obligatory EU-wide quota for renewable energy sources for heating and cooling of 27%. In this scenario, trade among suppliers in different EU member states is allowed. As with the Q0.55 scenario, the other policies of the Current Policy Scenario are assumed to continue until 2030. Likewise, current subsidies for the installation of technologies as well as fixed feed-in tariffs are assumed to phase out in 2020. There are no other subsidies for renewable heating and cooling.

Figure 2-3 shows the projected development of the heating and cooling demand in Europe under the Current Policy Scenario (CP). While the heating demand and the demand for process cooling are both decreasing, the demand for space cooling significantly increases by 41.5%.

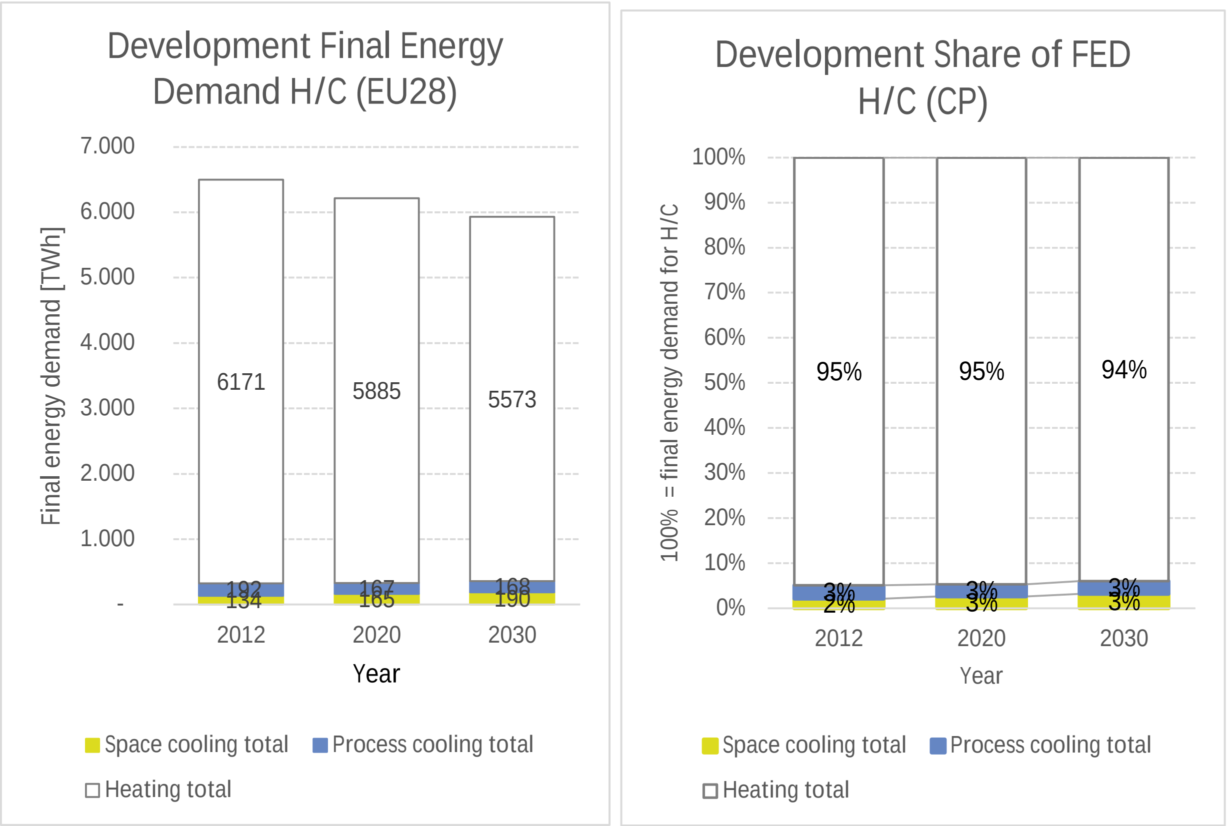
**Figure 2-3: Projected development of heating and cooling demand in the Current Policy Scenario (change of heating and cooling demand between 2012 and 2030)**



Source: *Öko-Institut based on Fraunhofer ISI et al. 2016d*

Figure 2-4 shows the projected shares of space cooling, process cooling and heating in the total energy demand for heating and cooling in the EU-28 in 2030. Even though space cooling demand increases until 2030 and heating demand decreases, space cooling still plays a minor role compared to heating. As space cooling demand is constantly rising, it is expected to exceed the demand for process cooling in the future.

**Figure 2-4: Projection for cooling demand in the EU-28**



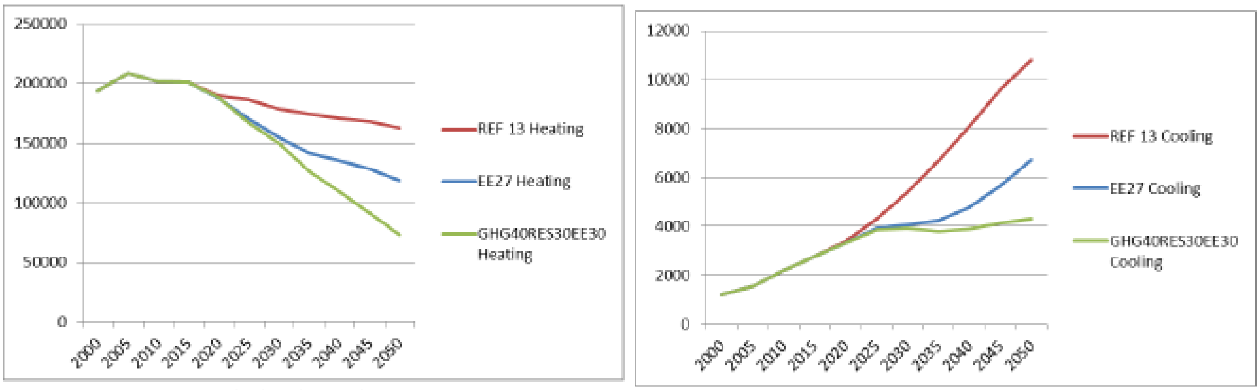
Source: *Öko-Institut based on Fraunhofer ISI et al. 2016d*

European Commission (2016a) considers projections of the heating and cooling demand until 2030 and 2050. Three different scenarios based on existing studies were analysed:

- **2013 Reference scenario (REF13)**: Similarly to the Current Policy Scenario (CP) (Fraunhofer ISI et al. 2016c), this scenario includes existing policies on the EU and Member State level adopted by spring 2012 (CP: by 2015).
- **EE27 policy scenario (EE27):** This scenario looks at how the H/C demand would have to evolve in case that the following goals, set by potential new policies, should be reached:
  Until 2030: Reduction of greenhouse gas (GHG) emissions by 40.2% as compared to 1990, renewable energy share (RES) of 27.8%, energy efficiency (EE) of 27%.
  Until 2050: Reduction of GHG emissions by 78.8% as compared to 1990.
- **GHG40RES30EE30 policy scenario:** This scenario looks at how the H/C demand would have to evolve in case that the following goals, set by potential new policies, should be reached:
  Until 2030: Reduction of GHG emissions by 40.6% as compared to 1990, RES share of 30.3% and EE share of 30%.
  Until 2050: Reduction of GHG emissions by 81.8% as compared to 1990.

The REF13 scenario is comparable to the Current Policies Scenario in Fraunhofer ISI et al. (2016c), however the time span is until 2050. Both approaches predict a slight reduction of the combined final energy demand for heating and cooling. While the heating demand decreases significantly, the cooling demand increases. Figure 2-5 shows the development within the residential sector under the different scenarios. Similar to Fraunhofer ISI et al. (2016c), the report states that, regardless of the predicted growth, cooling will continue to represent a small share of the final energy demand.

**Figure 2-5: Final energy use (Ktoe) for residential heating (left) and cooling (right) demand**



Source: *European Commission (2016a)*

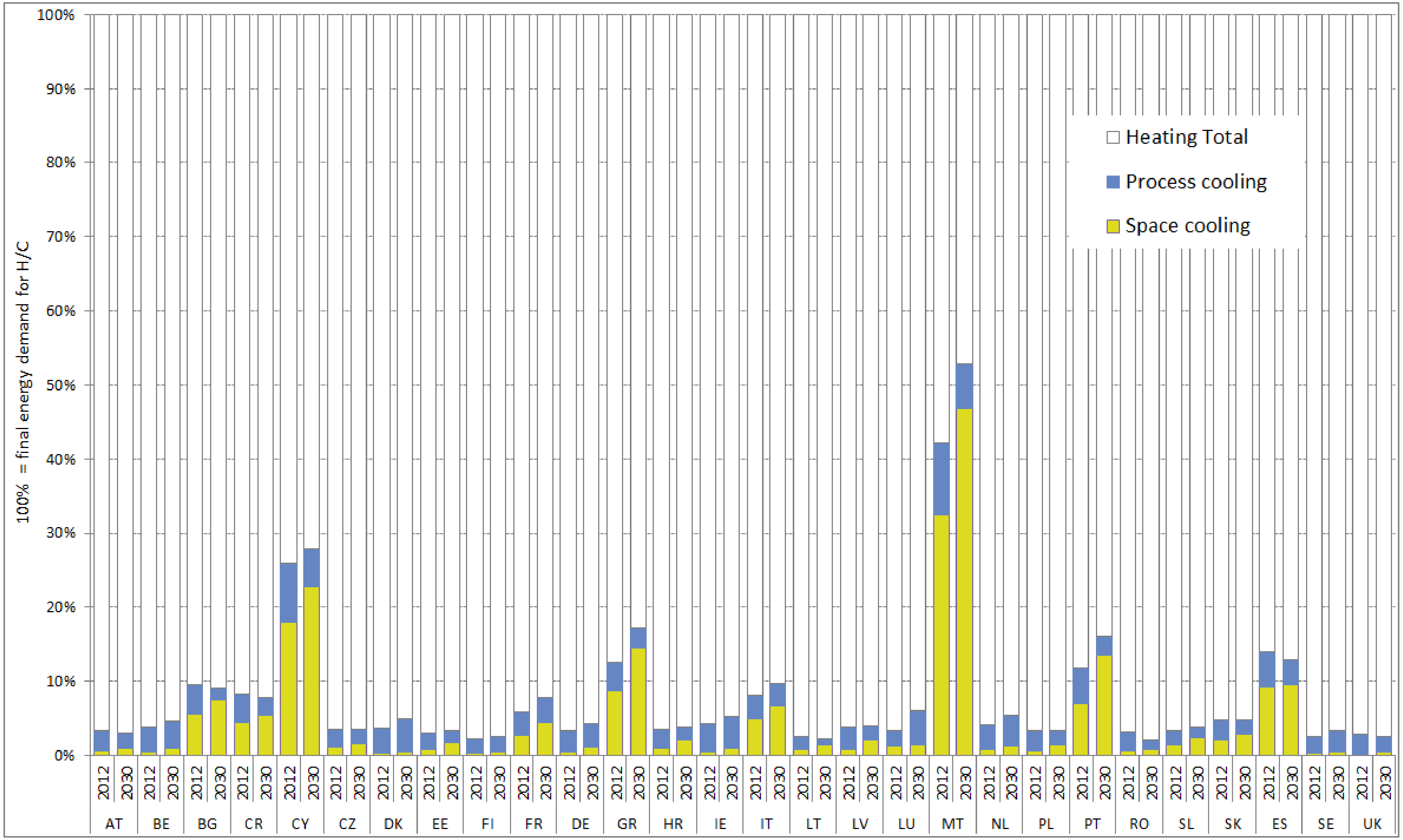
Also Pezzutto et al. (2017) state, that the space cooling market in Europe has a high potential for growth, especially in households.

Estimating the future cooling demand potential for residential space cooling (Jakubcionis and Carlsson 2017) and space cooling in the service sector (Jakubcionis and Carlsson 2018), the authors find a strong growth potential for residential space cooling.

At the country level, the situations for space cooling demand differ significantly from the EU-wide average. In Malta and Cyprus, space cooling accounts for a significant share of the total final energy demand for heating and cooling. Also in Greece, Portugal and Spain the space cooling share is clearly above the EU-wide average (compare Figure 2-6).

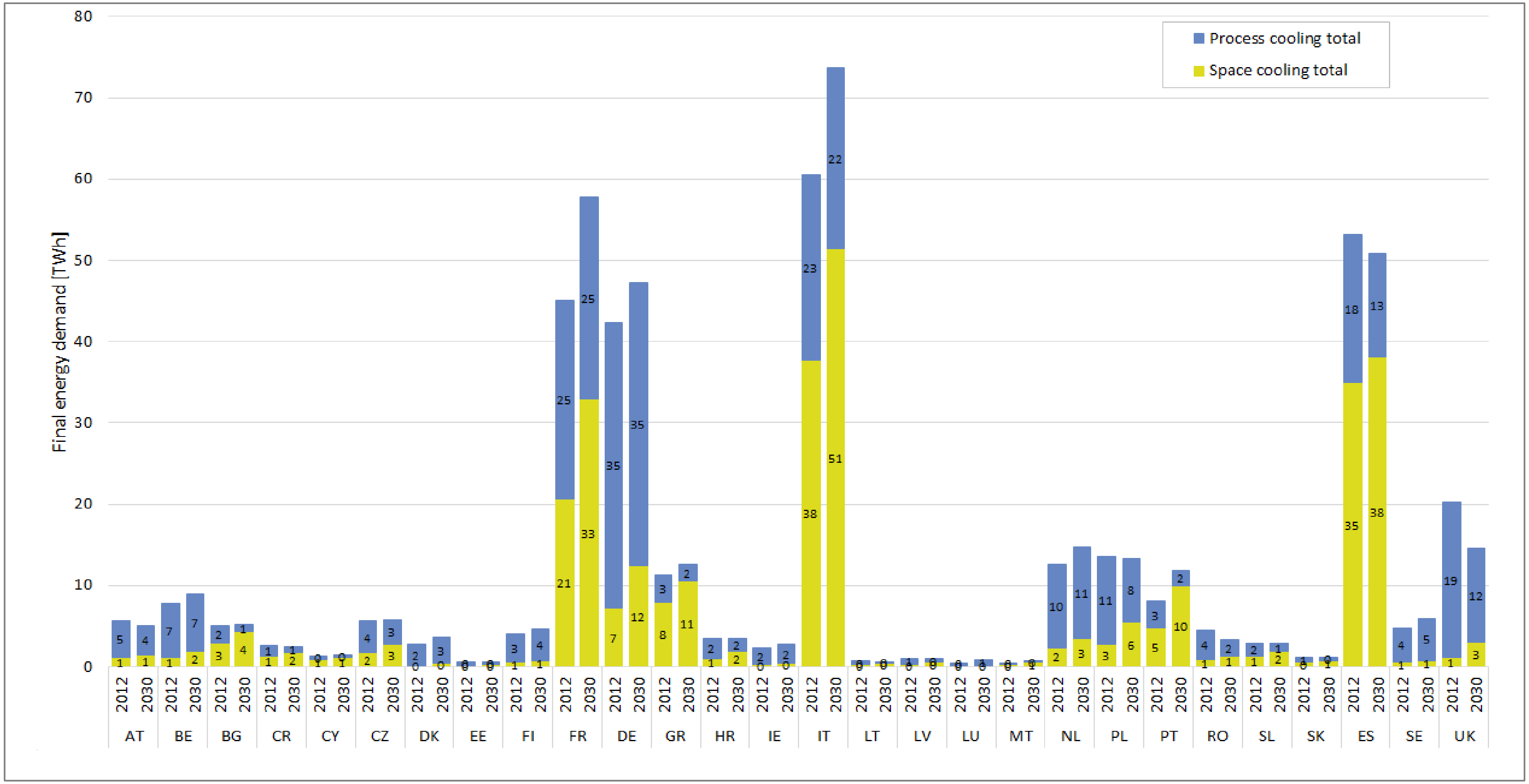
Regarding space cooling and process cooling demand in 2012 and 2030 in the EU, Italy, France and Spain have the biggest demand, followed by Greece, Germany and Poland (compare Figure 2-7).

**Figure 2-6: Shares of cooling and heating in the final energy demand for H/C in 2012 and 2030**



Source: *Öko-Institut based on Fraunhofer ISI et al. 2016d*

**Figure 2-7: Comparison space cooling and process cooling in 2012/2030 by country (total demand in TWh)**



Source: *Öko-Institut based on Fraunhofer ISI et al. 2016d*

:

The cooling demand up to date is almost completely provided by electricity, as compression cooling technologies are dominating the market of cooling technologies. Other energy sources play only a minor role (Fraunhofer ISI et al. 2016c).

**Box 1: Summary of findings on current and future space cooling demand EU**

- European energy statistics typically treat heating and cooling in an aggregated way and do not provide any disaggregated data on cooling.
- Heating and Cooling (H/C) account for about half of final energy demand in Europe.
- Space cooling demand is expected to increase considerably in the future.
- Cooling (space and process cooling) account for a relatively low but growing share of the final energy demand for H/C in Europe (2-6%).
- In the service/ tertiary sector, the share of cooling in the final energy demand for H/C is much higher than in the industrial and residential sector (between 9-13% and less than 1% respectively).
- While the energy demand for heating and process cooling is expected to decrease in the future, the space cooling demand is expected to increase significantly. However, in total numbers space cooling continues to account for only a small share of the final energy demand.
- Space cooling is most relevant in southern European countries, where it can account for a substantial share of the final energy demand for heating and cooling.
- So far, the cooling market is dominated by technologies that are powered by electricity.
- Data availability on cooling demand is insufficient. Systematic monitoring and analysis of the cooling sector in Europe is essential for developing policies to reduce the energy use for cooling.

# 3. Renewable and low carbon cooling technologies

## 3.1. Overview of cooling technologies

Cooling refers to the removal of unwanted heat from a selected object, substance or space and its transfer to another object, substance, or space. According to the second law of thermodynamics, heat cannot flow spontaneously from a space at a lower temperature to a space at a higher temperature. Therefore, keeping a space below the outside temperature either requires a colder medium to absorb heat or the input of external energy in order to move heat from the colder space to a warmer space.

The report clusters cooling technologies in the following way:

(c) Technologies which make use of existing substances with low temperatures and use the natural flow of heat from a warmer to a cooler object or space → **free cooling systems** *(see chapter 3.3)*

(d) Technologies that require external energy for cooling. These technologies are necessary to transport heat against its natural thermodynamic flow, from a cooler to a warmer space, e.g. if heat from inside a building is supposed to be transported to ambient air which is even warmer. This external energy can be provided by either fossil or renewable sources. The energy input can be in form of:

Electrical energy → **compression cooling systems** *(see chapter 3.4)*

Thermal energy → **Absorption/ adsorption and desiccant and evaporative cooling systems** *(see chapter 3.5)*

The simplest form of cooling is to use a natural heat sink to remove heat gains. This is referred to as “natural cooling” or “free cooling” and has been used since the ancient times, e.g. by storing snow and ice for cooling purposes. Other heat sinks commonly used for free cooling purposes include the outside air, water from the ocean, rivers and aquifers. The applicability of free cooling systems is limited by the availability of such heat sinks. Free cooling technologies require external energy (typically electricity for running pumps or fans) for transporting the cold medium.

The most commonly used cooling devices are vapour compression systems, which use electrically-driven compressors to transfer heat from a low-temperature space (e.g. a room) to a high-temperature space (e.g. the outside air). The large majority of currently used air condition systems in the EU are based on vapour compression systems.

Unlike vapour compression systems, absorption and adsorption cooling technologies use heat to produce cooling. In absorption cooling, the compression cycle is replaced by a chemical cycle taking place between the absorber, pump, and regenerator. Absorption cooling is more common than adsorption cooling, however both technologies currently play a negligible role in comparison to vapour compression systems.

Additionally to these technologies, there are several passive cooling strategies[8] which can be used in order to prevent the need for cooling. In all cases in which a cooling demand can occur, priority should be given to these passive cooling measures (e.g. building insulation, night ventilation, shading or building management) before considering the installation of an active cooling technology.

Figure 3-1 provides an overview of the most common cooling technologies.

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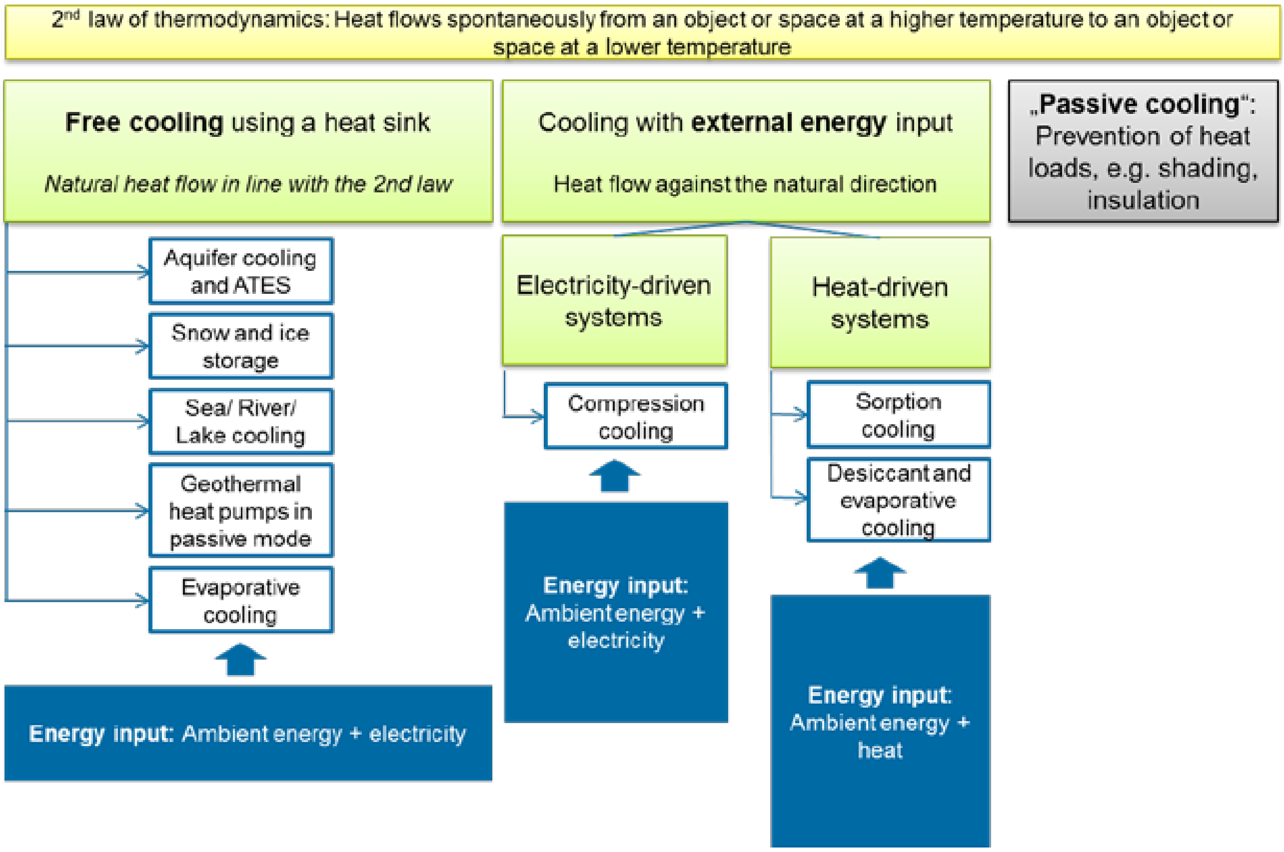
[8] In this report, the term *passive cooling* refers to strategies that prevent or reduce cooling loads and does not include free cooling strategies (Chapter 3.2) or passive cooling with reversible heat pumps (Chapter 3.2.4).

**Figure 3-1: Schematic overview of cooling technologies**



Source: *Öko-Institut*

## 3.2. Renewable cooling technologies

Unlike heating, where the combustion of fossil fuels is currently the main source of energy, all cooling technologies are based on the transfer of heat from the space that is cooled to an external medium (e.g. the outside air, the earth or water). In the vast majority of current cooling systems, the energy input to enable heat transfer is based on electricity. To a much lesser extent, cooling is provided by systems based on adsorption and absorption that require heat.

For electricity-based cooling (which as mentioned above accounts for almost 100% of the current cooling demand), cooling could be classified as “renewable” if the electricity is generated by renewable sources. In the statistics this could lead to double counting, if the renewable electricity is also counted as renewable energy.

For absorption and adsorption cooling, cooling could be classified as “renewable” if the heat is produced by renewable energy sources.

Apart from the energy input (electricity or heat), ambient energy could be classified as renewable cooling. In particular, free cooling systems are frequently referred to as renewable cooling.

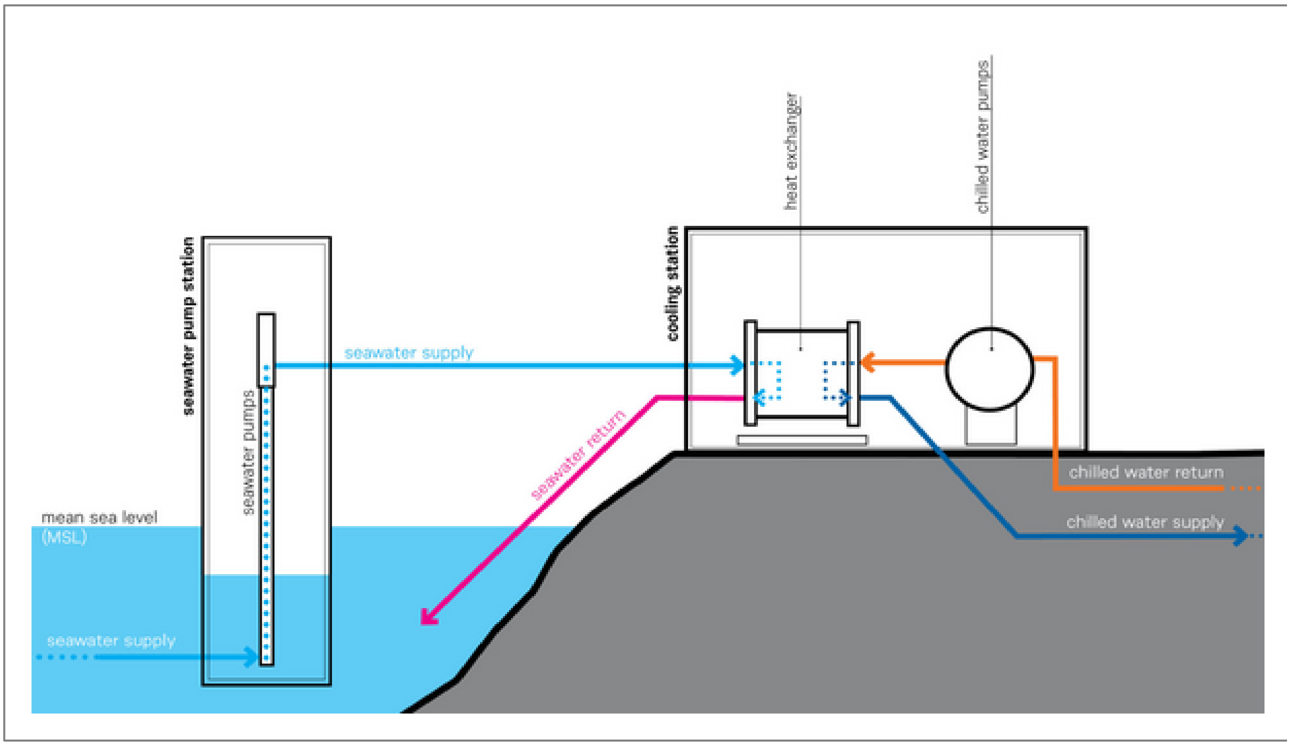
The data availability on renewable cooling technologies in general is scarce. As the market for renewable cooling technologies up to now is relatively small, only little information can be found on installed capacities in the EU member states. In the case of technologies which can be used for both heating and cooling, statistics mostly do not differentiate between heating and cooling purposes (Fraunhofer ISI et al. 2016a).

## 3.3. Free cooling technologies

Free cooling technologies use low temperatures from the surrounding, e.g. in form of cold water, snow and ice. Free cooling technologies do not use refrigeration cycles and the energy input is only needed for the operation of heat exchangers and the circulation of the cooling medium. The efficiencies can therefore be much higher than for conventional cooling systems.

The basic principle is the same for all free cooling technologies (except of evaporative cooling, see chapter 3.3.5): A pipeline transports the cooling medium (e.g. water) from a cold surrounding, the heat sink, to a heat exchanger. Within the building a second, closed-loop pipeline with freshwater circulation is installed. In the heat exchanger, heat is extracted from the freshwater and absorbed by the water from the heat sink. The fresh water is chilled and distributed through the building's cooling system. The slightly warmer water from the heat sink is transported back to the cold surrounding where the heat is released. Figure 3-2 shows a schematic depiction of such a free cooling system with the example of sea water.

**Figure 3-2: Schematic depiction of a free cooling system (example: sea water cooling)**



Source: *Courtesy Clark Nexsen (2013), https://www.clarknexsen.com/project/sea-water-air-conditioning-swac-study/*

The availability of suitable heat sinks for free cooling technologies depends on the geographical location, the geological formation of the underground and the climate conditions. At the same time, there are legal regulations for public water bodies concerning the withdrawal of cold and the reinjection of warm water. Depending on the availability of heat sinks, most of these technologies can be used on different scales from single buildings to larger commercial complexes and district cooling.

The following subsections give an overview on the different free cooling technologies and examples of successfully implemented systems.

### 3.3.1. Aquifer cooling[9] and Aquifer Thermal Energy Storages

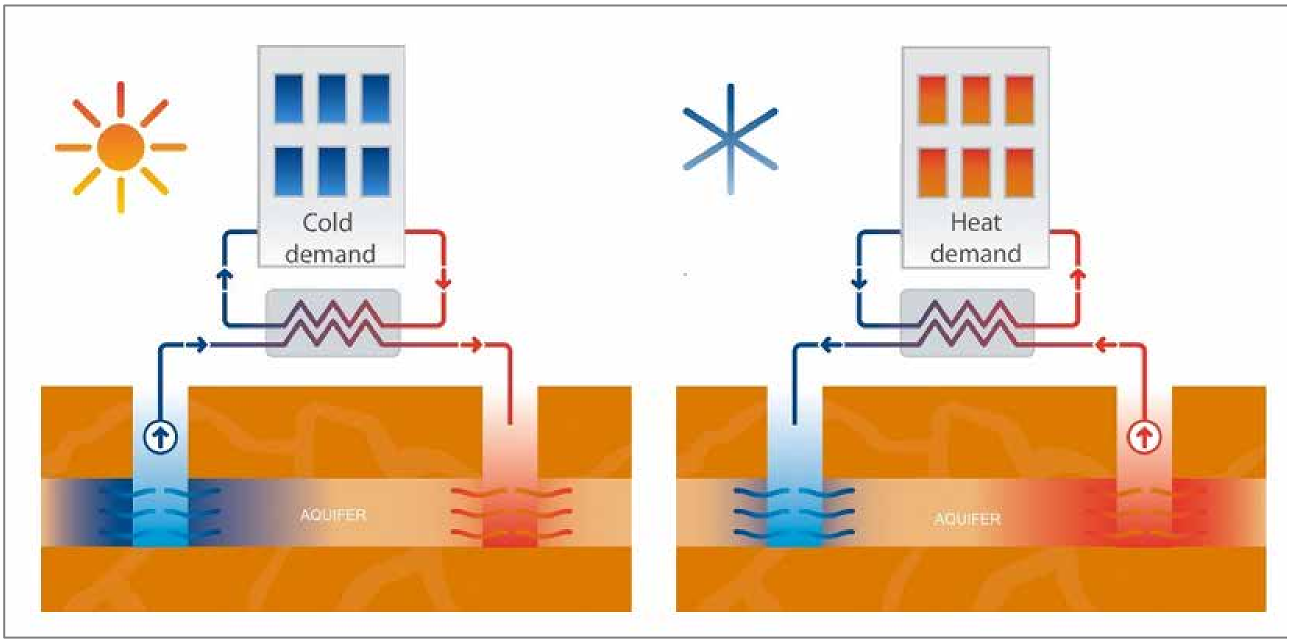
In aquifer cooling systems, cold groundwater is delivered by a suction well, led through a heat exchanger and reinjected through an injection well. A cooling-pipe system leads the cold water to fan convectors which cool down the temperature in single rooms.

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 10°C and re-injected back into the ground at a maximum of 16°C[10].

Aquifer Thermal Energy Storages (ATES) work according to the same principle. The difference is that suitable aquifers are used for (seasonal) storage of the thermal energy: In winter, the water is chilled to be used for cooling in summer. In summer, the heat can be stored for heating purposes during winter (Figure 3-3). In order to allow the storage of thermal energy, the aquifers need to be closed systems which are not exchanging water with underground water streams. Seasonal storage in aquifers for space cooling is usually used in combination with space heating.

ATES as cooling (and heating) technology is mainly used for large commercial buildings and for apartment buildings larger than 50 units. For smaller buildings, ATES are not yet suitable as planning and upfront investments exceed the benefits of the technology.

**Figure 3-3: Schematic depiction of seasonal Aquifer Thermal Energy Storages (ATES)**



Source: *IF Technology BV (2017), http://www.iftechnology.nl/aquifer-thermal-energy-storage-wko-in-dutch-is-catching-on-in-japan*

The world's largest energy storage system for space cooling and heating is located at the Stockholm Arlanda Airport. The German federal state parliament building ("Reichstag") is another exam-

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[9] The terms "aquifer cooling" and "groundwater cooling" are used synonymously.

[10] https://www.hotel-victoria.de/documents/95330/Umwelterklarung_2017_EMAS_III.pdf

ple 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).

The applicability of such technologies depends on the availability of pre-existing aquifer formations (Lanahan and Tabares-Velasco 2017). In Germany around 70% of the surface is suitable for energy storage in aquifers. It is assumed that if 2,000 aquifer storage installations with a capacity of 5-10 GWh each would be installed, 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. Suitable aquifers with ground water are available in about 90% of the country. In 2015, around 2 PJ (0,56 TWh) of energy for cooling purposes were provided by almost 2,000 ATES (Bosselaar, 2017, Renewable Cooling in the Netherlands).

### 3.3.2. **Seasonal snow and ice storage**

Another free cooling technology is based on the seasonal storage of snow or ice. The snow and ice can be stored indoors, on the ground, in the ground and underground (Nordell and Skogsberg 2007). There are different methods for insulating the storage pits and preventing loss of melting water (Kumar et al. 2017). When the snow and ice melts in summer, the run-off water with temperatures just above freezing temperature are led through a heat exchanger and can be used for cooling. The warmer water is routed back to the storage pit to be chilled again. Another option is to install a piping system which contains a coolant (e.g. water) and leads through the snow or ice storage without allowing a direct contact between snow/ ice and coolant. The only difference is that instead of using the melting water for the transportation of thermal energy, the coolant is used. In these systems, additional filter applications for melting water are redundant. However, depending on the technical components, efficiency losses might occur.

Cooling with snow and ice storage systems is mainly an option in the northern EU Member States or in mountainous regions with reliable snowfall and low temperatures during winter months.

A study from Kumar et al. (2017) shows that snow storage systems cool just equally well as conventional compression cooling systems while reducing greenhouse gas emissions and associated impacts. In contrast to some free cooling systems where heat is reinjected into water bodies, snow cooling systems do not change the overall temperature of a water body and thereby cannot have negative impacts on the connected ecosystems. The authors also state, that the Energy Efficiency Ratio (EER)[11] of the investigated snow storage systems is significantly higher than of a conventinal cooling system which results in a high energy-saving effect. Even though operation and maintenance cost can be considerably lower and the initial investment costs are comparable to conventional chiller cooling systems, the overall performance for such systems strongly depends on the individual regional, geographical and climatic conditions.

An example for the usage of a snow storage cooling system is the cooling system at the hospital in the city of Sundsvall, Sweden. This system is operating since 2000. 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 3-4). Up to 93% of the annual cooling load of the hospital can be covered by this system (Skogsberg 2005).

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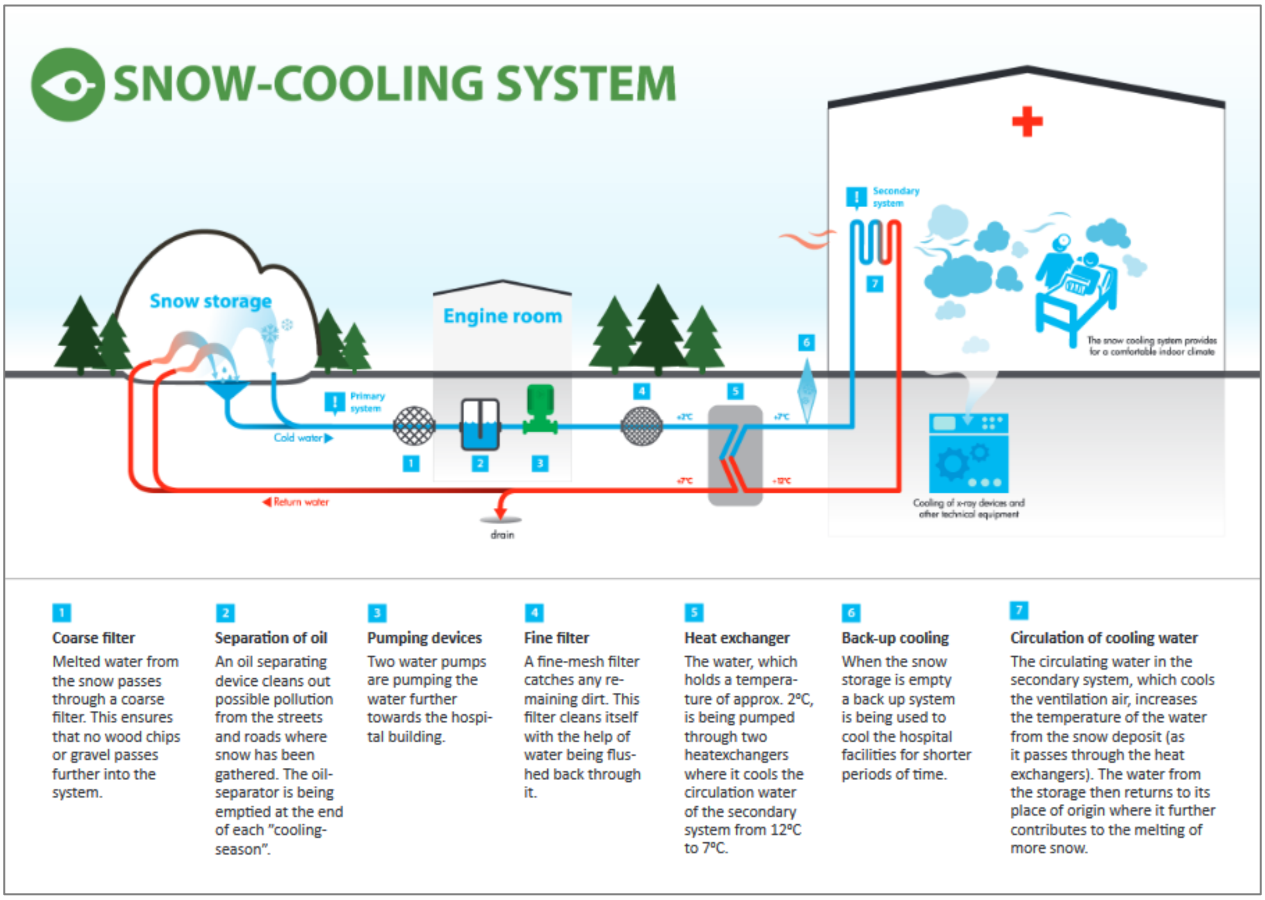
[11] The Energy Efficiency Ratio (EER) is the equivalent of the Coefficient of Performance (COP) in heat supply systems and describes the energy efficiency of a cooling system. The relation between EER and COP is: EER = COP * 3.41

Figure 3-4: Snow storage cooling system at Sundsvall Hospital, Sweden



1 **Coarse filter**
Melted water from the snow passes through a coarse filter. This ensures that no wood chips or gravel passes further into the system.

2 **Separation of oil**
An oil separating device cleans out possible pollution from the streets and roads where snow has been gathered. The oil-separator is being emptied at the end of each "cooling-season".

3 **Pumping devices**
Two water pumps are pumping the water further towards the hospital building.

4 **Fine filter**
A fine-mesh filter catches any remaining dirt. This filter cleans itself with the help of water being flushed back through it.

5 **Heat exchanger**
The water, which holds a temperature of approx. 2°C, is being pumped through two heatexchangers where it cools the circulation water of the secondary system from 12°C to 7°C.

6 **Back-up cooling**
When the snow storage is empty a back up system is being used to cool the hospital facilities for shorter periods of time.

7 **Circulation of cooling water**
The circulating water in the secondary system, which cools the ventilation air, increases the temperature of the water from the snow deposit (as it passes through the heat exchangers). The water from the storage then returns to its place of origin where it further contributes to the melting of more snow.

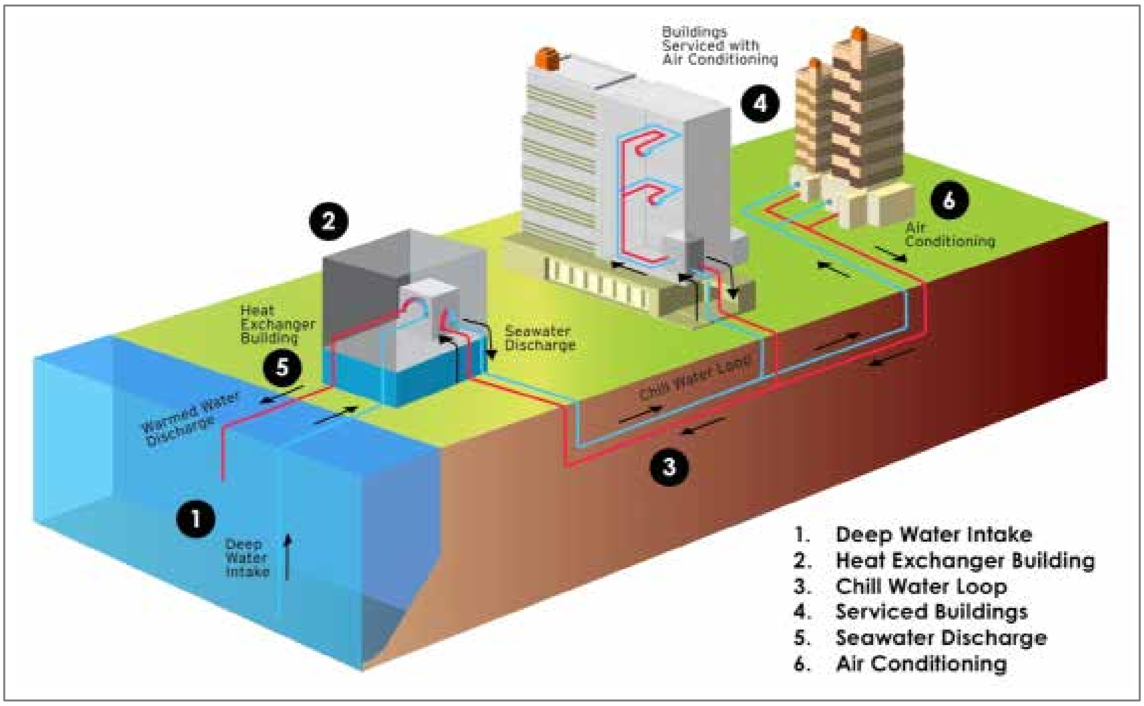
Source: *Region Västernorrland, https://www.rvn.se/sv/v1/In-english1/In-english/Environment-and-energy/Energy-Factor-2/Snow-cooling-in-Sundsvall/*

### 3.3.3. Free cooling with cold water

Free cooling with cold water from the ocean, rivers or deep lakes works according to the same principles as the above described technologies. The cold water is pumped through a pipe network and cools via a heat exchanger. The warmed-up water is led back to the sea, river or deep lake (Figure 3-5). This type of cooling is mainly used for district cooling systems.

The application of these technologies is limited to regions with suitable water sources. As water temperatures between 4°C and 7°C, are required, the climatic conditions in most European regions do not provide water with suitable temperatures during summer. Therefore, the potential of this technology is restricted; however considerable potentials may exist in hybrid systems combining seawater, deep lake or river cooling with other (renewable) cooling technologies.

**Figure 3-5: Schematic depiction of sea water district cooling system**



Source: *Ocean Thermal Energy Corporation (2014), http://otecorporation.com/2014/04/17/ocean-thermal-energys-seawater-air-conditioning/*

### 3.3.4. Geothermal heat pumps in passive mode

Ground and water coupled heat pumps that are used for heating in winter can also be used for free cooling in summer, by transporting heat without using its integrated compression cycle. This is possible if the ground (or water) has a lower temperature than the space to be cooled[12].

For free cooling the cold liquid that is circulating in the collector loops is 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 formation 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).

In order to use a heat pump for passive cooling in existing homes or buildings, the heating system must be adapted for the cooling process. As a minimum requirement, an electronic control unit to switch between the heating and cooling cycle needs to be added. The cooling application can be

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[12] Reversible heat pumps can also be used if the heat is transported from a warm area inside a building to an even warmer area outside the building (mostly ambient air). This requires significant amounts of input energy in order to run a compression cooling cycle, as the heat is transported against its natural flow direction. This process is described in chapter 3.4.2, as it is not a free cooling technology.

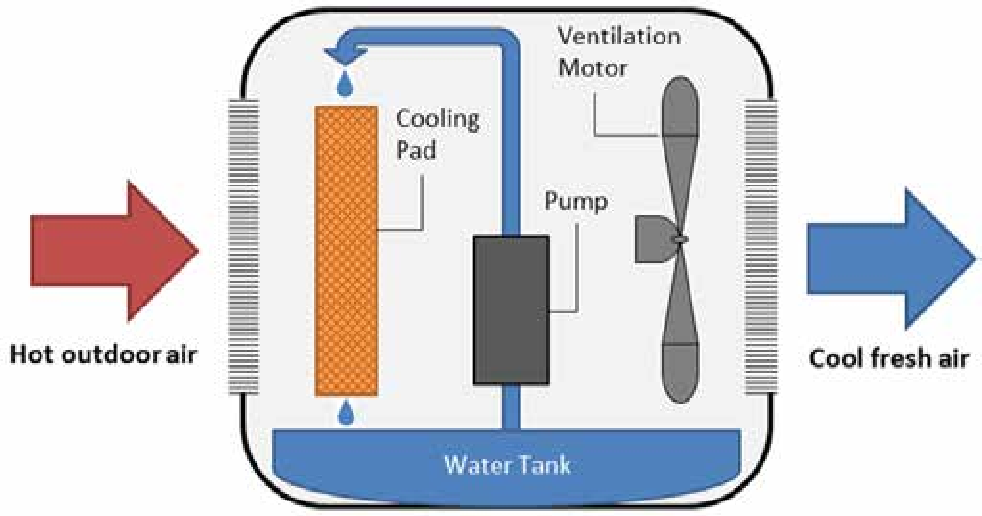
more easily integrated in newly built buildings. Integrating vapour barriers to the floor heating loops help to prevent depending on the dew point.

Free cooling with reversible heat pumps can 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. Aerothermal heat pumps can typically not be used for free cooling, as the temperature of the ambient air in summer is too high and additional compression cooling cycles are needed in order to provide a sufficient cooling effect (this kind of cooling with heat pumps is described in Chapter 3.4.2).

### 3.3.5. Evaporative cooling

Evaporative cooling differs from the cooling processes described above as it uses the fact evaporating water lowers the temperature of the surrounding air. Hot dry outside air is ventilated into the evaporative cooler, which contains a water tank. The water evaporates and colder wet air is ventilated inside the building (single-stage direct evaporative cooler, Figure 3-6).

**Figure 3-6: Principle of a single-stage evaporative cooler**



Source: *Öko-Institut based on Seeley International (2018), https://www.breezair.com.au/how-evaporative-works/*

More advanced devices known as indirect evaporative coolers or two-stage-coolers use the humid airstream to cool down another airstream which is not moist itself. However, the efficiency of these devices is lower than for single-stage 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 only a limited cooling effect can be reached. Furthermore, single-stage-coolers provide humid air which might be uncomfortable (van der Sluis, Sietze and Broeze 2009).

For a sustainable application of evaporative cooling, the origin of the used water is relevant as especially single-stage-coolers use large amounts of water. For assessing whether evaporative cooling is a suitable low carbon technology, additionally to carefully observing the water source for each individual case, the energy needed for water treatment must be included in the energy efficiency calculation.

## 3.4. Cooling systems using electricity-based refrigeration cycles

Cooling based on vapour compression can be considered renewable, if the electricity used to drive the compressor is generated from renewable sources. This chapter describes vapour compression cooling systems and their combination with on-site photovoltaic modules.

### 3.4.1. Vapour compression cooling systems

Vapour compression cooling systems are based on a refrigeration cycle (Figure 3-7). The refrigerant changes its state of aggregation to either liquid or vapour as the pressure changes. Within this process, the refrigerant either absorbs or discharges heat. In a compression cooling system the refrigerant continuously passes through four basic elements:

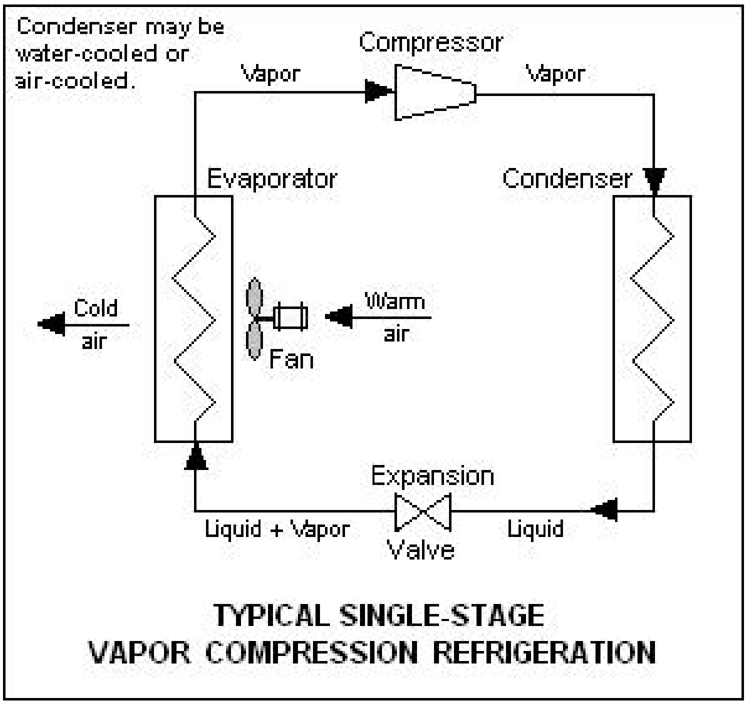
(1) An electricity-driven ***compressor*** compresses the refrigerant gas and thereby raises its temperature and pressure.

(2) In the ***condenser***, which is a heat exchanger, the high-pressure refrigerant releases its heat to the ambient air or water. In this process, the (still high-pressure) refrigerant liquefies. The liquid refrigerant after this process has approximately the same temperature as the ambient air or water. It is usually stored in an accumulator until it is needed again.

(3) An ***expansion valve*** separates the high-pressure side the compression cycle (right side of Figure 3-7) from the low-pressure side (left side of Figure 3-7). Depending on the amount of refrigerant which is passing through the expansion valve the cooling power is regulated.

(4) After passing the expansion valve, the liquid refrigerant is directed into the ***evaporator*** (also a heat exchanger). The liquid refrigerant evaporates under low pressure. The heat which is required to evaporate the refrigerant is absorbed from the medium which is cooled down.

**Figure 3-7: Schematic depiction compression cooling process**



*Source: Beychok, M. (2006), https://upload.wikimedia.org/wikipedia/en/7/75/Vapor_compression_refrigeration_cycle_%28single_stage%29.jpg*

There are several different types of compressors on the market: reciprocating compressors, scroll compressors, screw and centrifugal compressors. For space cooling in the residential sector there are three main approaches for the installation of the technology (Fraunhofer ISI et al. 2016a):

- **Movable Air-Conditioning and Ventilation:** One movable device which is placed in the room and contains all components of the compression cooling cycle. The waste heat is released through a tube which generally leaves the building through a window.
- **Single Split Devices:** The compressor and the condenser, which releases the heat, are placed outside the building. The expansion of the refrigerant and the evaporator, which releases the cold, are placed inside the building.
- **Multi Split Devices:** The basic principle is the same than with the single split devices. The difference is, that the refrigerant supplies more than one room via a central cooling unit.

Despite of increasing electricity prices, sales numbers for compression cooling systems are constantly increasing (Mugnier et al. 2014).

### 3.4.2. Reversible heat pumps

Heat pumps are devices which transport heat from a heat source (air, ground or water) to another substance or space. Reversible heat pumps can work in either thermal direction and can be used for heating and for cooling. Approximately 48% of heat pumps sold in Europe are reversible air-to-air systems (Nowak and Westring 2017). Heat pumps running in the cooling cycle work the same way as conventional air conditioners (vapour compression cooling).

There are three different types of heat pumps: aerothermal, geothermal and hydrothermal devices. Hydrothermal and geothermal heat pumps are generally grouped together as geothermal technologies (Fraunhofer ISI et al. 2016a).

In Europe, the countries with the widest use of heat pumps are Italy, France and Sweden, where governmental policy measures like tax credits and tax reductions have supported the heat pump market. In Italy, significant shares of the installed heat pumps are reversible aerothermal (air-to-air) heat pumps which are mainly used for cooling purposes.

Even though aerothermal heat pumps are typically less efficient than geothermal or hydrothermal heat pump technologies, they play a significant role due to the geographical limitations for the installation of such technologies. At the same time, geothermal systems have the potential to provide low-carbon cooling through district cooling systems.

### 3.4.3. **Photovoltaic cooling systems**

Photovoltaic (PV) cooling systems combine conventional electrical chillers or reversible heat pumps with PV modules. In contrast to compression cooling systems which use electricity from the public electricity grid, PV cooling systems allow using the locally generated electricity from the PV modules.

Solar cooling systems have the advantage that the required solar power usually peaks at similar times during the day as the cooling demand. Hence, PV cooling systems can release a lot of pressure from the electricity grids (IEA 2018).

Another advantage is that these systems do not put additional pressure on the electricity grid in peak-demand times. Air conditioning can account for a large share of the electricity demand. In residential areas in Madrid, it is estimated that air conditioning is responsible more than 30% of the energy demand during peak times (European Commission 2016a). Especially during hot days and in countries where a lot of air-conditioning is provided via grid-connected compression cooling systems, air conditioning can have a major impact on the electricity grids. In the summer of 2015 in Spain, a period of very high temperatures led to an 8% increase of the electricity demand due to air conditioning and set new records with daily average energy demand of 712 GWh (European Commission 2016a). Similar trends of electricity-driven air conditioning impacting the peak electricity demand can be observed in Italy (ibid).

PV cooling is currently mainly used in the Asian-Pacific region (Mugnier et al. 2014). In some EU countries, regulations for locally produced electricity are unfavorable for photovoltaic vapor compression cooling. For example, so-called “sun taxes” to be paid for on-site produced electricity make self-consumption financially unattractive and consequently discourage the use of PV vapor compression cooling systems (Löper 2016; López Prol and Steininger 2017).

The number of installations using self-produced electricity is expected to increase significantly in private buildings, especially in southern Europe (Fraunhofer ISI et al. 2016a). The technology for PV cooling is market-available and small systems are easy to install. The main obstacles for the diffusion of the technology are high costs and a lack of cost-effective storage technology. However, the investment costs for PV cooling systems are expected to decrease significantly within the next years (Mugnier et al. 2014).

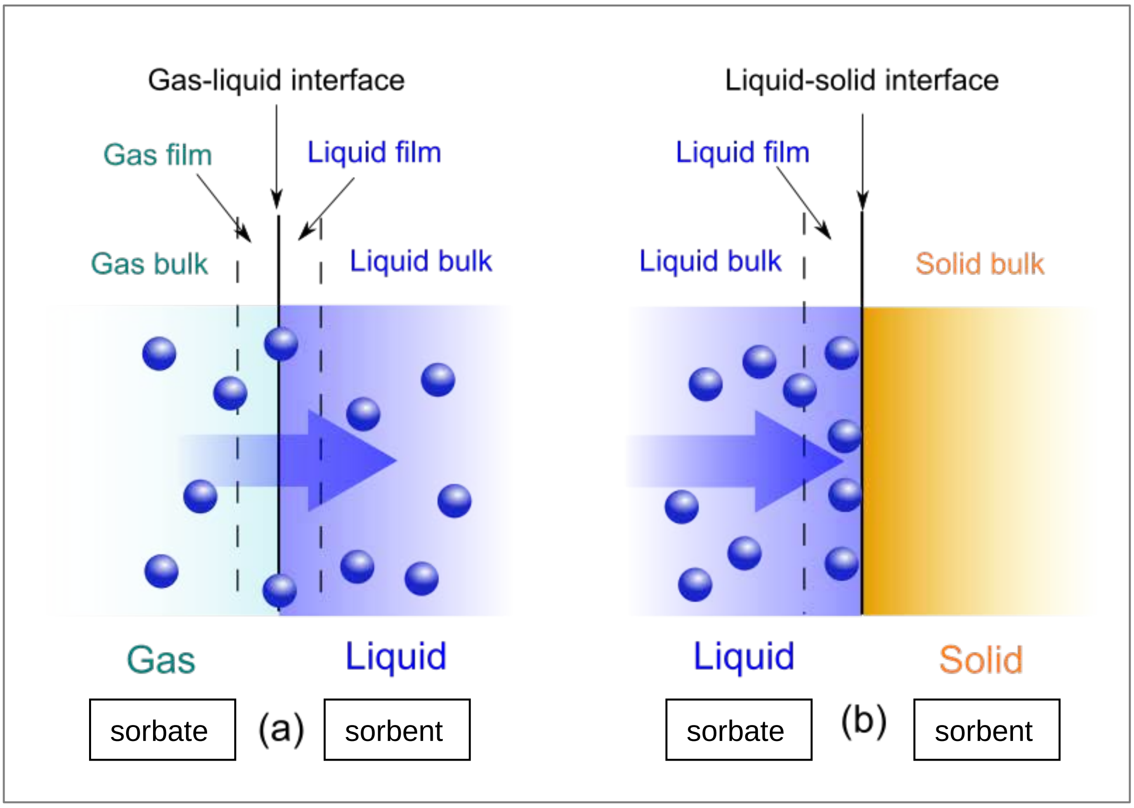
## 3.5. Cooling systems using heat from renewable energy sources

This section describes absorption and adsorption cooling technologies and discusses possible renewable heat sources to drive the cooling cycle (solar thermal, geothermal and hydrothermal energy and heat from biomass-based combined heat and power plants (CHP)).

### 3.5.1. Absorption and adsorption cooling

The term "sorption" describes a process which leads to an enrichment of a liquid or gaseous substance (sorbate). If the enrichment is happening by an uptake of the substance in the *interior* of the sorbent[13], the process is called *absorption*. If this enrichment is happening on a *surface* of the sorbent, the process is called *adsorption*. Figure 3-8 depicts examples of absorption and adsorption processes.

**Figure 3-8: Absorption (a) and adsorption (b) mechanism. Blue spheres are solute molecules**



Source: *Daniele Pugliesi (2012), https://commons.wikimedia.org/wiki/File:Absorption_vs_adsorption.svg*

Sorption cooling basically uses the same physical principle as vapour compression cooling: moving heat due to the evaporation and condensation of a refrigerant. The main difference to compression chillers is that ab-/adsorption chillers use heat rather than electricity as energy source. Furthermore, they do not use a compressor for generating the required pressure differences but use an ab-/adsorber, a generator and a pump.

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[13] The sorbent is a liquid or solid phase.

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. 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. (ESTTP, 2011).

Sorption cooling technologies today only account for a small share of the installed cooling technologies in Europe. However, they are interesting especially for using waste heat at a large scale such as district cooling networks (Dittmann et al. 2017).

### 3.5.2. Desiccant and evaporative cooling (DEC)

Desiccant and evaporative cooling (DEC) systems are called open cooling cycles as the refrigerant water is in direct contact with the atmosphere.

The basic principle for DEC-systems is the same as described in chapter 3.3.5 for evaporative cooling: A cooling effect is generated as water evaporates. The energy which is needed for the evaporation is taken from the ambient air which consequently cools down. The cooling effect is limited as the air can only absorb a certain amount of water. Consequently, the difference to evaporation in free cooling is that in DEC-technologies, a dehumidification of the air stream which is supposed to be cooled down allows higher cooling effects. The air passes through a desiccant bed, the dehumidification unit. This desiccant bed itself is continuously dehumidified as it is exposed to another, moderately heated air stream. With the integration of the desiccant bed, lower temperatures can be reached than through free evaporative cooling. Additionally, it allows the appliance in humid climate conditions and provides air with humidity on a level which does not decrease comfort (Dittmann et al. 2017).

DEC-systems consist 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). Up to now, DEC-cooling systems have a very low market share (Dittmann et al. 2017).

### 3.5.3. Cooling with solar thermal energy

In the future, the most important renewable energy source for cooling with heat is expected to be solar energy delivered by solar thermal systems (Mugnier et al. 2014). Solar thermal cooling can be done via ab-/adsorption chillers, desiccant sorption wheels (DEC) or liquid sorption (see Chapter 3.5.1 and 3.5.2) (Mugnier et al. 2014). Sorption cooling systems dominate the solar cooling market with around 71% of the installed capacity. Between 2015 and 2016, the market share continued to increase, while the share of desiccant cooling systems in the solar cooling market decreased (Weiss et al. 2017).

The thermal energy required for solar cooling applications is typically provided by non-concentrating collectors (e.g. flat plate or evacuated tube collectors). Concentrating collectors for solar cooling systems (e.g. parabolic trough or linear Fresnel collectors) are not very common yet, even though they can provide thermal energy with higher calorific values. However, the number of systems using concentrating collectors is increasing during the past years (ibid).

As the solar radiation and the demand of cooling are fluctuating – depending on temporarily changing weather conditions - thermal storage is needed additionally to the solar collectors. Thermal storage devices (e.g. hot water storage, phase change material (PCM) storage, ice storage) ensure sufficient supply of thermal energy for fulfilling the cooling demand, independently from solar radiation (Mugnier et al. 2014).

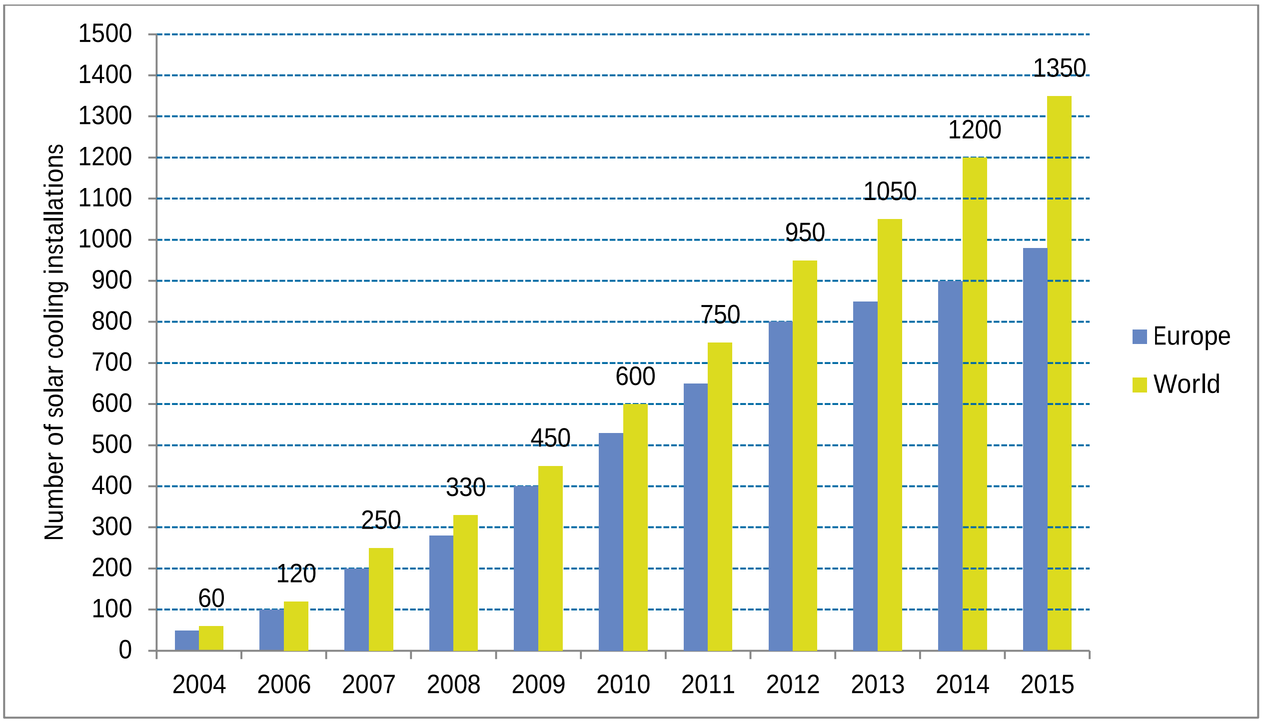
Many components of solar thermal cooling systems are fully developed technologies as they are also used for domestic hot water production and space heating. However, even though the technical components are available, conditions such as unfavourable high investment costs, fluctuating solar radiation and cooling load hours have a strong impact on the economic viability of such systems. Furthermore, low electricity prices in some countries make the use of electricity-driven cooling systems more attractive than the use of solar thermal cooling systems. This results in a still relatively small market for solar thermal cooling systems. Nevertheless, the manufacturing of small heat-driven chillers with a capacity up to 35 kW is constantly increasing, with some manufactures already producing on an industrial scale. In contrast to waste heat or gas-fired processes, larger solar sorption chillers with capacities between 35 and 200 kW are not very advanced yet (ibid.).

Solar cooling systems are suitable for many regions of the world. Hence, the global market potential for solar cooling systems is huge. The advantage of using solar energy for cooling purposes (also for PV compression cooling) is that the demand for cooling typically increases with the increase of solar irradiation (IEA 2018). This reduces the peak period power loads in summer. Thus, solar energy is a promising renewable energy source for cooling purposes.

Despite the huge potential, the market for solar thermal cooling is still a niche market. By the end of 2015, approximately 1,350 solar cooling systems were installed worldwide. In contrast, about 200 Million split-type air-conditioners are sold each year. However, between 2004 and 2015, the market for solar thermal cooling systems increased between 40% and 70% (Figure 3-9) (Mugnier et al. 2014; Weiss et al. 2017).

Mugnier et al. ((Mugnier et al. 2014) highlight high upfront investment costs as main reason for the relatively slow diffusion of solar cooling systems. With costs from 2,000 to 5,000 € per installed $kW_c$ for solar cooling systems investment costs for solar cooling are twice to five times higher compared to conventional cooling systems (Mugnier 2015). Depending on electricity prices and annual operation hours, the technology reaches its breakeven point after 10 to 18 years, where the technology lifetime is between 15 to 20 years.

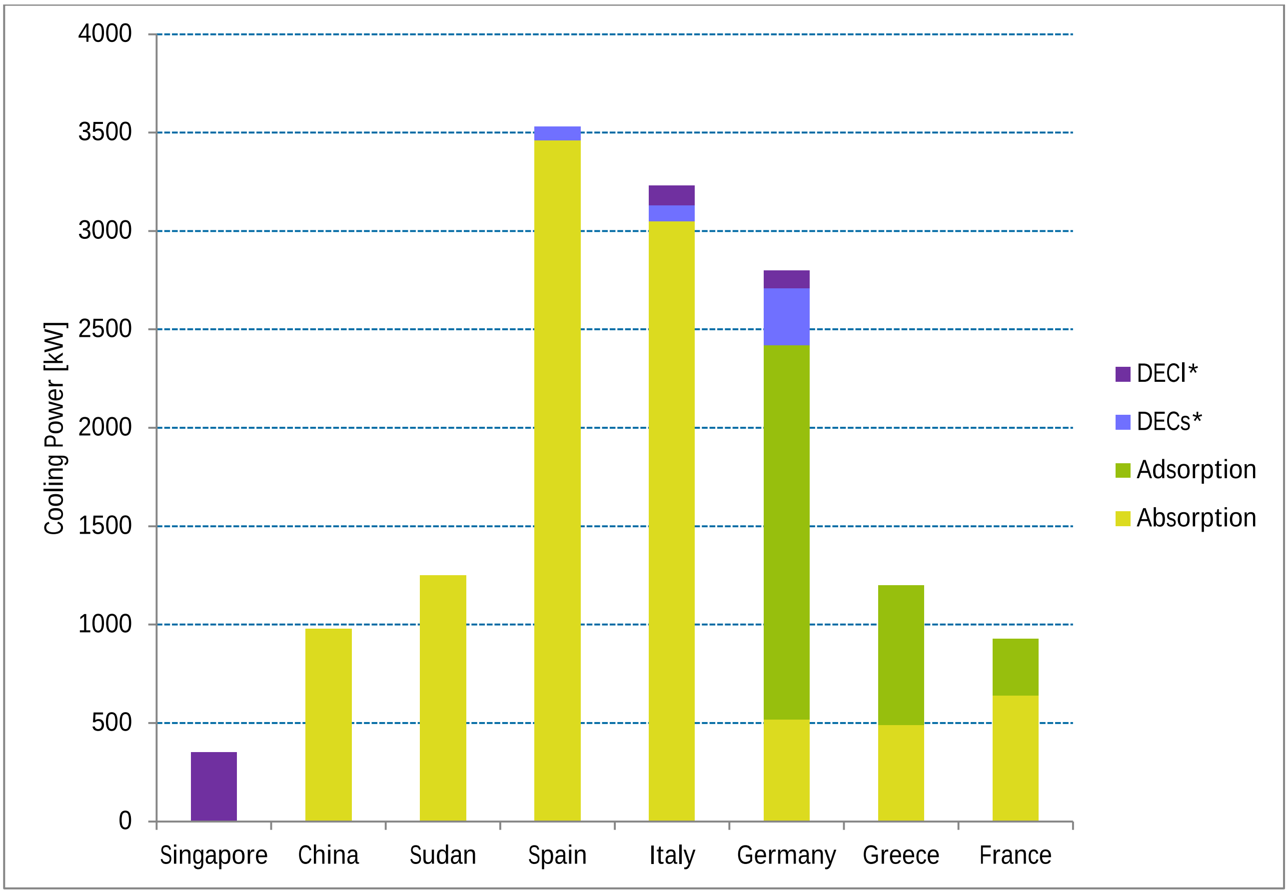
**Figure 3-9:** **Market development 2004 – 2015 of small to large-scale solar cooling systems: Number of solar cooling installations**



Source: *Solem Consulting/ TECSOL as cited by Weiss et al. 2017*

Around 70% of the solar cooling systems worldwide are installed in Europe (Weiss et al. 2017). Within Europe, the highest capacities of solar thermal driven cooling appliances are installed in Spain, Germany, Greece, Italy and France (reference year: 2012; Figure 3-10). More than 60% of the installations are within office buildings.

**Figure 3-10:** **Worldwide distribution of the cooling power assisted by solar energy in 2012 (by type of thermally driven chillers)**



*desiccant evaporative cooling systems with an open cycle with solid sorption material [DECs] or liquid sorption material [DECl]

Source: *Chwieduk et al. 2014*

Despite the mentioned obstacles, the investment costs are predicted to further decrease in the future, due to technology developments, and the market for solar thermal cooling will be growing in the next decades. For 2050, the International Energy Agency estimates that solar cooling accounts for 17 % of the total global energy use for cooling[14] (IEA 2018).

### 3.5.4. Cooling with geothermal heat

Geothermal heat with temperatures above 60/70°C can be used for district heating and cooling applications. Hydro-geothermal systems can provide the necessary temperature to run district heating systems and thermally driven chillers for district cooling. 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

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[14] Numbers based on ETP 2012 2DS scenario. In this scenario, the final energy demand for cooling is estimated to be 9EJ by 2050 IEA 2012.

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 (ETP-RHC Geothermal Panel 2009).

### 3.5.5. **Cooling with thermal energy from biomass**

Heat from biomass-based combined heat and power plants (CHP) 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 CHP with a thermally driven cooling process increases the conversion efficiency. The CHP plants could achieve a higher number of annual full-load hours as the heat can be used for more purposes. However, 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).

It is not expected that renewable cooling by biomass will play a major role in this context in the future due to the restricted availability of sustainable biomass and the competing utilisation pathways.

## 3.6. 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. Technically, existing district heating systems can be used for district cooling. However, up to now this is only done occasionally (Fraunhofer ISI et al. 2016c). 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 provided by different technologies, which can be free cooling technologies using natural local resources such as snow and cold water, heat-driven technologies (ab-/adsorption and desiccant and evaporative cooling), and electricity-driven technologies (compression cooling). 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. District cooling is used to provide space cooling for residential and commercial buildings. Up to now it is mostly used for cooling in commercial buildings. District cooling can be applied in very different climatic conditions, such as Sweden and Bahrain. District cooling systems (using renewable energy resources) offer several benefits such as economies of scale, reduced pressure on the electric grid and more cost-effective energy storage (IRENA 2017).

According to EcoHeat & 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 share of district cooling in the European cooling market is estimated to be less than 1% (in 2014). In the service sector the share is higher, with 1-2% (approximately 3 TWh) (Tvärne et al. 2014). Within the EU-28, Sweden and France are the countries with the highest district cooling sales (Fraunhofer ISI et al. 2016c). In the long term, combined district heating and cooling via Aquifer Thermal Energy Storage (ATES) systems and chilled water storages are expected to be the main technologies for district cooling (Galindo Fernández et al. 2016). An overview on different district cooling systems in Europe (Austria, Denmark, Finland, France, Spain and Sweden) can be found in “District Cooling

Showcases in Europe" published in the scope of the RESCUE (Renewable Smart Cooling in Urban Europe) project[15].

## 3.7. Passive cooling strategies

Passive cooling strategies aim at the prevention or reduction of cooling loads by considering the building structures and management. Before any of the cooling technologies described in the previous sections are installed, possibilities for the implementation of passive cooling strategies should be assessed. 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.

Brown (1997) identified the following main strategies for heat reduction:

(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.

# 4. Renewable cooling in the Renewable Energy Directive

This chapter discusses options to include renewable cooling in the RES-Directive and estimates the impact of including cooling on the target achievement.

Section 4.1 briefly describes the RES-Directive. Section 4.2 reviews the methodological approach for calculating the renewable energy shares for heating and cooling with a particular focus on the methodology to account for ambient energy in heat pumps. Section 4.3 proposes for options on how to include renewable cooling in the RES-Directive. Section 4.4 provides an estimate of the impact of including cooling in the target. Section 4.5 discusses sectoral restrictions and the cooling of waste heat.

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[15] http://www.rescue-project.eu/fileadmin/user_files/Work_package_3/D3_1_Showcases_report_final_update.pdf

## 4.1. The Renewable Energy Directive

The Renewable Energy Directive (2009/28/EC) establishes a policy framework for the promotion of renewable energy in the EU. It sets a target for the EU to fulfil at least 20% of its total energy needs with renewables by 2020. Article 3 specifies mandatory national renewable energy targets for each country, taking into account its starting point and overall potential for renewables. The national targets range from 10% in Malta to 49% in Sweden. Energy from renewable sources is defined in the RES-Directive as wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases (Article 2).

Within the RES-Directive, Member States have adopted National Renewable Energy Action Plans (NREAPs) including indicative sectoral targets for electricity, heating and cooling, and transport. Furthermore, the action plans outline planned policy measures; the different mix of renewables technologies that Member States expect to employ; and the planned use of cooperation mechanisms.

Progress towards national targets is measured every two years when EU countries publish national renewable energy progress reports. The 2017 report states that the EU as a whole achieved a 16% share of renewable energy in 2014. In 2016, the estimated share of renewable energy in the EU's gross final energy consumption was 17% (European Commission 2017).

On 30 November 2016, the Commission published a proposal for a revised Renewable Energy Directive envisioning a target of at least 27% renewables in the final energy consumption in the EU by 2030 (European Commission 2016b). The Council reached an agreement on 18 December 2017 (European Council 2017), while the European Parliament adopted its amendments on 17 January 2018 supporting a 35% target (European Parliament 2018).

On 14 June 2018 the Commission, the Parliament and the Council reached a political agreement which includes a binding renewable energy target for the EU for 2030 of 32% with an upwards revision clause by 2023. This must now be formally adopted by the European Parliament and the Council.

## 4.2. Methodology to calculate the share of RES-H&C

Article 5 of the RES-Directive outlines the calculation of the share of energy from renewable sources. It specifies that the gross final consumption of energy from renewable sources in each Member State shall be calculated as the sum of: (a) gross final consumption of electricity from renewable energy sources (RES-E); (b) gross final consumption of energy from renewable sources for heating and cooling (RES-H&C); and (c) final consumption of energy from renewable sources in transport (RES-T).

For heating and cooling, the ratio determining a Member State's RES-H&C share is defined in footnote 4 in the Template for Member State progress reports as *gross final consumption of energy from renewable sources for heating and cooling divided by gross final consumption of energy for heating and cooling*[16].

The following sections describe the procedure to calculate the RES-H&C shares and the accounting of energy from heat pumps.

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[16] The RES-Directive does not directly define the share, as Article 5 only defines the numerator of the ratio.

### 4.2.1. RES-H&C in the SHARES-tool

The progress reports include detailed information on the share of renewable energy sources for electricity, heating and cooling, and transport. The SHARES tool (SHort Assessment of Renewable Energy Sources) developed by Eurostat assists Member States in providing harmonised calculations of the renewable energy shares. The SHARES tool is designed to collect and present energy data derived from annual questionnaires in a harmonized way.

While the SHARES tool includes a methodology for calculating the renewable energy share for heating (including heat pumps), cooling is not accounted for in the tool.

For heating, the numerator 'gross final consumption of energy from renewable sources for heating and cooling' is, for the purpose of the calculations in the SHARES tool, defined as the sum of the following elements (Eurostat 2014):

- Final energy consumption of renewable energies other than electricity, heat and bioliquids in sectors other than transport
- Compliant bioliquids consumed in the 'Transformation sector - Blast furnaces', 'Industry sector' and 'Other sectors'
- Derived heat produced from geothermal, solar thermal, renewable municipal waste, solid biofuels and biogas as reported in the renewables questionnaire
- The share of biogas blended in the natural gas network applied to natural gas consumption in the 'Transformation sector - Blast furnaces', 'Industry sector' and 'Other sectors'
- The share of biogas blended in the natural gas network applied to derived heat produced from natural gas
- The contribution of renewable energy from heat pumps calculated based on Commission Decision 2013/114/EU14

The denominator 'gross final consumption of energy for heating and cooling is, for the purpose of the calculations in the SHARES tool, defined as the sum of the following elements

- Final energy consumption of all energies other than electricity in sectors other than transport. Using the terminology and definitions of joint annual energy questionnaires.
- All derived heat consumed in the 'Transformation sector-Blast furnaces', 'Industry sector' and 'Other sectors'
- The contribution of renewable energy from heat pumps calculated based on Commission Decision 2013/114/EU

### 4.2.2. Guidelines for calculating renewable energy from heat pumps

Annex VII to Directive 2009/28/EC sets out the rules for accounting of energy from heat pumps and requires the Commission to establish guidelines for Member States to estimate the necessary parameters, taking into consideration differences in climatic conditions. These guidelines on calculating renewable energy from heat pumps have been established in the Commission Decision

2013/114/EU[17]. The definition of renewable energy from heat pumps includes aerothermal, geothermal or hydrothermal heat extracted from the environment, whereas no definition of cooling (i.e. heat released to the environment) is provided. The rules and guidelines specified in Annex VII to the Directive 2009/28/EC as well as Commission Decision 2013/114/EU are summarized in

Box 2.

Box 2: Guidelines for calculating renewable energy from heat pumps (Directive 2009/28/EC and 2013/114/EU)

$E_{RES}=Q_{usable}*(1 – 1/SPF)$

where

$Q_{usable}$ = the estimated total usable heat delivered by heat pumps taking into account only heat pumps for which SPF > 1,15 * 1/η

$Q_{usable} = H_{HP} * P_{rated}$

$H_{HP}$=equivalent full load hours of operation [h]. Default values are provided in 2013/114/EU for three climate condition areas (warmer, average, colder)

$P_{rated}$=capacity of heat pumps installed, taking into account the lifetime of different types of heat pumps [GW]

SPF = the estimated average seasonal performance factor for those heat pumps. Default values are provided in 2013/114/EU for three climate condition areas (warmer, average, colder)

η is the ratio between total gross production of electricity and the primary energy consumption for electricity production and shall be calculated as an EU average based on Eurostat data.

Figure 4-1 illustrates the approach for including ambient heat as renewable energy according to the RES-Directive. The rationale behind the approach is that

- the electricity used to drive the heat pump is subtracted from the total heat delivered by the heat pump;
- only such heat pumps are taken into account where the delivered useful heat significantly exceeds the primary energy required for electricity generation.

The amount of energy $E_{RES}$ is added both to the enumerator and the denominator when calculating the renewable energy share[18].

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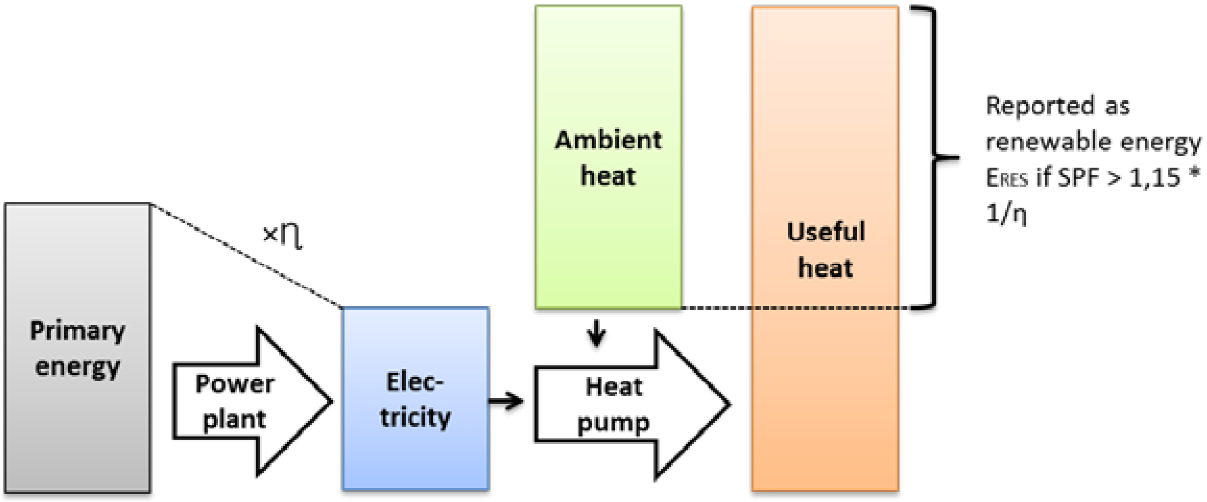
[17] Commission Decision of 1 March 2013 establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council

[18] Neither Annex VII to the Directive 2009/28/EC nor Commission Decision 2013/114/EU provide indications on how to include energy from heat pumps in the denominator, however, the SHARES tool adds the amount $E_{RES}$ to the denominator.

Figure 4-1: Schematic representation of accounting of energy from heat pumps in the RES-Directive

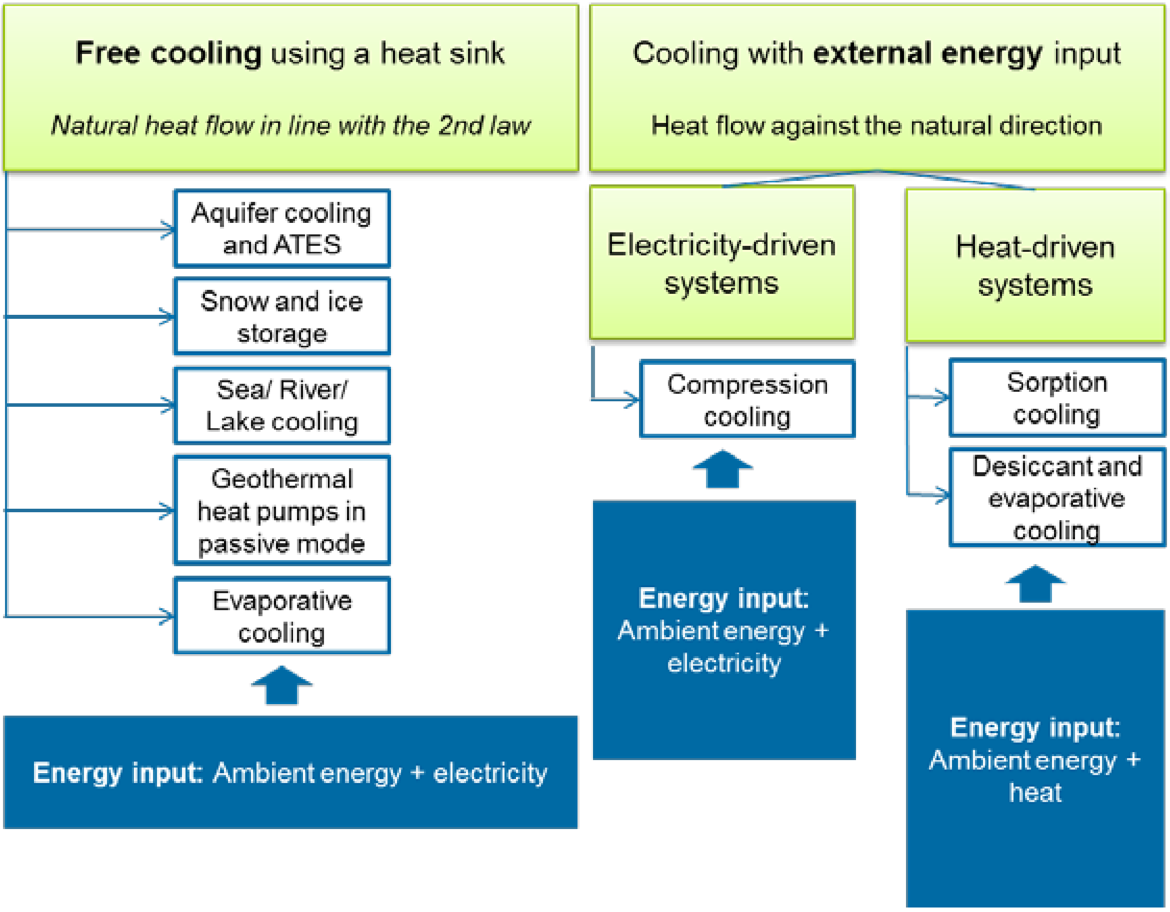


Source: *Öko-Institut based on European Commission 2015*

## 4.3. Options to include cooling in the RES-Directive

As discussed in Section 3.1 and resumed in Figure 4-2, all cooling technologies are based on the transfer of ambient heat, driven by a natural flow (free cooling) or by using electricity or heat to cool. With electricity being reported as RES-E and heat being reported as RES-H&C, the primary question is how to include the transfer of ambient heat for cooling purposes in the RES-Directive. This section describes different options to define renewable cooling in the RES-Directive.

Figure 4-2: Overview of cooling technologies and energy inputs



Source: *Öko-Institut*

As the guidelines for calculating renewable energy from heat pumps (see Box 3) define how ambient heat is covered, these guidelines may provide a useful basis for defining renewable cooling[19].

### 4.3.1. Transfer of ambient heat: heating vs. cooling

This section examines the main similarities and differences in treating ambient heat for heating and cooling purposes. While Figure 4-1 provides a schematic representation of the reporting of ambient heat, Figure 4-3 illustrates the situation for cooling. For cooling, the cooling device transfers heat from the space to be cooled to the environment (ambient energy). Furthermore, the heat that is generated through the auxiliary processes driven by electricity is released to the environment. The total ambient energy released to the environment is therefore the sum of the useful cooling and the heat related to the mechanical processes. The amount of useful cooling could be estimated in a

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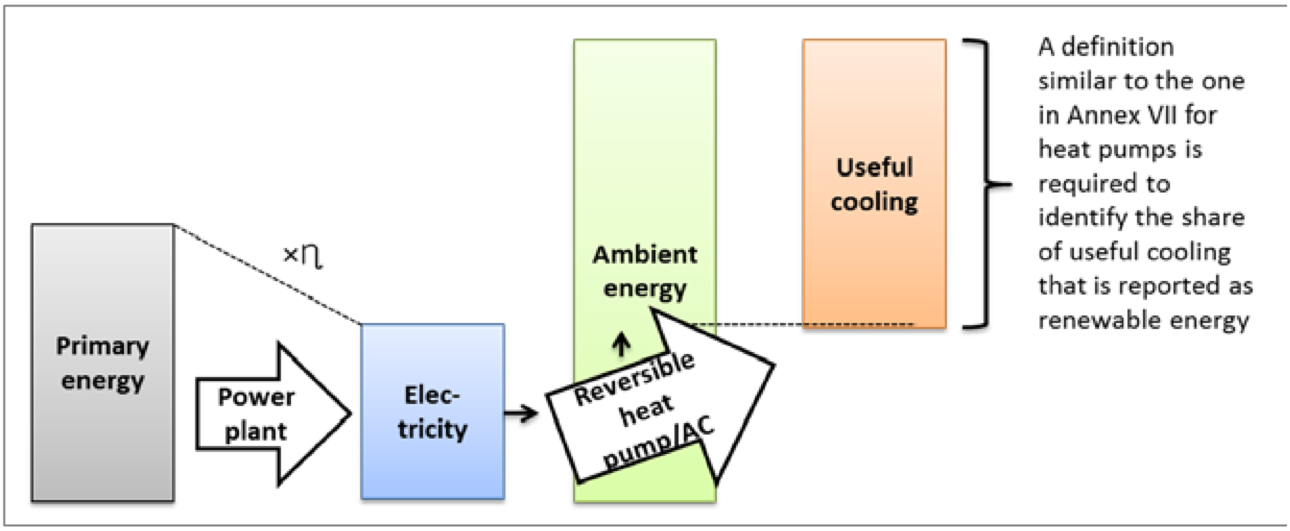
[19] While the Commission's proposal for the revision of the RES-Directives uses the term "ambient heat captured by heat pumps", the EU Parliament suggests the term "ambient energy and geothermal energy transferred by heat pumps for the production of heating or cooling" and proposes to empower the Commission to adopt delegated acts in order to supplement the Directive by establishing a methodology for calculating the quantity of renewable energy used for heating and cooling and district heating and cooling and to revise Annex VII on calculation of energy from heat pumps

similar way as the useful energy for heating with heat pumps, i.e. by multiplying the equivalent full load hours with the rated capacity).

**Figure 4-3: Schematic representation of possible methodologies for accounting ambient energy for cooling**



Source: *Öko-Institut*

Table 2 describes how the main parameters used in the guidelines for calculating renewable energy from heat pumps (see Box 2) can be used in definitions of renewable cooling.

**Table 3: Comparison of main parameters for calculating renewable energy for heating with heat pumps and cooling**

| | **Heating with heat pumps** | **Cooling** |
|---|---|---|
| Ambient energy transfer | Ambient heat is transferred from the ambient air/ground/water to the space that is heated. | Ambient heat is transferred from the space to be cooled to the ambient air/ground/water. |
| Usable heat $Q_{usable}$ | For heat pumps, the usable energy is calculated by the equivalent full load hours of operation multiplied by the installed capacity of heat pumps. For heat pumps, the usable heat is the sum of the electricity input and the ambient heat that is transferred. | For cooling, the usable energy can be calculated as the equivalent full load hours of operation multiplied by the installed capacity of cooling devices. |
| Definition of minimum SPF for $Q_{usable}$ | For heat pumps, the minimum SPF is specified in such a way that the primary energy input does not exceed the primary energy input of fossil-fuel-based heating systems. | For cooling, defining a minimum SPF (or SEER) is less straightforward, however, a similar approach could be followed. |
| Renewable energy $E_{RES}$ | The formula for calculating the renewable energy $E_{RES}$ (see Box 4) subtracts the electricity input from $Q_{usable}$. | For cooling, no subtraction is required as the electricity does not contribute to useful cooling but adds to the heat that is released to the environment. |

Based on the similarities and differences between heating and cooling, the following section proposes three options to include renewable cooling in the RES-Directive.

### 4.3.2. Methodologies to calculate renewable cooling in the RES-Directive

Based on the methodological approach for heat pumps, this section discusses three options to define renewable cooling for the purpose of the RES-Directive. The discussed methodologies would be applicable not only for reversible heat pumps and air conditioners but also for free cooling systems, where the system efficiency can be defined as the ration between the useful cooling provided by the installation and the energy input for driving the system.

The proposed options assume a definition of minimum requirements (similar to the minimum SPF for heat pumps) to determine the part of the useful energy that is accounted as renewable energy (see third row in Table 2). In general, the advantage of implementing minimum requirements is that the approach encourages Member States to implement low-carbon cooling technologies. If *all* ambient energy used for cooling would be counted (i.e. including all existing air conditioning devices), the RES-Directive would not generate any incentives for Member States to increase the share of low carbon cooling technologies. Moreover, increasing the cooling demand would automatically increase the share of renewable energy (see estimation in Section 4.4)

While the three options described in this section refer to the methodology to calculate *renewable cooling*, calculating the renewable energy share furthermore requires a definition of the cooling demand to be added in the denominator. For heat pumps, where all ambient heat that fulfils the minimum efficiency criteria is added, the same amount is added to the denominator. For heating, the denominator furthermore includes the final energy for all heating technologies apart from heat pumps (where heat pumps typically only account for a minor share). For cooling, in principle the same approach can be chosen, however, this would mean that depending on the definition of renewable cooling only a minor share of the total cooling demand is added to the denominator. The other alternative would be to add the total cooling demand (i.e. the useful cooling) to the denominator when calculating a Member State´s renewable energy share. However, in that case a methodology for collecting data of the Member States cooling demand would have to be developed as this is not included in current energy statistics.

#### Option 1: Minimum requirements on efficiency of the cooling system

Option 1 proposes to take the same approach as for heat pumps and only count ambient energy for cooling as renewable if the efficiency of the cooling system exceeds a certain threshold. Beside the similarity with the methodology for heat pumps, the advantage of this approach is that only technologies that fulfil minimum sustainability criteria are included. A challenge regarding the approach is that, compared to the approach for heat pumps, the definition of the minimum threshold is less straightforward: For heating, the minimum SPF is chosen in such a way that the fossil-fuel input needed for generating the electricity input is lower than the one for providing heating based on the combustion of fossil fuels. For cooling, choosing the minimum efficiency may be more challenging as no such basis exists and the choice has a strong impact on the technologies that are included. A further challenge may be the availability on data, especially for the stock of cooling technologies. As for heat pumps, Member States would be required to estimate the share of devices that meet the efficiency criteria in order to be able to estimate the eligible cooling production.

#### Option 2: Minimum requirements on temperature of the heat sink

Option 2 proposes to only count ambient energy for cooling as renewable if the temperature of the heat sink that is used is below a threshold temperature (e.g. 10° below the temperature of the ambient air). The advantage of this approach is that it favours technologies that use natural heat sinks that do not require electricity-driven cooling cycles. A challenge regarding the approach is that Member States would need to provide estimates of the installed capacity of the cooling systems that meet the requirement. However, as natural heat sinks are mainly used in larger installations and in district cooling systems, this information is typically available (although not collected in current energy statistics).

**Option 3: Requirement regarding the type of heat sink**

Option 3 proposes to define the share of ambient energy to be counted as renewable cooling based on the type of heat sink that is used. For example, heat sinks such as the ground, water or snow could be allowed, while excluding the ambient air. Similar to Option 3, an advantage is that typically technologies that use natural heat sinks not requiring electricity-driven cooling cycles would be included. As compared to Option 2, Option 3 may be favourable in terms of reporting, as in Option 2 the temperature level of the heat sink is possibly not known and differs throughout the year.

A discussion of the three options in an expert workshop concluded that option 1 would be the preferable option.

## 4.4. Estimated influence on target achievement

The choice of how to include cooling has implications on the status quo of target achievement:

For options 1-3, the share of renewable cooling (defined as outlined in the previous section) is added in the enumerator and the denominator when calculating a Member State´s renewable energy share. As the number in the enumerator is generally lower than the one in the denominator, this means that the renewable energy share increases. The magnitude of the increase depends on the way in which the minimum requirements are defined. If ambitious requirements are defined in most Member States the share of cooling demand that meets the criteria is minor and the effect will be small. If a large share of the total cooling demand is included, the renewable energy shares can increase significantly.

We estimate the effect on target achievement by comparing the reported renewable energy share in 2014 for selected Member states (Hungary, Italy, Malta, the Netherlands, Spain) to a hypothetical situation in which all cooling demand would be counted as renewable (i.e. where no minimum requirements as described in Options 1-3 are implemented).

The renewable energy share including renewable cooling is estimated using the following approach:

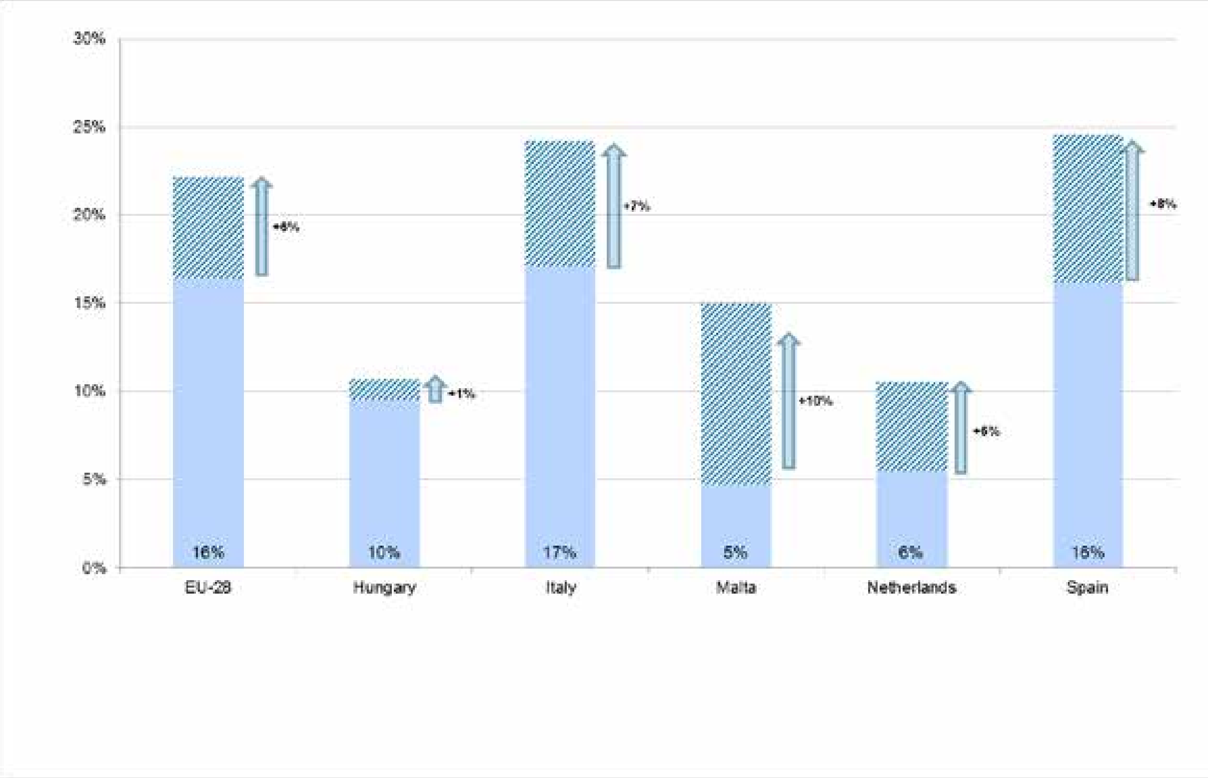
$$\text{Share of renewable energy} = \frac{\text{RES} - \text{E} + \text{RES} - \text{H} + \text{RES} - \text{T} + \text{renewable cooling}}{\text{FED} - \text{E} + \text{FED} - \text{H} + \text{FED} - \text{T} + \text{renewable cooling}}$$

where the final energy consumption from renewable sources (see enumerator) as well as the gross final energy consumption (see denominator) for electricity, heating and transport are taken from the Member States progress reports, and the useful cooling is taken from (Fraunhofer ISI et al. 2016a).

Figure 4-4 presents the estimated effect on target achievement if all cooling demand was reported as renewable cooling (thus giving an indication of possible effects if no ambitious minimum requirments are included): The figure shows the renewable energy shares reported for 2014 for the selected EU Member States and indicates how these shares would have increased. Including all cooling demand as renewable cooling would lead to an increase of the calculated renewable energy share in the EU-28 by about 6%. the impact differs largely between Member States and can reach values of up to 10% for countries with high cooling demand.

The considerable increase in the reported renewable energy shares would require an adjustment of the targets in order for the RES-Directive to remain a meaningful instrument to increase the renewable energy consumption in the EU.

**Figure 4-4: Estimated maximum impact on renewable energy shares in 2014 if all ambient energy for cooling purposes would be reported as renewable cooling**



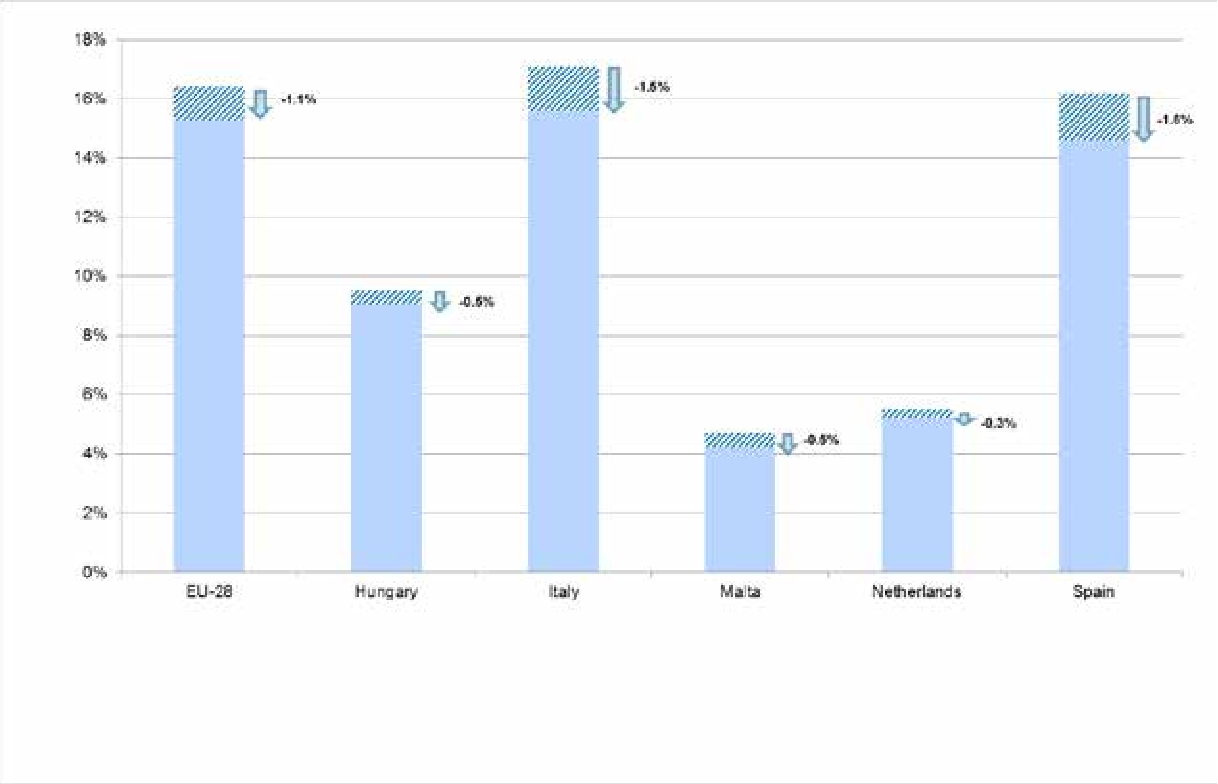
Source: *Öko-Institut*

Furthermore, we estimate the effect on target achievement if the total cooling demand would be included in the denominator, whereas the enumerator includes renewable cooling as defined in Options 1-3. The renewable energy share including renewable cooling is then estimated using the following approach:

$$\text{Share of renewable energy} = \frac{\text{RES} - \text{E} + \text{RES} - \text{H} + \text{RES} - \text{T} + \text{renewable cooling}}{\text{FED} - \text{E} + \text{FED} - \text{H} + \text{FED} - \text{T} + \text{useful cooling}}$$

Figure 4-5 presents the estimated effect on target achievement if the share of cooling demand to be reported is restricted as outlined in Options 1-3, while the denominator includes the total cooling demand. Here, where we illustrate the “worst-case”-situation in which the selected Member States have no cooling demand that classifies as renewable: The figure shows the renewable energy shares reported for 2014 for the selected EU Member States and indicates how these shares would have decreased. Including renewable cooling according to the methodologies described in Options 1-3, in the worst case where no renewable cooling is reported, leads to a decrease of the renewable energy share in the EU-28 by about 1.1%. The impact differs somewhat between Member States depending on the overall renewable energy share and the cooling demand.

**Figure 4-5: Estimated impact on renewable energy shares in 2014 when including ambient energy for cooling purposes as renewable cooling according to Options 1-3**



Source: *Öko-Institut*

The estimates presented in Figure 4-4 are based on estimates of the cooling demand (useful cooling) provided in *Fraunhofer ISI et al. 2016b* and assume that the full cooling demand is accounted as renewable cooling, without restrictions on efficiency, temperature levels or sectoral considerations. The estimates therefore describe the maximum impact, whereas an ambitious implementation of the definitions provided in Options 1-3 would lead to considerably lower contributions.

In order to include renewable cooling in the energy statistics in the EU Member States, the following has to be provided.

- A definition of renewable cooling.
- The outline of a monitoring methodology similar to Annex VII in the RES-Directive for heat pumps.
- A calculation methodology that can be used by the statistical offices of the member states to calculate the renewable cooling contribution.

- An adaption of the Eurostat SHARES-tool to enter the data for renewable cooling.
- Data collection in the member states, which could start on a voluntary basis.

### 4.5. Process cooling and waste heat

Process cooling currently accounts for almost 60% of the cooling demand in the EU and thus has a larger share than space cooling with around 40%. In countries with colder climates the relative importance of process cooling is even more pronounced.

Besides efforts to increase the energy efficiency of cooling systems as well as the renewable energy share, it is essential to avoid unnecessary cooling demand and to increase waste heat recovery.

If all sectors and all cooling demands are included in the RES-Directive, there is a risk that the cooling of waste heat which otherwise could be used for heating purposes is reported as renewable cooling.

Any methodology to include cooling in the RES-Directive (see Section 4.3) should avoid that the cooling of waste heat can be reported as renewable cooling. This could be achieved, for example, by excluding cooling in the industry sector. Another advantage of this approach is that data is particularly scarce in for the industry sector such that reliable monitoring is a challenge. Another option is to limit renewable cooling to a cooling demand for temperatures below ambient. Waste heat from industry is then excluded.

## 5. Summary and Conclusions

The implementation of policy strategies to address the increasing energy demand for cooling in EU Member States requires reliable data on the energy consumption for cooling. While several recent studies have provided estimates of the current and future cooling demand across the EU Member States, no data on cooling is available in the statistical data provided by Eurostat.

While almost 100% of the current space cooling demand is provided by electricity-driven vapour compression systems connected to the electricity grid, several low-carbon cooling technologies based on renewable sources are available. Such technologies include free cooling technologies using natural heat sinks, electricity-driven systems powered by on-site PV installations and solar-thermal systems that provide cooling using renewable heat.

Although the current RES-Directive refers to renewable heating and cooling, it does not provide a methodology for reporting renewable cooling and Member States have no possibilities to include renewable cooling into their renewable energy contribution. As electricity and heat are reported individually, the main option to include renewable cooling is by considering the ambient energy that is transferred from the space/substance that is cooled to the environment. In order to meaningfully include cooling in the RES-Directive, renewable cooling has to be included in EU energy statistics and a monitoring methodology that limits the additional administrative burden has to be developed.

As basically all cooling technologies are based on the transfer of heat, including all ambient energy transferred in cooling processes would mean that all countries could report near to 100% of their cooling demand as renewable cooling. This would also mean that any cooling demand is always included both in the enumerator and the denominator when calculating the renewable energy shares. This would automatically increase the renewable energy shares thus supporting Member States in achieving their targets towards the RES-Directive.

As for heat pumps, where the methodology outlined in the RES-Directive defines a minimum energy efficiency level, minimum performance requirements may be also introduced to identify the share of ambient energy that may be counted as renewable cooling. This report discusses three options for such requirements: Efficiency, temperature levels and the type of heat sinks. Due to its similarity to the approach for heat pumps, minimum energy efficiency standards seem the most practical option.

The way of defining such performance requirements in the RES-Directive has an impact on the technologies that can be reported as renewable cooling. It is therefore likely that the definition of minimum requirements is subject to controversial debates, particularly between technology suppliers of the various cooling technologies.

If cooling is included in the reporting of the RES-Directive, the targets would need to be adopted In order to maintain the ambition of the Directive. The report shows that including *all* cooling in the RES-Directive would lead to an immediate increase of the renewable energy shares, particularly in countries with high cooling demand. At current levels, the EU renewable energy share would increase by about 6%, while reaching up to 10% for Member States with high cooling demands. This is particularly important as cooling demand is expected to increase, such that the effect becomes more pronounced. At the same time, the figures shown in the report provide an upper limit, while ambitious minimum energy efficiency requirements in the definition of renewable cooling limit the share of cooling demand that classifies as renewable and thus the effect of including renewable cooling on target achievement.

A further challenge when including renewable cooling in the RES-Directive is related to efforts to increase waste heat recovery. As this report shows, industrial process cooling plays a rather prominent role. Energy for cooling waste heat should not be included as renewable cooling, as other options for waste heat recovery are preferable from an environmental perspective.

It is essential to address cooling in EU energy and climate policy in an integrated way, providing a consistent framework with other EU directives addressing cooling technologies such as the Ecodesign Directive, the Energy Performance of Buildings Directive or the F-gas Regulation.

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