European Commission

Renewable cooling definition options and calculation methodology

Part 2 of the study
“Renewable Cooling under the Revised Renewable Energy Directive ENER/C1/2018-493”

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1. Introduction

As part of the "Clean Energy for all Europeans" package [1], the EC proposed an update of the Renewable Energy Directive (RED - 2009/28/EC [2]). The revised RED was adopted in December 2018[3]). The RED II includes a specific chapter on mainstreaming renewable energy into heating and cooling (H&C), Article 23 and district heating and cooling (DHC), Article 24. To do so, the RED II requires Member States (MSs) to raise the share of renewable energy in H&C yearly by an average of 1.3 percentage points (ppt) from 2021 to 2030. MSs are allowed to count waste heat and cold in 1.3 ppt up to 40% of the increment. In case a MS decides not to use waste heat and cold to the average annual increase, it must implement an annual average of 1.1 ppt increase in the share of renewables in H&C. Additionally, the RED II also promotes renewable energy sources (RES) in district heating and cooling (DHC), requesting MSs to raise the share of RES and waste heat and cold by at least 1 percentage point yearly (2021-2030). MS can fulfil this 1 ppt increase by waste heat and cold without limitation.

While the RED II outlines the methodology to calculate RES shares for electricity, transport and heating, it does not provide methods on how to take into account renewable cooling. The RED II specifies that the EC shall adopt delegated acts to supplement the directive at the latest by the 31st of December 2021, including a methodology for calculating the amount of renewable energy utilized for cooling and district cooling (DC), and amend the directive accordingly.

In this context, the European Commission launched this study to develop a methodology for defining renewable cooling and for calculating corresponding RES-HC and RES shares. This also requires a rigorous analysis of the status quo of cooling technologies and the cooling related energy demand. The specific goals of the study are:

- Providing an overview of technologies for cooling, related technologies and their technological development trends;
- Quantifying actual cooling demand as well as its development until 2030 and 2050;
- Providing options of renewable cooling definitions, which are in line with the RED II as well as elaborating options of possible methods for calculating renewable energy shares;
- Investigating impacts of proposed definitions on renewable cooling, related methods on calculations;
- Delivering well-grounded recommendations for choosing a fitting definition of renewable cooling, calculation methods as well as on how statistical reporting can be improved and utilized for renewable cooling;

During the project duration (from end of 2019 until August 2021) a series of stakeholder consultation events took place, including a survey of EU Member States energy statistics representatives and Eurostat, presentation and consultation at the CA-RES and CA-EED, two dedicated stakeholder workshops as well as bilateral meetings and consultations. These numerous feedbacks served to continuously improve and further develop the project results.

This second part of the study intends to define the renewable energy quantity for cooling, which in the text will also be called "renewable cooling energy".

In section 2, a general introduction to cooling and cooling systems allows to introduce what could potentially be considered as renewable cooling according to the RED II [1] and to propose a possible scope for renewable cooling definitions.

In section 3, definition options to quantify the renewable cooling energy are elaborated; the potential implications of implementing these definition options are also discussed qualitatively. The quantitative impacts of these definition options can be found in part 3 of this study.

After consultation of Member states and other stakeholders, some choices regarding definition options have been made, which allow to build the calculation methodology to evaluate the renewable cooling energy quantity, presented in section 4.

2. Cooling and renewable cooling, concepts and scope

2.1. Cooling and heating

Heating is the addition of heat to an enclosed space or to a process in order to increase or maintain the space or process temperature. The supply temperature of the heating system being higher than the space or process to be heated allows the heat transfer (Figure 1). The heat transferred to the space or process is the heating supply.

Cooling is the extraction of heat from an enclosed space or from a process in order to reduce or maintain the space or process temperature at a specific set point. The supply temperature of the cooling system being lower than the space or process to be cooled allows the heat to be extracted from the space or process (Figure 1). The heat extracted corresponds to the cooling supply and is noted Q_{C_Supply}.

Consequently, there is no real energy supply in the case of cooling but energy extraction.

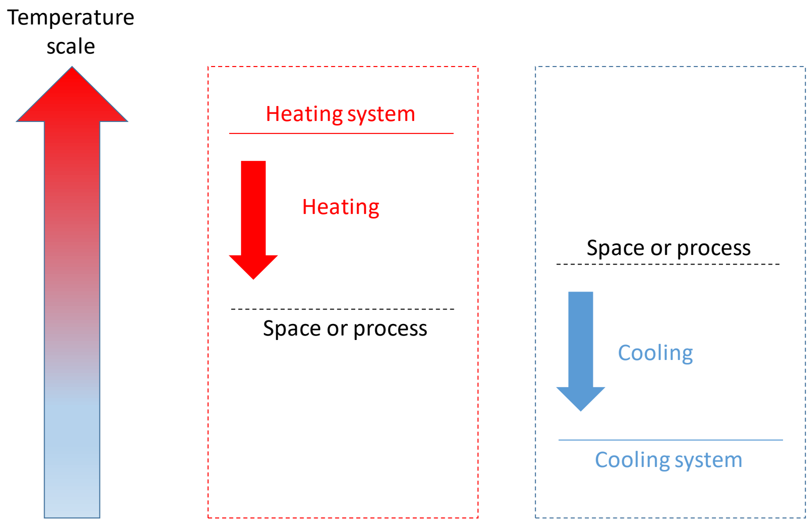

Figure 1 Illustration of heating and cooling principles, heating and cooling arrows correspond to heat transfers

For cooling systems, the extracted heat is rejected into and absorbed by the ambient air, ambient water or the ground. The environment (air, ground, and water) provides a sink for the heat extracted and thus functions as a cold source (Figure 2).

Conversely, for heating systems using renewable heat such as heat pumps, heat is extracted from the environment, which acts as a heat source. The heat extracted from the environment is supplied to the space / process to be heated (Figure 2).

Only heating systems can directly use renewable heat from the environment.

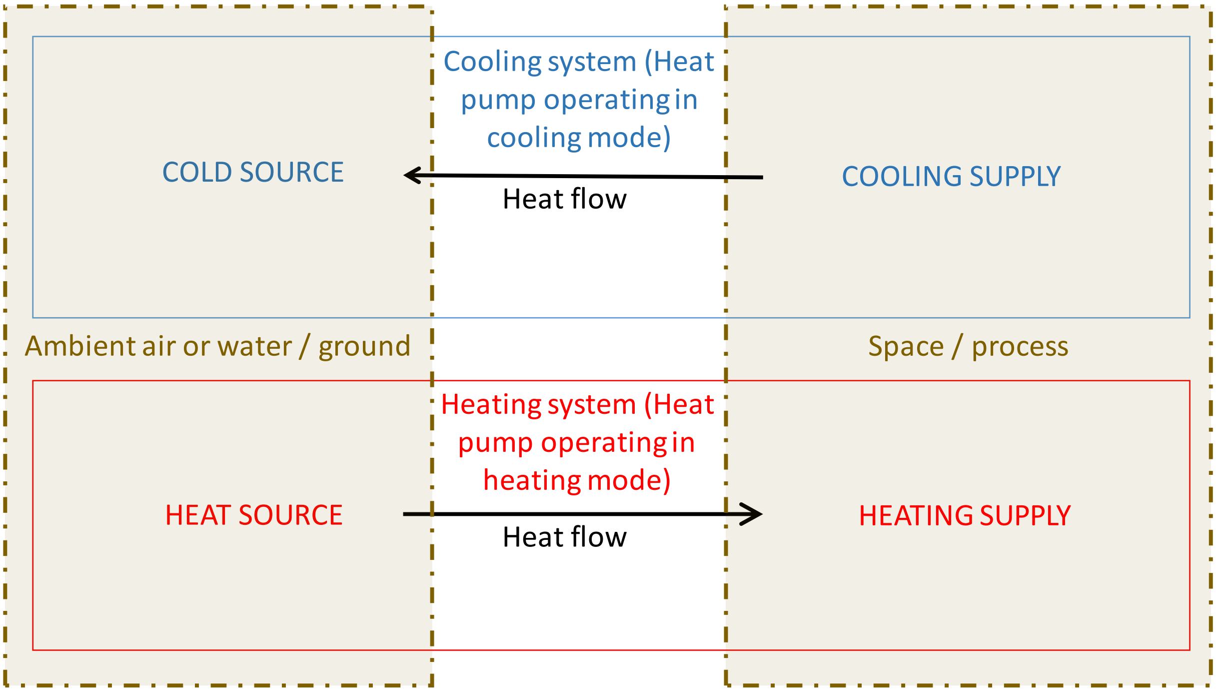

Figure 2 Terminology used in this study for cooling systems (including heat pumps operating in cooling mode) and for heating systems using heat from the environment (heat pumps operating in heating mode)

In general, cooling systems can be considered as devices similar to heat pumps working in cooling mode, which can extract heat from a space or process and reject it to the environment against the natural heat flow (Figure 3).

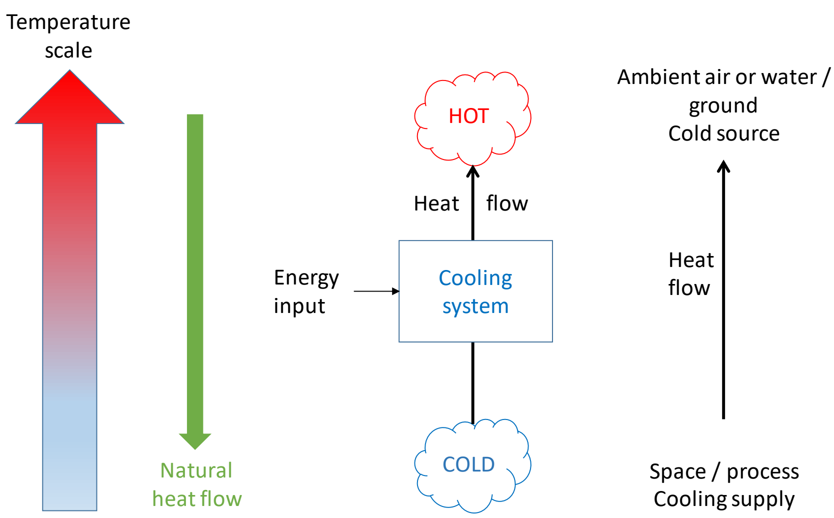

Figure 3 Cooling system principle

This heat extraction requires energy consumption, which is named here energy input. This energy input is an ancillary energy input needed to drive the cooling system (cooling generator) and heat extraction process. The energy input to the cooling system (cooling generator) can be electricity (e.g. electric heat pump), gas (e.g.gas driven heat pump) or heat (e.g. ab/adsorption cooling). In this later case, renewable heat can also be used for cooling, i.e. to drive the heat extraction process by the cooling generator) and thus renewable heat is used indirectly as an energy source to satisfy part or totality of the cooling system's energy consumption.

The energy consumption of the cooling system (cooling generator) as an ancillary energy input to cooling should be distinguihed from the extraction and absorption of the heat, which constitutes the main energy flow and the cooling process per se. In this main cooling process, the natural heat absorption capacity of the environment (air, water, ground) can be considered renewable, when it is replenishable and the heat absorbed does not damage the environment. In these cases we can speak of renewable cold source. The distinction between the two types of energy flows, i.e. "ancillary" energy input, which is needed to drive the cooling system/generator on the one hand and the proper (main) energy flow of cooling where the extraction and absorption of heat operates on the other hand will be further explained in section 2.3.

2.2. Cooling solutions

Passive cooling includes cooling solutions, which do not require the movement of a cooling medium (fluid). The use of window shades, blinds, building insulation or designs and green roofs are examples of passive cooling. Passive cooling also includes cooling by "the natural flow of energy" (green arrow in Figure 3): cooling can occur naturally without the intervention of a cooling system**.** Ventilation, which is the action of introducing ambient air into an enclosed space to ensure proper indoor air quality, is considered as being passive cooling. **Passive cooling is outside the scope of the renewable cooling calculation** in accordance with Article 7(3). This limitation of scope is further discussed in section 2.6.2.

When the natural flow from hot to cold is not available, insufficient or not used, the extraction of heat and thus the cooling is performed by an **active cooling system**. Active cooling systems aim at satisfying the need for cooling and require at least a pump or fan (for a more detailed definition of active cooling, see below). Under the active cooling system category, two different sub-categories are distinguished for the purpose of this study: **free cooling and cooling generators**.

For **free cooling**, the natural heat flow from hot to cold is available, and it is intensified by pumps and/or fans. **There are various free cooling solutions, which are all included in the scope of renewable cooling calculation**. This includes free cooling solutions in the case of cooling systems using air as cold distribution vector, which are also ensuring the ventilation function, provided that cooling is the primary function. Solutions are explained in detail in section 2.6.1.

Comfort fans are not part of free cooling solutions and are outside the scope of the renewable cooling calculation. This is explained in section 2.6.2.

In the situations where the natural heat flow is not available or not used, a **cooling generator** is required. This cooling generator will require an external energy input (of different forms depending on the cooling principle used, e.g. electricity in the case of electric vapour compression, heat in the case of absorption cooling) in addition to the energy required for pumps and fans. **All types of cooling generators (see section 2.6.1**) **are in the scope of the renewable cooling calculation.**

The following definition of active cooling is thus proposed:

- An **active cooling system** is either a free cooling system or a cooling system embedding a cooling generator, and for which cooling is one of the primary functions.
- A **free cooling system** is a cooling system using a natural cold source to extract heat from the space or process to be cooled via fluid(s) transportation with pump(s) and/or fan(s) and which does not require the use of a cooling generator.

- A **cooling generator** refers to the part of a cooling system that generates a temperature difference allowing heat extraction from the space or process to be cooled, using a vapour compression cycle, a sorption cycle or another energy-driven thermodynamic cycle.

The section 2.6 specifies in more details the cooling solutions included in the scope of renewable cooling calculations according to these definitions.

In accordance with the fourth paragraph of Article 7(3) of the RED II[1] [1], only active cooling is in the scope of the renewable cooling calculation.

Active cooling systems are simply named as "cooling systems" in the following sections.

2.3. Cooling system terminology, energy balance and Seasonal Performance Factor (SPF)

As mentioned in section 2.1, there are two types of energy flows that play a role in cooling: the 1) **cold source** and 2) the **energy input** to the cooling generator. Therefore, these two flows are considered when analysing the possible approach to calculate renewable cooling quantities.

1) Cold source

Cooling systems extract heat from the room or process to be cooled. The heat extracted is transferred or rejected outside the cooling system, ultimately in the environment in ambient air, ambient water or to the ground. Where the heat is transferred is called the **cold source**. Cold source can also be called **heat sink**, because as explained in section 2.1, in the case of cooling the cold source absorbs the rejected heat.

The cold source can be genuinely cold, i.e. have a lower temperature than the temperature of the space / process to be cooled, as would be the case for free cooling.

The cold source can have a higher temperature than the temperature of the space or process to be cooled. In that situation, a cooling generator is needed.

2) Energy input

When it follows the natural flow of energy (Figure 3), the heat extraction and rejection only requires energy for heat transportation (energy required to put heat carriers in motion).

This transfer of heat requires additional energy when it goes against the natural flow of energy from hot to cold. This heat transfer must be used when there is a need for cooling and when the natural flow of energy is not available, not sufficient or not used. This transfer of heat is operated by a cooling generator.

The sum of the energy consumption for heat transportation and to operate the cooling generator is named **energy input**, and is noted E_{INPUT}.

The energy balance of cooling systems can simply be written as in Equation 1; it is also shown in Figure 4.

$$Q_{C\_Source} - E_{INPUT} = Q_{C\_Supply} \qquad \textit{Equation 1}$$

[1] "*...Thermal energy generated by passive energy systems, under which lower energy consumption is achieved passively through building design … shall not be taken into account …*"

Where:

- Q_{C_Source} is the heat rejected to the cold source.
- E_{INPUT} is the energy input to the cooling system.
- Q_{C_Supply} is the cold supplied to the room or process to be cooled.

The energy balance of cooling systems is illustrated in Figure 4.

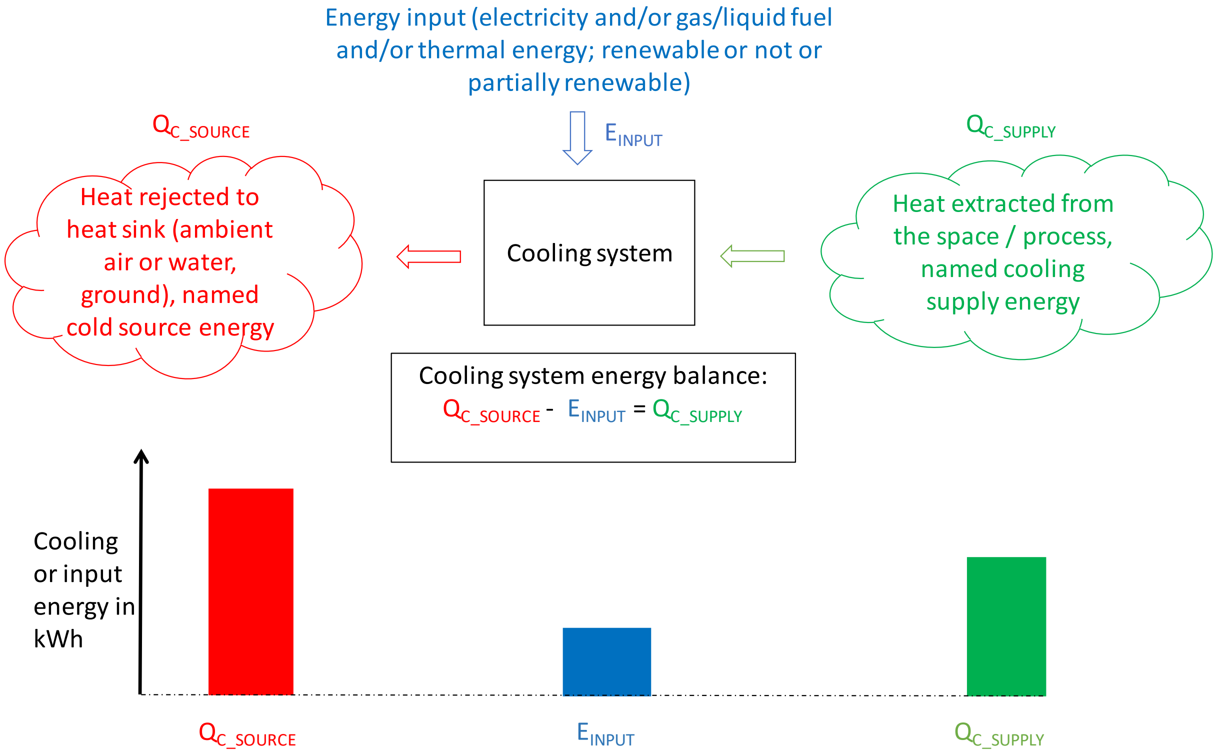

Figure 4 Energy balance of cooling systems

The SPF is the Seasonal Performance Factor, which is a ratio used to measure the efficiency of cooling systems during the cooling season. Using the same notation as in Equation 1, the SPF of a cooling system is defined in Equation 2:

$$SPF = Q_{C\_Supply} / E_{INPUT} \qquad \textit{Equation 2}$$

The SPF formula calculates how much cooling is produced and supplied by the system divided by the external energy input. Higher SPF is better, because more cooling is produced for the same energy input.[2]

[2] As described later, the SPF can be defined in final and primary energy terms, in the latter case denoted as SPF_p, which is identical to $\eta_{s,c}$ defined in Regulation (EU) 2281/2016.

2.4. How to define renewable cooling?

2.4.1. Cold source

According to the RED II Article 2 definitions (1), (2) and (3), renewable energy is defined as follows:

"(1) 'energy from renewable sources' or 'renewable energy' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;

(2) 'ambient energy' means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water;

(3) 'geothermal energy' means energy stored in the form of heat beneath the surface of solid earth;"

There is not a definition for ambient air in the RED II but ambient air is defined in article 2.1 of Directive (EU) 2008/50 [2]: *"'ambient air' shall mean outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC where provisions concerning health and safety at work apply and to which members of the public do not have regular access"*.

Thus, ambient air is **outdoor air** and indoor air is not part of ambient air. This is in line with Eurostat's definition of renewable energy source ("Renewable energy sources, also called renewables, are energy sources that replenish (or renew) themselves naturally." [3]) as indoor air temperature does not renew naturally. It should also be noted that in the case of cooling indoor air is neither a cold source/heat sink nor an energy input (see section 2.3). On the contrary, indoor air is the source of excess heat (waste heat in the terminology of REDII), which should be removed/extracted to attain the desired comfort temperature (set point). It follows that the question whether indoor air is renewable or not would be only relevant in case its energy content or heat absorption capacity would be used; while the whole rationale of cooling is that this energy content is not needed and not used, but should be simply removed. From an energy flow and balance perspective, the energy content of indoor air could become energy input only where it is recovered as waste heat for heating or cooling purposes (see section 3.5 and 4.6).For cooling systems, the capacity of the environment (either by ambient air, ambient water or to the ground) to absorb heat can potentially be seen as a renewable energy element, i.e. renewable cold source. Using previous notations, **the use of such cold source could potentially qualify as renewable cooling**.

2.4.2. Cold source and SPF criteria

In the case of **free cooling** systems, the cold source temperature is lower than the temperature required to cool the space or process. In this condition, a naturally available cold source is directly used for cooling. This is a parallel situation with the availability of geothermal or ambient heat at a higher temperature than the one that would be required for heating: the direct use of this heat is counted as renewable heat.

The availability of a low temperature cold source enabling the use of free cooling is considered as renewable cooling in the literature [4] and is one of the criteria used in practice to select cooling systems that can qualify as renewable cooling systems in the Netherlands [5] and in France [6].

However, free cooling is not the only criterion used to qualify as renewable cooling. To qualify as renewable cooling in the Netherlands and in France, an additional cooling efficiency criterion has to be fulfilled (SEER≥20 in France[3], EER≥8 in the Netherlands[4]); efficiency requirements in France and Netherlands are set at a level that currently can only be reached by free cooling systems. Indeed, renewable cooling schemes intend to promote cooling systems that will decrease the energy consumption for cooling. Their efficiency must then be higher than the one of a standard or reference[5] cooling system. It should also be noted that even if a low temperature cold source is available, it does not mean that it will be efficient to use it for free cooling; it depends on the cold source, on the cooling system and on-site specificities.

Cooling generators can operate both with low and high temperatures of the cold source. The temperatures of cold sources vary along the year and with climate. Hence, a temperature difference between the cold source and the space/process to be cooled, which allows identifying free cooling systems, cannot be used to define renewable cooling for cooling generators.

However, a lower temperature cold source will increase the efficiency of the cooling generator. Cooling efficiency (with SPF metrics) is a mandatory parameter of the Renewable Energy Directive for heat pumps used in cooling mode[6]. Article 7(3) sixth sub-paragraph of the RED II postulates: "*That methodology shall include minimum seasonal performance factors for heat pumps operating in reverse mode*". For the context of this study, the scope of the renewable cooling definition must not be limited to heat pumps but rather comprise all relevant technologies.

Hence, a strict definition of renewable cooling would be to only accept free cooling as renewable cooling. Free cooling systems are cooling systems with the highest possible SPF values. In the context of the RED II, , we propose to use the SPF of cooling systems as the main criterion to qualify the presence of cold source energy to potentially count as renewable cooling. High SPF can qualify renewable cooling in line with the REDII's requirements, as it is an indicator showing that final energy input significantly exceeds the primary energy input – a criterion for renewable energy use in heating and cooling. High SPF can be achieved with efficient cooling technologies even in the absence of a cold source with constant lower temperature that the cooling set point.

For free cooling, high SPF will ensure energy consumption reduction as compared to standard cooling solutions. For cooling systems integrating a cooling generator, high SPF may incentivise the development of low temperature cold sources for free cooling and to improve cooling generator efficiency.

[3] The requirement for renewable cooling in France have been described in [6]. The document sets a threshold of an SEER=20 in terms of final energy.

[4] The requirement for renewable cooling in the Netherlands is described in Harmelink, 2018 (https://www.rvo.nl/sites/default/files/2019/05/Eindrapport%20koude%20in%20BENG%203%20Harmelink.pdf). It sets a threshold of EER = 8 in terms of final energy.

[5] The standard solution being electric vapour compression, as highlighted in the paragraph related to vapour compression in section 2 of Part 1 of this study.

[6] Energy efficiency expressed in SPF is a main (proxy) criterion to establish whether there is any and if so, how much renewable energy quantity used for heating from heat pumps. Article 7(3), third paragraph' first sentence reads: "*Ambient and geothermal energy used for heating and cooling by means of heat pumps and district cooling systems shall be taken into account for the purposes of point (b) of the first subparagraph of paragraph 1* [i.e. to calculate renewables' share in heating]*, **provided that the final energy output significantly exceeds the primary energy input** required to drive the heat pumps*". (highlight from the authors) The dividing line between renewable and non renewable heating via heat pumps is defined by the SPF threshold, which should be higher than SPF > 1,15 * 1/η (See Annex VII of REDII) (higher than 2.5 at the time of adoption of Annex VII and higher than 2.4 as a result from increased default η defined in the amended Energy Efficiency Directive's, 2018/2002, Annex IV).

In both cases, the SPF also depends on the temperature of the cooling supply[7]. In general, the higher the desired cooling temperature, the higher the SPF. Qualifying renewable cooling via a SPF could thus provide incentives for both the use of a lower temperature cold source and of higher temperature of the cooling supply in space or process temperature.

2.4.3. Cold source, link to waste heat and waste cold

As explained in section 2.4.1, the cold source is the heat absorption capacity of the environment; the quantity of cold source is the same as the quantity of heat absorbed by the environment and can potentially be seen as renewable cooling energy. From the system perspective, the heat released to the environment is waste heat. From an environmental and energy efficiency point of view, it is preferable to recover that waste heat than to release it to the environment. However, the fact that waste heat is recovered for heating or for cooling (via heat driven cooling system) or as energy input to another end-use, does not make the heat recovered renewable and thus this heat does not qualify as renewable heating or renewable cooling.

The situation is equivalent for heat pumps used for heating: when a heat pump takes heat out of a heat source (air, water, ground), it cools the heat source and produces waste cold. It is in general more efficient to use this waste cold for cooling purpose, if feasible, than to release it to the environment. However, even if recovered, waste cold from heat pump released into the heat source in the course of the heating process does not qualify as renewable cooling but remains waste cold.

The promotion of waste heat and cold use in general is in the scope of the EED and not of the RED II, with the exception when these are used through district heating and cooling systems. Indeed, in the RED II, article 2(9) waste heat and cold are defined as follows: *"'waste heat and cold' means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;"*

Waste heat input in heat driven cooling generators, if distributed by a district cooling system (see article 2(9) above) could be counted towards the Article 23 and 24 targets [11], [23]. A possible quantification is proposed in section 3.5 and a corresponding methodology in section 4.6.

Waste cold as a cold source/heat sink, if mediated by a district cooling system (see article 2(9) above) could be counted towards the Article 23 and 24 targets of the RED II. A possible quantification is proposed in section 3.5 and a corresponding methodology in section 4.7.

Taking the energy balance of cooling systems according to Figure 4 as a starting point, Figure 5 describes how waste heat and waste cold relate to the different streams of the energy balance and the accountability according to the renewable energy directive.

[7] For instance, the same space can be cooled by a fan coil, with average chilled water temperature around 10 °C or with a high temperature emitter such as a cold beam, with average chilled water temperature around 16 °C. The higher the chilled water temperature, the higher the SPF of the cooling generator.

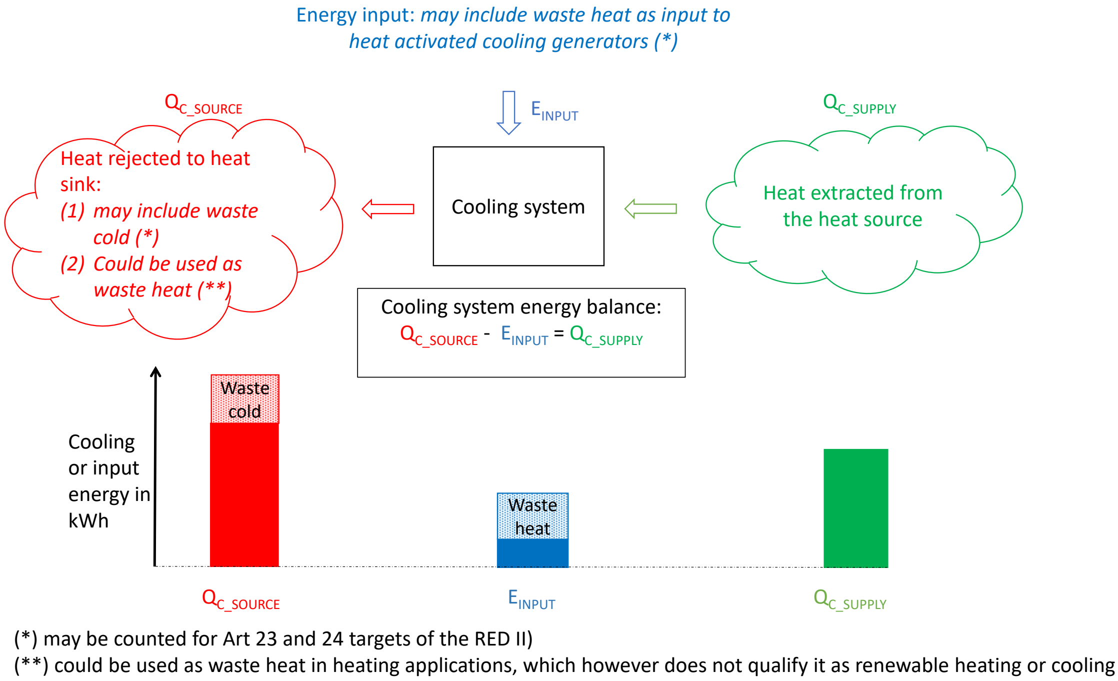

Figure 5 Waste heat and cold in relation to the energy balance of cooling systems

2.4.4. Renewable energy input

The main objective of integrating renewable cooling in the RED II is to cut the emissions of GHG due to cooling[8]. The SPF criteria should help decreasing the final energy consumption for cooling and integrate renewable energy. Another contribution could arise from the increase of the renewable energy share in the energy input to cooling systems.

Presently, cooling systems may use four types of energy carriers as energy input to the cooling generator: electricity, gas, liquid fuel, and heat. These can be renewable or non-renewable. Here is the present situation by energy input type:

- Electricity: The main energy input for cooling today is electricity, i.e. more than 99% of cooling devices are driven by electricity today[9]. Renewable electricity (as part of grid electricity or supplied by local renewable electricity) is already used as an energy input.
- Gas: Gas operates combustion engine vapour compression and absorption cooling generators. This can be renewable gas (either from the grid or issued from local production) or fossil gas. The share of gas as energy input to cooling generators is negligible today.
- Liquid fuels: Liquid fuels operate combustion engine vapour compression cooling generators. This can be renewable liquid fuel (either blended in transportation distribution or issued from local production) or fossil liquid fuel. The share of liquid fuels as energy input to cooling generators is negligible today.

[8] GHG emissions and global warming potential of refrigerants is not in the scope of this study and is addressed in the F-gas Regulation (Regulation (EU) No 517/2014). The impact on GHG-emissions assessed in part 3 of this study [28] is limited to CO2-emissions.
[9] Please see section 2 on cooling technologies and section 3 on cooling consumption in report 1 of this study [30].

- Heat: Heat operates absorption cooling generators today. The share of heat is estimated to be around 1 %, this is mainly non-renewable heat (waste heat) and a small share of solar heat.

For grid electricity, gas, and liquid fuel energy input, cooling system may already have a fraction of their energy input coming from renewable energy, which depends on the penetration of renewable energy in these energy carriers for each MS. The grid renewable energy input share will be growing in the coming years with the progressive decarbonisation of these energy carriers.

The development of concomitant renewable energy be it self-consumed renewable electricity, gas or fuel, or renewable heat could help the incorporation of additional renewable energy input. These concomitant renewables could have an important role to mitigate grid electricity peaks in the summer, particularly if coupled with energy storage.

Options to promote the development of renewable energy input for cooling are proposed in chapter 3.

2.5. Scope of renewable cooling definition: cooling sectors and applications

This part discusses which sector and application is to be included in the scope of the renewable cooling definition.

The scope encompasses both space cooling and process cooling.

As explained in report 1 section 1.1 of this study [30]:

- **Space Cooling** (SC) is defined as the extraction of heat from air to cool indoor air to a specific temperature and ensure healthy conditions and thermal comfort to the occupants of an enclosed space (e.g. buildings). SC lowers the temperature of the air.
- **Process cooling** (PC) is defined as the extraction of heat from processes, from products or from a confined space containing these processes or products in view of maintaining the required set temperature.

Scope limitations for each sector are discussed below.

Means of transportation

Cooling system energy input in case of transportation (e.g. cars, trucks, ships) is in general supplied by the transportation engine and thus pertains to transport and fuel efficiency regulations. **It is thus proposed that the scope of the renewable cooling definition is stationary cooling and does not cover cooling systems in means of transportation.**

Process cooling: sectors and applications

As shown in Part 1 of this report[10], process cooling encompasses very diverse types of applications in different sectors. Temperature at which cooling is needed varies between cryogenic temperature level up to several hundred Celsius degrees.

The temperature range of the cooling supply for which low temperature cold sources could grow and displace the use of cooling generators depends on the temperature of ambient air, ambient water and ground temperature, which varies within the EU and along the year. This temperature range's lower bound can be defined by using as a low limit the temperature of ambient water

[10] In Table 2 section 1.3 on process cooling and in the annex "Process cooling - sectors, subsectors, processes, and technologies"

under the form of ice i.e. 0 °C. The temperature range's higher bound can be approached by observing most severe ambient conditions in Europe: in Regulation 2281/2016 [7], cooling tower design allows to cool down condenser water from 35 to 30 °C for an ambient air condition of 35 °C dry bulb and 24 °C wet bulb; with 24 °C being close to maximum wet bulb monthly average in hottest EU climates[11], it can be concluded that **cooling supply temperature levels above 30 °C can be almost exclusively supplied with evaporative cooling.** Hence, the temperature range of the cooling supply for which low temperature cold sources could grow and displace the use of cooling generators is estimated to lie between [0 °C – 30 °C]. This temperature range is one of the parameters used hereafter to screen potential cooling process sectors and applications to be included in the scope.

For process cooling with low cooling supply temperature, it is proposed to exclude refrigeration equipment from the renewable cooling definition. Refrigeration is understood here as the activity of continuously maintaining or decreasing the temperature of perishable materials like foodstuffs within prescribed limits at chilled or frozen operating temperature. Accordingly, refrigeration equipment is defined in Article 1 (m) of Regulation (EU) 2281/2016 [7], as cooling equipment "*of which the primary function is the purpose of producing or storing perishable materials at specified temperatures*". Refrigeration equipment mostly use vapour compression systems with refrigerant fluid at very low evaporating temperatures typically below – 10 °C [7]. Evaporating temperatures are too low to allow for the direct use of natural cold sources for free cooling. This means that due to the required temperature levels the use of a heat sink, which can be understood as renewable capacity to absorb the heat, can be considered as very unlikely and extremely rare. Consequently, the main way of making refrigeration equipment renewable is through their energy input. When electricity driving refrigeration equipment is renewable, it is already accounted for in the renewable electricity shares under the REDII. The efficiency improvement potential is already covered by Ecodesign [8] [10] and labelling [9] regulations. Consequently, there would be no benefit of including refrigeration equipment in the scope of renewable cooling definition.[12]

As regards **high temperature process cooling**, any thermal power plant, combustion and other high temperature processes offer the possibility to recover waste heat. Incentivizing the release of high temperature waste heat into the environment without heat recovery through renewable cooling would be against the "energy efficiency first" principle and environmental protection. In that perspective, the 30 °C temperature limit is not enough to distinguish those processes; indeed, in a steam power plant, condensation may occur at 30 °C or lower. The cooling system of the power plant may supply cooling at a temperature lower than 30 °C.

To define the scope here, a first possibility is to build a "**negative list**" of processes to be excluded from the scope based on the fact that waste heat recovery should be prioritized. It could contain cooling of power/work generation plants including cogeneration, cooling of hot fluids resulting from combustion or from an exothermic chemical reaction. There are however other cooling processes for which the heat rejected to the environment can be recovered. The JRC[13] established such a list based on a literature review of waste heat recovery, which contains additional processes: cement, iron and steel manufacturing, wastewater treatment plants,

[11] Based on historical data for period 1990-2014, hottest average wet bulb temperature in Sevilla and Athens is about 26 °C. Source: http://ashrae-meteo.info/

[12] In isolated, off-grid locations, refrigeration combined with off-grid PV installations could become an increasingly important technology. However, the study team does not consider this constellation as sufficiently relevant for EU-27 to include it in the RES-C calculation under the renewable energy directive.

[13] For a detailed discussion of waste heat, its interpretation under the Energy Efficiency and Renewable Energy Directives, its sources and uses, please see JRC paper on waste heat [23].

information technology facilities (such as data centres), power transmission and distribution facilities, as well as cremation and transportation infrastructures.

However, as shown in Table 1, the number of sectors to be included in the scope when combining the constraints mentioned above is limited. As a consequence, it is proposed to describe the sectors, which are in the scope rather than a list of sectors that are excluded.

Table 1 Screening of cooling processes to be included in the scope of renewable cooling definition[14]

SECTOR	APPLICATION	TEMPERATURE LEVELS	TYPICAL TECHNOLOGY	Low temperature / Refrigeration	High temperature / Waste heat recovery priorised	In the scope of renewable cooling definition
Food, beverages and tobacco	Quick freeze	-45 °C	Vapour compression	X		No
Food, beverages and tobacco	Freezing	-30 °C	Vapour compression	X		No
Food, beverages and tobacco	Cold store	-8 - 3 °C	Vapour compression	X		No
Food, beverages and tobacco	Cooling of products, process streams and supporting medias	0 – 250 °C	Vapour compression, free cooling		X	No
Food, beverages and tobacco	Drying (humidity control)	-40 – 20 °C	Vapour compression	X		No
Food, beverages and tobacco	Condensation	0 – 200 °C	Vapour compression, free cooling		X	No
Food, beverages and tobacco	Vacuum systems (condensable parts)	-50 – 40 °C	Vapour compression, free cooling. Ejector	X		No
Iron and steel	Controlled cooling	100 – 800 °C	Free cooling		X	No
Textile and leather	Cooling after wash	30 – 70 °C	Vapour compression, free cooling		X	No

[14] This table is a reproduction of Table 2 in section 1.1 of the part 1 of this study. It is completed with the constraints regarding process cooling inclusion detailed above the table.

Paper, pulp and printing	Drying (humidity control)	-40 – 25 °C	Vapour compression	X		No
Chemical and petrochemical	Cooling of products, process streams and supporting medias	-40 – 1000 °C	Vapour compression, free cooling. Ejector		X	No
Plastic moulding	Hydraulic cooling. Mould tempering	-5 – 90 °C	Vapour compression, free cooling		X	No
Data center	Electronic	10 – 35 °C	Vapour compression, free cooling		X	No
Fishery	Storage of fresh fish	-25 - 0 °C	Vapour compression	X		No
Agriculture	AC and product cooling	0 - 30 °C	Vapour compression, free cooling			Yes

Because a cooling system can always serve several applications with different temperature levels, it does not seem feasible to exclude only certain types of applications of a specific sector. For that reason, only sectors for which there is no risk of including processes, which do not satisfy the constraints are selected.

Process cooling is required all year long as opposed to space cooling. Heat released by process cooling to the environment could, if recovered, be used to displace fossil fuel heating and this should be prioritized over cooling efficiency as it brings larger GHG emission reductions. Including all process cooling in renewable cooling definition may thus be detrimental to climate objective by preventing process system integration. It is thus proposed to limit the definition for the purposes of calculating renewable energy understood as heat sink (cold source) used for cooling to those types of process cooling sectors for which cooling is not needed all year long and where heat recovery is not deemed possible. Process cooling in the agricultural sector (for breeding and for greenhouses) is the only sector identified to match these requirements (according to Table 1). In addition, the agricultural sector offers known renewable cooling solutions (respectively evaporative cooling for breeding, and PV generation for greenhouses). However, process cooling sectors outside of the scope of using renewable heat sinks/cold sources, could still be qualified as renewable when they use renewable energy (such as electricity) as an energy input to the cooling generator, should such criterion based on the energy input rather than on the presence/use of renewable heat sink/source become a selected approach. This study looks into both criteria as possible defining factors, i.e. cold source/heat sink and energy input. However, due to the legal requirements in REDII (e.g. no double counting of electricity, use similar approach for cooling as applied for heating in Annex VII of REDII), the preferred option and methodology developed in this study in depth qualifies renewable cooling mainly via the presence of renewable heat sink/cold source and the SPF metric, with the latter being considered as proxy indicating the presence/use of renewable heat sinks/cold sources.

As a synthesis, the following definition is proposed as regards the scope of the renewable cooling definition in the context of the renewable energy directive:

In the context of this study and for the proposed definition of renewable cooling calculation methodology, cooling is defined as the extraction of heat from an enclosed space (to ensure human comfort) or from a process in order to reduce or maintain the space or process temperature at a specified (set) temperature. The extraction of heat from a process is limited to sites where no processes take place other than those with a temperature range of 0-30°C. According to the information available to the study team and listed in Table 1, only the agricultural sector complies with the requirements of including only processes in the range of 0-30°C. **Cooling systems in means of transportation (non-stationary cooling), refrigeration equipment[15], and processes with excess heat generation** (such as in thermal power plants and other combustion and chemical processes), where part of the heat is not useful and thus needs to be removed (cooled), i.e. the cooling of waste heat, **are excluded.**

2.6. Scope of renewable cooling definition: cooling systems

The article 7(3) of the RED II explains what should be included in the scope of renewable cooling calculation:

- "*Ambient and geothermal energy used for heating and cooling by means of heat pumps and district cooling systems shall be taken into account […]*."
- *"Thermal energy generated by passive energy systems, under which lower energy consumption is achieved passively through building design […] shall not be taken into account"*

Given the variety of cooling solutions, it is necessary to explicitly define which cooling solutions are excluded because they are considered to be passive energy systems, and which ones are considered as active, and consequently are included in the scope of renewable cooling definitions. To that purpose, the different cooling solutions are screened: section 2.6.2 describes active cooling solutions and section 2.6.2 describes passive cooling solutions.

This list of solutions, which are included in the scope of renewable cooling calculation is summarized in the definitions for cooling systems given in section 2.2 and reported below:

- An **active cooling system** is either a free cooling system or a cooling system embedding a cooling generator, and for which cooling is one of the primary functions.
- A **free cooling system** is a cooling system using a natural cold source to extract heat from the space or process to be cooled via fluid(s) transportation with pump(s) and/or fan(s) and which does not require the use of a cooling generator.
- A **cooling generator** refers to the part of a cooling system that generates a temperature difference allowing heat extraction from the space or process to be cooled, using a vapour compression cycle, a sorption cycle or another energy-driven thermodynamic cycle.

2.6.1. Active cooling

2.6.1.1. Cooling generators

Cooling generators are energy-driven thermodynamic cycles able to generate a temperature difference, which allows heat extraction from the space or process to be cooled. The heat extracted is rejected to the environment. By definition, **all cooling generators can be understood as heat pumps working in cooling mode** (reverse mode if heating is taken as the reference).

[15] Refrigeration includes freezing, e.g. such as foodstuff or chemical and pharmaceutical products.

Beside vapour compression and sorption, there is a very large number of technologies used by cooling generators, which are described in report 1 section 2 of this study: Thermoelectric, Thermionic, Thermotunnel, Electrocaloric, Electrochemical, Vapour compression, Pulse tube, Ejector, Vortex tube, Stirling/Ericson, Reverse Brayton, Bernouilli cycle, Elastomeric, Critical flow cycle, Membrane heat pump, Thermoacoustic, Magnetocaloric, Desiccant, Heat of reaction, Potential energy use, Absorption and adsorption, Transcritical thermal compression heat pump. It is thus important to have a generic definition for cooling generators.

Convection, Conduction, Freeze/melt cycle, Evaporative cooling, sky radiative cooling are key cooling principles (described in more detail in report 1 section 2 of this study) but not cooling generator technologies. The temperature of the cooling they can supply is dependent over the cold source they are using.

2.6.1.2. Free cooling

Article 7(3) of the RED II specifies that ambient and geothermal energy used for cooling and district cooling should be in the scope of renewable cooling calculations. Hence, the cold source of all free cooling solutions used by district cooling should be in the scope of renewable cooling calculations. This encompasses all free cooling solutions allowing to chill water in district cooling installations. This type of free cooling is named indirect, because of the need of an intermediate fluid between the environment and the space or process to be cooled.

Indirect free cooling systems include the heat rejection systems of water cooled cooling generators (see part 1 section 1.2 paragraph on “Types of heat rejection systems”) to ambient air (dry coolers, evaporatively-cooled air-to-water heat exchangers, cooling towers), to ambient water (in general, a simple heat exchanger or a series of heat exchangers between ambient water and chilled water), to the ground (underground water, aquifer, seasonal or long term cold storage underground in ATES systems) or other natural or man-made cavities; sky radiative cooling is part of the free cooling solutions to ambient air, which can be indirect (i.e. it can be used to chill water).

Air-to-water or water-to-water cooling generators may include built-in free cooling solutions: when the natural heat flow is available to make use of free cooling, the compressor is stopped; a pump circulates the refrigerant inside the cooling generator to assist heat extraction and rejection. As part of indirect free cooling solutions, cooling generator embedded free cooling based on refrigerant is also in the scope of renewable cooling definitions.

If indirect free cooling is included in the scope for district cooling, it should also be included for other cooling systems in order to ensure a level playing field for all cooling systems.

Direct free cooling is a common solution for cooling systems using air (instead of water) to supply cooling to the space or process. Cold ambient air is introduced, which replaces hotter exhaust air. Direct free cooling is available for rooftop and cooling air handling units (see report 1 section 1.2 of this study for a description of these cooling solutions).

Introduction of fresh air for ventilation purpose (air renewal to ensure indoor air quality) is not free cooling. **This type of ventilation is considered to be passive cooling and is not included in the scope of renewable cooling calculation** (see section 2.6.2.3).

What distinguishes rooftop and cooling air handling units from classical ventilation air handling units is the fact that cooling the space or process is one of the primary function of the unit. Cooling with air necessitates air flows that are larger than the ones required for ventilation only and consequently large recirculation ratios (in order to avoid the introduction of large quantities of hot ambient air) and the inclusion of a mixing section between recirculated air and ambient air. This is the existence of this air flow difference between cooling and ventilation needs which enables to do free cooling, by introducing more or less ambient air in function of the outdoor and indoor temperatures and of the cooling needs.

The share of the cooling supply due to mechanical[16] ventilation air flow should be deducted from the cooling supply of air-based cooling systems, which ensure both cooling and ventilation functions. The fan power due to ventilation should also be deducted (see paragraph on SPF boundary conditions in section 3.4.2).

Water may be evaporated in the air stream so that its evaporation contributes to further reduce the cold air supply temperature (**evaporative cooling**). This is included in this report in direct air free cooling solutions. Again, the share of the cooling supply due to ventilation air flow should be deducted.

In the case of ventilation air handling unit, for which cooling the space / process is not one of the primary functions, cooling can still be supplied via the ventilation air flow to the space / process. Cooling can be supplied using the same cooling generator that is used for space / process cooling. But it can also be supplied by evaporative cooling, desiccant evaporative cooling or via a ground-to-air or an ambient water-to-air heat exchanger. These latter free cooling solutions are also part of the renewable cooling definitions. **This type of free cooling of the ventilation air may be included as free cooling in the scope of the renewable cooling calculations.**

However, when cooling is supplied by cold recovery solutions, either in air handling units or as component of space exterior wall[17], the corresponding cooling supplied to the space/process is not renewable cooling but waste cold recovery. As it is not delivered to a district cooling but recovered internally, it is not to be included in renewable cooling calculation; where such system is included in a cooling system using renewable cooling solutions, its cooling supply should not be accounted for; the fan power due to the cold recovery should also be deducted of the cooling system energy input (see paragraph on SPF boundary conditions in section 3.4.2). **Internal recovery of cold is not in the scope of renewable cooling calculations.**

Mechanical ventilation can be maintained although not needed for indoor air quality or the airflow can be increased (in comparison to strict fresh air requirements for ventilation purpose only) when ambient temperature is lower than indoor air temperature. This solution may allow to precool the building (cold storage in building structure) and so to reduce the need for cooling during occupation. Here again, the normal ventilation airflow should be deducted to compute the cooling supply of such system (and fan power should also be deducted of the energy input; see paragraph on SPF boundary conditions in section 3.4.2).

2.6.2. Passive cooling

2.6.2.1. Building design

Building design strategies may prevent or reduce the need for cooling; this includes for instance, building insulation, green roof, vegetal wall, shading or increased building mass. **Decreasing the need for cooling by building design is part of passive cooling solutions and is consequently not included in the scope of renewable cooling calculation.**

2.6.2.2. Passive cooling solutions

When the outside temperature of ambient air, surface water or ground are of lower temperature than the space or process to be cooled, the natural flow of energy (green arrow in Figure 3) from

[16] Mechanical ventilation means ventilation using fan by opposition to natural ventilation for which fresh air introduction is due to wind and or temperature difference between ambient air and indoor air.
[17] See paragraph “Enthalpy recovery (heat exchanger)” in part 1 section 2 of this study report.

hot to cold can be used[18]. Cooling by the natural flow of thermal energy without the intervention of a cooling device is passive cooling. Heat is extracted by conduction, convection, radiation or mass transfer, without the need for fans and pumps. Cooling by the natural flow of energy without the need for fans and pumps is considered as passive cooling and **is consequently not included in the scope of renewable cooling calculation.**

2.6.2.3. Ventilation

Ventilation (either natural or forced) is the introduction of ambient air inside a space with the aim to ensure appropriate indoor air quality. Ventilation may lead to the introduction of cold ambient air and thus may reduce the cooling supply at some periods of the year but cooling is not intentional (and ventilation may also contribute to heating the air in the summer and thus to increase the cooling load). **Thus, in general ventilation is considered to be passive cooling and is not included in the scope of renewable cooling calculation**.

However, where ventilation air is used as a heat transport medium for cooling, the corresponding cooling supply, which can be supplied either by a cooling generator (section 2.6.1.1) or by free cooling (see section 2.6.1.2), is part of renewable cooling calculation.

In situations for which the ventilation airflow is increased above ventilation requirements for cooling purpose, the cooling supply due to this extra air flow is part of the renewable cooling calculation.

2.6.2.4. Comfort fans

Comfort fan products include a fan and electric motor assembly. Comfort fans move air and provide summer comfort by increasing the air speed around human body, which gives a thermal feeling of coolness. As opposed to ventilation (see section 2.6.2.4), there is no introduction of ambient air in the case of comfort fans; comfort fans only move indoor air. Consequently, they are not cooling indoor air but heating it (all electricity consumed is ultimately released as heat in the room where the comfort fan is used). As such, **comfort fans are not cooling solutions and are out of the scope of the renewable cooling definition**.

[18] This is the case for example when the outside temperature is colder than the indoor temperature and cooling can be achieved by simply opening the windows, and other more sophisticated strategies.

3. Options to quantify renewable cooling

In Chapter 1, the basic concepts regarding renewable cooling were presented. This part intends to propose definition options as regards the quantification of renewable cooling.

First, the definitions of the heating and cooling renewable energy share (or RES-HC share) and of the global renewable energy share (or global RES share) are presented. These definitions are necessary inputs to the second part, which focuses on the quantification of renewable cooling at cooling system level. Then, options for the integration of renewable cooling quantity in RES-HC and global RES share are proposed. This gives the necessary considerations to propose several possible options to satisfy the energy efficiency criteria, notably that the “final energy output significantly exceeds the primary energy input” and the inclusion of “minimum seasonal performance factors (SPF) for heat pumps operating in reverse mode” limits, enshrined in the Article 7(3) of REDII to qualify cooling systems as renewable. Finally, a method to account for waste heat and cold is proposed.

During the project duration (from end of 2019 until August 2021) a series of stakeholder consultation events took place, including a survey of EU-Member states energy statistics representatives and Eurostat, presentation and consultation at the CA-RES and CA-EED, two dedicated stakeholder workshops as well as bilateral meetings and consultations. These numerous feedbacks served to continuously improve and further develop the different options to quantify renewable cooling. Moreover, previous work like the definition provided for NL or FR [6] or Braungardt et al, 2019 [31] was considered as input.

3.1. RED II definition of RES-HC and global RES shares

The global RES share is the ratio of the gross final consumption of energy from renewable sources divided by the gross final consumption of energy, calculated at MS level.

The gross final consumption of energy from renewable sources is subdivided into 3 sectors: electricity, heating and cooling, and transport. The same division applies to the gross final consumption of energy.

The RES-HC share is the ratio of the gross final consumption of energy from renewable sources in the heating and cooling sector divided by the gross final consumption of energy in the heating and cooling sector, calculated at MS level.

As regards cooling systems, in accordance with the second subparagraph of Article 7(1), which prohibits double counting, electric energy input to cooling systems is included in the denominator of the global RES share and the renewable electricity share, but is not included in the denominator of the RES-HC share. Likewise renewable electricity (RES-E) is not included in the RES-HC share numerator, but in the RES-E numerator. The same situation applies to self-consumed renewable electricity. Renewable electricity consumed by cooling systems is not part of the RES-HC numerator.

Conversely, gas/fuel consumption energy input to cooling systems is included at both the denominator of the global RES share and of the denominator of the RES-HC share, whether renewable or non-renewable. Renewable gas/fuel consumed by cooling systems is part of the RES-HC numerator.

The same situation as for gas/fuel applies to heat energy input for cooling systems. Renewable heat consumed by cooling systems is part of the global RES share and of the RES-HC numerator.

3.2. Renewable energy quantity for cooling at cooling system level

In this part, the definition of the renewable cooling energy quantity at cooling system level is discussed. In sections 3.2.1 and 3.2.2 below we describe that cooling systems are to comply with the minimum SPF requirements in order to be included in the renewable cooling definition. Under this condition, possible expressions of the renewable cooling energy quantity are discussed in sections 3.2.1 and 3.2.2. The renewable cooling energy quantity at cooling system is then defined in part 3.2.3 to integrate the minimum SPF requirement. In report 3 of this study, the national renewable cooling energy quantity is established.

The study aims to examine all options and possibilities for defining and calculating renewable cooling. Consequently, this analysis is not restrained by the provision of REDII, but aims to provide a comprehensive analysis that could help policy and decision makers and *inter alia* could inform the work of the Commission on the Delegated Act. This implies that some of the options investigated to define the renewable cooling energy quantity may not be compatible with the provisions of the RED II.

3.2.1. Cold source energy

The renewable energy quantity for cooling is noted $E_{RES\text{-}C}$. In this section, only the contribution of the cold source to the renewable energy quantity presented in section 2.4.1 is discussed. The potential contribution of a renewable energy input to the expression of the renewable cooling energy quantity is discussed in section 3.2.2.

As explained in section 2.4.1, according to the RED II (Article 2 definitions (2) and (3)), what could potentially be counted as renewable cooling is the capacity of the cold source to absorb the heat transferred to the environment by the cooling system. In practice, this is equal with the sum of the heat removed from the space or process to be cooled and of its energy input. The quantity of the transferred heat to the cold source is the first possible quantity of renewable cooling proposed[19]:

$$E_{RES-C1} = Q_{C_{Source}} (= Q_{C_{Supply}} + E_{INPUT})$$ *Equation 3*

Where, $Q_{C_{Source}}$ is the heat transferred to the cold source (or heat sink), $Q_{C_{Supply}}$ is the cooling supply or cooling load, and E_{INPUT} is the energy input to the cooling system.

In terms of energy accounting, $E_{RES\text{-}C}$ will be integrated in the global RES share both at the numerator and denominator level. But the energy input to cooling systems is already counted in the denominator of the global RES share and renewable electricity share, if it is electricity, and in renewable heating, if the energy input is gas, liquid or heat. Adding $E_{RES\text{-}C1}$ to the denominator could then be interpreted as double counting of E_{INPUT}. Indeed, the energy input is counted a first time as a final energy consumption and a second time under $E_{RES\text{-}C1}$, as according to Equation 1, $Q_{C\_Source} = Q_{C\_Supply} + E_{INPUT}$.

[19] This does not yet consider constraints on the qualification of the system as renewable in the form of SPF thresholds. This will be introduced and discussed in section 3.2.3.

In addition to the apparent double counting, at equal cooling energy supply, the higher the energy input, the higher $E_{RES\text{-}C1}$ would be. It means that less efficient systems would have higher renewable cooling energy quantities.

A second option has been proposed in the literature [4] and was adopted by the Netherlands [5] for accounting renewable energy for free cooling systems[19]:

$$E_{RES-C2} = Q_{C\_Source} - E_{INPUT} \;(= \; Q_{C_{Supply}}) \qquad \text{Equation 4}$$

In comparison to $E_{RES\text{-}C1}$, as proposed in Equation 3, in Equation 4 the energy input is subtracted, and the double counting issue raised for $E_{RES\text{-}C1}$ is avoided. In addition, $E_{RES\text{-}C2}$ is equal to the cooling energy supply and is consequently independent from the cooling system efficiency. This is thus also an advantage compared to $E_{RES\text{-}C1}$.

In Recital 33 of the RED II, $E_{RES\text{-}C}$ can be understood as the "energy removed from the area" (which is Q_{C_Supply}) minus the energy input. It is also the solution used by France [6] to quantify renewable cooling energy for free cooling systems. It is noted as $E_{RES\text{-}C3}$.

$$E_{RES-C3} = Q_{C\_Supply} - E_{INPUT} \;(= Q_{C_{Source}} - 2 \times E_{INPUT}) \qquad \text{Equation 5}$$

In the case of $E_{RES\text{-}C3}$, after adding $E_{RES\text{-}C}$ to the RES share denominator it would only contain the cooling energy supply, as the E_{INPUT} contained from the gross final consumption would be subtracted again. This however is problematic as the energy input to cooling would not be counted in the denominator at all, while it is included in the current denominator. Therefore, from an accounting point of view, the $E_{RES\text{-}C3}$ expression is not compatible with global energy balances.

To choose between $E_{RES\text{-}C1}$ and $E_{RES\text{-}C2}$, priority is given to apply the energy efficiency criteria and avoid double counting. Therefore, **the starting point to define renewable energy quantity for cooling is chosen as in Equation 4 and reproduced here as Equation 6 below**[19].

$$E_{RES-C} = Q_{C\_Source} - E_{INPUT} \; = \; Q_{C_{Supply}} \qquad \text{Equation 6}$$

$E_{RES\text{-}C}$ is in fact equal to the cooling supply (if certain conditions are met as detailed in the following sections), howeverthe formulation as a difference between Q_{C_Source} and E_{INPUT} in Equation 6 is kept as it allows consistency with the RED II Article 2 (2) and (3) (see section 2.4.1), according to which what could potentially be seen as renewable cooling would be the cold source.

The applications of the criteria enshrined in Article 7(3) to calculate the quantity of renewable cooling are considered in section 3.2.2.

3.2.2. Definitions and possible bonus for renewable energy input

As discussed in the previous chapter, this analysis considers two components to differentiate out renewable cooling: the nature of **the cold source** and the nature of **the energy input** to the cooling system.

The objectives pursued here are to build renewable cooling definition options, which could help in the incorporation of additional renewable energy generation and to mitigate grid electricity peaks in the summer. Mitigating grid electricity peaks can be achieved in various ways, e.g. via renewable energy input other than electricity, such as solar heat, or via locally generated renewable electricity.

In this section, we first discuss the nature of the energy input and what types of energy input could be considered for the purpose of including it in the criteria to calculate renewable cooling. Then, proposed options for the renewable cooling energy quantity including the renewable energy input components are proposed.

It should be noted that the inclusion of the renewable energy input in the calculation of renewable cooling is one of the options, but may not be retained as the final preferred option.

Definition of renewable energy input

All cooling systems require electricity for pumps and or fans, but the main energy input type to the cooling generators of cooling systems vary. In most cases (more than 99% of cooling), the energy input is **electricity**. In the remaining less than 1%, the energy input is heat[20]. Each of these carriers can be renewable and non-renewable.

In principle, as the electricity supply in Member States is being gradually decarbonized, the share of the energy input for cooling systems supplied by renewable electricity increases. However, renewable electricity generation may not be concomitant to the cooling electricity consumption.

It is possible to design the renewable cooling definition in a way to support the development of renewable electricity generation **concomitant to cooling electricity consumption**.

Concomitance of renewable electricity generation and cooling electricity consumption can be defined by the different terms below, depending on the envisaged system boundary:

a) Local: Off-grid electricity only
b) Local: renewable generation under the same point of delivery of the distribution grid as the cooling system,
c) Local: renewable generation under the same interconnection between the electricity transmission and distribution grid (same secondary transformer Medium Voltage / Low Voltage) as the cooling system.
d) National: renewable generation in the same MS as where the cooling system is located

In order to relieve the grids at peak times, there is a need to define the geographic areas of concomitant renewable electricity generation. Southern European countries are already summer peaking. Grid interconnections with neighbouring countries are limited. Thus, concomitant renewable electricity generation should at least be located in the same country (option "d)" above).

The growing demand of cooling in cities is likely to exacerbate distribution grid congestion issues, which could be mitigated by the development of **local and concomitant** renewable electricity generation. A definition of renewable electricity including both the local and concomitant characteristics would thus offer the maximum contribution to relieving the strain on the grids at

[20] See part 1 section 3 and 7 on the evaluation of final energy consumption for cooling in Europe. Combustibles have only a sporadic presence in practice.

peak times. This would be the case for options c), b) and a). Options a) and b) are stricter as they allow targeting the cooling system level. They can for instance support strict obligations to cover additional cooling electricity consumption with concomitant local electricity generation. But these options would prevent to consider larger scale renewable electricity generation nearby, which could be less costly and which may appear necessary at least for district cooling installations. Option c) would help correcting imbalances between generation and consumption due to cooling at the level of the distribution grid. Going from option a) to d), concomitance of renewable energy generation and of cooling electricity consumption becomes more difficult to prove or estimate.

The rules defined for local and concomitant renewable electricity should apply equally to all cooling systems, either a simple cooling generator or a large and complex district cooling system[21]. In order to get a fair treatment of simple cooling generators and district cooling systems, the option c) is retained for local renewable electricity generation.

Other renewable energy inputs, such as renewable heat, gases and liquids (especially if not produced from renewable electricity at the same time as the peak) can also help in mitigating the strain on electricity grid stemming from peaking electricity consumption in cooling systems. In this respect, solar thermal cooling may be one of the promising technologies.

Renewable gas injection into the grid is increasing. This is already promoted through the RED II. Developing gas engines vapour compression or heat activated cooling generators consuming gas could both help further increase the consumption of renewable gas. It would also relieve the electric grid at peak time; as a consequence, there is no need to ensure a local and concomitant character for renewable gas, as is required for electricity. Renewable gas injected to the grid and consumed for cooling could thus be promoted through renewable cooling definitions. The same rationale applies to **renewable liquid and solid fuels**.

Renewable heat generation as an energy input to heat activated cooling generator could allow the addition of renewable heat as an energy input for cooling. This renewable heat can be directly generated from solar, geothermal or ambient heat or can be supplied by a district heating system[22], with a given percentage of renewable heat in its heat generation mix. When renewable heat is obtained from renewable electricity, the same local and concomitant characteristics could be used to judge of the renewable electricity content of the heat for the renewable cooling definitions.

In case both renewable and fossil energy input under the form of fuel, gas or heat, are supplied to the cooling system, there is still a need to check the concomitance of the renewable energy input and of the cooling consumption. For instance, in the case of a district heating supply to a heat activated cooling generator, the renewable energy input content may vary significantly depending on the season. And although in average the renewable heat is e.g. 50 % renewable, this figure could be lower in the summer. In that sense, it is necessary to check the concomitance of the renewable energy input and of the cooling system energy input also for solid, liquid and gaseous fuels, and heat.

As regards **concomitance estimation**, the study team proposal is to use measurement (metering), which appears as the only means to assess the consumption of local renewable energy by cooling systems properly. However, alternatively well substantiated calculations may also be appropriate as long as they consider the high number of diverse variants of systems in

[21] District cooling is addressed in part 1 section 1.4.

[22] A more usual configuration is that district cooling systems provide directly cooling via pipes and heat exchangers located in the premises of the consumer. District heating on the other hand can provide the energy input, i.e. heat that is required to drive local cooling generators. In this later case, district heating supplies distributed cooling generators (ab/adsorption chillers) with heat required to drive them.

terms of different ratio of renewable energy generation and cooling load, the relevance of non-cooling related loads, electrical as well as thermal storage and practical, real-life management of these storage systems. To properly account for the total annual share of the cooling system energy input indeed supplied by local renewable generation, a maximum acquisition time step[23] should be specified: it should be typically lower or equal to 15 minutes for electricity and 1 hour for solid, liquids, gaseous fuels and heat.

Metering has additional benefits: it could allow increasing the very limited knowledge on the real energy input to cooling systems and could also allow detecting potential problems with local renewable energy generation.

Bonus system for renewable energy input

Two options are considered for the possible inclusion of renewable energy input in the calculation of renewable cooling: a modification of the formulation of the renewable cooling quantity for cooling, which is described here below, and the inclusion of renewable energy input in the formulation of the SPF threshold (cf section 3.4).

The cooling quantity that could be considered renewable if certain conditions are met can be expressed as previously established in section 3.2.1 under Equation 6 and reproduced below. This calculation formula is hereafter called option A1.

$$E_{RES-C} = Q_{C\_Source} - E_{INPUT}$$

Equation 7

In order to incentivise the development of local renewable energy, an alternative formulation to option A1, called A2, is proposed under Equation 8. In option A2, E_{INPUT_RE} is limited to the share of the energy input to cooling systems corresponding to the consumption of concomitant local renewable energy generation. In a third option B, E_{INPUT_RE} includes all renewable energy input to cooling systems, either from local concomitant generation or from the grid.

$$E_{RES-C} = (Q_{C\_Source} - E_{INPUT}) + E_{INPUT\_RE} = Q_{C\_Supply} + E_{INPUT\_RE}$$

Equation 8

Where:

- E_{INPUT_RE} is the renewable energy input share to the cooling system.

Options A2 and B would entail to count renewable electricity generation in both the RES-HC share and the RES-E share. Counting the same electricity twice, would go against the legal requirements in the second sub-paragraph of Article 7(1) of RED II stipulating: „With regard to point (a) [calculation of RES-E], (b) [calculation of RES-HC], or (c) [calculation of RES-T] of the first subparagraph, gas, electricity and hydrogen from renewable sources shall be considered only once for the purposes of calculating the share of gross final consumption of energy from renewable sources." **It means that options A2 and B are not in conformity with the requirements of the RED II, when the energy input is electricity, and would only become**

[23] Time period between two output of the measurement system.

feasible after a modification of the RED II. Thus, option A1 is considered as the one being described further in the calculation (chapter 4 and the guidance document [29]).

Despite this preference for option A1 due to current legal conditions, all three options are analysed in report 3 of this study [28].

3.2.3. Inclusion of SPF constraints

The section introduces consideration to include the parameter s_{SPF}, reflecting Seasonal Performance Factor (SPF) requirements (cf. section 3.4) to give the final expression of $E_{RES\text{-}C}$ for each definition option.

S_{SPF} is defined at cooling system level as the share of the cooling supply, which can be considered as renewable according to the SPF requirements, expressed as a percentage. The term is discussed and defined in more detail in chapter 3.4. $E_{RES\text{-}C}$ at cooling system level should then be written as in Equation 9 and Equation 10 below.[24]

Option A1:

$$E_{RES-C} = (Q_{C_{Source}} - E_{INPUT}) \times s_{SPF}$$

Equation 9

Option A2 and option B:

$$E_{RES-C} = (Q_{C_{Source}} - E_{INPUT}) \times s_{SPF} + E_{INPUT\_RE}$$

Equation 10

3.3. Options to integrate national renewable cooling contribution in RES-HC share and global RES share

The national renewable cooling quantity, noted $E_{RES-C-MS}$, is the sum of the contribution of all cooling systems (Equation 11) that qualifies renewable according to an SPF treshold:

$$E_{RES-C-MS} = \sum E_{RES-C}$$

Equation 11

Where $E_{RES\text{-}C}$ is the renewable cooling energy quantity of cooling systems which qualify as renewable, as described in section 3.2.

In order to integrate the national renewable cooling energy quantity in the RES-HC share and global RES share calculations, two options can be adopted.

For both methods, the numerator of the RES-HC share and of the global RES share are increased by $E_{RES-C-MS}$.

[24] According to the discussions in chapter 3.4.4, s_{SPF} needs to be replaced by s_{SPF_RE} if the study team's suggestion for the "Modified SPF metrics, when considering only grid electricity and fossil fuel, gas and heat energy input" is applied.

In option 1, the gross final energy consumption for the heating and cooling sector (denominator in the RES-HC share), and the total gross final energy consumption (denominator in the global RES share), are increased by the quantity of $E_{RES-C-MS}$, i.e. adding only the aggregated quantities of those cooling supply from cooling systems, which qualify as renewable. In option 1, as the same quantity is added to both the numerator and denominator of the shares, the RES-HC and global RES shares can only increase. Progressively, as more and more cooling systems will comply with the SPF requirements (as discussed in report 3 of this study), the RES-HC and global RES shares will continue to increase.

In option 2, the gross final energy consumption of the heating and cooling sector (denominator in the RES-HC share), and the total gross final consumption of energy in all sectors (denominator in the global RES share), are increased by the sum of the cooling supply of all cooling systems whether they satisfy the SPF constraint or not. This operation leads to a reduction of the RES-HC share and of the global RES share at the introduction of cooling in the shares calculation, if the quantity added to the numerator ($E_{RES-C-MS}$) is low (i.e. if the share of the cooling systems which qualify as renewable is low). This option increases significantly the burden for statistical reporting by Member States because the cooling supply of all cooling systems, and not only of the ones qualifying as renewable, should be reported. **For this reason, option 1 is proposed in the calculation methodology (chapter 4) and the guidance document [29].[25]**

The impact of options 1 and 2 combined with different SPF constraints is analysed in the 3rd part of this report (impact assessment of definition options).

Comparison with heat pumps and renewable heating

Option 1 reflects the way in which heat pumps are accounted for in SHARES: Only renewable heat from heat pumps is included in both numerator and denominator. Heat pumps not passing the SPF threshold and thus not being counted as renewable energy, are not included.

However, there is an important difference between the heating and the cooling case. For heating, the final energy consumption of all other heating systems (except electric heating) is included in the denominator. This would not be the case under option 1 for cooling. So in reality, the accounting of renewable heat from heat pumps is closer to option 2: heat pump renewable heat is added to the numerator while renewable energy from heat pumps used for heating and all heating supply is included at the denominator.

Comparatively, for cooling in the case of option 2, the impact on the gross final energy consumption and consequently on the global RES share and RES-HC share would be much larger because the cooling supply is presently not included at all.

Integration of cooling in national energy balances

Currently, the cooling supply of cooling systems is not included in national energy balances, and only their energy input is. Adding the cooling supply to the gross final energy consumption of the national energy balances would increase the gross final consumption of energy. This change in accounting conventions would affect negatively the EU and national energy efficiency shares. The impact would however be limited in the case of option 1, where the same renewable cooling quantity is added to both the numerator and denominator, as long as the number of cooling systems and their renewable cooling output qualifying as renewable remains low.

Alternatively, the inclusion of renewable cooling can be done only for the calculation of the global RES share and of the RES-HC share; and not in energy balances. In this case, the impact of the

[25] The study team emphasizes that this choice is due to pragmatic reasons. Considering the nature of the RES and RES-HC calculations, the integration of the full cooling supply could also be justified.

integration of renewable cooling is limited to renewable energy targets, whichever option (1 or 2) is chosen.

3.4. SPF requirements

3.4.1. Objectives and constraints

As explained previously, the renewable cooling definition and calculation aim at promoting the development of cooling solutions that are highly efficient and utilise renewable cold sources. These are cooling systems with high seasonal performance factors, including free cooling as defined in section 2.5.2. The definitions could also help developing (local) renewable energy input to cooling systems, if the related option is chosen.

While setting SPF requirements in the context of renewable cooling calculation, the corresponding gains should be additional to the ones resulting from existing energy efficiency measures and energy performance requirements as defined in Regulation (EU) 206/2012 [13], Regulation (EU) 626/2011 [22], Regulation 2281/2016 [7] and in the Energy Efficiency Directive [16].

When defining SPF requirements, it is necessary to ensure a fair treatment of the different energy sources and of the different cooling technologies. These requirements should allow a calculation methodology of limited complexity, comparable to the one used for heat pumps in Commission decision (EU) 2013/114 [12], which can be based upon available standard SPF data, while respecting the specific characteristics of cooling[26]. SPF requirements should also allow each MS to have access to renewable cooling solutions, considering the specific climatic conditions.

The analysis in the following sections uses these objectives and constraints as guiding principles to develop the SPF requirements for renewable cooling.

3.4.2. SPF definition, availability and boundary conditions

According to the RED II article 7.3, minimum SPF_P are required for reversible heat pumps that can operate in both heating and cooling mode. Since cooling generators are heat pumps in technical and operational terms, even if by manufacturing design not all cooling generator can function in both heating and cooling mode, it would be unfair to exclude non-reversible heat pumps from the scope of cooling and of renewable cooling. This analysis therefore proposes to apply the SPF_P requirements to all types of cooling systems. The methodology proposed thus takes into consideration the availability of SPF_P values for cooling systems.

Standard and measured SPF

Standardised SPF values are available for electric vapour compression cooling generators and combustion engine vapour compression cooling generator due to the presence of Ecodesign requirements (in Regulation (EU) 206/2012 [13] and (EU) 2281/2016 [7]). These standardized SPF are described in section 1.5 of the part 1 of this report. Values are available for these cooling generators up to 2 MW for comfort cooling and up to 1.5 MW for process cooling. Other technologies and capacity scales standard values are not available. As regards district cooling, standard values are not available but measurements are used and available; these allow to compute SPF values at least on a yearly basis.

[26] See section 2.1 comparing heating and cooling and describing the specific characteristics of cooling.

This study thus proposes to use two distinct cooling system categories: one category using standard SPF values and the other category (where standard values are not available or measurement is standard practice) measured SPF values, separated by cooling capacity thresholds. For cooling generators with a cooling capacity below 1.5 MW, standard SPF_P could be used, while measured SPF would be necessary for district cooling and for cooling generators with cooling capacities higher than or equal to 1.5 MW.

In addition, for all cooling systems without standard SPF, which includes all free cooling solutions and heat activated cooling generators, a measured SPF would be required in order to be accounted as renewable cooling.

SPF and climate variability

Standardised operating conditions are described in Ecodesign regulations ([7], [13]). A single average climate is considered for the whole EU, which prevents from incorporating the climate impact in standard SPF requirements.

However, where measured data is available, climate impact on SPF is included and climate impact could be accounted for in establishing the SPF thresholds. The problem is that currently very limited measured SPF data is available to do so. Consequently, the impact of climate on SPF is not used in setting SPF requirements.

Standard SPF by cold source type

For water cooled cooling generators, only two sets of cold source temperature are required in Ecodesign regulations and thus made publicly available by manufacturers. It corresponds to the standard cases, in which heat is released to the cold sources (heat sink) via a cooling tower[27] and to ground coupled application[28]. Hence, standardised SPF_P values consider the better performance of ground low temperature cold source. The ground coupled conditions, a constant inlet temperature of 10 °C, are representative of aquifer conditions in the average climate. There is no possibility to distinguish the various types of ground coupled installations (which would have different inlet temperatures and different SPF_P). Ambient water conditions are not available, but also mainly used in district cooling systems where standard SPF_P is not proposed to be used. Thus, the study team does not see the need to differentiate SPF_P thresholds by cold source type as it is already taken into account in the SPF_P metrics itself.

However, the development of air as a cold source in particular in cities is not sustainable because the heat released by the cooling generators contribute to heating the ambient air. In the summer, they contribute to the urban heat island effect, which in turn increases the need for and the consumption (energy input) for cooling. In addition, there may be an important cooling consumption increase when superposing at different building heights the heat rejection systems of cooling generators on tall building facades or inner courts. This effect is already observed in some other parts of the world [14].

Regarding ambient waters, the temperatures of rivers is increasing due to climate change and growing heat rejection by industries and power plants, which is already a source of concern in Europe [15]. Their capacity to absorb more heat should not be strained further in view of global warming and the need to preserve biodiversity in natural water bodies.

Consequently, Member States should be free to exclude certain categories of cooling systems of the renewable cooling energy definitions in presence of cold sources that should be preserved for specific geographic areas.

[27] Cooling towers are described in part 1, in section 1.2, Figure 11.
[28] These conditions are presented in part 1, section 1.5, Table 5.

SPF metrics

In order to ensure a fair treatment of all cooling technologies and of the different energy sources, SPF requirements incorporate a metric of primary energy conversion efficiency[29]. Such a metrics is already in use in Regulation (EU) 2281/2016 [7] and Annex VII of REDII establishing the basic methodology for calculating renewable energy from heat pumps used for heating[30]. However, since its publication, the default primary energy coefficient has evolved and is now of 2.1 (1/η=2.1, where η is the average ratio of total gross production of electricity to the primary energy consumption for electricity production in the EU defined in Regulation 2002/2018 [16]) instead of 2.5 as set in Regulation (EU) 2281/2016 [7].

For instance, for electric vapour compression cooling generators, the SPF (the index p is used to clarify that the SPF is defined in terms of primary energy) is defined as follows:

- For space cooling: $SPF_p = \frac{SEER}{\frac{1}{\eta}} - F(1) - F(2)$
- For process cooling: $SPF_p = \frac{SEPR}{\frac{1}{\eta}} - F(1) - F(2)$

Where:

- SEER and SEPR are seasonal performance factors[31] (SEER stands for “Seasonal Energy Efficiency Ratio”, SEPR stands for “Seasonal Energy Performance Ratio”) in final energy defined according to Regulation (EU) 2281/2016 [7] and (EU) 206/2012 [13],
- η is the average ratio of total gross production of electricity to the primary energy consumption for electricity production in the EU (η = 0.475 and 1/η=2.1) [16][32],
- F(1) and F(2) are correction factors according to Regulation (EU) 2281/2016. These coefficients do not apply to process cooling in Regulation 2281/2016 [7], as the SEPR final energy metrics is directly used. In absence of adapted values, the same values used for SEER conversion are also used for the SEPR conversion.[33]

SPF boundary conditions

It is proposed to use the cooling generator SPF boundary conditions defined in Regulation (EU) 2281/2016 [7] and in Regulation (EU) 206/2012 [13]. In the case of water-to-air and water-to-water cooling generators, the energy input required to make the cold source available is included via the F(2) correction factor. The SPF boundary conditions are shown in Figure 6. These boundary conditions apply for all cooling systems, either free cooling systems or systems containing cooling generators.

These boundary conditions are similar to the ones for heat pumps (used in heating mode) in Commission Decision 114/2013 [12]. The difference is that for heat pumps, the electricity consumption corresponding to auxiliary power consumption (thermostat-off mode, standby mode,

[29] This is already the case for heat pumps used for heating, where the minimum SPF threshold is calculated by using η expressing power system efficiency (See Annex VII of REDII and Commission Decision 114/2013 establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies).
[30] According to Annex VII “Only heat pumps for which SPF > 1,15 * 1/η shall be taken into account” for the purposes of establishing renewable energy from heat pumps used for heating.
[31] Report 1 of this study on “Cooling Technologies Overview and Market Share” provides more detailed definitions and equations for these metrics in chapter 1.5 “Energy efficiency metrics of state-of-the-art cooling systems”.
[32] In report 3 [28] of this study on the impact assessment, the main calculations were done using EU-wide η-values, in one case remaining constant until 2050 and in another case being gradually reduced. Subsequently, an additional analysis is being provided on the impact of a system where Member States can choose between the national value and the average EU value.
[33] In order to simplify the calculations and due to the limited impact, the factors F(1) and F(2) could also be dropped in the implementation of the calculation procedure.

off mode, crankcase heater) is not taken into account to evaluate the SPF. However, as in the case of cooling both standard SPF values and measured SPF will be used, and given the fact that in the measured SPF auxiliary consumption is taken into account, it is necessary to include auxiliary power consumption in both situations.

For district cooling, distribution cold losses and distribution pump electric consumption between the cooling plant and the customer substation should be included in the estimation of the SPF. This is necessary to ensure a fair treatment between individual cooling systems and district cooling systems.

In the case of air based cooling systems ensuring also the ventilation function, the cooling supply due to ventilation air flow should not be accounted. The fan power due to ventilation should also be discounted in proportion of the ratio of the ventilation air flow to the cooling air flow.

In the case of air based cooling systems with internal cold recovery, the cooling supply due to the cold recovery should not be accounted. The fan power due to the cold recovery heat exchanger should be discounted in proportion of the ratio of the pressure losses due to the cold recovery heat exchanger to the total pressure losses of the air based cooling system.

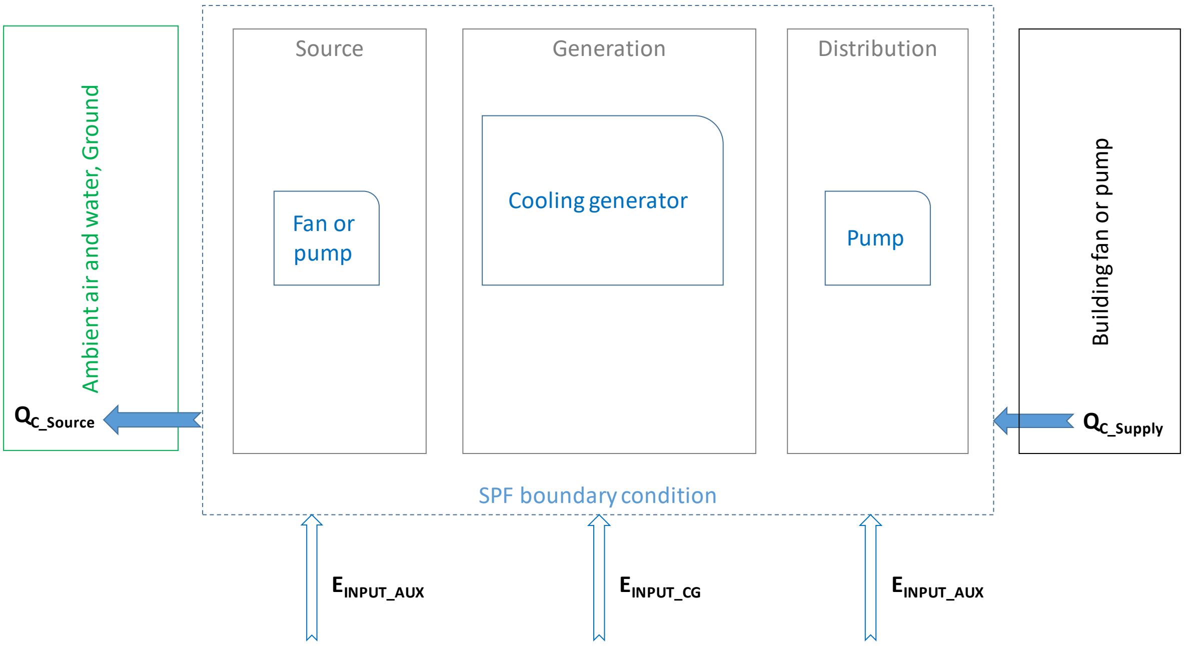

Figure 6 Illustration of SPF boundary conditions for cooling generator using standard SPF and district cooling (and other large cooling systems using measured SPF), where E_{INPUT_AUX} is the energy input to fan and/or pump and E_{INPUT_CG} the energy input to the cooling generator

3.4.3. Possible forms of SPF$_P$ thresholds2

The simplest form of efficiency requirement is to use a **single threshold**, which is the option currently adopted by the Netherlands [5] and France [6]. Such single threshold can be expressed by the following set of conditions, applied at cooling system level:

If $SPF_P < SPF_{pLIM\_THRE}$, $S_{SPF_P} = 0$ %.

If $SPF_P \geq SPF_{pLIM\_THRE}$, $S_{SPF_P} = 100$ %.

Where:

- SPF_{pLIM_THRE} is the SPF_P threshold.
- s_{SPF_P} is the share of the system cooling supply that satisfies the SPF_P threshold and is thus counted as renewable

In order to ensure additional gains over existing energy efficiency measures (see section 3.4.1), $SPF_{pLIM\_THRESHOLD}$ should be ambitious and promote only targeted systems considered as innovative.

An alternative approach is to use a **progressive threshold**. This progressive approach can be built with different methods. Two of such possible methods are proposed in the following.

In the **first progressive approach**, the s_{SPF_P} is linearly linked to the SPF_P and two thresholds parameters ($SPF_{pLIM\_PROG1\_LOW}$ and $SPF_{pLIM\_PROG1\_HIGH}$) are used to define this linear function.

If $SPF_P < SPF_{pLIM\_PROG1\_LOW}$, $s_{SPF_P} = 0$ %.

If $SPF_{pLIM\_PROG1\_LOW} \leq SPF_P \leq SPF_{pLIM\_PROG1\_HIGH}$, $s_{SPF_P} = \frac{SPF_P - SPF_{pLIM\_PROG1\_LOW}}{SPF_{pLIM\_PROG1\_HIGH} - SPF_{pLIM\_PROG1\_LOW}}$ %.

If $SPF_P > SPF_{pLIM\_PROG1\_HIGH}$, $s_{SPF_P} = 100$ %.

$SPF_{pLIM\_PROG1\_LOW}$ would be based upon the efficiency of standard cooling systems (minimum eco-design requirements). $SPF_{pLIM\_PROG1\_HIGH}$ can be adjusted to the value of the target to be reached, corresponding for instance to $SPF_P \geq 9.5$ for free cooling in France [6] (SEER ≥ 20, converted to primary SPF_P as 20/2.1=9.5)[34].

In the **second progressive approach**, it is proposed to use the following metrics, for which the share of renewable cooling is proportional to the energy input reduction as compared to a reference noted SPF_{pLIM_PROG2}:

If $SPF_P < SPF_{pLIM\_PROG2}$, $s_{SPF_P} = 0$ %.

If $SPF_P \geq SPF_{pLIM\_PROG2}$, $s_{SPF_P} = (1 - \frac{SPF_{pLIM\_PROG2}}{SPF})$ %.

SPF_{pLIM_PROG2} would be based upon the efficiency of standard cooling systems (minimum eco-design requirements).

- A numerical example for visualising the different options of defining SPF_P thresholds as proposed in this study is shown in Figure 7.

This example is based on the following set of values and is discussed further in section 3.4.5:

- $SPF_{pLIM\_THRE} = 6$
- $SPF_{pLIM\_PROG1\_LOW} = 2.8$
- $SPF_{pLIM\_PROG1\_HIGH} = 9.5$
- $SPF_{pLIM\_PROG2} = 2.8$

[34] The threshold of EER=8 in final energy terms defined in the Netherlands would translate into a value of 8/2,1=3,8 in primary energy terms. However, for both thresholds (FR and NL) it should be noted that a direct comparison is difficult since they build on a single threshold system, not a progressive one as proposed here.

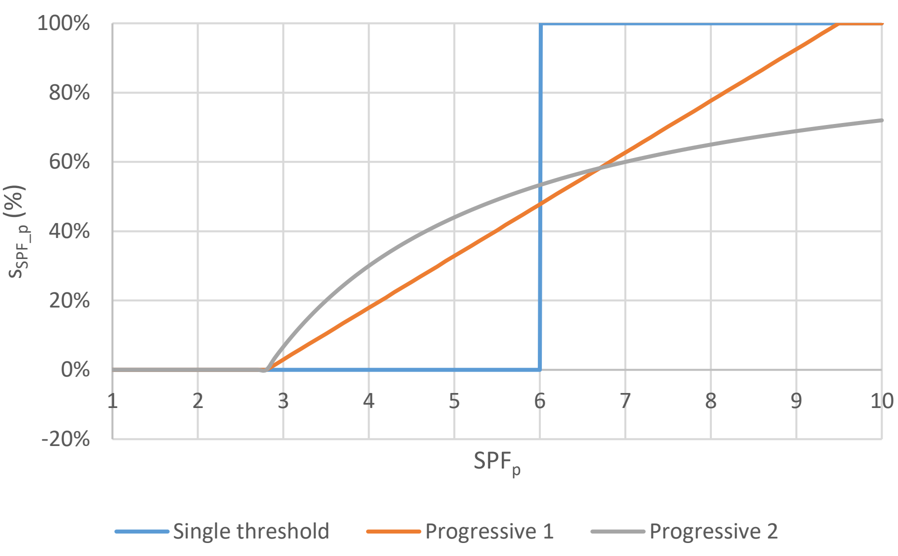

Figure 7 Illustration of exemplary single and progressive thresholds

For the progressive metrics, when the SPF_P passes from 2.8 (progressive threshold) to 5.6, energy input for cooling is divided by two and s_{SPF_P} value reaches 50 % with progressive method 2 and 43 % with progressive method 1.

The free cooling minimum SEER in France [6] corresponds to a SPF_P in primary energy (with conversion explained in section 3.4.2) of 20/2.1= 9.5. The single threshold and progressive threshold 1 would give s_{SPF_P} = 100 % while the progressive threshold 2 would give s_{SPF_P} = 70%, which translates the energy input reduction of 70% as compared to the reference chosen (SPF_{pLIM_PROG1}=2.8 here).

The progressive thresholds can be at the same time more ambitious for very efficient systems and it also allows to account for renewable cooling shares for products which are less efficient. The complementarity to existing energy efficiency measures is discussed in section 3.4.5.

3.4.4. Promoting renewable energy input through a modified SPF_P threshold

In the following, we discuss the possible integration of renewable energy input (as defined in section 3.2.2, i.e. concomitant and local characteristics for electricity and renewable fuel, gas and heat) in a modified SPF_P threshold: (1) Pure primary energy SPF_P metrics, with a single primary energy factor for electricity, (2) Primary energy SPF_P metrics, with distinct primary energy factors for grid and local renewable electricity and (3) Modified SPF_P metrics, when considering only grid electricity and fossil fuel, gas and heat energy input. Each of these options may be linked to the forms of SPF_P thresholds as described in chapter 3.4.3.

In chapter 3.4.2 we discussed that an SPF_P metrics based on final energy is not suitable because it would not allow an appropriate treatment of cooling systems using different energy sources and energy input. Therefore, this option is not further discussed.

Primary energy SPFP metrics, with a single primary energy factor for electricity and separate thresholds for heat activated cooling systems

The primary energy SPF_P metrics proposed (cf section 3.4.2) allows to compare all cooling systems on a single scale.

But the same SPF_P threshold cannot be used for both electric vapour compression (which can be either driven by electricity or by a gas or fuel combustion engine) and heat activated solutions (with heat, gas or other fuels as energy input), as the latter have much lower SPF_P values than electric driven vapour compression solutions. The reduced energy efficiency in terms of seasonal coefficient of performance (SCOP/SPF_P) is compensated by higher primary energy efficiency stemming from the need for less energy transformation. This is especially true for heat activated solutions with 100 % renewable heat. Cooling driven by renewable heat is one of the low carbon solutions. Their added benefit is that they do not use electricity and thus represent a diversification potential away from the almost 100% electricity based cooling, which considering the rapid growth in cooling and the propensity for cooling to concentrate in high peak demand periods, would further contribute to a more sustainable and stable cooling and energy system. In particular in case of solar heat cooling, the peak solar yield and peak cooling demand largely coincides. This provides advantages regarding the relief of the electricity grid due to cooling demand peaks. Thus, in the choice of SPF_P metrics, heat activated solutions need to be considered and treated on an equal footing with other cooling systems and harnessed for their diversification potential[35]. Specific thresholds would thus be required for heat activated cooling systems.

However, renewable heat, if obtained from renewable gas or other fuels (biogas or liquid fuels), could also serve as an energy input to combustion engine vapour compression cycle. And the use of a specific SPF_P threshold for heat activated cooling generator would distort the competition in favour of heat activated cooling generators, which are less efficient. Hence, the development of gas or fuel vapour compression cooling generators (whose market share is very low today), which could also help relieving the electricity grid at peak time, would be discouraged. This could be used as an argument for specific SPF_P values for bio-based gas, solids or liquids. However, another more universal option of SPF_P metrics is proposed below. Another issue is that there are various possible cooling technologies, which can use renewable heat as energy input. However, their efficiency at maturity is not yet known. It is not evident that using the SPF_P level of existing technologies (e.g. absorption cooling) is the best choice to make in order to promote an efficient use of renewable heat.

Overall, the study team does not propose this solution of a « *Primary energy SPF_P metrics, with a single primary energy factor for electricity and separate thresholds for heat activated cooling systems"* due to the challenges and problems discussed above.

Primary energy SPFP metrics, with distinct primary energy factors for grid and local concomitant renewable electricity

In order to favour the development of local renewable energy input[36], local renewable and grid renewable energy can be distinguished by using a single primary energy factor for the grid (for the complete mix including renewables). This formulation may be adjusted country by country with national primary energy factors; however, this would tend to lower the additional incentive for countries with already high RES-E shares and the study team proposal is to use a single EU average primary energy factor for the grid.

[35] Solar heat activated cooling solutions are considered as renewable cooling solutions by international literature (see IEA Solar Heating and Cooling Technology Collaboration Programme (SHC TCP) at: IEA SHC || Projects (iea-shc.org); Solar Heat Worldwide 2021 report; Solarthermalworld.org Newsletter).

[36] The most obvious case is electricity. However, the distinct primary energy factors can also be applied e.g. for gas or other fuels and heat.

$$SPF = \frac{Q_{C\_Source}}{E_{INPUT1} \times PEF1 + E_{INPUT2} \times PEF2 + \cdots + E_{INPUT\_GRID} * PEF_{GRID}}$$ *Equation 12*

Where:

- E_{INPUTi} are local renewable energy inputs from different sources
- $PEFi$ are the primary energy factors of local renewable energy sources
- E_{INPUT_GRID} is the share of energy input from the grid
- PEF_{GRID} is the primary energy factor of the grid

The difference in primary energy factor between the grid and local renewable would allow to increase the SPF_P when grid electricity is replaced with local renewable electricity: for instance, the primary energy factor of PV generation is 1 and the one of the grid 2.1 (cf section 3.4.2). However, for fuels (gas, solid, liquid) or heat energy input, the difference between grid/fossil primary energy factor and renewable primary energy factor is minimal, and even possibly not in favour of local renewable energy. Hence, such a metrics would not allow to favour the development of renewable energy for local renewable gas/fuel or heat.

Overall, the study team does not propose this solution of a « *Primary energy SPF_P metrics, with distinct primary energy factors for grid and local concomitant renewable electricity"* due to the challenges and problems discussed above.

Modified SPF_P metrics, when considering only grid electricity and fossil fuel, gas and heat energy input (SPF_{pRE})

As a consequence, an alternative metrics, which is noted SPF_{pRE}, could be applied. The renewable energy input (as defined in section 3.2.2, which includes local and concomitant renewable electricity and renewable fuels, gas and heat) consumed by the cooling system is removed from the denominator. Thus, what remains at the denominator is grid electricity input to the cooling system (fossil and renewable electricity from the grid) and non-renewable fuel, gas or heat energy input to the cooling system. It is defined as follows in Equation 13:

$$SPF_{P\_RE} = \frac{Q_{C\_Supply}}{E_{INPUT} - E_{INPUT\_RE\_LOCAL}} = \frac{SPF_P}{1 - \tau_{RE}}$$ *Equation 13*

Where:

- SPF_P is the primary energy seasonal performance indicator defined in section 3.4.2.
- $E_{INPUT\_RE\_LOCAL}$ is the local and concomitant renewable electricity and renewable fuel, gas and heat energy input to the cooling system.
- τ_{RE} is the ratio between $E_{INPUT\_RE\_LOCAL}$ and the total energy input to the cooling system.

In case there is no local renewable self-consumption, $SPF_{P\_RE} = SPF_P$. However, there can be a rather theoretical case, when the share of total renewable energy input reaches 100 % of the energy input. In this case, SPF_{pRE} tends to infinity, which is not an issue *per se* as this metrics is only used indirectly to define the renewable cooling share. In calculation terms, when the renewable energy input reaches 100%, the entire cooling supply can be counted as renewable. Different options how SPF_{P_RE} criteria and different threshold forms would affect the achieved renewable cooling share are discussed below.

This metrics rewards equally energy efficiency and local renewable energy input developments. It also has the advantage to offer the possibility to fix a single threshold for all types of cooling generators, heat activated solutions included.

It is important to note that there is no accounting of the renewable energy input as energy quantity. Rather, the renewable energy input affects the share of cold supply that can be considered as renewable. Thus, the modified SPF_{pRE} metrics may be applied also under option A1 as described in chapter 3.2.2.

Overall, the study team proposes this solution of a « *Modified SPF_P metrics, when considering only grid electricity and fossil fuel, gas and heat energy input”*.

It is to be noted that SPF_{pRE} contains a bonus compared to SPF_P but its use is optional, as it requires measurement and more elaborate data collection. The use of SPF_P still yields renewable cooling quantities when part of a national cooling stock passes the minimum SPF_P threshold. The choice of the types of SPF value to be used should balance the need for more efforts to measure and collect data with the potentially higher renewable cooling quantities yielding from this effort.

The way how SPF_{pRE} is proposed to be included in the overall calculation methodology is described in chapter 4.3.

Combination of SPF_{pRE} and different threshold forms

In section 3.4.3, three possible forms for SPF_P threshold were proposed, a single and two progressive thresholds. According to the considerations above for a modified SPF_P metrics to considering only grid electricity and fossil fuel, gas and heat energy input, the corresponding equations are modified by replacing SPF_P by SPF_{pRE} and s_{SPF_P} by $s_{SPF_{P\_RE}}$. This is illustrated below:

- Single threshold:

If $SPF_{pRE} < SPF_{pLIM\_THRE}$, $s_{SPF_{P\_RE}} = 0\ \%$.

If $SPF_{pRE} \geq SPF_{pLIM\_THRE}$, $s_{SPF_{P\_RE}} = 100\ \%$.

- Progressive threshold 1 (with 2, i.e. a low and high thresholds):

If $SPF_{pRE} < SPF_{pLIM\_PROG1\_LOW}$, $s_{SPF_{P\_RE}} = 0\ \%$.

If $SPF_{pLIM\_PROG1\_LOW} \leq SPF_{pRE} \leq SPF_{pLIM\_PROG1\_HIGH}$, $s_{SPF_{P\_RE}} = \frac{SPF_{p\_RE} - SPF_{p\_LIM\_PROG1\_LOW}}{SPF_{p\_LIM\_PROG1\_HIGH} - SPF_{p\_LIM\_PROG1\_LOW}}\ \%$.

If $SPF_{pRE} > SPF_{pLIM\_PROG1\_HIGH}$, $s_{SPF_{P\_RE}} = 100\ \%$.

- Progressive threshold 2 (with 1 minimum threshold):

If $SPF_{pRE} < SPF_{pLIM\_PROG2}$, $s_{SPF_{P\_RE}} = 0\ \%$.

If $SPF_{pRE} \geq SPF_{pLIM\_PROG2}$, $s_{SPF_{P\_RE}} = \left(1 - \frac{SPF_{P\_LIM\_PROG}}{SPF_{P\_RE}}\right)\ \%$.

The result of combining these thresholds and the SPF_{pRE} metrics is shown for reference parameters defined in section 3.4.5 and already used in Figure 7: for the single threshold in Figure 8, for the progressive threshold 1 in Figure 9, and for the progressive threshold 2 in Figure 10.

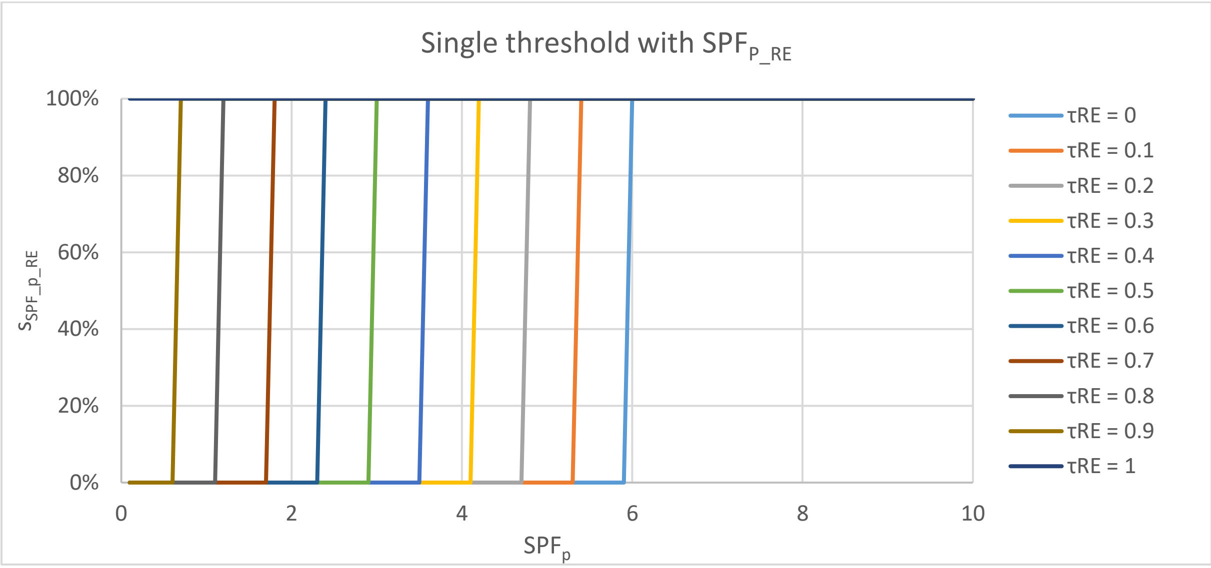

Figure 8 Illustration of $s_{SPF_{P\_RE}}$ variation with single SPF_{pRE} threshold, for various SPF_P values and shares of renewable energy input (τ_{RE})

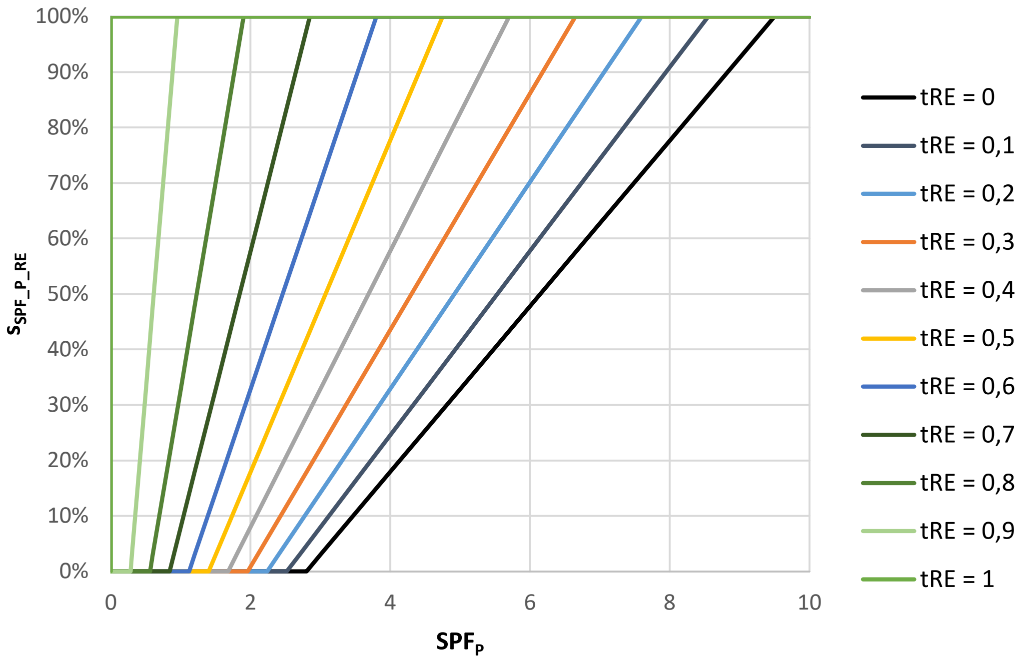

Figure 9 Illustration of $s_{SPF_{P\_RE}}$ variation with progressive SPF_{pRE} threshold 1, for various SPF_P values and shares of renewable energy input (τ_{RE})

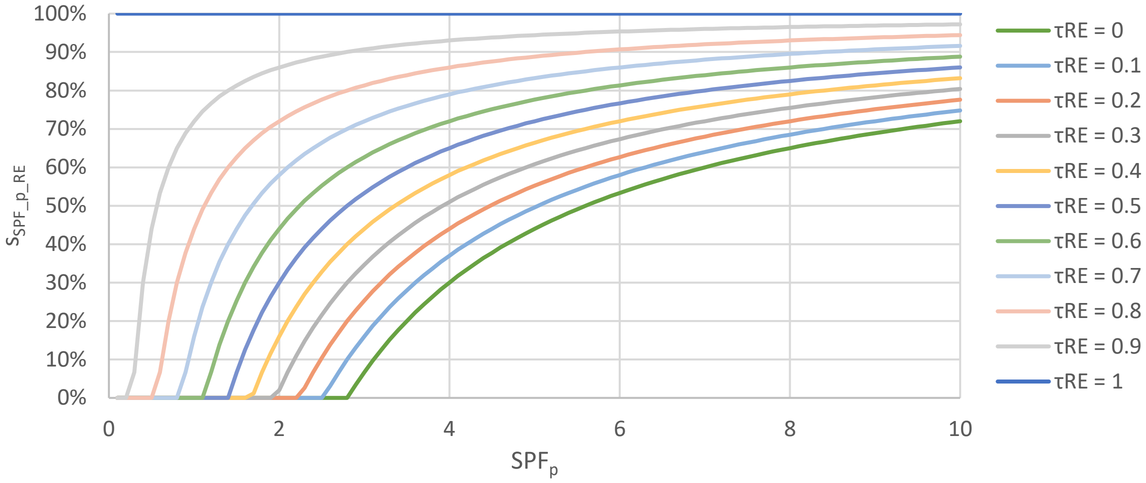

Figure 10 Illustration of $s_{SPF_{P}\_RE}$ variation with progressive SPF_{pRE} threshold 2, for various SPF_P values and shares of renewable energy input (τ_{RE})

3.4.5. Choice of a SPF_P threshold form

To compare the merit of the different thresholds, numerical values need to be established for their parameters. Methods to establish these values are proposed below. The resulting shares of the cooling supply counted as renewable are then illustrated by numerical examples to understand their impact at cooling system level and to propose a preferred threshold type.

In the first version of the definitions and methodology, presented to the stakeholders in November 2020, separate thresholds were considered for different configurations of cooling generators (air-to-air, water-to-air, air-to-water, water-to-water). Furthermore, different thresholds were proposed for cases of comfort and for process cooling. The method has been judged too complex by the stakeholders. Thus, it is now proposed to use the same thresholds for all cooling generators and for both sectors.

Single threshold

The single threshold method was initially built to favour the development of cooling systems with higher SPF_P than existing cooling systems or to favour systems with local and concomitant renewable electricity or with renewable fuel, gas or heat energy input. Accordingly, the single threshold was proposed to be set right above the SPF_P of the most efficient cooling generators currently in place. This same principle is used here.

If a single SPF_P threshold is considered for all cooling systems, the most efficient cooling generator to be used as reference corresponds to electric vapour compression water-to-water cooling generators with an SEPR value of 11.7. This leads to an SPF_P close to 5.5. Thus, this should be considered a low value to be used for the single threshold. A supplementary margin of 10% is used to reach an SPF_P of 6 and ensures that no standard cooling generator may be counted as renewable cooling.

Progressive thresholds 1 and 2

For the progressive thresholds, there are two options as outlined above: one with a single threshold using a minimum SPF_P value and another with 2 thresholds, using a minimum and a high SPF_P threshold value. The minimum SPF_P threshold is the same in both methods. The minimum threshold value (low threshold for progressive method 1 and single minimum threshold for method 1) is proposed to be set to the reference SPF_P of new products, on which renewable cooling definitions may have an influence. This minimum threshold is based on the minimum requirement proposed in the ongoing revision of the ecodesign regulation 206/2012. The impact of this threshold value is analysed in the impact assessment part (Part 3) of this study [28]. Most common products (larger sales in number and in kW) are small air conditioners where minimum SEER is proposed to be set to 6 [17]. This corresponds to an SPF_P value of 2.8.

For the progressive threshold 1, an "SPF_P high" threshold should also be set to correspond to cooling systems for which the cooling energy supply is considered as being fully renewable. This value is proposed to be set at 9.5, based on the existing minimum SPF_P threshold in France [6], which uses a single threshold SEER of 20, corresponding to an SPF_P of 9.5.[37]

Resulting $s_{SPF_{p}\_RE}$ values for various cooling systems

The reference parameters of the different thresholds are summarized in Table 2. These parameters have been used to draw the single threshold curves in Figure 8, the progressive threshold 1 curves in Figure 9, and the progressive threshold 2 curves in Figure 10.

Table 2 Exemplary reference parameters for single and progressive thresholds

Threshold form	Parameter	Reference SPF_P value
Single Threshold	SPF_{pLIM_THRE}	6
Progressive threshold 1	$SPF_{pLIM\_PROG1\_LOW}$	2.8
	$SPF_{pLIM\_PROG1\_HIGH}$	9.5
Progressive threshold 2	SPF_{pLIM_PROG2}	2.8

$s_{SPF_{p}\_RE}$ values obtained with the different threshold forms and reference parameters in Table 2 are computed for various cooling systems and presented in Table 3.

[37] The threshold of EER=8 in final energy terms defined in the Netherlands would translate into a value of 8/2,1=3,8 in primary energy terms. However, for both thresholds (FR and NL) it should be noted that a direct comparison is difficult since they build on a single threshold system, not a progressive one as proposed here.

Table 3 Evaluation of $s_{SPF_{p\_RE}}$ for various cooling systems and exemplary reference parameters

Cooling system	Energy input source	SEER	SPF_p	SPF_{pRE}	Single threshold	Progressive 1	Progressive 2
					$s_{SPF_{p\_RE}}$	$s_{SPF_{p\_RE}}$	$s_{SPF_{p\_RE}}$
Solar absorption 1	80 % solar + 15 % grid gas + 5 % grid electricity	NA	0.5	2.0	0%	0%	0%
Elec. VC 1	Grid electricity	6	2.8	2.8	0%	0%	1%
Elec. VC 2	Grid electricity	8	3.8	3.8	0%	15%	26%
Solar absorption 2	80 % solar + 15 % grid gas + 5 % grid electricity	NA	1	3.9	0%	17%	29%
Elec. VC 1 + PV	Electricity, 70 % grid, 30 % local	6	2.8	4.0	0%	18%	31%
Elec. VC 3	Grid electricity	10	4.7	4.7	0%	29%	41%
Elec. VC 2 + PV	Electricity, 70 % grid, 30 % local	8	3.8	5.4	0%	39%	48%
Free cooling 1	Grid electricity	13	6.2	6.2	100%	51%	55%
Elec. VC 3 + PV	Electricity, 70 % grid, 30 % local	10	4.7	6.8	100%	59%	59%
Free cooling 2	Grid electricity	20	9.5	9.5	100%	100%	71%
Solar absorption 3	95 % solar + 3 % grid gas + 2 % grid electricity	NA	1	13.9	100%	100%	80%

VC: vapour compression, PV: photovoltaics, NA : non applicable

Pros and cons of using the single threshold calculation method

Advantages of the single threshold method are that it is clear and transparent in its structure, and easy to understand and communicate how renewable cooling is calculated.

On the other hand, there are several drawbacks of the single threshold: It does not give credits to efficiency gains in addition to the standards required by Ecodesign and/or Energy labelling regulations. Once the single threshold is reached, the method does not incentivise further improvement, which limits in practice the possibility to decrease SPF_{pLIM_THRE} without including a very large share of cooling generators without local renewable energy input.

With the single threshold, a small change in the SPF_P or SPF_{pRE} of the cooling system around the threshold changes the renewable cooling quantity from 0 % to 100 % of the cooling supply. This threshold effect does not appear at Member State scale because of the wide distribution of SPF_P and SPF_{pRE} of cooling systems. However, the rigidity to accommodate further improvements at cooling system level remains. In particular, this is the case for district cooling or other larger scale systems where there are pre-existing systems with no renewable cooling: with the single threshold, investing in renewable cooling at cooling system level would not lead to any impact on the renewable cooling quantity as long as the threshold would be reached on the total system level.

The stakeholder consultation also highlighted that it was a problem to have a single threshold for the whole EU while different countries may have different access to renewable cold sources. For systems which are assessed based on measured data, it is more difficult to obtain high SPF_P values in Southern countries than in Northern countries because the temperatures of cold sources are much less favourable in average. But even in the case where standard SPF_P values are used (which are established for an average climate), there could be less installations using low temperature cold sources under warm climate conditions (these cold sources having higher temperatures in warm climates than in cold climates, which affects their economic competitiveness).

Pros and cons of the progressive threshold

In contrast to the single threshold, there is a slightly higher administrative and communicative effort to calculate the share of renewable cooling. In the case of progressive method 1 (low and high threshold), two values need to be determined and –if required – dynamically adjusted in case of technological progress.

On the other hand, there are several advantages: Progressive methods give credits to efficiency gains which for vapour compression cooling generators are already regulated by Ecodesign and/or Energy labelling regulations (SPF_P of cooling generators with no local renewable energy input between 2.8 and 6 in Figure 9 and Figure 10). On the system level – for the case of large scale systems, such as district cooling, progressive threshold methods also give credits to incremental improvements and gradual investments in renewable cooling technologies. Last but not least, a progressive metric allows limiting the impact of differences in climatic conditions as described above.

For all these reasons, a progressive threshold is proposed.

Pros and cons of the progressive threshold 1

As an advantage, the progressive threshold 1 is more flexible to use than the progressive threshold 2 because of the requirement of setting two thresholds.

However, as a disadvantage, in the progressive threshold 1 method, the link between s_{SPF_P} and SPF_P (or SPF_{pRE}) is a convention: there is no physical meaning corresponding to a linear increase in SPF_P (or SPF_{pRE} value). Moreover, it becomes myopic for SPF_P or SPF_{pRE} values above the high threshold,

Pros and cons of the progressive threshold 2

Conversely, with the progressive threshold 2, the link between s_{SPF_P} and SPF_P (or SPF_{pRE}) is proportional to the reduction of grid and/or fossil fuel consumption as compared to the reference cooling solution. Progressive threshold 2 thus has a clear physical meaning. Moreover, the progressive method 2 can also reward very high SPF_P or SPF_{pRE} levels.

The disadvantages are that progressive threshold 2 fails to recognise very high SPF cooling systems as fully renewable, while in practice they may be justified to consider them as such. Furthermore, any new additional energy efficiency improvements yield diminishing return in terms of additional renewable cooling quantity.

The study team did not identify a clearly preferred option between progressive threshold 1 and 2 as both have merits. Therefore **both are presented** in **the calculation methodology (chapter**

4). The progressive threshold 2 method with one minimum threshold was modelled in the impact assessment of this study (Part 3), and this is the method that was presented in the stakeholder consultation workshop of 15 July 2021. Considering the point that above a certain threshold 100% of the cooling supply should be counted as renewable, **the study team – after discussion with the European Commission and stakeholders – selected progressive threshold 1 for the guidance document [29]**. However, it should be noted that progressive threshold 2 implementation only differs from progressive threshold 1 in the equation formula for sSPF$_P$**. The selection and elaboration of the methodology for calculating renewable cooling for the purposes of REDII remains in the competence of the European Commission, which can use, choose and combine the approaches developed in this study.**

3.5. Integration of waste heat and waste cold (RED II Art 23 and 24)

Waste heat and waste cold can help to reach the renewable heating and cooling and renewable district heating and cooling targets (RED II Articles 23 and 24). As regards cooling, waste heat energy input to cooling systems and waste cold, can be taken into account to reach the specific targets for the annual increase in RES-HC, with the condition that it can only be accounted for the case of district cooling (RED II, Article 2 (9)).

As regards waste heat energy input to cooling generators, it is proposed to use the same method as for renewable cooling to quantify the waste heat contribution to the renewable cooling target, which is noted E_{WHC} in Equation 14:

$$E_{WHC} = (Q_{C_{Source}} - E_{INPUT}) \times s_{SPF_{P\_}WHC}$$

Equation 14

Where s_{SPF_WHC} is defined for a cooling system using waste heat as energy input to an activated cooling generator, as the share of the cooling supply which can contribute to reach the specific targets for the annual increase in RES-HC according to the SPF$_P$ requirements, expressed as a percentage.

In the calculation of $s_{SPF_{P\_}WHC}$, waste heat energy input could be discounted, the same way as a local renewable energy input is discounted in the SPF$_{pRE}$ calculation, by comparing SPF$_{pWHC}$ (Equation 15) and the SPF$_P$ threshold. The same SPF$_P$ threshold numerical values used for renewable cooling could also apply for cooling systems using waste heat energy input.

$$SPF_{P\_WHC} = \frac{Q_{C\_Supply}}{E_{INPUT} - E_{INPUT\_WHC}}$$

Equation 15

It is proposed that the waste cold contribution to renewable cooling energy quantity, noted E_{WC}, is counted as the contribution of renewable cold sources:

$$E_{WC} = (Q_{C_{Source}} - E_{INPUT}) \times s_{SPF_{p}\_WC}$$ *Equation 16*

Where s_{SPF_WC} is defined for a cooling system using waste cold, as the share of the cooling supply which can contribute to reach the specific targets for the annual increase in RES-HC according to the SPF_P requirements, expressed as a percentage.

In the calculation of $s_{SPF_P\_WC}$ for waste cold cooling systems, the cooling supply due to the waste cold and the energy input should be used to compute the SPF_P of the waste cold cooling system. And the same SPF_P threshold used for renewable cooling could be applied.

When waste cold results from a heat pump which is simultaneously used in heating and in cooling mode and delivers its heat into the perimeter of the same district heating and cooling system, the cooling mode energy input to the heat pump and to its auxiliaries should be calculated in proportion to the ratio of the cooling supply to the sum of the cooling and heating supplies (Equation 17). Only periods where simultaneous cooling takes place should be taken into account.

$$E_{INPUT} = (E_{INPUT_{HP}} + E_{INPUT_{AUX}}) \times \frac{Q_{C_{Supply}}}{Q_{C_{Supply}} + Q_{H_{Supply}}}$$ *Equation 17*

Where E_{INPUT} is the energy input to the heat pump system to be considered in the evaluation of E_{WC} for simultaneous heating and cooling, $E_{INPUT_{HP}}$ is the energy input of the heat pump used simultaneously in heating and in cooling mode, $E_{INPUT_{AUX}}$ is the energy input of the heat pump's auxiliaries (e.g. fans, pumps, controls), $Q_{H_{Supply}}$ is the simultaneous heating energy supply energy, $Q_{C_{Supply}}$ is simultaneous cooling energy supply.

As waste heat and cold are limited to district cooling, only measured SPF_P can be used.

4. Calculation methodology

4.1. Introduction

The impacts of the main options proposed in section 3 are analysed in report 3 of the study [28]. In particular, this includes the following points:

- The definition options of the renewable cooling energy quantity A1, A2 and B (section 3.2.3)
- The choice of the denominator of the global RES share and RES-HC share, whether it considers all cooling systems, or it considers only the share of renewable cooling (section 3.3).
- In addition, the impact of the choice of the threshold, single threshold or progressive thresholds, and the sensitivity of the impacts to the absolute value of the thresholds (section 3.4.4).

Considering the two prior dimensions leads to following combinations, which are subsequently analysed regarding their impact on expected RES and RES-HC shares in report 3 of the study [28]:

- 1.A1: renewable cooling quantities are added to the numerator and denominator of the RES share calculation; renewable cooling quantity does not include renewable energy input
- 1.A2: renewable cooling quantities are added to the numerator and denominator of the RES share calculation; renewable cooling quantity includes local, concomitant renewable energy input
- 1.B renewable cooling quantities are added to the numerator and denominator of the RES share calculation; renewable cooling quantity includes all renewable energy input, even from the grid
- 2.A1: the denominator of the RES share calculation is increased by the total cooling supply; renewable cooling quantity does not include renewable energy input
- 2.A2: the denominator of the RES share calculation is increased by the total cooling supply; renewable cooling quantity includes local, concomitant renewable energy input
- 2.B the denominator of the RES share calculation is increased by the total cooling supply; renewable cooling quantity includes all renewable energy input, even from the grid

Following the discussion in chapter 3, the evaluation of the impacts, and the consultations with Member States and stakeholders, **the following choices have been made regarding the proposed option:**

- **The renewable cooling energy quantity is defined according to option A1.**
- **Only the renewable energy quantity is added to the denominator of the global RES share and RES-HC share.**
- **A progressive threshold 1 for the SPF_P (with a low and a high threshold value) is used.**

As regards the scope, the definition in section 2.5, which includes part of process cooling applications, is used hereafter.

In the following sections, the methodology to calculate the renewable energy quantity for cooling is explained in detail (section 4.2 to section 4.8).

4.2. Scope

Cooling refers to the extraction of heat from an enclosed or indoor space (comfort application) or from a rocess in order to reduce the space or process temperature to specified temperature (set point). The following applications are not in the scope:

- Cooling systems in means of transportation.
- Cooling systems for which the primary function is the purpose of producing or storing perishable materials at specified temperatures (refrigeration).
- Cooling systems with space or process cooling temperature set points lower than 2 °C.
- Cooling systems with space or process cooling temperature set points above 30 °C
- In addition and in line with the argumentation in chapter 2.5, Table 1, sectors where heat generation processes are used and where cooling is used to eliminate the resulting excess (waste) heat, are excluded.

A **cooling system** is:

- For space cooling, either a free cooling system or a cooling system embedding a cooling generator, and for which cooling is one of the primary functions.
- For process cooling, a cooling system embedding a cooling generator, and for which cooling is one of the primary functions.

A **free cooling system** is a cooling system using a natural cold source to extract heat from the space or process to be cooled via fluid(s) transportation with pump(s) and/or fan(s) and which does not require the use of a cooling generator.

A **cooling generator** refers to the part of a cooling system that generates a temperature difference allowing heat extraction from the space or process to be cooled, using a vapour compression cycle, a sorption cycle or another energy-driven thermodynamic cycle.

In the context of defining renewable cooling energy quantity, **renewable energy input** refers to the self-consumption of local renewable energy generation by the cooling system. Hereby, local renewable energy generation can be one of the following:

- Renewable heat generation,
- Off-grid renewable electricity or gas generation,
- local renewable energy generation supplied under the same interconnection between the transportation and distribution grid as the cooling system in the case of grid electricity and gas, or a renewable electricity or gas generation source located nearby the cooling system, where the distance corresponding to the term “nearby” as used in the EPBD is to be defined by each Member States.
- Renewable fuel generation not already accounted for elsewhere (in renewable electricity, renewable heat or renewable gases used in other sectors) in the gross consumption of renewable energy sources.

4.3. Methodology outline

The renewable cooling energy quantity at MS level ($E_{RES-C-MS}$) is the sum of the quantities calculated for each cooling system (E_{RES-C}):

$$E_{RES-C-MS} = \sum E_{RES-C}$$ *Equation 18*

However, for a **specific geographic area** with environmental constraints limiting the possibility to release heat to ambient air, ambient water or to the ground (e.g. limiting river overheating in the summer, heat island effect), a part or all of the cooling systems can be excluded from the scope of calculating the renewable cooling energy quantity[38].

The **renewable energy quantity for cooling $E_{RES\text{-}C}$** is defined as the part of the cooling supply that is generated with a certain energy efficiency expressed as Seasonal Performance Factor, which quantitatively corresponds to a portion of the heat released by the cooling system to ambient air, ambient water or to the ground.

It is calculated as follows (Equation 19):

$$E_{RES-C} = (Q_{C_{Source}} - E_{INPUT}) \times s_{SPF\_p} = Q_{C_{Supply}} \times s_{SPF\_p}$$ *Equation 19*

$Q_{C_{Source}}$ is the amount of heat released to ambient air, ambient water or to the ground by the cooling system.

E_{INPUT} is the energy consumption of the cooling system, which can be electricity and/or gas and/or fuel and/or heat depending on the specific cooling system.

$Q_{C_{Supply}}$ is the cooling energy supply of the cooling system.

s_{SPF}: is defined at cooling system level as the share of the cooling supply, which can be considered as renewable according to the SPF_P requirements, expressed as a percentage.

Calculation of s_{SPF}

1) Progressive threshold 1 (two thresholds: low and high)

The **calculation of $s_{SPF,P}$** includes a low SPF_P threshold denoted SPF_{plow} and a high threshold denoted SPF_{phigh}. Above the low threshold s_{SPF_P} increases with increasing SPF_P values (Equation 20 and Equation 21):

If $SPF_P < SPF_{pLOW}$, $s_{SPF_P} = 0$ % and if $SPF_P > SPF_{pHIGH}$, $s_{SPF_P} = 100$ %. *Equation 20*

If $SPF_{pLOW} \leq SPF_P \leq SPF_{pHIGH}$, $s_{SPF_P} = \frac{SPF_p - SPF_{p\_LOW}}{SPF_{p\_HIGH} - SPF_{p\_LOW}}$ %. *Equation 21*

[38] These situations are described in section 3.4.2.

For cooling systems having part or all of their energy input supplied by local and concomitant renewable electricity or renewable fuel, gas or heat energy input[39] $s_{SPF,P}$ is noted $s_{SPF_P,RE}$ and calculated following Equation 22 and Equation 23:

If $SPF_{pRE} < SPF_{pLOW}$, $s_{SPF_{P\_RE}} = 0$ % and if $SPF_{pRE} > SPF_{pHIGH}$, $s_{SPF_{P\_RE}} = 100$ %. *Equation 22*

If $SPF_{pLOW} \leq SPF_{pRE} \leq SPF_{pHIGH}$, $s_{SPF_{P\_RE}} = \frac{SPF_{p\_RE} - SPF_{p\_LOW}}{SPF_{p\_HIGH} - SPF_{p\_LOW}}$ %. *Equation 23*

The SPF_{pLOW} and SPF_{pHIGH} thresholds for the standard SPF_P method (chapter 4.4) and for the measured SPF_P method (chapter 4.5) are 2.8 and 9.5, respectively.

2) Progressive threshold 2 (one minimum threshold)

The **calculation of $s_{SPF,P}$** includes a minimum SPF_P threshold denoted SPF_{pMIN}; above this threshold, s_{SPF_P} increases with increasing SPF_P values (Equation 20 and Equation 21):

If $SPF_P < SPF_{pMIN}$, $s_{SPF} = 0$ %. *Equation 24*

If $SPF_P \geq SPF_{pMIN}$, $s_{SPF} = (1 - \frac{SPF_{PMIN}}{SPF})$ %. *Equation 25*

For cooling systems having part or all of their energy input supplied by local and concomitant renewable electricity or renewable fuel, gas or heat energy input[39] $s_{SPF,P}$ is noted $s_{SPF,P,RE}$ and calculated following Equation 22 and Equation 23:

If $\frac{SPF_P}{1-\tau_{RE}} < SPF_{pMIN}$, $s_{SPF_{P\_RE}} = 0$ %. *Equation 26*

If $\frac{SPF_P}{1-\tau_{RE}} \geq SPF_{pMIN}$, $s_{SPF_{P\_RE}} = (1 - \frac{SPF_{PMIN}}{SPF_P} \times (1 - \tau_{RE}))$ %. *Equation 27*

The minimum SPF_P threshold is 2.8.

Calculation of renewable SPF_p[39]

[39] Considering local renewable energy input in the calculation may be understood as a bonus to further promote corresponding systems. It is up to the Commission to decide whether this shall be considered or not. If not, this the following paragraph is not relevant.

$SPF_{p,RE}$ is defined as $SPF_p/(1-\tau_{RE})$

τ_{RE} is the defined as the ratio of the sum of local and concomitant renewable electricity and renewable fuel, gas and heat energy input (E_{INPUT_RE}) and the total energy input (E_{INPUT}) of the cooling system (Equation 28):

$$\tau_{RE} = \frac{E_{INPUT\_RE}}{E_{INPUT}}$$

Equation 28

Requirements regarding the calculation of τ_{RE} are given in section 4.8.

The SPF_P of the cooling system is a necessary input to the calculation of s_{SPF} and E_{RES-C}.

In the case of cooling generators with a standard cooling capacity of less than 1.5 MW and for which a standard SPF_P value is available, a simplified methodology can be used (section 4.4).

In any other situations, the SPF_P of the cooling systems should be measured (section 4.5).

For Member States, where waste heat and cold is not used to reach the targets indicated in the first paragraph of Article 23 of the RED II, only the $\mathbf{E_{RES\text{-}C\text{-}MS}}$ quantity should be included in the gross final consumption of energy from renewable sources in the heating and cooling sector and in the gross final consumption of energy from all energy sources in the heating and cooling sector.

For Member States where waste heat and cold is used, the following terms should be added to $E_{RES\text{-}C\text{-}MS}$:

- the contribution to the renewable heating and cooling target corresponding to waste heat as an energy input by district cooling systems, noted $\mathbf{E_{WHC\text{-}MS}}$, and which should be calculated following the methodology established in section 4.6,
- the contribution to the renewable heating and cooling target corresponding to waste cold used as cold source by district cooling systems, noted $\mathbf{E_{WC\_MS}}$, which should be established following the methodology established in section 4.7.

4.4. Calculation of $E_{RES\text{-}C}$ using standard SPF_P

For the calculation of $E_{RES\text{-}C}$, corresponding to Equation 19 to Equation 28, it is necessary to evaluate $Q_{C_{Supply}}$ and SPF_P. In this section, this is described for the case of systems where standard SPF_P values can be applied.

Default method to estimate $Q_{C_{Supply}}$

The cooling energy supplied can be written as in Equation 29:

$$Q_{C_{Supply}} = P_C \times EFLH$$

Equation 29

P_C is the standard rated cooling capacity and $EFLH$ is the number of equivalent full load hours.

The following default method is proposed to compute $EFLH$:

- For space cooling in the residential sector: EFLH = 96 + 0.85 * CDD
- For space cooling in the tertiary sector: EFLH = 475 + 0.49 * CDD
- For process cooling: EFLH = τ_S * (7300 + 0.32 * CDD)

τ_S is an activity factor to account for the operation time of the specific processes (e.g. all year long τ_S=1, not on week-ends τ_S=5/7). There is, however, no default value proposed.

Climate is represented using cooling degree days (CDD) computed with a base of 18 °C. CDD values to be used as input to the determination of $EFLH$ are long term yearly average values. A single CDD value can be used for a whole country. Distinct values for different climate zones can also be used, provided that other input data (standard capacity, SPF_P) are also available in these climate zones.

The methodology used to define default EFLH is described in the report 1 of this study, in section 3.1 and in the annex.

Definition of standard SPF_P values

SPF_P values are expressed in terms of primary energy efficiency calculated following the methods used in Regulation (EU) 2281/2016 [7] to determine the space cooling efficiency $\eta_{S,C}$ for the different types of cooling generators. The primary energy factor in Regulation (EU) 2281/2016 is calculated as 1/η, where η is the average ratio of total gross production of electricity to the primary energy consumption for electricity production in the whole EU. With the evolution of this coefficient in the revision of the Energy Efficiency Directive (EU) 2002/2018 [20], the primary energy factor of 2.5 in Regulation (EU) 2281/2016 should be replaced by 2.1 when calculating the SPF_P values.

The standard operating conditions and the other parameters necessary for the determination of the SPF_P are the ones defined in Regulation (EU) 2281/2016 and in Regulation (EU) 206/2012, depending on the cooling generator category. Boundary conditions are the ones defined in the EN14511 standard [21].

For reversible cooling generators (reversible heat pumps), which are excluded from the scope of Regulation (EU) 2281/2016 because their heating function is covered by Commission Regulation (EU) No 813/2013 with regard to ecodesign requirements for space heaters and combination heaters, the same SPF_P calculation that is defined for similar non reversible cooling generators in Regulation (EU) 2281/2016 should be used.

Default $s_{SPF_P,RE}$ values[39]

In order to facilitate the use of the methodology, default values for $s_{SPF_P,RE}$ have been elaborated. For the calculation of the $s_{SPF_P\_RE}$ default values, the distribution of SEER for each cooling technology was used (Table 4) [25, 26, 27]. For each technology, the percentage of cooling generators with the respective SEER is provided. Using the calculation method described, the $s_{SPF_P,RE}$ was calculated for different τ_{RE} ranging from 0% to 100%. By doing this first for each energy efficiency class, subsequently we determined the $s_{SPF_P\_RE}$ for each technology according to the share of each efficiency class in the stock of systems.

The results of this calculation can be observed in Table 5. Technology efficiency classes with an SEER above 6 achieve a positive contribution of $s_{SPF_P\_RE}$ without any local renewable energy input. With 100% of renewable local energy input the $s_{SPF_P\_RE}$ results in 100% independently of the technology's efficiency.

If Member States decide to choose the default values instead of the detailed calculation, the capacities and resulting cooling supply needs to be assessed for each cell of Table 4. Since the use of τ_{RE} should only be understood as additional, optional bonus, the first column of Table 5 with τ_{RE}= 0 may be interpreted as the default column. As explained below, τ_{RE} should be derived based on measurements.[40] Indications for possible values for τ_{RE} , which may result from this measurement have been calculated for selected exemplary cases in Annex 6.1.

Table 4 Distribution of SEER for different technologies in EU-27 [25, 26, 27]

Distributions	**Mobile**	**Small Split (<5 kW)**	**Big Split (>5 kW, incl. ducted)**	**VRF**	**Rooftop + Packaged**	**Chillers (A/W) < 400 kW**	**Chillers (A/W) > 400 kW**	**Chillers (W/W) < 400 kW**	**Chillers (W/W) > 400 kW**
SEER<2		0%	0%	0%	14.2%	0%	0%	0%	0%
2<=SEER<3	100%	2.5%	3.9%	7.3%	41%	7.4%	4%	1%	1%
3<=SEER<4		9.7%	12.3%	19.7%	36.9%	60.8%	46%	9%	4%
4<=SEER<5		19.9 %	28.5%	29.5%	7.1%	30.2%	46%	33%	17%
5<=SEER<6		27.4 %	34.3%	24.8%	0.8%	1.5%	4%	44%	30%
6<=SEER<7		29%	17.5%	14.1%	0.06%	0%	0%	12%	32%
7<=SEER<8		9.7%	3.1%	3.8%	0%	0%	0%	2%	12%
8<=SEER<9		1.5%	0.4%	0.7%	0%	0%	0%	0%	3%
9<=SEER<10		0.2%	0.01%	0.1%	0%	0%	0%	0%	1%
10<=SEER<11		0.02 %	0%	0.02%	0%	0%	0%	0%	0%
SEER>=11		0%	0%	0%	0%	0%	0%	0%	0%

[40] Alternatively, a well substantiated calculation of concomitant renewable energy input may be done for each group of cooling systems, considering generation profiles for renewable energy generation and cooling loads for each acquisition time period (see chapter 4.8).

Table 5 $s_{SPF_{pre}}$ default values for different τ_{RE} levels

	$s_{SPF_{pre}}$ for τ_{RE}=										
	0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Small Split (<5 kW)	2.4 %	4.8 %	9.1%	15.1 %	23.9 %	36.9 %	56.5 %	81.8%	96.9 %	100%	100%
Big Split (≥ 5 kW, incl. ducted)	1.0 %	2.4 %	5.7%	10.8 %	18.5 %	30.3 %	48.2 %	75.2%	95.7 %	100%	100%
VRF	1.1 %	2.3 %	4.9%	9.1%	15.9 %	26.7 %	43.4 %	68.7%	92.6 %	100%	100%
Rooftop + Packaged	0.0 %	0.0 %	0.1%	0.3%	1.0%	4.5%	11.1 %	27.1%	58.8 %	94.9 %	100%
Chillers (A/W) < 400 kW	0.0 %	0.0 %	0.1%	1.1%	3.6%	11.4 %	24.3 %	46.6%	85.2 %	100%	100%
Chillers (A/W) ≥ 400 kW	0.0 %	0.0 %	0.3%	2.0%	5.9%	14.7 %	28.8 %	52.7%	89.9 %	100%	100%
Chillers (W/W) < 400 kW	0.7 %	1.8 %	5.1%	10.3 %	18.5 %	30.5 %	48.7 %	77.0%	97.8 %	100%	100%
Chillers (W/W) ≥ 400 kW	3.2 %	6.1 %	11.0 %	17.9 %	27.6 %	41.6 %	62.1 %	87.1%	98.8 %	100%	100%
Mobile	0.0 %	0.0 %	0.0%	0.0%	0.0%	0.0%	1.8%	16.7%	46.4 %	100%	100%

4.5. Calculation of $E_{RES\text{-}C}$ using measured SPF_P

For the calculation of $E_{RES\text{-}C}$, corresponding to Equation 19 to Equation 28, it is necessary to evaluate $Q_{C_{Supply}}$ and SPF_P for the cooling system. This is done here through measurement of the cooling energy supply and of the energy input. The boundary conditions for measurement are described hereafter, as well as the method to compute the SPF_P from the measurement of the cooling energy supply and of the energy input.

In the case of a cooling system embedding several cooling generators and/or free cooling systems, $E_{RES\text{-}C}$ can be estimated for the whole cooling system or the cooling system can be subdivided in smaller cooling systems, hereafter named subsystems. $E_{RES\text{-}C}$ can be estimated for each subsystem and summed up to reflect the entire cooling system. The methodology to subdivide a cooling system and the quantities to be used to compute E_{RES-C} at subsystem level are explained hereafter.

The cooling energy supply contribution of waste heat as an energy input and of waste cold as a cold source is evaluated separately by creating ad-hoc subsystems. The cooling energy supply and the energy input to these subsystems should not be counted to estimate the cooling system E_{RES-C} contribution. The methods to estimate the heating and cooling target contribution of cooling systems using waste heat as an energy input and/or waste cold as a cold source are respectively detailed in section 4.6 and section 4.7.

SPF_P calculation

All calculations are done in primary energy. Electricity input should be multiplied by 1/η, where η is the average ratio of total gross production of electricity to the primary energy consumption for electricity production in the EU (1/η=2.1 [20])[41].

Boundary conditions

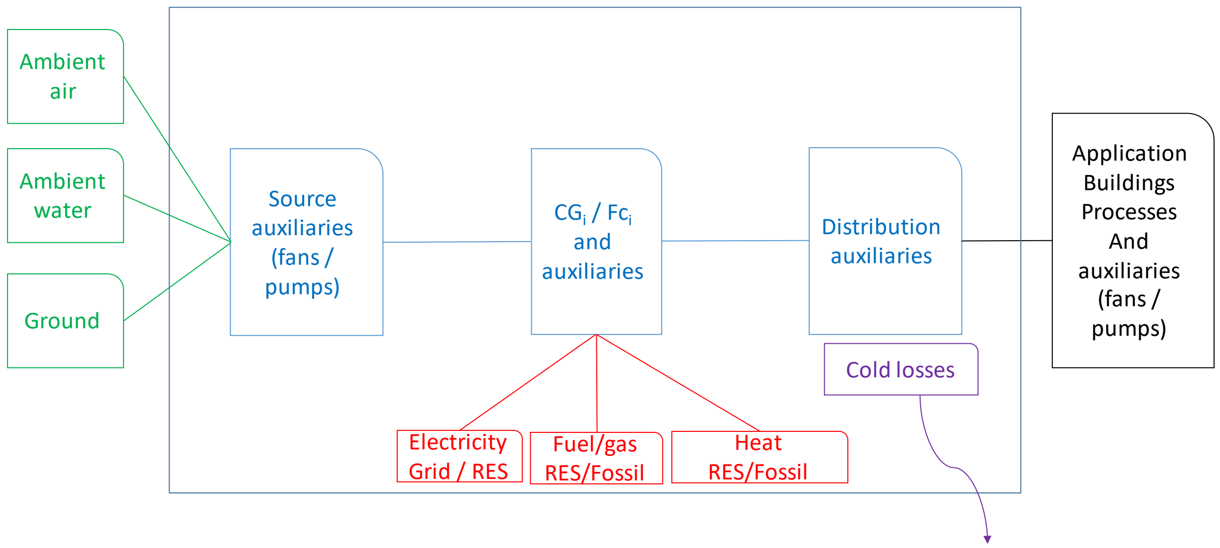

Figure 11 Boundary conditions for the calculation of E_{RES-C} using measured SPF_P

The boundary conditions are shown in Figure 11.

The energy input of the cooling system is the sum of the auxiliaries necessary to reject the heat to the environment, the auxiliaries of the cooling generators and potentially additional auxiliaries required for free cooling and for cooling distribution to the building or process to be cooled. The auxiliaries corresponding to cooling distribution inside the building, e.g. secondary pumps and terminal units (e.g. fan coils, fans of air handling units) are not accounted for.

When the pump or fan used to supply the fluid to the cold side of the cooling generator (or to the heat exchanger of a free cooling system) is also the distribution pump or fan used to distribute cooling in the building / process, only the part of the fan or pump energy consumption necessary to circulate the cooling fluid through the cooling generator (or to the heat exchanger of a free cooling system) shall be included in the energy input of the cooling system.

[41] The same approach is used in Annex VII of REDII for calculating renewable energy from heat pumps used for heating.

In case of air based cooling, when the cooling system also ensures the ventilation function, only the additional energy input due to cooling should be included in the energy input of the cooling system. The measurement of the cooling energy supply should be net of the effect of fresh air introduction for ventilation purposes.

Cold losses may occur in case of large cooling distribution systems (e.g. in district cooling) and correspond both to heat exchange with the environment of the cooling distribution system and heat additions due to fluid circulation inside the cooling distribution system. The gross cooling energy supply of the cooling system should be decreased of the cold losses in order to estimate the net cooling energy supply (e.g. for district cooling, the net cooling supply is the cooling supplied to the buildings / processes). The net cooling energy supply is to be used to estimate E_{RES-C} (Equation 30).

$$Q_{C\_Supply\_net} = Q_{C\_Supply\_gross} - Q_{C\_LOSS}$$ *Equation 30*

Q_{C_LOSS} are the cooling system cold losses, $Q_{C\_Supply\_net}$ is the net cooling supply and $Q_{C\_Supply\_gross}$ is the gross cooling supply before the correction due to the cold losses.

Division in subsystems

The cooling system can be divided into subsystems. A cooling subsystem is a physical part of the cooling system, which comprises at least either one cooling generator or a free cooling system. In order to adapt to the different possible control modes of the cooling system, subsystems can be defined for time periods lower than a year, as long as the yearly energy balance of the cooling energy supplied and of the energy input of the cooling system is respected.

Cold losses of the cooling system should be shared amongst cooling subsystems in proportion of the cooling energy supplied by each of the cooling systems. For calculating the net supply of cooling subsystem *i*, the following equation should be used (Equation 31):

$$Q_{C\_Supply\_net\_i} = Q_{C\_Supply\_gross\_i} - \frac{Q_{C\_LOSS} * Q_{C\_Supply\_gross\_i}}{(\sum_{i=1}^{n} Q_{C\_Supply\_gross\_i})}$$ *Equation 31*

When dividing a cooling system into subsystems, the auxiliaries (e.g. controls, pumps and fans) of the cooling generator(s) and/or free cooling system(s) must be included in the same subsystem(s). For auxiliaries, which cannot be allocated to a specific subsystem, as for instance district cooling network pumps (which deliver the cooling energy supplied by all cooling generators), their energy consumption should be allocated to each cooling subsystem in the proportion of the cooling energy supplied by the cooling generators and/or the free cooling systems of each subsystem (Equation 32).

$$E_{INPUT\_AUX\_i} = E_{INPUT\_AUX1\_i} + E_{INPUT\_AUX2} * \frac{Q_{C\_Supply\_net\_i}}{\sum_{i=1}^{n} Q_{C\_Supply\_net\_i}}$$ *Equation 32*

Where:

- $E_{INPUT\_AUX1\_i}$ is the auxiliary energy consumption of subsystem "i"
- E_{INPUT_AUX2} is the auxiliary energy consumption of the entire cooling system, which cannot be allocated to a specific cooling subsystem

4.6. Waste heat contribution to the renewable heating and cooling, and district heating and cooling targets.

While waste heat does not count as renewable energy, it can contribute to fulfil up to 40% of the renewable heating and cooling target[42] and up to 100% the renewable district heating and cooling target[43].

The contribution to the renewable heating and cooling (Article 23) and district heating and cooling (Article 24) targets of district cooling systems or subsystems using waste heat as an energy input at MS level (E_{WHC-MS}) is the sum of the quantities calculated for each cooling system (E_{WHC}) (Equation 33):

$$E_{WHC-MS} = \sum E_{WHC}$$

Equation 33

In order to calculate E_{WHC}, the same equations that are used for the calculation of E_{RES-C} (Equation 19 to Equation 28) should be used, wherein the equations E_{RES-C} is replaced by E_{WHC_RE} (the quantity of cooling supply based on renewable energy and waste heat) and E_{INPUT_RE} is replaced by the sum of E_{INPUT_RE} (if there is any local and concomitant renewable electricity or renewable fuel, gas or heat energy input) and E_{INPUT_WH}, where E_{INPUT_WH} is the waste heat energy input to the cooling system. The waste heat contribution to the renewable heating and cooling and district heating and cooling targets is calculated according to the share of waste heat energy input on the sum of waste heat and renewable energy input (Equation 34):

$$E_{WHC} = E_{WHC\_RE} \frac{E_{INPUT\_WH}}{(E_{INPUT_{WH}} + E_{INPUT_{RE}})}$$

Equation 34

And accordingly the share of renewable cooling quantity from this cooling system is calculated according to Equation 35:

$$E_{RES-C} = E_{WHC\_RE} \frac{E_{INPUT\_RE}}{(E_{INPUT_{WH}} + E_{INPUT_{RE}})}$$

Equation 35

[42] Article 23(2)(a) of the revised renewable energy directive (2018/2001).
[43] Article 24(4)(a) of the revised renewable energy directive (2018/2001).

The cooling energy supply and the energy input should be measured in order to calculate the SPF_P, following the provisions established in section 4.5.

4.7. Waste cold contribution to the renewable heating and cooling, and district heating and cooling target

The same way as waste heat, waste cold does not count as renewable, but it can contribute to fulfil up to 40% of the renewable heating and cooling target and up to 100% the renewable district heating and cooling target[44].

The contribution to the renewable heating and cooling and renewable district heating and cooling targets of district cooling systems or subsystems using waste cold at MS level (E_{WC-MS}) is the sum of the quantities calculated for each cooling system (E_{WC}) (Equation 36):

$$E_{WC-MS} = \sum E_{WC} \qquad \textit{Equation 36}$$

The contribution to those targets of district cooling systems or subsystems using waste cold is noted $\mathbf{E_{WC}}$. In order to calculate E_{WC}, the same equations that are used for the calculation of E_{RES-C} (Equation 19 to Equation 28) should be used.

In these equations, the cooling supplied by the waste cold source should be included in the evaluation of cooling energy supplied by the cooling system.

The energy supply linked to waste cold (which can be a cold source used by a pump or fan and/or a cooling generator depending on the specific situation) should be included in the calculation of the cooling system's energy balance. However, in case waste cold is the result of a heat pump simultaneously generating cooling and heating both used simultaneously by the district heating and cooling system, only part of the heat pump energy input and of the energy input of the auxiliaries allowing the heat transfer to both sides of the cooling generator (heating and cooling sides) should be included in the energy supply of the cooling system. This part should be calculated as the ratio between the cooling supply and the sum of the heating and cooling supply.

The cooling energy supply and the energy input should be measured in order to calculate the SPF_P, following the provisions established in section 4.5.

4.8. Estimation of $\boldsymbol{\tau_{RE}}$ 39

For the calculation of τ_{RE} for cooling systems with local and concomitant renewable electricity or renewable fuel, gas or heat energy input, both the renewable energy input E_{INPUT_RE} to the cooling

[44] See above under Section 4.7.

system and the total energy input E_{INPUT} to the cooling system should be measured.[45] Alternatively, a well substantiated calculation of concomitant renewable energy input may be done for each group of cooling systems, considering generation profiles for renewable energy generation and cooling loads for each acquisition time period (see below). These calculations need to consider the high number of diverse variants of systems in terms of different ratio of renewable energy generation and cooling load, the relevance of non-cooling related loads, electrical as well as thermal storage and practical, real-life management of these storage systems. In case of integrated systems (i.e. where the renewable energy generation unit is integral part of the cooling system), only cooling loads need to be considered. For all other systems, i.e. where the renewable energy generation unit is not an integral part of the cooling system, other loads, e.g. due to electric household appliances need to be subtracted from the renewable generation for each acquisition time step in order to derive the net renewable energy generation to be considered as concomitant local renewable energy input to the cooling system.

τ_{RE} should be computed as the integral of the ratio of the renewable energy input to the total energy input to the cooling system at each time step over the year (Equation 37).

$$\tau_{RE} = \int \frac{E_{INPUT_{RE}}(t)}{E_{INPUT}(t)} dt$$

Equation 37

The calculation time step is equal to the acquisition time period (time period between two outputs of the measurement system).

The acquisition time period should allow for a precise estimation of the local renewable energy generation consumed by the cooling system, i.e. both of the local renewable energy generation and of the cooling system energy consumption.

Acquisition time period should be lower than 15 minutes for electricity and not more than one hour for gas, fuel and heat.

The same measurement provisions apply to the estimation of waste heat energy input to cooling systems and to waste cold.

[45] From the view of the study team, the development of default values for τ_{RE} would be very difficult if not impossible. It would be related to considerable uncertainties and may increase the uncertainty and ambiguity. The same is true for related calculations done by MSs without proper measuring of the systems. However, this aspect remains open for further discussion in the context of implementing the methodology.

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6. Annex

6.1. Exemplary calculation of the share of local, concomitant renewable energy input (τRE)

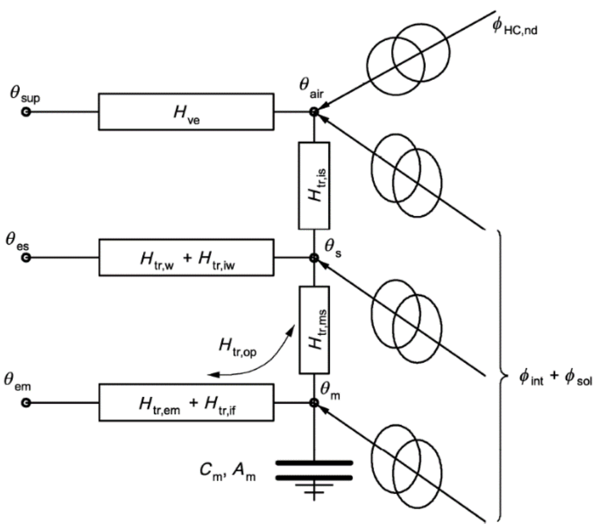
6.1.1. Intention and objective of exemplary case calculations

This chapter is dedicated to demonstrate the calculation of the share of local, concomitant renewable energy input on total energy input (τ_{RE}) for some exemplary cases. The share of local, concomitant renewable energy input on total energy input depends on numerous factors like the hourly profile of cooling demand in a certain building, the hourly profile of PV generation or the profile of other electrical loads in the building. For this reason, no default values can be provided. However, in order to illustrate possible ranges for different cases, in the following we calculate exemplary cases and resulting τ_{RE} – values. In case that no measurement is possible, MS may also apply an estimation based on a similar approach as the following.

We want to emphasize that in the following exemplary cases, cooling is provided by electrically driven cooling generators, and the local renewable energy is assumed to be produced by a photovoltaic system (PV). As PV production and cooling energy needs are different depending on the climate, the calculation is done for 3 different climate zones (warmer, medium, colder climate). The cities Athens (warmer), Strasburg (medium), and Helsinki (colder) represent the cases in different climate zones.

6.1.2. Description of the method for the exemplary case calculation

To calculate the cooling demand a 5 resistance 1 capacity (5R1C) model is utilized for 3 different buildings in 3 different building categories, namely single-family house (SFH), multifamily house (MFH), and Office. The 5R1C model takes outside temperature, solar radiation gains in an hourly resolution for one year as an input. In the model, the 5 resistances describe the thermal transmission coefficients, distinguished between windows ($H_{tr,w}$), walls ($H_{tr,op}$), ventilation (H_{ve}), and the thermal conductance between the surface temperature and indoor temperature node ($H_{tr,is}$). The thermal capacity represents the building's thermal mass. This model is described in the EN ISO 13790 [24].



The model calculates the indoor temperature based on solar gains and losses/gains through the building envelope. Whenever the indoor temperature would rise above 27°C, the building will receive cooling energy to keep the indoor temperature at a constant 27°C or below. 27°C was chosen as indoor temperature because although cooling generators are often set to cool down to lower temperatures, usually only a single room or part of the building is cooled. The overall mean temperature is therefore estimated with 27°C.

Solar gains for each building are estimated on an hourly basis by using the effective window area of the buildings in each celestial direction and calculating the direct and diffuse solar radiation through them. The effective window area is smaller than the real window area, as the glassing factor and the shading factor are considered.

Temperature, as well as measured radiation and PV production, are taken from PV GIS for the year 2015 in an hourly resolution. The direct and diffuse solar radiation on a horizontal plane is converted onto vertical planes facing the celestial directions (north, east, west, south). By multiplying them with the effective window area, the solar gains are computed for every hour.

With the above-mentioned input parameters, the 5R1C model calculates the cooling demand for each hour. By dividing this cooling demand with the SEER of an exemplary cooling system, the final cooling energy (E_{INPUT}) is obtained.

We assume that PV is mainly installed to ensure a high share of self-electricity consumption for the electric load of the building in general, independent of the fact whether a cooling system exists or not. A standard profile for electricity consumption is used to simulate the household's electricity consumption excluding cooling. It is assumed that this reference electricity load (E_{REF}) will always be covered first by the PV system. If there is a surplus of PV electricity, then this electricity is used to power the cooling generator. Therefore, the available renewable energy input for cooling in every time step t is:

$$\overline{E_{INPUT\_RE,t}} = \overline{E_{PV_t}} - \overline{E_{REF\,t}}$$

Now τ_{RE} is derived by summing up $\overline{E_{INPUT\_RE,t}}$ and $\overline{E_{INPUT,t}}$ across all timesteps and dividing them:

$$\tau_{RE} = \frac{\sum_t \ E_{INPUT\_RE,t}}{\sum_t \ E_{INPUT,t}}$$

6.1.3. Description of the different building cases and underlying assumptions

The three buildings chosen differ especially in their properties regarding insulation and thermal mass. For each category, a rather old building with high thermal mass and bad insulation (1), a medium well-insulated building with medium thermal mass (2), and an energy-efficient building with low thermal mass (3) was selected.

Table 6 Building properties

Building type	Building Nr	A_f m^2	H_{op} W/K	$H_{tr,w}$ W/K	H_{ve} W/K	C_m kJ/K	A_m m^2	Specific internal gains W/m^2
SFH	1	167	401	148	47	338	3.5	3
SFH	2	183	142	172	52	214	3	3
SFH	3	214	106	72	61	148	2.7	3
MFH	1	681	775	404	193	338	3.5	3
MFH	2	721	248	615	204	214	3	3
MFH	3	669	140	265	189	148	2.7	3

A_m represents the effective mass-related area specified in square meters. C_m is the specific internal thermal mass capacity. A_f is the total heating/cooled floor area in the building, and H_{op}, $H_{tr,w,}$ and H_{ve} are resistances of the 5R1C model.

The SPF_P is assumed to be constant over the year, with the average SEER taken from part 1 of this report for small split systems in Finland, Germany, and Greece. For a more detailed calculation, the SPF_P would have to be derived as a function of the outside temperature and indoor cooling temperature for a specific cooling technology.

Window areas are different for every selected building type. The effective window areas for each house in each region are provided in Table 7. The east and west area are added together as there is no difference in solar radiation gains other than that they are time-shifted.

Table 7 Effective window area in celestial directions

Building type	House Nr	Average effective window area west-east m^2	Average effective window area south m^2	Average effective window area north m^2
SFH	1	12	6	2
SFH	2	14	8	2
SFH	3	10	4	2
MFH	1	39	15	6
MFH	2	62	19	9
MFH	3	35	21	6

6.1.4. Results and interpretation

The resulting values for τ_{RE} are visualized in Figure 12. It is visible that the values between the different buildings differ up to 10%. This means that the building properties and the resulting cooling demand for each house has an impact on the resulting τ_{RE}. The small PV was chosen to be 1 kWp and represents the small PV for both the SFH and MFH. As MFH usually have a bigger roof and therefore more PV potential, the large PV was chosen to be 6 kWp for the MFH and 4 kWp for the SFH.

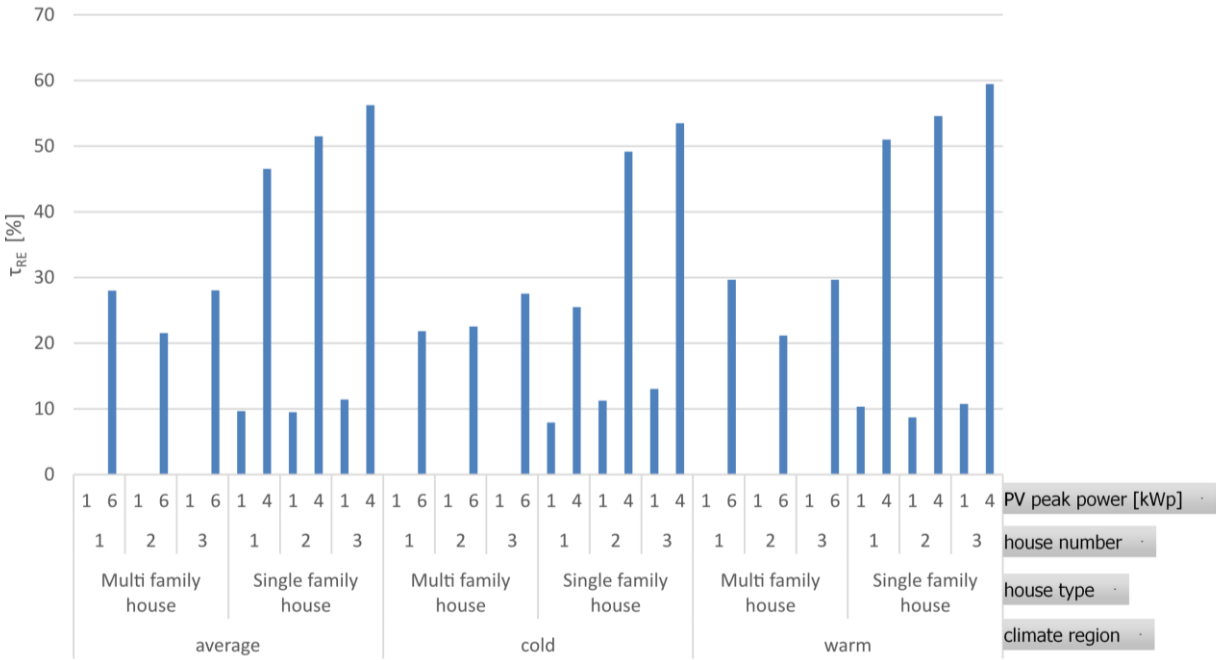


Figure 12 τ_{RE} for the exemplary cases

Table 8 depicts the average result of all three buildings in each climate zone with two different PV sizes respectively. As we can see, the small PV does not result in a positive value of τ_{RE} for the MFH. This is due to the fact that the produced PV electricity never exceeds the electric load of the MFH.

Table 8 Average τ_{RE} for 3 different buildings in climate zones warm, average and cold with different PV size

Building type	climate	τ_{RE} with PV small (1kWp) [%]	τ_{RE} with PV large (4&6 kWp) [%]
SFH	warm	10%	55%
MFH		0%	27%
SFH	average	10%	51%
MFH		0%	26%
SFH	cold	11%	43%
MFH		0%	24%

The cooling demand of a building is heavily dependent on structural properties as well as location, window area and shading. Figure 13 demonstrates the different cooling demands of the above described buildings in different climate zones. With a higher cooling demand the achievable τ_{RE} value decreases.

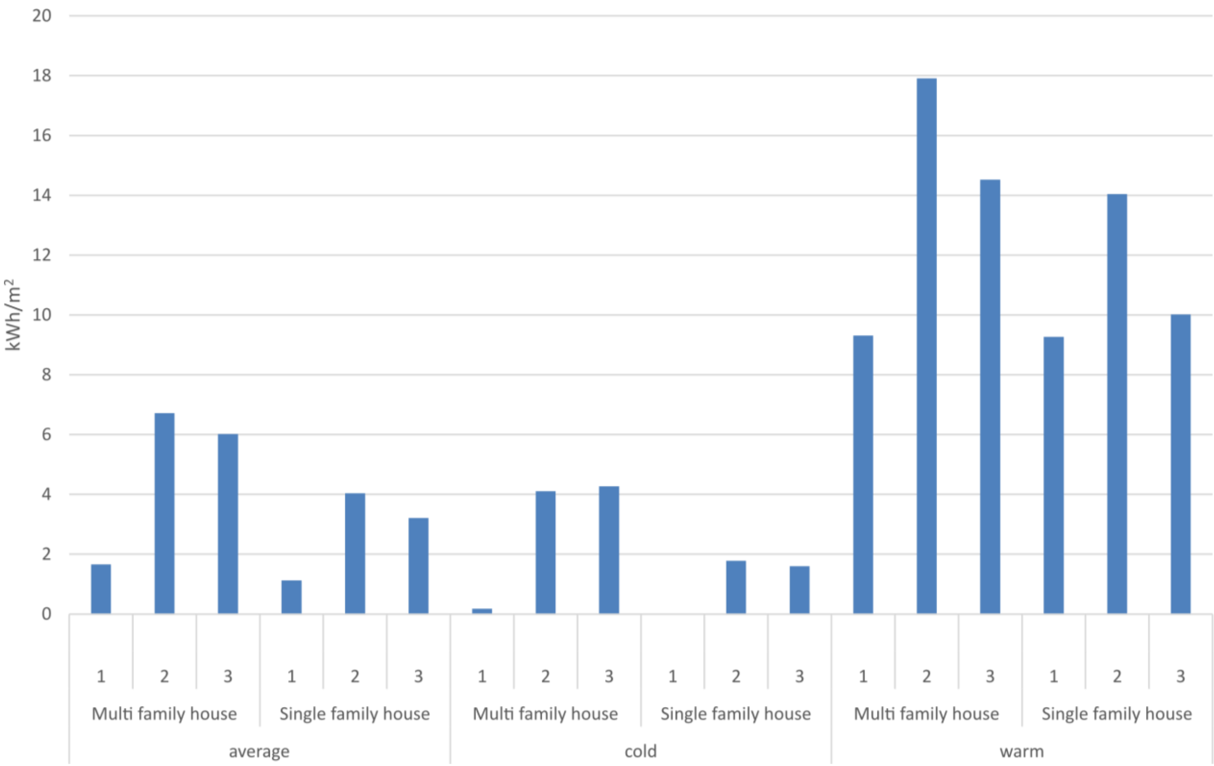


Figure 13 Annual final cooling consumption (energy input) per m² for 3 different buildings in 3 climate zones for SFH and MFH.

All calculated values for τ_{RE} and final cooling demand which were used in Figure 12 and Figure 13 are provided in Table 9 in 6.1.5.

For office buildings, according to our assumptions the electric load is higher than the produced electricity from PV even if the whole roof is covered with PV. The calculation was performed for a 5 story office building with 2400m^2 and an estimated electric consumption of 14W/m^2. This results in a yearly consumption around 300 MWh electricity. The norm load profile for the office was taken from (https://www.ednetze.de/geschaeftspartner/lieferanten/lastprofile-temperaturtabellen/). It distinguishes Workdays, Saturdays and Sundays and the 4 seasons. In Figure 14 an exemplary case is provided to visualize that the τ_{RE} remains at 0% with an installed PV capacity of 30 kWp. The load of the office building is at all times higher than the produced electricity from the PV. Therefore, no electricity is available for the cooling generator. For this reason, office buildings are not included in the exemplary calculation of the share of local, concomitant renewable energy input.

We want to emphasize, that for other geometries and properties of the assumed office buildings, also positive values of τ_{RE} might result.

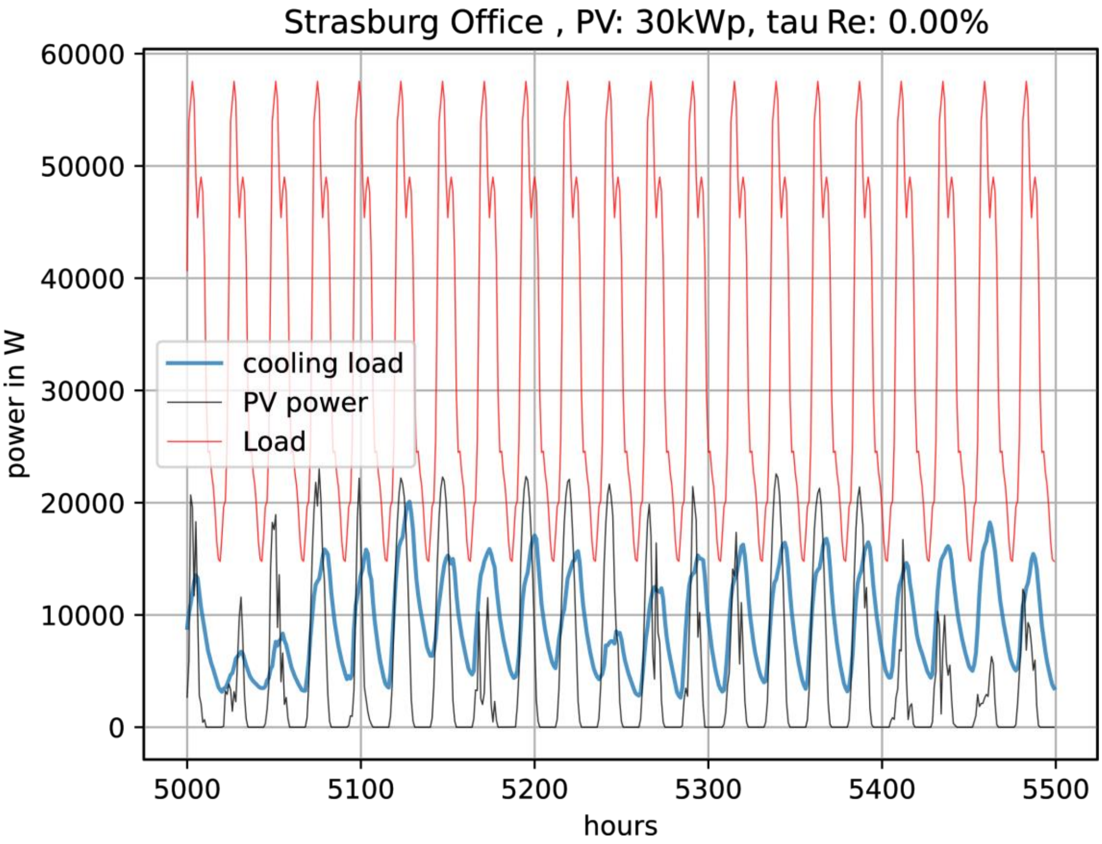


Figure 14 Hourly simulation of cooling load, PV generation and non-cooling related electric load in a summer period for an office building

6.1.5. Detailed results of the share of local, concomitant renewable energy input

Table 9 Results for τ_{RE} and final cooling demand of exemplary buildings.

climate region	building category	Building type number	PV peak power [kWp]	τ_{RE} [%]	total final cooling demand [kWh]
warm	Single family house	1	4	51.0	1547
warm	Single family house	1	1	10.3	1547
warm	Single family house	2	4	54.6	2570
warm	Single family house	2	1	8.7	2570
warm	Single family house	3	4	59.5	2143
warm	Single family house	3	1	10.7	2143
warm	Multi family house	1	6	29.6	6341
warm	Multi family house	1	1	0.0	6341

warm	Multi family house	2	6	21.2	12913
warm	Multi family house	2	1	0.0	12913
warm	Multi family house	3	6	29.7	9714
warm	Multi family house	3	1	0.0	9714
average	Single family house	1	1	9.7	188
average	Single family house	1	4	46.5	188
average	Single family house	2	1	9.5	739
average	Single family house	2	4	51.5	739
average	Single family house	3	1	11.4	688
average	Single family house	3	4	56.2	688
average	Multi family house	1	1	0.0	1131
average	Multi family house	1	6	28.0	1131
average	Multi family house	2	1	0.0	4841
average	Multi family house	2	6	21.5	4841
average	Multi family house	3	1	0.0	4028
average	Multi family house	3	6	28.0	4028
cold	Single family house	1	1	7.9	1
cold	Single family house	1	4	25.5	1
cold	Single family house	2	1	11.2	325
cold	Single family house	2	4	49.2	325
cold	Single family house	3	1	13.0	342
cold	Single family house	3	4	53.5	342
cold	Multi family house	1	1	0.0	122
cold	Multi family house	1	6	21.8	122
cold	Multi family house	2	1	0.0	2963
cold	Multi family house	2	6	22.5	2963
cold	Multi family house	3	1	0.0	2854
cold	Multi family house	3	6	27.5	2854

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