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Space Cooling Market in Europe: Assessment of the Final Energy Consumption for the Year 2016

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Abstract: This study investigates Europe's space cooling energy field. The work aims to assess the European Union (plus the United Kingdom) final energy consumption for space cooling in both the residential and service sectors with 2016 as a baseline. An extensive literature review of datasets and journal papers has been conducted to fill the knowledge gaps of the investigated energy branch. The European space cooling market is mainly dominated by vapour compression (VC) technologies which, in this study, have been grouped as room air conditioners (RACs) and centralized air conditioners (CACs). These technology groups have been investigated, and their installed capacities, energy efficiency levels (seasonal energy efficiency ratio—SEER), equivalent full load hours (EFLHs), and amount of space cooling units installed have been identified as essential parameters to calculate the final energy consumption for space cooling. Overall, the total value of the European final energy consumption for the space cooling sector, including both the residential and service sectors, results in 106 TWh/year.

Keywords: space cooling; final energy consumption; Europe; market; assessment; 2016

1. Introduction

Renewable energy sources (RES) and energy efficiency have become central points for the European Union (EU) to transit from fossil fuels towards achieving energy goals by 2020. The goals mentioned above involve a 20% greenhouse gas (GHG) emissions reduction, a 20% improvement in energy efficiency, and a 20% increase in RES shares compared to 1990 levels [1]. These targets were established by the EU Member States in 2009 with the Renewable Energy Directive (RES—Directive) legislation [2].

The Energy Efficiency Directive (EED) was initially established in 2002 and revised in 2018, resulting in the EDDII increasing the 20% energy efficiency target to 32.5% [1]. The EDDII was mainly revised to improve energy efficiency usage towards lowering bills and dependence on fossil fuel sources in the EU [3].

Moreover, the RES-Directive was revised in 2018. In the REDII, the mandatory target was upgraded to 32% of RES share in final energy consumption (FEC) by 2030 for the EU [4–6]. To accomplish this, its production needs to be increased by up to 2.5 times above the current level [1]. Additionally, the Emissions Trading System (ETS) tool monitored

GHG emissions, aiming to cost-effectively cut the pollutant from large-scale industry in the energy sector [7].

Per the REDII, concerning the heating and cooling (H&C) sector, the EU Member States need to increase the yearly RES shares by 1.3 average percentage points (ppt) in the period 2021–2030 [4]. This increase is mainly due to the fact that the most significant share of EU primary energy consumption (PEC) in 2018 was the result of the H&C sector [8,9]. In addition, the H&C sector has been identified as the largest contributor to environmental emissions [10]. Overall, the whole H&C sector is shared by space heating (SH), domestic hot water (DHW), space cooling (SC) for building comfort, and process cooling (PC), which involves industries. The EU H&C PEC accounted for around 800 Mtoe/y in 2016, while the entire EU's PEC accounted for approximately 1600 Mtoe/y [8]. It is worth mentioning that around 85% of the generation for H&C is from fossil fuel sources, while only the remaining 15% involves RES. However, the cooling need in the EU has expected to increase its production from RES in the upcoming years [8].

The heat removal against the second law of thermodynamics is referred to as "cooling". In the current study, the term "cooling" is mainly referred to as SC because the specific term includes both SC and PC definitions. The term SC is associated with ensuring the thermal comfort condition to the occupants of an enclosed space. Space cooling applications are involved in many sectors, mainly in the tertiary (trade, education, offices, health, hospitals, retirements, restaurants, hotels, and other nonresidential buildings) and residential (single-dwelling, multi-dwelling houses, and apartment) sectors. In contrast, the term PC refers to removing heat in the industry sector (e.g., plastic mold cooling [11]). PC also involves the heat removal from products of space needed to be maintained to a specific temperature for industry purposes [12]. Moreover, it has been observed that if the EU's final energy consumption (FEC) for SC and PC were considered together, they only count for 4% of the EU's total FEC, which is the energy consumed by end users, resulting in 1200 Mtoe/y [3]. The observed range between 134–192 TWh/y and 152–192 TWh/y have been assessed to SC and PC, respectively [13].

In addition, the present research excludes "refrigeration" applications whose functions are mainly related to storing perishable materials at certain temperatures and instead focuses on space cooling for human comfort purposes [14].

It is important to clarify that the acronyms of vapour compression (VC) and air conditioning (AC) are considered synonymous terms in the current text of the study. Moreover, Table A1 presents the full nomenclature list of the acronyms utilized in the text.

In this study, the useful energy demand (UED) and final energy consumption (FEC) for cooling have been distinguished. Notably, the UED is the net heat removed from the space/process to be cooled. In contrast, the FEC for cooling is the energy input of the cooling generators. As such, the two quantities differ by disparate conversion factors. The energy efficiency ratio (EER) for electrically driven cooling equipment is >1. Because of that, the cooling FEC results are lower compared to the cooling UED [11,15,16].

The current study is focused on SC for the residential and service sectors, and it has been observed that the EU's specific and total FEC has been increasing over the past thirty years from 1990 [16]. This increase is mainly due to global warming, extreme weather events, population growth and welfare, urbanization, and data centre energy needs [17].

Notably, it is worth mentioning that, although the cooling needs on the EU27+UK market are increasing, scientific literature has barely explored the topic of "cooling". Therefore, information and data are limited for the SC sector, both in the residential and service sector. In contrast, the space heating (SH) sector is primarily explored in the scientific literature [18].

According to the limited data mentioned above and although SC is a sensitive topic for sustainable energy exploitation, it must be said that significant difficulties have been encountered throughout this study, especially during the information and data retrieval phase. Therefore, it is important to mention that, in this study, a meaningful amount of data regarding the EU27+UK cooling market is founded on approximations [18,19].

Overall, this study aims to assess the FEC of the EU27+UK for SC, including the residential and service sectors, with 2016 as a baseline. The main reason why 2016 has been chosen as a baseline is for data and information availability reasons.

One of the essential parts of this study has been to create a complete and reliable dataset for SC of the EU27+UK. Therefore, to accomplish the objective mentioned above, different aspects, such as data inventory, data reliability, and data definition and comparability, have been considered before conducting the analysis:

- Data inventory;
- Data reliability;
- Data definition and comparability.

1.1. Data Inventory

Establishing an SC data inventory for the EU27+UK zone started with the preparation of the current information. Overall, the usage of data and information collected at the EU27+UK level offers a significant advantage because it offers a wide terrestrial view (e.g., EurObserv'ER [20], EUROHEAT&POWER [5], and EHPA [21]). Moreover, it should be mentioned that it has been impossible to ensure data completeness. The attempts to close the data gaps not only involved the extrapolation and the assembly process from sizeable online data sets (e.g., EUROSTAT [22], EU Buildings Database [23], and ENERGY PLUS [24]), reports (e.g., SET-Nav Pathways 2019 [25]), but also a search of the data source by source such as scientific journal papers to ensure a rigorous approach (e.g., Jakubcionis et al., 2017 [26], Jakubcionis et al., 2018 [27], Dittmann et al., 2017 [28], Fleiter et al., 2016 [29], Werner et al., 2016 [30]).

Notably, concerning the aforementioned scientific journal papers, the space cooling topic has been brought to light by estimating the EU space cooling demand potential in the residential and service sector mainly by using data from the US as a proxy [26,27]. In the latter, it has been stated that a relevant space cooling demand increase can be expected in the upcoming years, which could lead to stress in energy supply systems. A georeferenced approach was used to establish the potential residential space cooling demand at NUTS 3 regions of the EU for both of the studies, while no georeferenced approaches at NUTS 0 (Member States) level have been conducted [31]. Moreover, Werner et al., 2016 point out in their research that information about SC demands by location and country is required for planning district cooling (DC) systems [30]. In this case, to assess the EU DC demand, estimations have been based on cold deliveries which eventually have been addressed as lower than other estimations based on electricity inputs and assumed performance ratios for service sector buildings. Jakubcionis et al., 2017, and 2018 estimated the potential residential and service sectors' space cooling demands, which are referred to as the aforementioned UED [26,27]. As stated before, it differs from what the current work aims, which is the FEC that includes the energy efficiency of the SC system in the denominator of its calculations. Therefore, a breakdown of the space cooling market technologies has been identified as essential by the current study. While the studies have only accounted for mean energy efficiencies, the current research aims to include parameters such as installed capacities, energy efficiencies, and number of units installed grouped per types and sector. In this case, Dittmann et al., 2017 have been identified as a relevant reference that could have been provided a great overview on the different VC technology types present on the EU market [28]. Fleiter et al. 2016 has been addressed as the greatest source of important parameters, which have been essential for the SC FEC computation. Notably, the latter indicated information such as SC power peak capacities, as well as their correlated energy efficiencies for the largest part of the SC technologies in the EU market [29].

In addition, it is crucial that the data and information can be comprehended, interpreted, and, eventually, appropriately utilized by any user when needed [32]. Therefore, comprehensible metadata representation, contextual information, documentation, and annotations are required [33]. The creator, time references, title, access circumstances, restrictions, and term of data usage documentation have been provided.

1.2. Data Reliability

Several sources have been analysed and assessed for their reliability and related data. Many gaps discovered throughout the in-depth investigations have been filled. The remaining data and information pointed out as unreliable, misleading, or uncertain have been excluded from the current study.

As previously mentioned, while the SH sector of the EU27+UK market has been widely investigated in scientific literature, gaps, uncertainties, and unreliable information and data have been discovered regarding the SC EU27+UK market. It can be concluded that most of the information present in the scientific literature is based on estimations.

Based on what has been stated above, all the data collected on SC concerning the residential and the service sectors (i.e., placed capacities, equivalent full-load hours, quantity of operative units, energy efficiency coefficients per technology type and country) were adequately processed and statistically assessed. Overall, the process of synchronizing data from the sources to establish consistency has been a concrete challenge in the current study since information have been collected at a disaggregated level. Section 2, Materials and Methods, describes, in detail, the methodology adopted to achieve the objective. Moreover, Section 4 Discussion presents additional sources, mainly used to critically evaluate the study's results stated in Section 3 Results.

1.3. Data Definition and Comparability

Regarding the current study, not all the collected data can be considered comparable, although most data providers utilise standard formats and units. The increase in data comparability has been necessary. Therefore, to accomplish this, differences, gaps, and inconsistencies have been adjusted. The issues mentioned are mainly due to different methods, assumptions, specifications, time-references, measures of different data, and information providers [34].

The most recent year in data comparability has been identified as 2016 for the EU27+UK, while older data have been refused [18]. The reason is related to improving the reliability and quality of the dataset and adding value throughout the current study to the already existing information regarding SC in the EU27+UK market.

Overall, the current study aims to assess the European final energy consumption for space cooling, with 2016 as the baseline. The novelty of this work is that it provides a complete assessment on how much energy was spent for space cooling in 2016 in Europe by considering both the residential and service sectors with a clear overview of the technologies applied for space cooling in the European market and their essential parameters which were investigated, evaluated, and applied in the calculations that led to the main results of this research.

Concerning the paper's structure, Section 1 aims to introduce the study in a broad context, while Section 2 aims to present the material and methods utilised with detailed information gathering, filtering, and assessment. Moreover, Section 3 presents the results from the outputs given by Section 2, including tables and figures. Eventually, Section 4 critically discusses the obtained results, and Section 5 concludes with potential developments and implications.

2. Materials and Methods

To assess FEC for cooling purposes per technology and country of the EU27+UK, the breakdown of VC technologies proposed by Dittman et al., 2017 [28] (Horizon 2020 Heat Roadmap Europe 4-HRE4–project [35]) has been taken over because it is one of the most precise scientific literature sources that was identified. Moreover, this source provides data for the residential and service sectors. Compared to the breakdown of VC technologies provided by the HRE4 project, the only difference of this study is the moveables and window units part, where the windows units have been removed due to being negligible in terms of sale numbers as stock installed.

Therefore, the classification for the present investigation for the SC part is as follows:

RACs:

- Moveables
- Small split (<5 kW)
- Big split (>5 kW, inclusive ducted technologies)

CACs:

- VRF (Variable refrigerant flow) system
- Rooftop system + Packaged
- Chiller (air-to-water) < 400 kW
- Chiller (air-to-water) > 400 kW
- Chiller (water-to-water) < 400 kW
- Chiller (water-to-water) > 400 kW

According to data availability, mentioned in Section 1.1 data inventory, different CAC types have been assembled in a joined section—rooftop systems plus packaged units. Moreover, data and information collected on split systems enabled the distinction of sales by capacity, but not by different types—split or multi-split systems.

It is worth mentioning that VC systems provide the absolute majority (nearly 100%) of Europe's cooling needs [29,36,37]. Concerning thermally driven heat pumps (TDHPs), it must be underlined that the current market penetration is negligible compared to VC technologies. However, EUROVENT data suggest that TDHPs account for approximately 1% of the EU's cooling market [38]. Further cooling technologies find very little space in the EU27+UK SC market and have not been considered in the present investigation [39].

Moreover, based on the provided VC technologies breakdown, an analysis of the cooling market has been performed. Among others, the authors mainly researched the following data per technology and country:

- Quantity of installed units for cooling
- Equivalent full load hours (EFLHs)
- Capacities installed
- Energy efficiency levels (SEER)

The work input (electricity) per cooling type has been calculated. The average capacities per SC type have been divided by their respective SEER means to obtain these values. To recover dependable values inside the bottom-up approach, a wide information investigation was conducted. Just technical documentation was used for information gathering. The collected data was amalgamated and assessed. To this extent, the quantity of the gathered sources, data that lie external to a series of plus or minus one standard deviation close to the mean of a particular information pool have been disposed. The combined estimations have then been utilized to process an additional solid mean. Unfortunately, it was not always possible to amass at least two pieces of information for each investigated case, and in these instances, no factual elaboration was carried out. Conclusively, the FEC SC per EU2+UK country has been computed. To retrieve the yearly EU 27+UK FEC for each technology and country, the quantity (number—Nr.) of SC units were multiplied by their relative mean EFLHs (time—T) enclosed by a year and its work input (W electricity) according to Equation (1) below.

$$FEC_{\ cooling} = Nr._{Units} \times T_{equivalent\ full\ load\ hours} \times W_{electricity} \quad (1)$$

where

- Nr_{units} is the number of units installed for space cooling for a certain technology, sector, and European Member state.
- $T_{equivalent\ full\ load\ hours}$ is the equivalent full load hours.
- $W_{electricity}$ is the work input of the space cooling system, intended as the fraction of the system power capacity and its respective energy efficiency level. Electricity is the energy input that allows the cold as output.

Moreover, the following text explains how the EFLHs perform the calculations mentioned above were computed.

2.1. Calculation of Equivalent Full Load Hours

As discussed above, SC processes aim to achieve defined thermal comfort levels for the occupants of different residential and tertiary sectors. In this regard, it can be assumed that SC needs are mainly impacted by environmental factors such as ambient temperature (indoor and outdoor dynamics), occupancy density at the building and district level, and population density at the city and regional levels. To calculate the EFLHs for SC in the residential and tertiary sectors, it was decided to use normalized load curves. The latter mirror results in changes in electricity need and transform the annual hourly consumption structure.

The cooling load has been considered linearly dependent on the outdoor temperature, and calculations are performed based on the typical hourly Meteo file (Weather files of typical years from the Meteonorm software v7.1 with a period reference going from 2000 to 2009). Based on the Meteonorm file, the Cooling Degrees Day (CDD) and Heating Degree Days (HDD) calculation has been implemented with a temperature reference of 18 °C and derived for one city of each EU27+UK country [40].

As several climates are selected for France, Italy, and Spain, the climate in this country has been weighted by their climate zones by their different building floor areas for the residential and service sectors.

Moreover, monthly CDD and HDD by a meteorological station (ASHRAE 2017 Climatic Design Conditions (Most stations of the ASHRAE are sourced through the Integrated Surface Database (ISD) from NOAA (www.ncdc.noaa.gov, accessed on 11 January 2022) between 1990 and 2014 except for Berlin, period of 1982–2003, 1996–2014 and 1990–2013 with a temperature reference of 18.3 °C) were used to evaluate the cooling season length for each location. Months in the SC period are as follows:

- Residential sector: CDD18 $\geq$ 10 and HDD18 $\leq$ 81 (and at least two months, July and August, Estonia, and Ireland).
- Service sector: CDD10 > HDD10; service cooling season has been established by the number of the months where the CDD are superior to the HDD with a reference temperature of 10 °C based on the ASHRAE Meteo file.

It is important to note that the ranking of EFLHs per European Member State does not depend solely on the geographical location of the various nations but a series of other factors (e.g., consumer behavior, building occupancy schedule, etc.). In this case, the aforementioned factors have not been considered because poor data availability has been encountered for space cooling technology, building type, sector, and European country.

2.2. Residential Sector

To assess the SC load in the residential sector, the outdoor temperature, where the SC need starts to be required for thermal comfort, has been assumed to be 20 °C [41]. Notably, the thermal balance point of the building is defined as the average outdoor temperature below which SC is not needed and the average outdoor temperature above which space heating is also not needed [42].

Moreover, the SC load was assumed to be 100% at the maximum temperature encountered in the typical year.

The length of the SC season according to different climates is presented in Table 1.

Overall, the SC system was assumed to be switched on for the whole SC season in the residential sector. Therefore, the yearly number of EFLHs in the residential sector is evaluated by Equation (2) below.

$$\mathrm{EFLHs} = \sum_{\mathrm{i,\ season}} \frac{\mathrm{Ti} - 20}{\mathrm{Tmax} - 20}, \mathrm{Ti} > 20 \tag{2}$$

where

- T_i is a certain hourly outdoor temperature
- T_{max} is the maximum outdoor temperature reached during the whole cooling season

Table 1. Length of the space cooling season according to different climates.

Countries	n° of Months Residential Cooling Season	n° of Months Tertiary Cooling Season
Austria	5	7
Belgium	3	7
Bulgaria	4	7
Croatia	5	7
Cyprus	7	12
Czech Republic	3	6
Denmark	2	5
Estonia	2	5
Finland	2	5
France	4	7
Germany	3	6
Greece	6	12
Hungary	4	7
Ireland	2	6
Italy	6	9
Latvia	2	5
Lithuania	2	5
Luxembourg	2	6
Malta	7	12
Netherlands	2	6
Poland	3	5
Portugal	7	12
Romania	5	7
Slovakia	4	7
Slovenia	4	7
Spain	5	9
Sweden	2	6
United Kingdom	2	5

2.3. Service Sector

Concerning the EFLHs calculation for the service sector, the method used to simulate the air conditioning needs (W/m^2 at 30 min time step) of the commercial building stock for each country in EU27+UK is presented. The method is similar to the one used for the residential sector. However, a complete parameterization was carried out to respect the particularities of the commercial sector. The central adaptations concern the size and geometry of the buildings, the internal loads, the ventilation rate, and the thermal model.

For each climate, the commercial building stock was represented by 2000 individual buildings for each sector of activity: offices, trades, hospitals, hotels, and restaurant buildings simulated with Smart-E, the simulation platform of Mines ParisTech [43–46]. Each simulated building had a specific SC surface, geometry, occupancy, and thermal parameters collected. It is worth mentioning that, concerning the thermal parameters, no internal heat gain or solar heat gain simulations on buildings have been conducted.

Once all the required parameters mentioned above have been collected, the one-week simulation outputs for each specific EU27+UK country climate have been derived. Remarkably, the outputs concern different subsectors such as offices, trade, hospitals, and restaurant buildings. Generally, it has been observed that turning on the air conditioning in the morning creates significant peaks in cold demand. Moreover, the internal and solar gains are of the same order of magnitude as the space cooling requirements. These two phenomena must be correctly parameterized (average and in diversity) to accurately represent the UED. Besides, hospitals, hotels, and office buildings have the highest SC demand due to a higher surface area than trade and restaurant buildings.

Figure 1 highlights the EFLHs output per subsector based on CDD. The CDD estimates the EFLHs evaluation of the EU27+UK countries with 18° as the reference temperature.

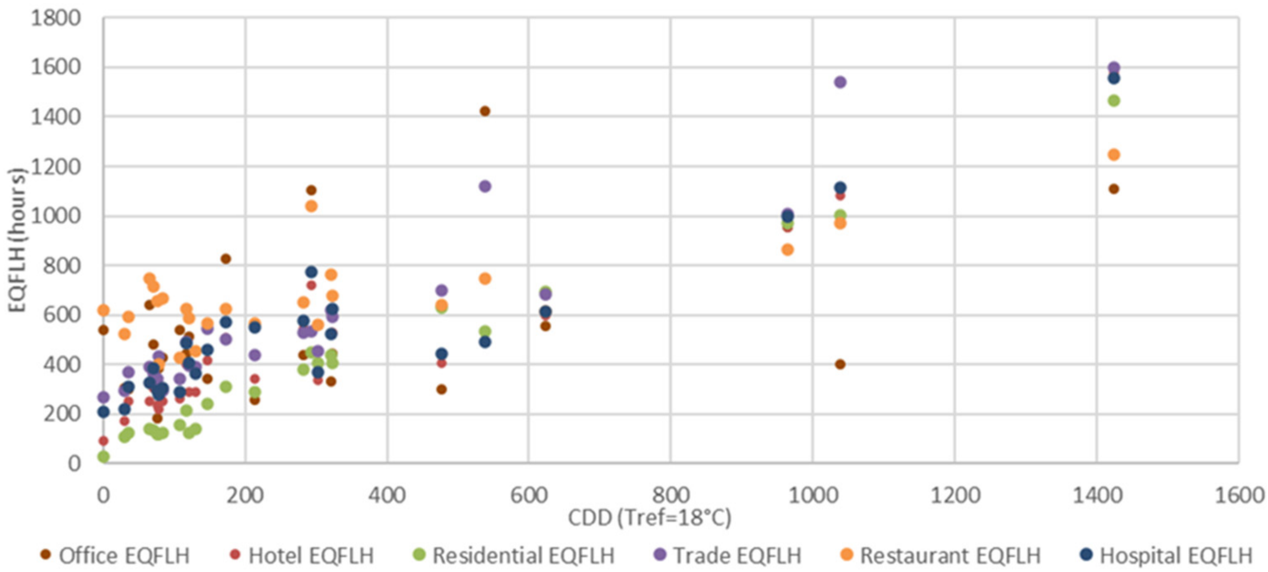

Figure 1. Equivalent total load hours based on CDD of each country.

Once the EFLHs have been initially obtained for different sectors: offices, trade, hotels and restaurants, and hospitals and retirements, subsequently, they have been weighted and distributed for each EU27+UK country to contribute to Equation (1) properly for the EU27+UK FEC.

It is important to mention that several EU27+UK countries, such as Spain, France, Italy, and Germany, presented more than one city to which the EFLHs have been addressed.

The weighting procedure started considering the necessity to obtain a single representative value of kWh/m^2 y per countries such as France, Spain, Italy, and Germany. More than one kWh/m^2 y value has been associated. To do that, and to properly weight the different kWh/m^2 y values related to different cities, the constructed area data (Mm^2) of the service sector have been retrieved from the building stock of the H2020 HotMaps project (see HotMaps Deliverable 2.3 [47]).

Moreover, once the data (Mm^2) have been retrieved from each subsector (offices, trade, hotels, etc.), they have also been expressed in the percentage of the total constructed area (Mm^2) of the service sector. Lastly, once the data was set up, the final kWh/m^2 y values have been obtained for Paris, Lyon, Marseille, Milan, Rome, Palermo, Berlin, Frankfurt, Madrid, Barcelona, and Seville.

Next, the values of kWh/m^2 y, W/m^2, and EFLHs were compared with cities' CDD, resulting in graphs for each subsector. It has been observed that kWh/m^2 y and W/m^2 y are relatively linear/monotonous as a function of CDD, while there is background noise in EFLHs, which does not appear on kWh/m^2 y curves. Moreover, starting from the kWh/m^2 y values obtained above, the constructed area (Mm^2) of the building stock of the H2020 HotMaps project has been associated with each kWh/m^2 y value per subsector, resulting in the weighted constructed area (Mm^2) for the cities mentioned above.

Once again, the EFLH values per subsectors mentioned above needed to be weighted with the constructed area (Mm^2) of the building stock of the H2020 HotMaps project to obtain a single EFLHs value per country. In order to conduct the EFLHs weighting procedure, different options were computed. It has been considered either directly weighing the average of the EFLHs values or weight average EFLH values obtained from the correlations of CDD per building subtype from the building stock of the H2020 HotMaps project. It has been observed that it could have been preferable to use EFLHs correlations versus CDD by building type, rather than picking one specific EFLH for a specific building/climate and then weighting them by building type.

Overall, the weighting of EFLHs was obtained through correlations, and the values have been weighted by using each country's repartition of building types.

3. Results

3.1. Residential Sector

Due to many values (for all single EU27+UK countries), the following figures display the primary outcomes in aggregated form for the entire EU27+UK. Figure 2 shows the FEC for SC (TWh/y) for each country.

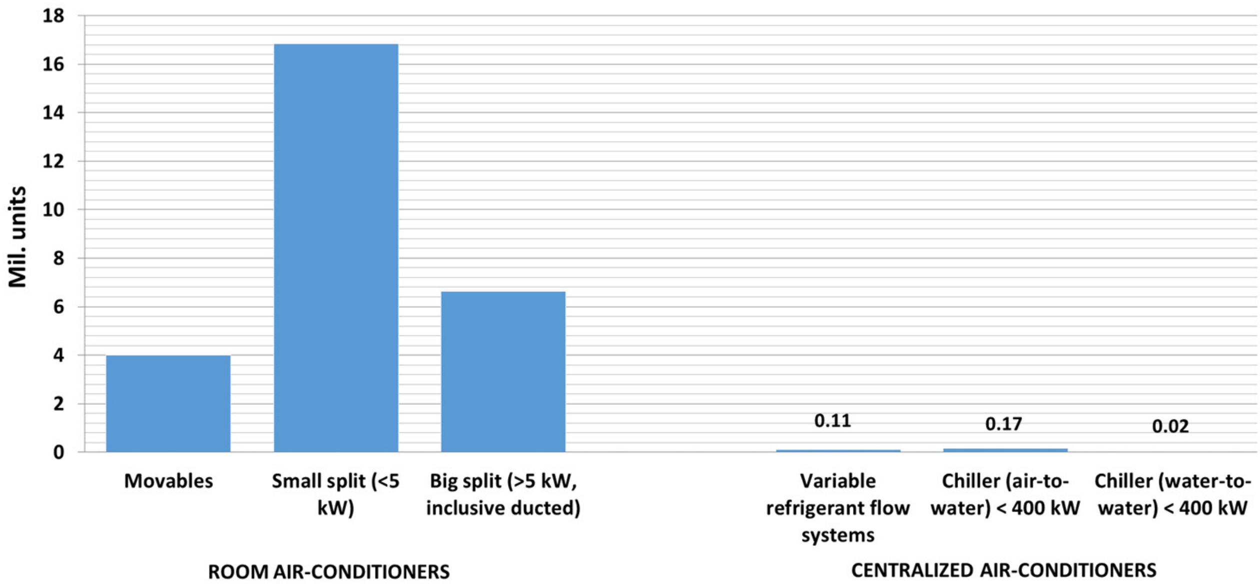

Figure 2. The number of installed units per space cooling type in the residential sector, EU27+UK, the reference year 2016; due to not being very visible, the amount of certain centralized air conditioners are indicated by values over their bars.

Small split (<5 kW) systems account for the majority of SC units per type with more than 16 million (mil.) installed devices. Big split (>5 kW, inclusive ducted systems) systems follow with almost 7 mil. units. Lastly, the RAC systems technologies are moveables, with around 4 million units. The quantity of installed CAC systems comes out to be around 0.17 mil. VRF systems, about 0.11 mil. chiller (air-to-water < 400 kW) and approximately 0.02 mil. chiller (water-to-water) < 400 kW.

Moreover, it must be underlined that rooftop in addition to packaged units, chiller (air-to-water) > 400 kW, and chiller (water-to-water) > 400 kW come out to be not present in the residential sector. Nevertheless, it could not be entirely accurate as a restricted presence of such SC technologies in the residential sector is provided as well [32,48].

Next, Figure 3 indicates the average installed capacity per SC type in kW.

Chiller (water-to-water) > 400 kW results as the greatest set up average value, greater than 750 kW. Furthermore, chiller (air-to-water) > 400 kW come after with around 620 kW. Then, chiller (water-to-water) < 400 kW follow with about 115 kW, and chiller (air-to-water) < 400 kW result in providing an average installed capacity of around 80 kW. Among CACs, VRF technologies result in about 65 kW. Lastly, rooftops with packaged units come with around 25 kW.

Moreover, Figure 4 shows details regarding the SEER. It is worth mentioning that no installed units of rooftop with packaged units, chiller (air-to-water) > 400 kW and chiller (water-to-water) > 400 kW were discovered in the residential market. Figure 4 highlights information regarding these SC technologies.

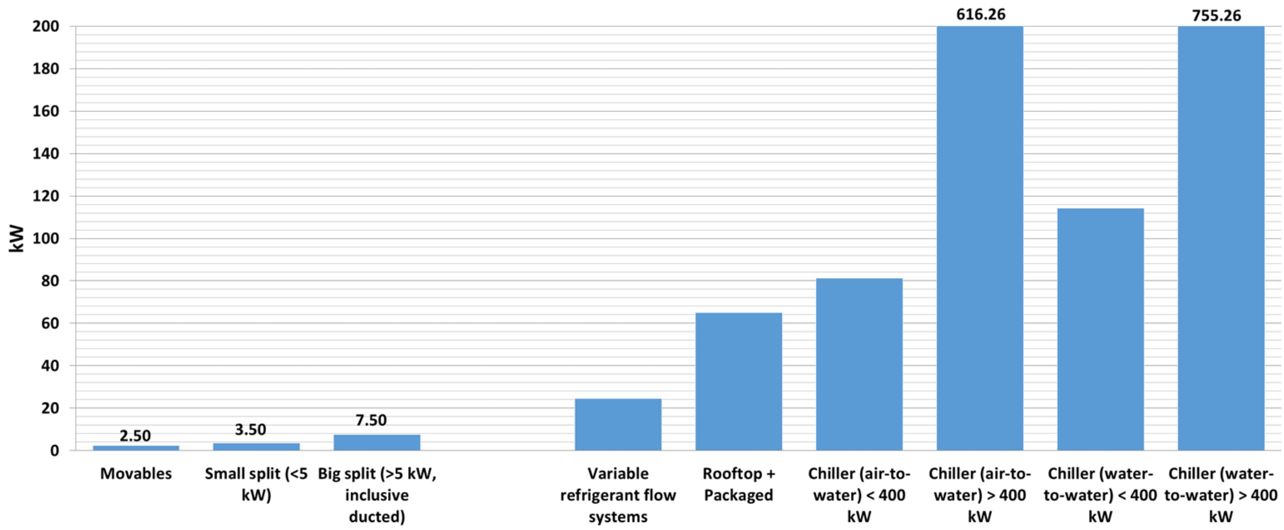

Figure 3. Average installed capacity per space cooling type in the residential sector, EU27+UK, the reference year 2016; due to not being very visible, the average installed capacity of room air conditioners are indicated by numbers over their bars.

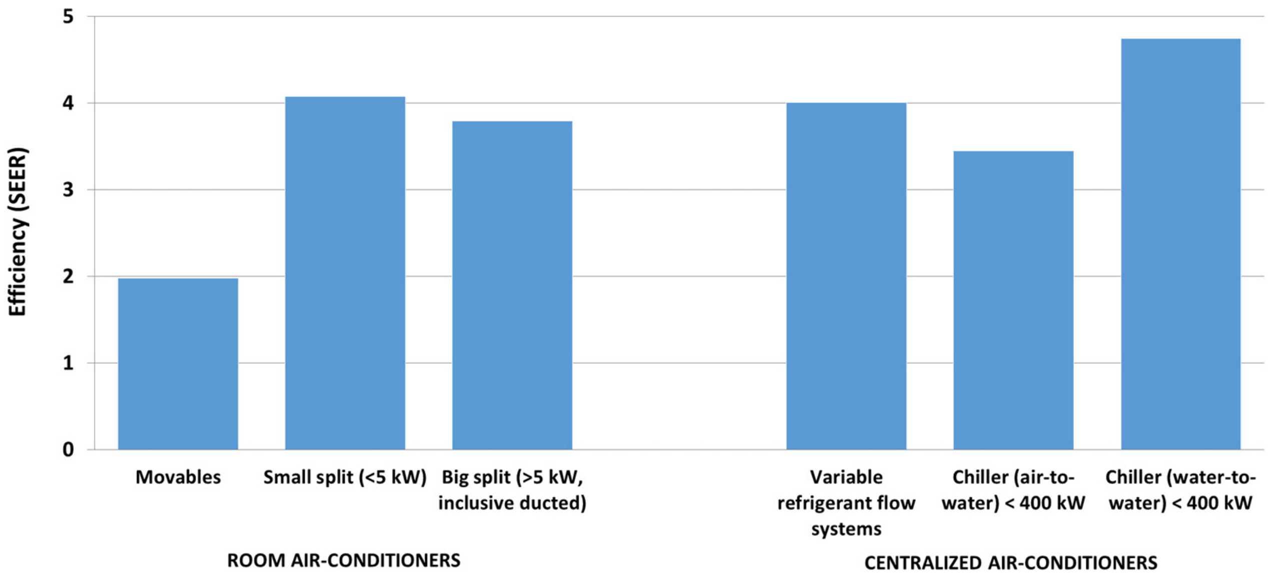

Figure 4. Seasonal energy efficiency ratio per space cooling type in the residential sector, EU27+UK, the reference year 2016 (indicated values refer to the weighted average per final cooling consumption).

The most efficient SC type emerges to be chiller (water-to-water) < 400 kW with a SEER of almost 5. Small split (>5 kW inclusive ducted) systems follow a SEER value of more than 4. VRF systems and big split (<5 kW) come next with a SEER of around 4. Chiller (air-to-water) < 400 kW come next, associated with a SEER of about 3.5. Moveables are last, with a SEER of nearly 2.

Using the assembled mean capacity and SEER values per SC type, the relative electricity input in kW has been computed.

Moreover, Figure 5 displays information regarding the EFLHs of Europe's residential sector country-by-country.

As visible in Figure 5, the EFLHs of Europe's residential sector are highest in Cyprus, with values reaching around 1200 EFLHs. Spain and Malta follow more than 800 EFLHs each, while Portugal, Italy, and Greece follow more than 600 EFLHs. Romania and Croatia come next, with values below 600 EFLHs. The remaining 19 countries show values below

400 EFLHs. Europe's residential sector's mean (please see the horizontal line in Figure 5 above) results in about 340 EFLHs.

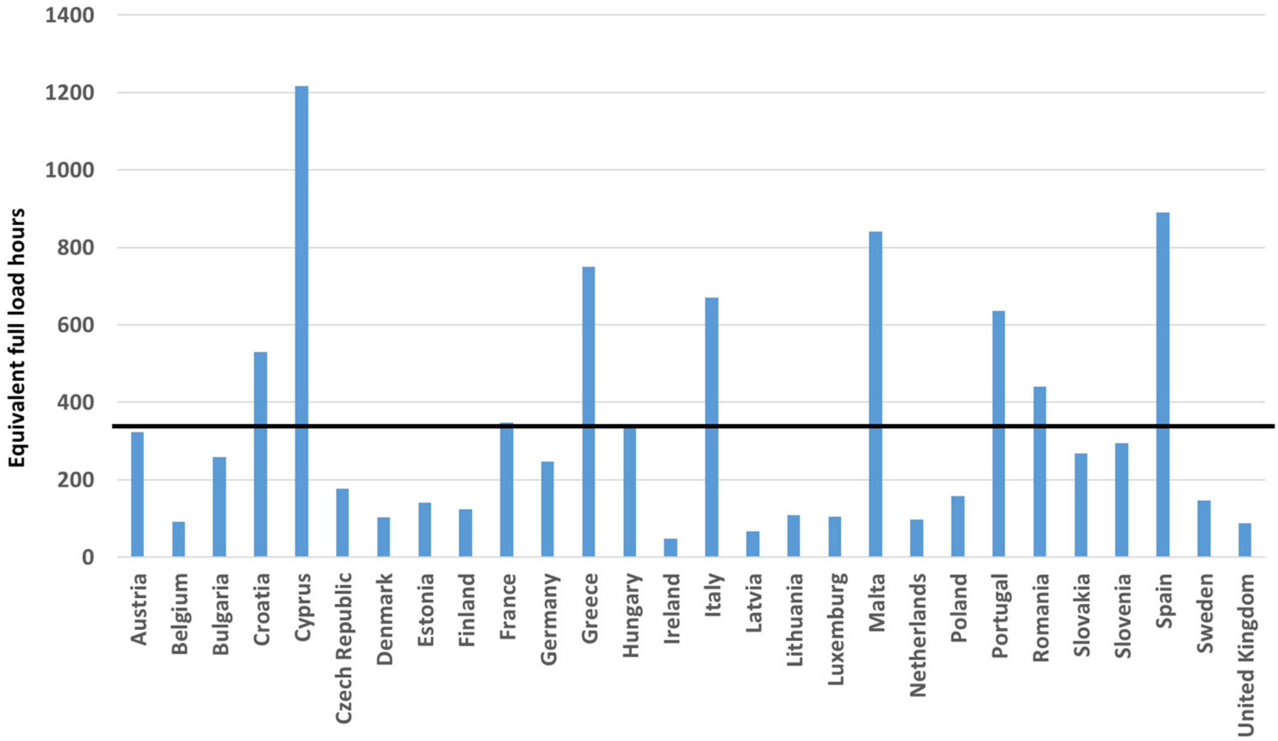

Figure 5. Equivalent full load hours in the residential sector, EU27+UK.

Please note that the ranking of EFLHs per country does not depend solely on the geographical location of the various nations but on a series of other factors, such as consumer behaviour. This applies not only to the residential sector but also to the service.

Integrating the data of Figures 4 and 5 in Equation (1) results in Table 2.

Table 2. Final energy consumption for space cooling per type of technology in the residential sector, EU27+UK, the reference year 2016.

Technology	Final Energy Consumption [TWh/y]
RACs	
Movables	1.68
Small split (<5 kW)	9.79
Big split (>5 kW, inclusive ducted)	8.78
CACs	
Variable refrigerant flow systems	0.22
Rooftop + Packaged	/
Chiller (air-to-water) < 400 kW	1.40
Chiller (air-to-water) > 400 kW	/
Chiller (water-to-water) < 400 kW	0.19
Chiller (water-to-water) > 400 kW	/

As visible in Table 2, the greatest energy-consuming SC model are small split (<5 kW) systems with nearly 10 TWh/y of the total SC energy use registered. Big split (>5 kW, inclusive ducted) systems follow with almost 9 TWh/y. Moveables come next with almost 2 TWh/y. Chiller (air-to-water) < 400 follow with more than 1 TWh/y. VRF systems and chiller (water-to-water) < 400 kW are to find at the penultimate and last position with 0.22 TWh/y and 0.19 TWh/y each.

Thus, RAC types account for the total part of the EU27+UK residential sector SC FEC with more than 90%. The overall amount comes out to be more than 22 TWh/y. Finally, Table 3 shows the FEC shares per country.

Table 3. Final energy consumption for space cooling per country in the residential sector, EU27+UK, the reference year 2016.

Country	TWh/y	Percentage
Austria	0.05	0.24%
Belgium	0.02	0.08%
Bulgaria	0.05	0.24%
Croatia	0.07	0.32%
Cyprus	0.40	1.80%
Czech Republic	0.02	0.11%
Denmark	0.01	0.03%
Estonia	0.03×10^{-2}	0.00%
Finland	0.002	0.01%
France	0.76	3.47%
Germany	0.87	3.95%
Greece	3.44	15.58%
Hungary	0.11	0.50%
Ireland	0.02×10^{-2}	0.00%
Italy	10.38	47.07%
Latvia	0.03×10^{-2}	0.00%
Lithuania	0.001	0.01%
Luxembourg	0.001	0.00%
Malta	0.24	1.10%
Netherlands	0.02	0.08%
Poland	0.03	0.14%
Portugal	0.24	1.07%
Romania	0.33	1.48%
Slovakia	0.01	0.06%
Slovenia	0.01	0.05%
Spain	4.95	22.42%
Sweden	0.01	0.06%
United Kingdom	0.03	0.12%
EU27+UK	22.06	100%

As shown in Table 3, there are five countries (Italy, Spain, Greece, Germany, and France) accounting for more than 90% of Europe's final cooling consumption. Thus, the remaining 23 countries account for the left 10%.

3.2. Service Sector

In contrast to the residential sector, in this case, the big split (>5 kW, inclusive ducted systems) systems are ranked first, with almost 20 mil. units. Small split (<5 kW) systems follow with almost 10 mil. units. In the third position, VRF units are allocated with almost 2 mil. units. Rooftop plus packaged units come next, with about 1.4 mil units, followed by chiller (air-to-water) < 400 kW with around 0.31 mil. units. Movables follow with more than 0.20 mil. units. The remaining chiller types show solely minor values: 0.09 mil. chiller (water-to-water) < 400 kW, 0.06 mil. chiller (air-to-water) > 400 kW, and finally 0.05 mil. chiller (water-to-water) > 400 kW.

The average setup capacity per SC type for the service sector corresponds to these households—please see Figure 6.

Furthermore, Figure 7 highlights details concerning the SEER.

The most efficient SC types emerge to be chiller (water-to-water) > 400 kW and chiller (water-to-water) < 400 kW with a SEER value of more and almost 5, respectively. Small split (<5 kW) follows with a SEER value of more than 4. VRF, rooftop plus packaged units, and big split (>5 kW, inclusive ducted) technologies come next with a SEER of about 4. Chiller (air-to-water) < 400 kW and chiller (air-to-water) > 400 kW come next with SEER values of more than 3. Movables are in the last position with a SEER of more than 2.

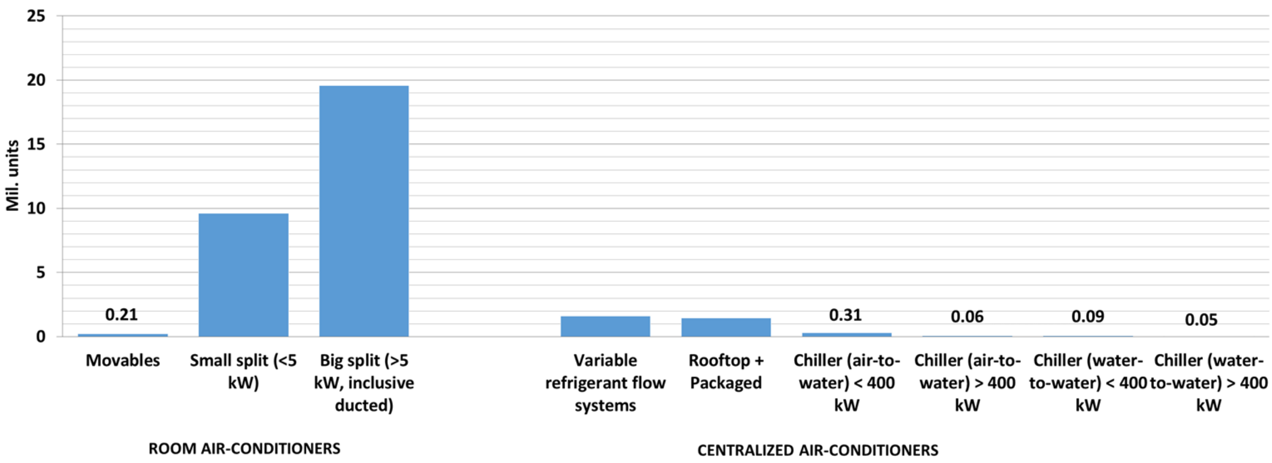

Figure 6. The number of installed units per space cooling type in the service sector, EU27+UK, the reference year 2016; due to not being very visible, the amount of certain centralized air conditioners are indicated by values over their bars.

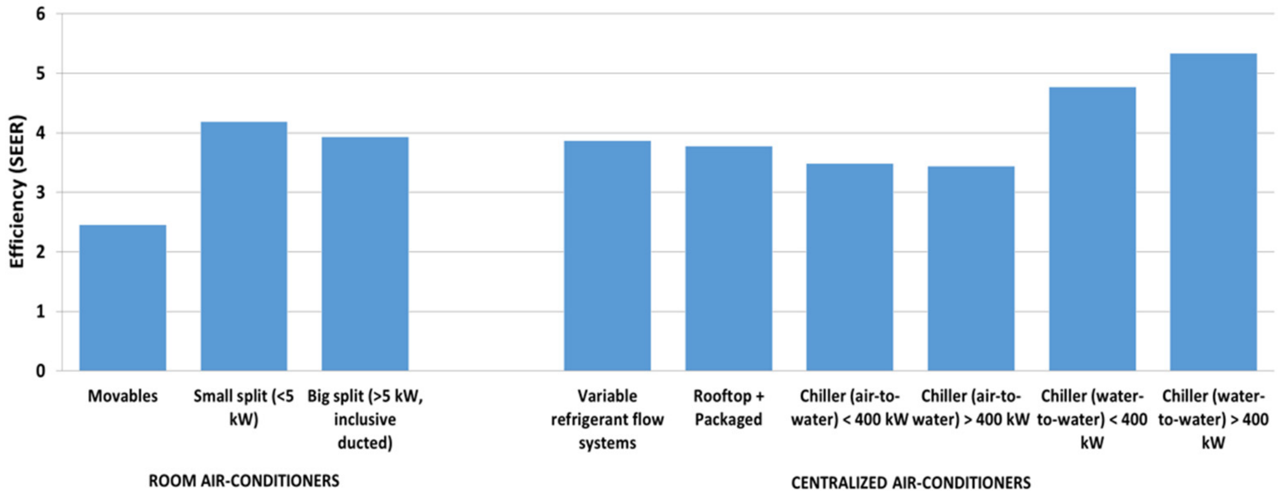

Figure 7. Seasonal energy efficiency ratio per space cooling type in the service sector, EU27+UK, the reference year 2016 (indicated values refer to the weighted average per final cooling consumption).

Again, through the collected average capacity and SEER values per SC type, the corresponding electricity input in kW has been calculated.

Furthermore, Figure 8 displays information regarding the equivalent full load hours (EFLHs) of Europe's service sector country-by-country.

As visible in Figure 8, the EFLHs of Europe's service sector are highest in Cyprus (as was the case for Europe's residential sector), with values reaching more than 1000 EFLHs. Malta follows with almost 100 ELFHs. Greece and Spain follow with values of more than 900 EFLHs. Italy and Croatia follow with almost 900 EFLHs and 800 EFLHs, respectively. Romania, Portugal, and France follow with values of over 700 EFLHs. Hungary, Slovakia, Bulgaria, Austria, and Slovenia follow with values of over 600 EFLHs. The remaining countries show values lower than 600 EFLHs. The service sector's mean (please see the horizontal line in Figure 8 above) results in slightly more than 650 EFLHs.

Table 4 show that the most energy-consuming SC type are big split (>5 kW, inclusive ducted) systems with more than 30 TWh/y. Rooftop plus packaged units come next with more than 20 TWh/y. Variable refrigerant flow systems follow with more than 8 TWh/y. Chiller (air-to-water) > 400 kW and small splits come next with more than 7 TWh/y and 6 TWh/y, respectively. Chiller (water-to-water) > 400 kW and chiller (air-to-water) < 400 kW follow with almost 5 TWh/y, respectively. Chiller (water-to-water) < 400 kW comes with more than 1 TWh/y, and movables are positioned last with 0.15 TWh/y.

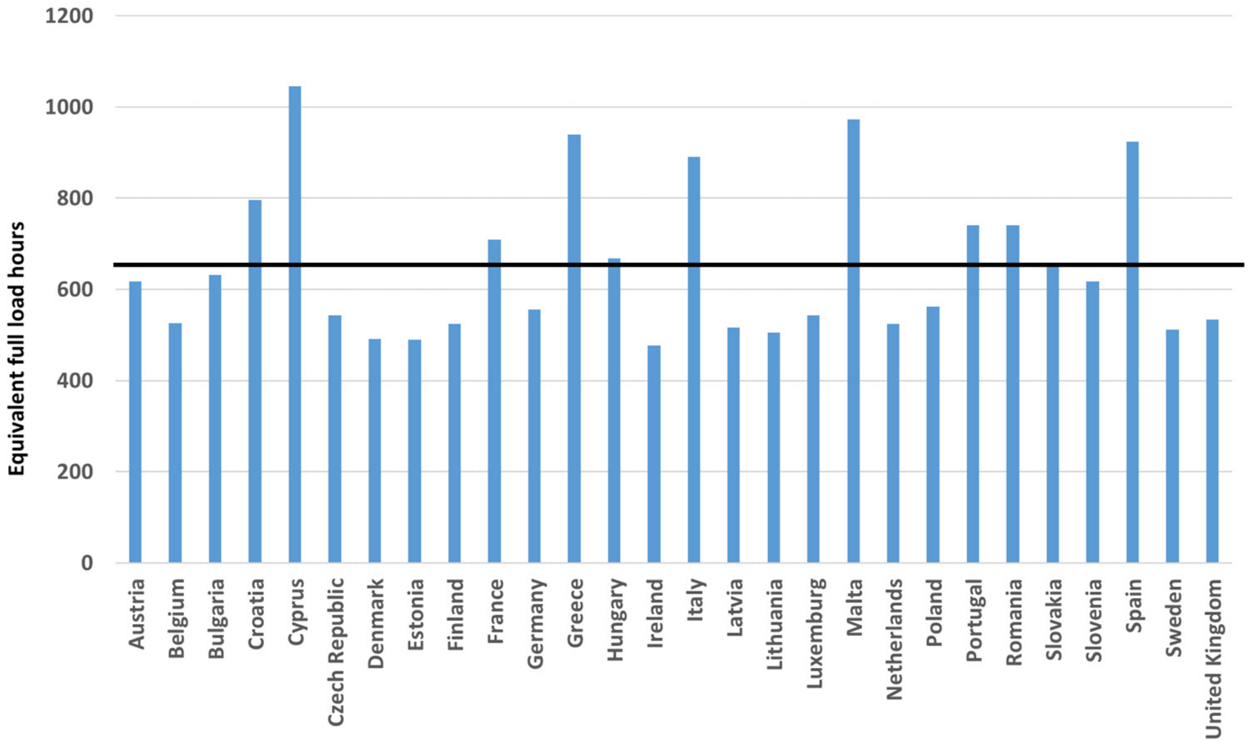

Figure 8. Equivalent full load hours in the service sector, EU27+UK.

The data of Figures 7 and 8 in Equation (1) results in Table 4.

Table 4. Final energy consumption for space cooling per type in the service sector, EU27+UK, the reference year 2016.

Technology	Final Energy Consumption [TWh/y]
RACs	
Movables	0.15
Small split (<5 kW)	6.18
Big split (>5 kW, inclusive ducted)	30.58
CACs	
Variable refrigerant flow systems	8.09
Rooftop + Packaged	20.55
Chiller (air-to-water) < 400 kW	4.78
Chiller (air-to-water) > 400 kW	7.44
Chiller (water-to-water) < 400 kW	1.36
Chiller (water-to-water) > 400 kW	4.91

Thus, in contrast to the residential sector, CACs prevail with around 60% of the final SC consumption. The total amount of final SC consumption in Europe's service sector comes out to be 84 TWh/y. Finally, Table 5 shows the final cooling consumption shares per country.

Table 5. Final energy consumption for space cooling per country in the services sector, EU27+UK, the reference year 2016.

Country	TWh/y	Percentage
Austria	0.80	0.95%
Belgium	0.93	1.10%
Bulgaria	0.42	0.50%
Croatia	0.40	0.48%
Cyprus	0.31	0.37%
Czech Republic	0.75	0.89%
Denmark	0.42	0.50%
Estonia	0.19	0.22%
Finland	0.53	0.63%
France	15.51	18.46%
Germany	1.59	1.90%
Greece	2.60	3.09%
Hungary	0.89	1.06%
Ireland	0.20	0.23%
Italy	14.89	17.72%
Latvia	0.20	0.24%
Lithuania	0.20	0.24%
Luxembourg	0.22	0.26%
Malta	0.22	0.27%
Netherlands	1.02	1.21%
Poland	1.43	1.70%
Portugal	0.80	0.95%
Romania	1.17	1.39%
Slovakia	0.33	0.39%
Slovenia	0.25	0.30%
Spain	33.58	39.95%
Sweden	0.76	0.90%
United Kingdom	3.43	4.09%
EU27+UK	84.04	100%

As was the case for the residential sector, in this case, just scarcely, states account for most of the EU27+UK SC FEC amount of the entire EU27+UK. Spain, France, Italy, the UK, Greece, and Germany account for more than 80% of Europe's final SC consumption for the service sector. Thus, the remaining 22 countries account for the left 20%.

3.3. *Residential and Service Sectors*

Notably, Table 6 results from aggregating the outcomes of Tables 2 and 4.

Table 6. Final energy consumption for space cooling per type in the residential and service sectors, EU27+UK, the reference year 2016.

Technology	Final Energy Consumption [TWh/y]
RACs	
Movables	1.83
Small split (<5 kW)	15.97
Big split (>5 kW, inclusive ducted)	39.36
CACs	
Variable refrigerant flow systems	8.31
Rooftop + Packaged	20.55
Chiller (air-to-water) < 400 kW	6.18
Chiller (air-to-water) > 400 kW	7.44
Chiller (water-to-water) < 400 kW	1.55
Chiller (water-to-water) > 400 kW	4.91

As shown in Table 6, the most energy-consuming SC types are big split (>5 kW, inclusive ducted) systems with almost 40 TWh/y. Rooftop plus packaged units follow with more than 20 TWh/y. Small split systems follow with almost 16 TWh/y. VRF systems and chiller (air-to-water) > 400 kW follow with more than 8 TWh/y and 7, respectively. Chiller (air-to-water) < 400 kW comes next with more than 6 TWh/y. Chiller (water-to-water) > 400 kW follows with almost 5 TWh/y. Movables follow with almost 2 TWh/y. Chiller (water-to-water) < 400 kW are last placed with more than 1 TWh/y.

The entire quantity of EU27+UK SC FEC of the residential and service sector ends up at 106 TWh/y.

Concerning the total final SC consumption (residential and service sectors), the RACs and CACs account for about the same percentage, with approximately 50% of each EU27+UK FEC.

In conclusion, Table 7 results from aggregating the outcomes of Tables 3 and 5.

Table 7. Final energy consumption for space cooling per country in the residential and service sectors, EU27+UK reference year 2016.

Country	TWh/y	Percentage
Austria	0.85	0.80%
Belgium	0.94	0.89%
Bulgaria	0.47	0.45%
Croatia	0.47	0.44%
Cyprus	0.71	0.66%
Czech Republic	0.77	0.73%
Denmark	0.43	0.40%
Estonia	0.19	0.18%
Finland	0.53	0.50%
France	16.28	15.34%
Germany	2.47	2.32%
Greece	6.04	5.69%
Hungary	1.00	0.94%
Ireland	0.20	0.18%
Italy	25.27	23.82%
Latvia	0.20	0.19%
Lithuania	0.21	0.19%
Luxembourg	0.22	0.21%
Malta	0.47	0.44%
Netherlands	1.04	0.98%
Poland	1.46	1.38%
Portugal	1.04	0.98%
Romania	1.50	1.41%
Slovakia	0.34	0.32%
Slovenia	0.26	0.25%
Spain	38.52	36.31%
Sweden	0.77	0.73%
United Kingdom	3.46	3.26%
EU27+UK	106.10	100%

Once again, just a few countries account for most of the final SC consumption amount of the entire EU27+UK. Spain, Italy, France, Greece, the UK, and Germany account for more than 85% of Europe's final SC consumption for the residential and service sectors. Thus, the remaining 22 countries account for the remaining 15%.

4. Discussion

According to this study, the EU27+UK FEC for the SC sector was assessed in 2016 as a baseline.

It is worth mentioning that in the H&C sector, SH is broadly studied in scientific literature, while SC is still unexplored. Initially, during the literature review phase, little information has been found. The essential sources were EurObserv'ER [20], EUROHEAT&POWER [5], and EHPA [21], which provided territorial views and data such as the CDDs, essential for the EFLHs calculation phase. In addition, sources such as EU Buildings Database [23], and EHPA's Online Stats Tool [21] provided building data fundamental for Section 2.

The sources mentioned above were fundamental for the EFLHs calculation phase. Similarly, the study by Dittmann et al., 2017 [28], included in the H2020 HRE4 project, was the most precise and reliable source for the space cooling unit's amount and capacity installed data for the EU27+UK SC sector. Furthermore, the SEER values were retrieved by following the respective computation practice recommended in the European Standards EN 14825 [49].

The residential and service sectors in the EU27+UK involve space cooling equipment technologies such as Moveables, small split (<5 kW), and big split (>5 kW, inclusive ducted systems) grouped under the RACs, and VRF system, rooftop system + Packaged, chiller (air-to-water) < 400 kW, chiller (air-to-water) > 400 kW, chiller (water-to-water) < 400 kW, and chiller (water-to-water) > 400 kW, grouped under CACs.

While in the residential sector the RAC types prevail with about 90% of the EU27+UK SC FEC, in the service sector, approximately 60% is provided by CACs. Including the residential and service sectors, the RACs and CACs are responsible for around 50% of the EU27+UK SC FEC each.

Throughout the current study, it has been observed that in the EU27+UK SC sector, including both the residential and service parts, the most energy-consuming SC types are big split (>5 kW, inclusive ducted) systems 40 TWh/y out of the total EU27+UK FEC. Rooftop plus packaged units follow with more than 20 TWh/y, and small split systems come next with almost 16 TWh/y. All the remaining VC systems follow with minor consumptions less than 10 TWh/y.

Overall, the sources mentioned above provided the input data for Equation (1), which eventually calculated the SC FEC for the EU27+UK, resulting in around 106 TWh/y in 2016 for both the residential and service sectors.

The EU27+UK countries, listed from the most consuming to the least, resulted in Italy, Spain, France, Greece, the UK, and Germany involving more than 85% of EU27+UK SC FEC for the residential and service sectors, respectively. The remaining 22 member states account for the left 15%.

To enhance the result discussion, to the outcomes of Table 7 presented in values of TWh/y has been applied a conversion factor by resulting in a EU27+UK average of around 215 kWh/y per capita for the total space cooling energy consumption including both the residential and the service factor [50]. A further detail that expresses the space cooling energy consumption per country can be found in Table A2 of Appendix A. It has been observed that, in 2016, on average, in the residential sector of the EU27+UK, the FEC for electricity has been around 1500 kWh/y per capita. Following what has been presented above, one-sixth of the total electricity consumption was meant for SC [51–53]. According to EUROSTAT, disaggregated values of the EU27+UK FEC for SC in the residential sector have been analyzed to create a benchmark for this study [54]. In this case, FEC for SC values of the Member States such as Cyprus, Denmark, Estonia, Ireland, Latvia, Lithuania, Sweden, and the United Kingdom were not available. Hence, disaggregated values as such have not been considered a valid benchmark for this study. Moreover, as aforementioned, the EU27+UK FEC for space cooling involving the residential and service sector accounted for more than 105 TWh/y. Because the SC market for almost its totality is dominated by VC machinery, electricity is the main type of energy consumed. In 2016, according to the EEA (European Environment Agency), the EU27+UK FEC for electricity in the residential and service sectors accounted for around 1600 TWh/y [55]. Overall, in the EU27+UK, it has been observed that the FEC for SC accounts for the 6.5% of the FEC for electricity in both residential and service sectors.

Finally, although data and information are few, it must be said that potential future studies related to the current topic could include the remaining cooling technologies apart from VC per sector and subsector. According to EUROVENT statistics, TDHPs account for about 1% of the EU27+UK cooling market, while the remaining 99% is dominated by VC technology [38]. However, TDHPs are mainly powered by waste heat, and thus final energy consumption indications are negligible in this case.

The cooling equipment producers have been identified as crucial EU27+UK market participants. Therefore, more reliable and precise datasets of their products' technical parameters have become an impending necessity. Not all collected information appears to be trustworthy. This information concerns the particular market size and efficiency values for cooling equipment. Such data have been excluded from carried-out calculations.

Although data and information retrieval from private companies might encounter accessibility issues [56], easier accessibility to research and development (R&D) reasons is hoped soon.

5. Conclusions

The main findings of the current study concerning the European space cooling final energy consumption with 2016 as baseline are presented in the following text. The outcomes are presented for both the residential and the service sectors.

Overall, the final energy consumption for space cooling of both sectors accounted for more than 105 TWh/y in 2016.

In the following text, the main features which entail the cooling technology types share, as well as the final energy consumption shares for the European member states for each sector, are presented.

5.1. Residential Sector

- The most energy-consuming space cooling technologies are small split (<5 kW) systems with nearly 10 TWh/y of the total space cooling energy use registered. Big split (>5 kW, inclusive ducted) systems follow with almost 9 TWh/y. Moveables come next with almost 2 TWh/y. Chiller (air-to-water) < 400 follow with more than 1 TWh/y. Variable refrigerant flow systems and chiller (water-to-water) < 400 kW are to find at the penultimate and last position with 0.22 TWh/y and 0.19 TWh/y each.
- Room air conditioner types account for the absolute majority of the European space cooling final energy consumption with more than 90%. Centralized air conditioner types account for the remaining 10% part of the bullet above.
- The total amount of the European space cooling final energy consumption comes out to be more than 22 TWh/y.
- There are five countries (Italy, Spain, Greece, Germany, and France) accounting for more than 90% of the European space cooling final energy consumption. The remaining 23 countries account for the left 10%.

5.2. Service Sector

- The most energy-consuming space cooling technologies are big split (>5 kW, inclusive ducted) systems with more than 30 TWh/y. Rooftop plus packaged units come next with more than 20 TWh/y. Variable refrigerant flow systems follow with more than 8 TWh/y. Chiller (air-to-water) > 400 kW and small split come next with more than 7 TWh/y and 6 TWh/y, respectively. Chiller (water-to-water) > 400 kW and chiller (air-to-water) < 400 kW follow with almost 5 TWh/y, respectively. Chiller (water-to-water) < 400 kW comes with more than 1 TWh/y, and movables are last positioned with 0.15 TWh/y.

- Centralized air conditioner types account for the absolute majority of European space cooling final energy consumption with more than 60%. Room air conditioner types account for the remaining 40% part of the bullet above.
- The total amount of the European space cooling final energy consumption comes out to be 84 TWh/y.
- A select few countries account for the greatest part of the European space cooling final energy consumption. United Kingdom, Spain, France, Greece, Italy, and Germany account for more than 80%. The remaining 22 countries account for the left 20%.

5.3. Residential and Service

- The most energy-consuming SC type are big split (>5 kW, inclusive ducted) systems with almost 40 TWh/y. Rooftop plus packaged units follow with more than 20 TWh/y. Small split systems come next with almost 16 TWh/y. VRF systems and chiller (air-to-water) > 400 kW follow with more than 8 TWh/y and 7, respectively. Chiller (air-to-water) < 400 kW come next with more than 6 TWh/y. Chiller (water-to-water) > 400 kW follow with almost 5 TWh/y. Movables follow with almost 2 TWh/y. Chiller (water-to-water) < 400 kW are last positioned with more than 1 TWh/y.
- Room air conditioners and Centralized air conditioners account for about the same percentage, with approximately 50% of the European space cooling final energy consumption.
- The total amount of the European space cooling final energy consumption, including both the residential and service sectors, comes out to be 106 TWh/y.
- Once again, not many European member states account for the absolute majority of the European Union space cooling final energy consumption. Italy, Greece, Spain, the United Kingdom, France, and Germany account for more than 85%. The remaining 22 countries account for the remaining 15%.

In conclusion, the current study encountered significant data and information retrieval issues because most of the data are not available, fragmented, outdated, or even accessible. The cooling sector is still barely explored in scientific literature, although it significantly contributes to the European final energy consumption. Therefore, greater attention from the private as well the public sector on the topic is significantly auspicial, which could eventually lead to support on meeting the climate and energy requirements mentioned in Section 1.

The conjunction of rising temperatures, evolving building design, and growing preference for thermal comfort has led to an increase in space cooling energy needs. As per statistics, space cooling is no longer a statistically small consumer of electricity; instead, it is a new developing sector that contributes between 5% and 20% of overall electricity consumption in various European countries. As a consequence, the European Union and its Member States are dealing with the implementation of the renewable cooling calculation methodology to better link the renewable energy sources with the space cooling sector under Article 7 (3) of the 2018 Renewable Energy Directive. The current study aimed to bring to the surface the topic of space cooling, which is barely explored in scientific literature, to better support decisions for the future sustainable pathways that the European Union is going to run across in the upcoming years.

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Conflicts of Interest: The information and views set out in this article are those of the author and do not necessarily reflect the official opinion of the European Commission.

Appendix A

Table A1. Nomenclature.

Acronym	Name
AC	Air conditioning
ASHRAE	American Society of heating, refrigerating, and air conditioning engineers
CACs	Centralized air conditioners
CDD	Cooling degree day
DC	District cooling
DHW	Domestic hot water
EEA	European Environment Agency
EED	Energy Efficiency Directive
EER	Energy efficiency ratio
EFLHs	Equivalent full load hours
Eq	Equation
ETS	Emission trading system
EU	European Union
FEC	Final energy consumption
GHG	Greenhouse gas
H&C	Heating and cooling
H2020	Horizon 2020
HDD	Heating degree day
IDS	Integrated surface database
NUTS	Nomenclature of territorial units for statistics
PC	Process cooling
R&D	Research and development
RACs	Room air conditioners
RED	Renewable energy directive
RES	Renewable energy sources
SC	Space cooling
SEER	Seasonal energy efficiency ratio
TDHP	Thermally driven heat pump
UED	Useful energy demand
VC	Vapour compression
VRF	Variable refrigerant flow
Wh	Watt-hour

Table A2. Final energy consumption for space cooling per country in the residential and service sectors expressed in kWh/y per capita, EU27+UK reference year 2016.

Country	Demography *	kWh/y	kWh/y per Capita
Austria	8,700,471	850,000,000	97.70
Belgium	11,311,117	940,000,000	83.10
Bulgaria	7,153,784	470,000,000	65.70
Croatia	4,190,669	470,000,000	112.15
Cyprus	848,319	710,000,000	836.95
Czech Republic	10,553,843	770,000,000	72.96
Denmark	5,707,251	430,000,000	75.34

Table A2. *Cont.*

Country	Demography *	kWh/y	kWh/y per Capita
Estonia	1,315,944	190,000,000	144.38
Finland	5,487,308	530,000,000	96.59
France	66,638,391	16,280,000,000	244.30
Germany	82,175,684	2,470,000,000	30.06
Greece	10,783,748	6,040,000,000	560.10
Hungary	9,830,485	1,000,000,000	101.72
Ireland	4,726,286	200,000,000	42.32
Italy	60,665,551	25,270,000,000	416.55
Latvia	1,968,957	200,000,000	101.58
Lithuania	2,888,558	210,000,000	72.70
Luxembourg	576,249	220,000,000	381.78
Malta	450,415	470,000,000	1043.48
Netherlands	16,979,120	1,040,000,000	61.25
Poland	37,967,209	1,460,000,000	38.45
Portugal	10,341,330	1,040,000,000	100.57
Romania	19,760,585	1,500,000,000	75.91
Slovakia	5,426,252	340,000,000	62.66
Slovenia	2,064,188	260,000,000	125.96
Spain	46,440,099	38,520,000,000	829.46
Sweden	9,851,017	770,000,000	78.16
United Kingdom	65,379,044	3,460,000,000	52.92
Average	18,220,781	3,789,642,857	214.46

* EU27+UK Population data have been collected for the reference year 2016 [50].

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