Project No: IEE/13/650

Quantifying the Heating and Cooling Demand in Europe

Work Package 2

Background Report 4

Co-funded by the Intelligent Energy Europe Programme of the European Union

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Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

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1.1 Background

Building heat demands for space heating and hot water preparation in residential and service sectors are quantified in the Stratego project by use of international energy statistics, a set of default conversion efficiencies for fuels used in final consumption, and a separate inquiry on electricity used for heating purposes. The assignment is to estimate the current heating demands in European buildings by country and by NUTS3 region using a top-down approach, partly to establish national and regional average values, partly to provide input data for the specific purpose of creating a high resolution heat demand density map for Europe in order to identify future possibilities for district heating systems. In the following, an account is given for the establishment of country and regional average values, while a separate section (see Background report 5 & 6) is dedicated to the approach and measures used to create the Pan-European heat demand density map.

Building heat demands account for significant shares of total energy use in European Union Member States today and the provision of energy services to meet these demands may utilise several different fuel supply sources and energy carriers. As will be presented in the following, fossil fuel supply sources are, on average, dominating alternatives in EU28 at current, where coal, oil products, and natural gas especially, represent 68% of the total supply to the building heat market (78% including electricity, which often is generated by use of fossil fuels). This indicates that the European building sector has an important role to play in the future decarbonisation of the European energy system, since there is plenty of room for improvements in this sector. One such improvement could be obtained by replacing some of the current fossil supply with recovered excess heat from energy and industry activities, as well as with renewable heat resources. District heating, which at current account for only a minor share of the total EU28 building heat market (12%), represent a key technology for the viability of such an approach.

One would perhaps think that building heat demands are a main issue mainly in Northern Member States, where colder climates and longer winter seasons emphasise the demand for these energy services, but since building heat demands reflect levels of building insulation, levels of energy services available and desired, levels of comfort etc., no such clear division exist in Europe today. Quite contrary, building heat demands are substantial also in central and, to some extent, as well in Southern Member States. In the future, by refurbishments of the current building stock and by new construction of low energy houses, the heat demands of European buildings are expected to decrease. However, since in parallel, specific buildings spaces and the use of domestic hot water are expected to increase, the future heat demands of European building remain difficult to predict. In this section, focus is on the current situation and the reference year for all statistical information used is 2010.

1.1.1 Method and data

To assess heat demands for space heating and hot water preparation in EU28 residential and service sector buildings, the approach within the Stratego project centres on the use of national level energy statistics (corrected energy balances for the year 2010 from the International Energy Agency (IEA, 2014)) and a separate survey on electricity used for heating purposes. The objective is to establish national volumes of fuel and energy supply to European buildings for heating purposes and, by use of default conversion efficiencies, assess the end-use heat demands to which this supply correspond (i.e. the EU28 building heat market). As can be seen in Table 1, default conversion efficiencies are set to reflect current average performance to be expected from individual boilers (using different fuel sources) and electrical appliances (heat pumps and resistance heaters) in contemporary building installations today. To facilitate a comprehensive understanding of the distribution between the residential and the commercial & public services sector, all data is in this context separated with respect to the residential sector (including non-specified (other) sector), the service sector, and the EU28 total.

Table 1. Fuel supply sources and energy carriers extracted from international energy statistics and anticipated average conversion efficiencies in local boilers and electrical appliances. Default values set to reflect average performance in contemporary building installations at current

Fuel supply sources and energy carriers	Average conversion efficiency
Coal and coal products	65%
Peat	60%
Crude, NGL, and feedstocks	80%
Oil Products	80%
Natural gas	85%
Geothermal (heat)	100%
Solar/wind/other	100%
Biofuels and waste	65%
Heat (District heat)	100%
Electricity for heat pumps (residential sector)	300%
Electricity for resistance heaters (residential sector)	100%

Table 2. Shares of electricity in residential sector heat demands (HD), by EU28 Member States, used data sources, and relative distribution of electrical heat demand in terms of heat pumps and other electric heating

Member States	Share of electricity in residential HD [%]	Data source, share of electricity in residential HD	Heat pumps[a] [%]	Other electric [%]
Austria	6	(Kranzl et al., 2012)	33	67
Belgium	3	(Entranze, 2014b)	0	100
Bulgaria	14	(Entranze, 2014b)	10	90
Croatia	6	(Entranze, 2014b)	0	100[b]
Cyprus	27	(CYSTAT, 2011)	0	100
Czech Republic	8	(Zahradník et al., 2012)	30	70
Denmark	3	(Entranze, 2014b)	14	86
Estonia	3	(Entranze, 2014b)	0	100
Finland	17	(Kiuru et al., 2012)	6	94[c]
France	13	(Entranze, 2014b)	2	98
Germany	7	(Kockat and Rohde, 2012)	17	83
Greece	7	(Entranze, 2014b)	0	100
Hungary	4	(Entranze, 2014b)	0	100
Ireland	5	(Entranze, 2014b)	0	100
Italy	6	(Zangheri et al., 2012)	0	100
Latvia	1	(Entranze, 2014b)	0	100
Lithuania	0	(Entranze, 2014b)	0	100
Luxembourg	5	(Entranze, 2014a)	0	100
Malta	77	(Valletta, 2014)	0	100[b]
Netherlands	2	(Entranze, 2014b)	82	18
Poland	1	(Entranze, 2014b)	1	99
Portugal	19	(Entranze, 2014b)	0	100
Romania	1	(Atanasiu et al., 2012)	0	100
Slovak Republic	3	(Entranze, 2014b)	30	70
Slovenia	1	(Entranze, 2014b)	0	100[b]
Spain	18	(Entranze, 2014b)	25	75
Sweden	26	(Entranze, 2014b)	68	32
United Kingdom	9	(Palmer and Cooper, 2012)	4	96

[a] *All data on relative shares, heat pumps versus Other electric, gathered from (Entranze, 2014a) unless otherwise noted*

[b] *No Entranze data available. Assumed distribution.*

[c] *No Entranze data available. Used data source: (Statistics Finland, 2008). NOTE; Shares refer to Residential and Service sector total.*

Since, in international energy statistics, electricity use in residential and service sectors never is specified in terms of electricity used for electrical or heating purposes, alternative information sources are used in the Stratego assessments to better estimate this share of the total building heat demand. For the residential sector assessments, the Entranze portal (Entranze, 2015) with associated country reports and publications (Atanasiu et al., 2012; Entranze, 2014a, b; Kiuru et al., 2012; Kockat and Rohde, 2012; Kranzl et al., 2012; Zahradník et al., 2012; Zangheri et al., 2014; Zangheri et al., 2012), have been the main information sources used for this end. Where available, also some national reports (CYSTAT, 2011; Palmer and Cooper, 2012; Statistics Finland, 2008; Valletta, 2014) were used. As detailed in

Table 2, national shares of electricity used for heating purposes in the residential sector are established by a selection of these sources, however mainly by use of (Entranze, 2014b).

Table 3. Electricity supply for final consumption in service sector, anticipated average electricity for heating purposes, total service sector heat market, and calculated electricity shares of service sector heat demands (HD), by EU28 Member States, data for 2010

Member States	**Electricity supply[a] [EJ]**	**Electricity for heating (19.7%)[b] [EJ]**	**Total heat market - excluding electricity[c] [EJ]**	**Total heat market [EJ]**	**Share of electricity in service HD [%]**
Austria	0.047	0.009	0.068	0.078	12
Belgium	0.080	0.016	0.109	0.125	13
Bulgaria	0.029	0.006	0.011	0.017	34
Croatia	0.019	0.004	0.011	0.015	25
Cyprus	0.008	0.002	0.002	0.003	46
Czech Republic	0.050	0.010	0.070	0.080	12
Denmark	0.039	0.008	0.047	0.055	14
Estonia	0.009	0.002	0.008	0.010	18
Finland	0.064	0.013	0.014	0.026	48
France	0.512	0.101	0.379	0.480	21
Germany	0.555	0.109	0.781	0.890	12
Greece	0.065	0.013	0.014	0.027	48
Hungary	0.041	0.008	0.078	0.086	9
Ireland	0.026	0.005	0.031	0.036	14
Italy	0.308	0.061	0.341	0.402	15
Latvia	0.009	0.002	0.014	0.016	11
Lithuania	0.010	0.002	0.013	0.015	13
Luxembourg	0.007	0.001	0.010	0.011	12
Malta	0.0023	0.0004	0.0000	0.0004	100
Netherlands	0.126	0.025	0.244	0.269	9
Poland	0.157	0.031	0.164	0.195	16
Portugal	0.059	0.012	0.016	0.028	41
Romania	0.027	0.005	0.045	0.050	11
Slovak Republic	0.029	0.006	0.049	0.055	10
Slovenia	0.011	0.002	0.009	0.011	19
Spain	0.302	0.060	0.088	0.148	40
Sweden	0.118	0.023	0.086	0.109	21
United Kingdom	0.351	0.069	0.278	0.347	20
EU28 Total	**3.061**	**0.604**	**2.982**	**3.586**	**17**

a As reported in (IEA, 2014).

b Average share for space and water heating of 19,7% for EU27 tertiary sector in 2007, according to (Bertoldi and Atanasiu, 2009).

c As reported in (IEA, 2014) and by use of default conversion efficiencies for fuel transformations according to Table 1.

An important piece of information for the residential sector assessments was also the division of electricity used for heating purposes with respect to heat pumps and “other electric” (mainly resistance heaters), available in (Entranze, 2014a). By this division at national level, it is possible in the Stratego assessment to estimate the often-obscure actual heat demand represented by heat supply from heat pumps. Since, according to Table 1, a default conversion efficiency of 300% is designated electrical heat pumps in this context, the corresponding heat demand satisfied by this technology is anticipated at three times the electrical supply.

For the Stratego service sector assessment, another approach was used since the Entranze data refers mainly to the residential sector only. Additionally, information on end use distributions of Member States service sector electricity use is very rare in general (no coherent data source seem to be available at current), which further necessitated an alternative approach. Based on a EU27 average value for the tertiary sector in 2007 (19.7% of all electricity use designated to space and water heating herein, according to (Bertoldi and Atanasiu, 2009)), electricity volumes for heating purposes are assessed by applying this share uniformly to total electricity supplies for final consumption per Member State (IEA, 2014), as detailed in Table 3. By subsequently adding hereby calculated volumes of electricity used for heating purposes to total Member State heat markets excluding electricity (IEA, 2014), assessments of total service sector heat markets are made available. From this, national shares of electricity use in service sector total heat demands, albeit somewhat granular, may be established.

Hereby, national level assessments of total fuel and energy volumes supplied and used for heating purposes in EU28 residential and service sector buildings are possible to estimate. Based on this, the next step involves national and regional population statistics, to assess specific heat demands (per-capita values), regional climate index factors (European Heating Index (EHI)), to adjust national values to regional conditions, and a proper regional division of the European continent to capture local conditions. Population statistics was gathered from Eurostat, on Member State level from (ES, 2014b) and on regional level from (ES, 2013), while geographical data on NUTS3 regions, the third level of European administrative units, were retrieved from the Eurostat/GISCO portal (ES, 2014a). According to 2010 (EU27) and 2008 NUTS classification, 35 European countries contain a total of 1453 defined regions today, among which 1302 are found in main land continental EU28 Member States (ES, 2010, 2011).

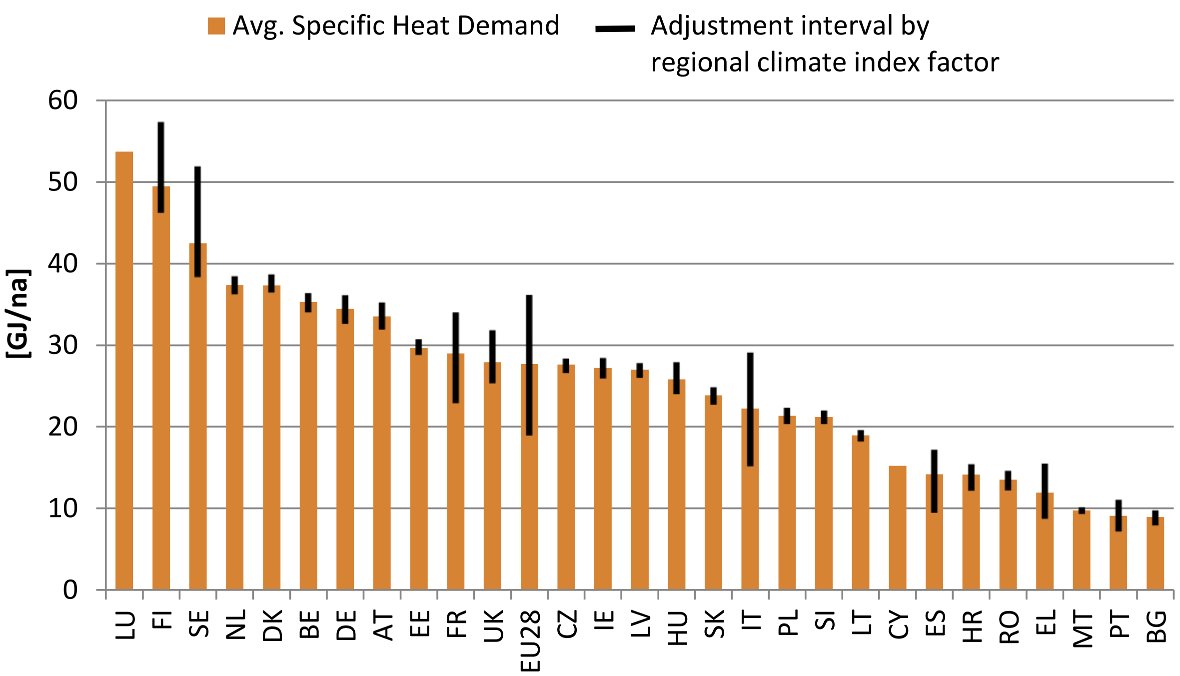

Figure 1. Average EU28 and Member State specific heat demands for final consumption of space heating and hot water preparation, with indicated adjustment interval by adaption of regional climate index factors. Data for year 2010.

To compensate for climatic variations within single Member States, present in countries with far north south stretches or large topological differences, regional climate conditions relative national climate conditions are anticipated by use of the European Heating Index (Werner, 2005). Typical index factor values range from ~0.6 in Southern Europe to ~1.5 in Northern

Scandinavia (relative average European conditions at 1.0). By this procedure, average national specific heat demands are increased by a factor ~1.3 (e.g. regions in northern Italy, Greece, and Sweden), and decreased by a factor ~0.7 (e.g. regions in southern Spain, Italy, Greece, and France), in most extreme instances, see Figure 1. (See also Figure 12 in the Appendix for a continental EU28 map of used index factors per NUTS3 region and Member State). Hereby, average national specific heat demands are adjusted and related to NUTS3 region population counts, whereby estimates of local climate adjusted regional heat demands are made available, as illustrated in Figure 13 in the Appendix.

As also visible in Figure 1, national average specific heat demand values range from approximately 10 to 50 GJ per-capita, with a EU28 national average at ~28 GJ per-capita. In preparation for visual representation, finally, all data was assembled in a relational database and spatially analysed within the ArcMap 10.1 GIS interface (ESRI, 2014).

1.1.2 Results

When compiling all reported fuel supplies and energy volumes from the considered sources and calculating the corresponding end use heat demand in EU28, the results show that a total annual energy supply of 15.5 EJ was supplied to buildings in residential and service sectors during the year 2010, as illustrated at left in Figure 2. Natural gas and oil products dominate the supply, followed by biofuels and waste, district heat, and electricity, respectively, while geothermal and other renewable sources are strictly marginal.

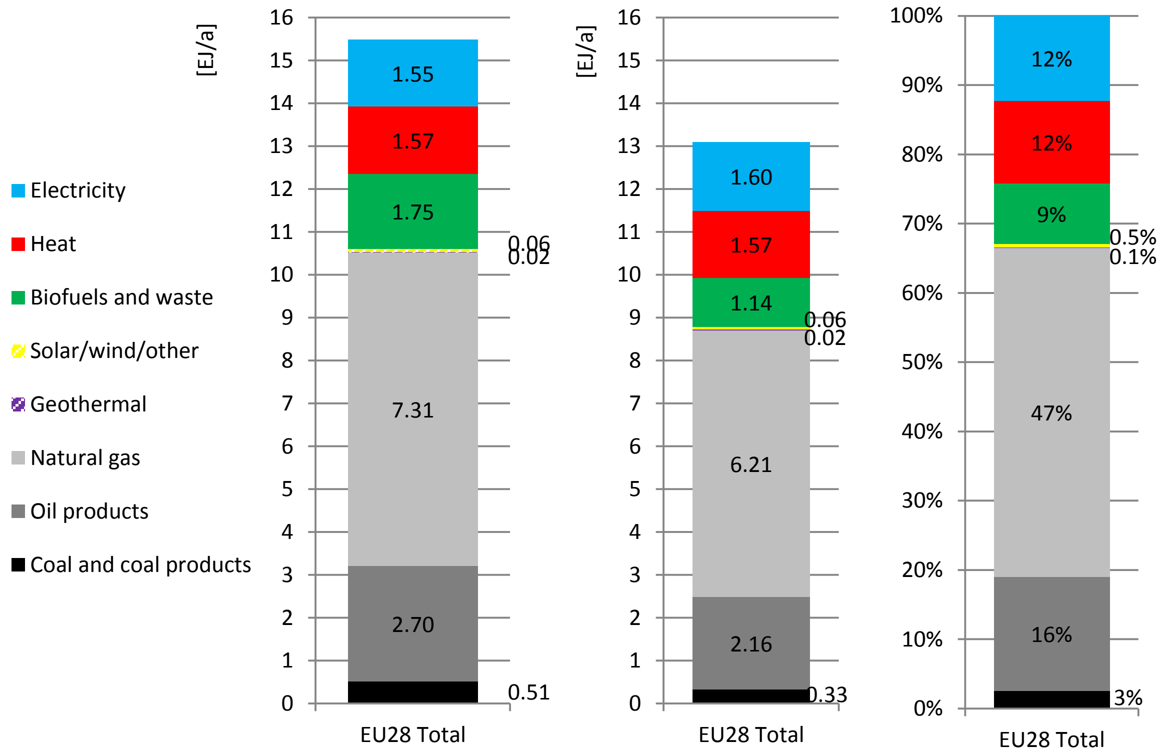

Figure 2. EU28 residential and service sector building heat market in 2010. At left, fuel and energy supply for final consumption to provide useful heat, by origin of fuel supply and energy sources. At centre, useful heat demand after local conversions. At right, distribution of residential and service sector building end use heat demands by fuel supply source and energy carrier.

In terms of useful heat demand, see Figure 2 at centre, the total residential and service sector building heat market constitute an energy volume of approximately 13.1 EJ, after e.g. conversion heat losses in local boilers and high thermal efficiencies of individual heat pumps.

This volume is higher than previous assessments performed in the Heat Roadmap Europe context ((Connolly et al., 2014; Connolly et al., 2013), where a corresponding EU27 end use heat demand of 11.8 EJ is assessed for the same year. Three plausible explanations for this difference are (i) use of corrected 2010 data, (ii) use of unique default conversion efficiencies per fuel and energy source (instead of uniform conversion efficiencies for all sources), and (iii) higher detail of electricity used for heating purposes.

Once more, it is apparent that fossil fuel supply sources dominate the European building heat market at current, representing some 66% of the total end use heat demand, while district heating represents 12% (with a useful heat volume of 1.57 EJ) and the electric heat demand accounting for 12% (1.60 EJ), as presented in Figure 2 at right.

In Figure 3, the total end use heat demand, i.e. the EU28 residential and service sector building heat market, is presented by fuel supply and energy volumes for each Member State, and it is clear that Germany, France, the United Kingdom, and Italy, represent largest national heat markets at current.

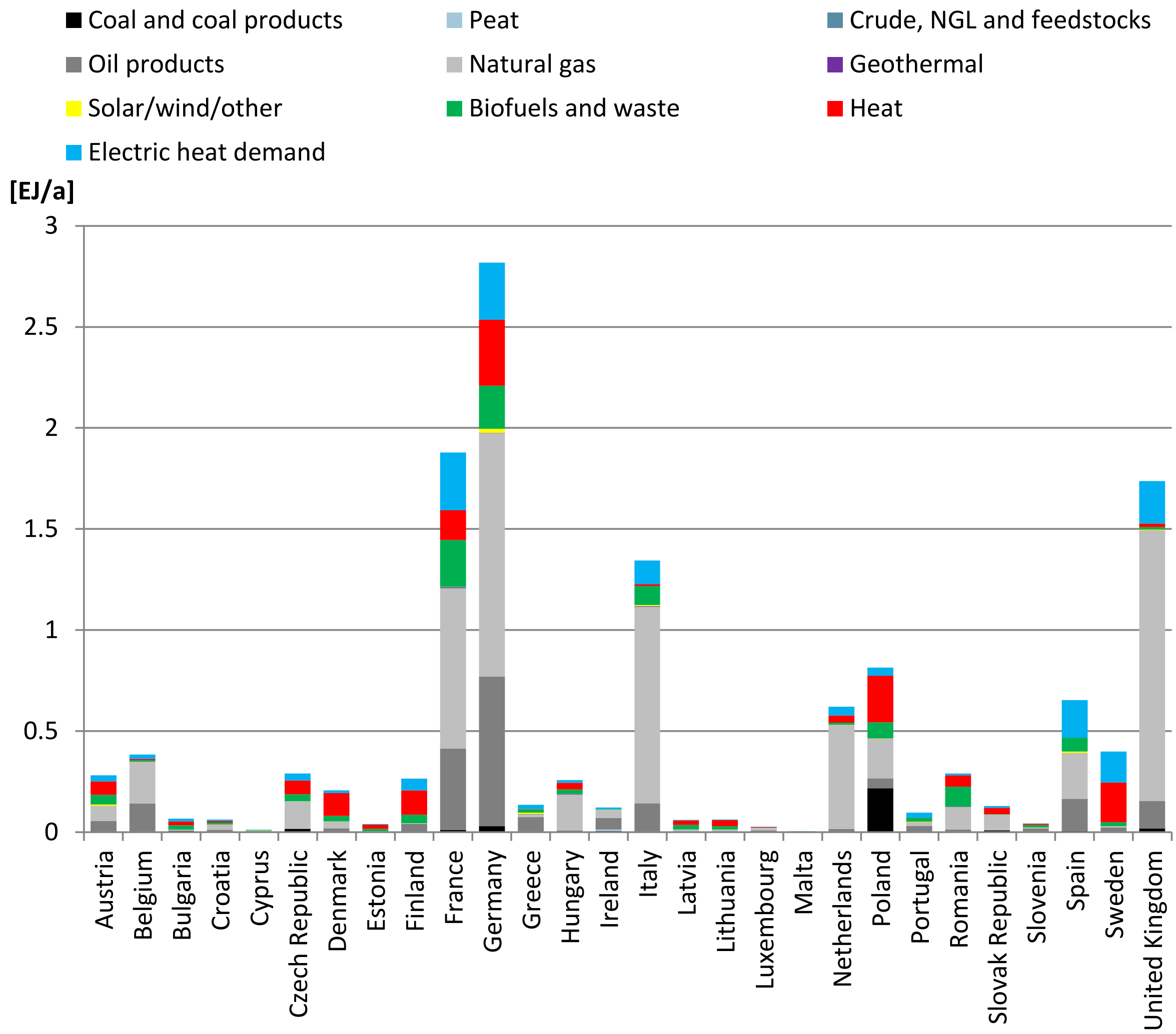

Figure 3. Stratego assessment of the EU28 residential and service sector building heat market in 2010, by Member States and fuel supply sources and energy carriers, data for year 2010.

As a complement to Figure 3, the results for the assessed EU28 residential and service sector building heat market is presented also in numerical form in Table 5 in the Appendix. If considering the relative shares of fuel supply sources and energy carriers used on respective

Member State heat markets, as depicted in Figure 4, a wide variety of national preferences is visible. The use of peat, for example, is limited essentially only to a few Member States (Ireland and the Baltic States), which is also the case for coal (however, approximately a 27% heat market share for coal in Poland). The use of oil products is pronounced in some instances (more than 50% national heat market share in Greece), while being a more or less abandoned alternative in e.g. the Czech Republic, the Slovak Republic, the Netherlands, Lithuania, and Hungary. Natural gas, on the other hand, account for substantial heat market shares in several countries today, especially so in the Netherlands (83%), the United Kingdom (77%), Italy (72%), and Hungary (69%), and the average national heat market share for natural gas among all EU28 Member States is 32%.

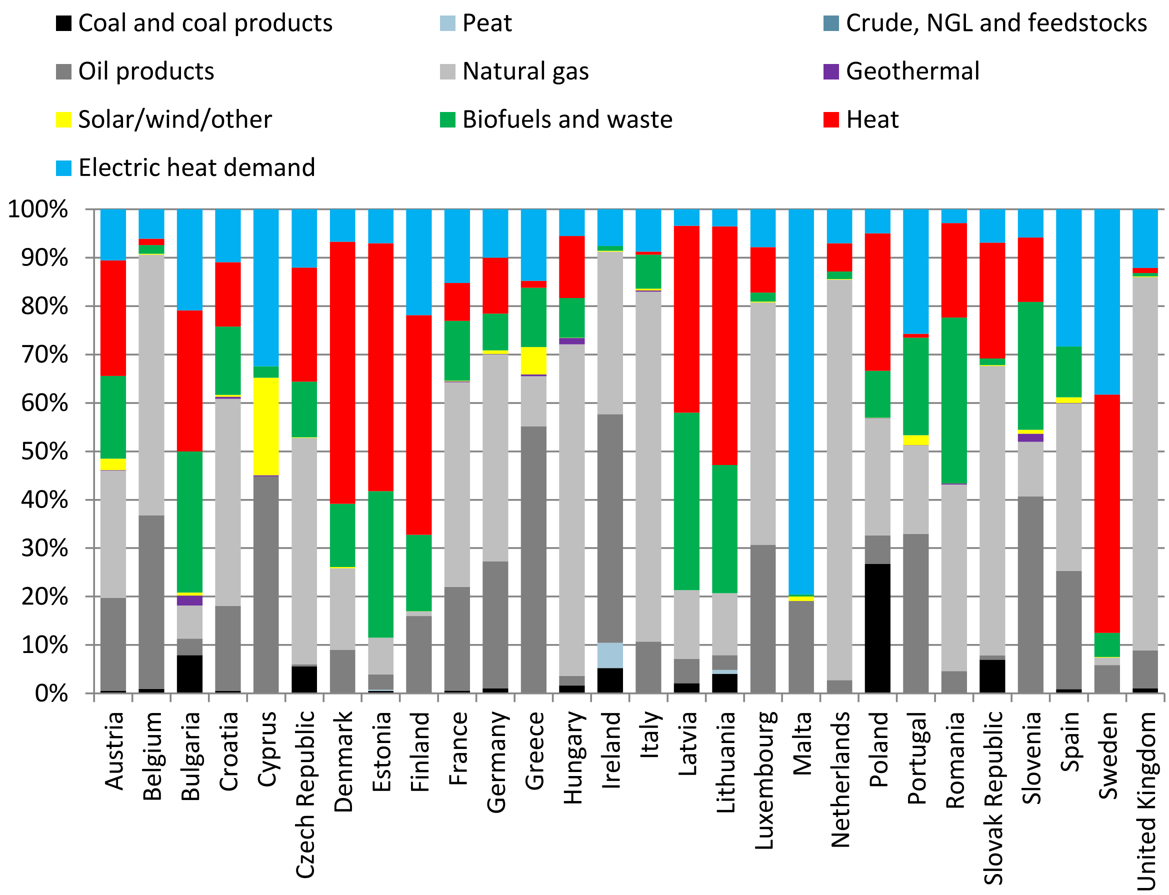

Figure 4. Distribution of EU28 Member States end use heat demands for space heating and hot water preparation in residential and service sector buildings. By fuel supply source and energy carrier, data for year 2010. Note that this is an updated version of the same graph, which was reference by the European Commission in October 2014 (EC, 2014).

In terms of renewable heat sources, geothermal heat reaches marginal heat market shares only in a couple of Member states today (e.g. Bulgaria, Hungary, and Slovenia), while largest volumes are found in France (~3.5 PJ annually). On national scale, the relative heat market share of 20% for solar/wind/other sources in Cyprus is without competition the highest in Europe today, although largest volumes of this category appear in Germany (20.3 PJ), Greece (7.7 PJ), and Spain (7.6 PJ). Biofuels and waste reaches highest national heat market shares in Latvia (37%), Romania (34%), and Estonia (30%), which is far above the average national heat market share of 13% for this environmentally important resource. Finally, district heating reaches half of total national heat market shares in some Northern Member States (54% in Denmark, 51% in Estonia, 49% in both Sweden and Lithuania), but account for significant national heat market shares also in Bulgaria (29%), Poland (28%), Austria, the Czech

Republic, and the Slovak Republic (all three at approximately 24%). Electricity for heating purposes on national European heat markets averages at 15% (12% of total EU28 building heat market) and is most pronounced in the Republic of Malta (80%), Sweden (38%), Cyprus (32%), and in Portugal (26%). However, largest electric heat demand volumes appear in France (285 PJ), Germany (282 PJ), the United Kingdom (210 PJ), and Spain (185 PJ).

1.1.3 Some conclusions

The major conclusions from these Stratego estimations to quantify building heat demands for space heating and hot water preparation in residential and service sectors are that:

1. Use of international energy statistics, default conversion efficiencies for fuels and energy carriers used in final consumption, and a separate inquiry on electricity used for heating purposes, allow estimations of the current building heat demands for space heating and hot water preparation in European residential and service sectors

2. The EU28 building heat market is anticipated at 13.1 EJ for the year 2010. Natural gas represents close to half of this market at current (47%) and fossil fuel sources dominate the useful heat demand in general (66%). District heating represents 12%, the electric heat demand 12%, biofuels and waste 9%, while coal and coal products, as well as geothermal and other renewable resources, are only marginally utilised

3. Residential and service sector building heat demands in 1302 EU28 NUTS3 regions, established by using a top-down approach based on national per-capita values and compensated for regional climate conditions, provides input data for creating a Pan-European heat demand density map at square kilometre grid cell resolution

4. Four Member States (Germany, France, the United Kingdom, and Italy) represent largest total heat demand volumes, all with national building heat markets above one EJ per year, while relative shares of fuel supply sources and energy carriers used on EU28 Member States national heat markets are widely distributed

5. Benchmarking to previous assessments performed in the Heat Roadmap Europe project suggests that the use of corrected 2010 data, unique default conversion efficiencies, and a deeper assessment of electricity used for heating purposes, provides a more realistic, and slightly higher, assessment of the EU28 building heat market

1.2 European cooling demands

1.2.1 Background

The assignment within the Stratego project is to estimate the current cooling demands in European buildings by country and by location by a bottom-up method for planning and modelling purposes. Another specific purpose is to provide input for creation of a detailed cold density map for Europe in order to identify the Pan-European possibilities for district cooling networks.

The main delimitation is that only space cooling demands for getting lower indoor temperatures in buildings during summers are considered. Other cold demands in buildings as refrigerators or freezers are not included in these estimations.

The cold currently generated for space cooling can either be generated in each room by individual cooling devices (room air-conditioners – RAC), by central cooling (central air-conditioning – CAC) in each building, or by district cooling systems in dense urban areas.

1.2.2 Method

The current cooling demand by country is the product of three parameters: the average specific cooling demands, the building spaces used, and the saturation rates. The latter are the proportions of building spaces currently having cooling devices installed.

The full cooling demands constitute of the products of the specific cooling demands (per building space area) and the building space areas. The current cooling supplies constitute of the products of the cooling demands and the saturation rates. Cooling supplies are almost always lower than the full cooling demands, since all cooling demands are not met by cooling supplies. Hence, higher indoor temperatures are mostly accepted during warm summer days.

Building spaces are divided into residential and service sector building spaces, since the average specific cooling demands in service sector buildings are normally higher than in residential buildings. Service sector buildings constitute of all buildings excluding residential, industrial, and agricultural buildings. Typical service sector buildings are used for offices, education, hotels, health care, trade, sports etc.

Specific cooling demands, building space floor areas, and saturation rates have been gathered from various literature sources. Aggregated estimations of the European cooling demands have earlier been very rare, but during 2014 several new estimations have been published, giving a possibility to benchmark the Stratego estimations obtained here with other independent estimations.

All cooling demands and supplies are here expressed as useful cold to be used inside buildings, except when otherwise is clearly stated. Cold is defined as heat removal. This cold use interface is equivalent to cold deliveries from chiller evaporators or from district cooling systems. Hereby, cooling demands and supplies are not generally expressed as electricity input to chiller compressors.

1.2.3 Intermediate estimations

1.2.3.1 Specific cooling demands

By tradition, cooling supplies as the output from cooling devices are seldom measured, making it difficult to estimate the actual cooling demands in buildings. This statement is also valid for the electricity supply used as input to these cooling devices. This electricity supply is normally just a part of all electricity delivered and measured for a building when cooling is applied.

Some literature information about cooling demands in Europe have been published, but many of these published demands are not measured, but theoretically estimated by combining climate data with standard efficiencies for cooling devices. Hence, gathering existing cooling demands in Europe is not an easy task and a proper Pan-European survey of cooling demands and supplies by countries and by locations has never been published before.

However, one exception exists with respect to measurements of cooling supplies. When district cooling systems are used, the cooling supplies are regularly measured in order to create invoices for these cold deliveries. Hereby, these systems can provide information about aggregated and average cooling demands. These systems deliver cold to mostly service sector buildings.

In total, twenty annual cold deliveries have been gathered from district cooling systems and these values consider both aggregated deliveries and deliveries to specific buildings. These values are presented in Figure 5 as red squares with the European Cooling Index (ECI) as independent variable. This index was defined and presented in (Dalin et al., 2005) as an indicator of local cooling demands at a time when proper actual specific cooling demands were not available. The values considering six specific buildings from (Swedblom et al., 2014) have also smaller diagonal black squares. These twenty values are grouped into three main clusters. The highest cluster consists of three highest values and these were obtained from one Spanish and two Italian district cooling systems. The intermediate cluster represents some French district cooling systems, while the remaining values with ECI values between 45 and 85 constitute the lowest cluster based on information from district cooling systems in Finland, Sweden, Norway, and Switzerland. The average red line represents the best linear fit to these twenty values.

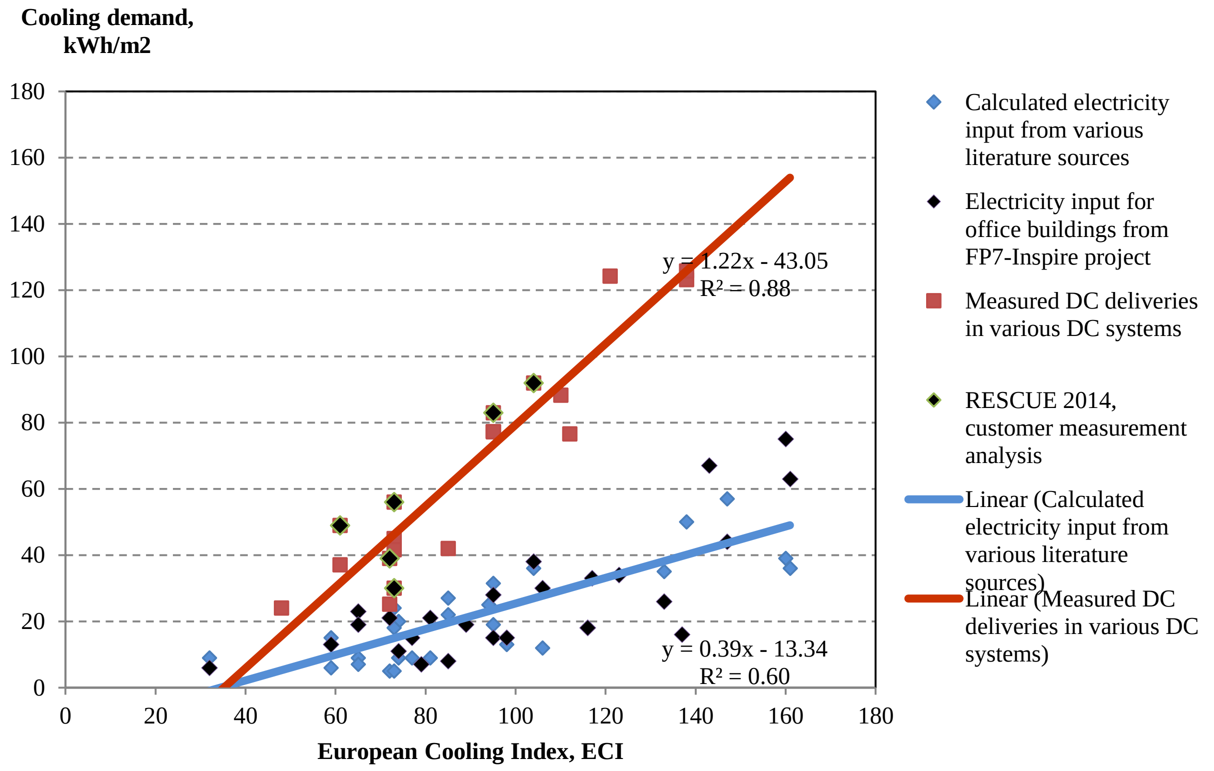

Figure 5. Estimated specific cooling demands for service sector buildings with direct use of district cooling or use of electricity input to compressor chillers.

Further fifty-three values have been gathered from various literature sources considering electricity input to cooling devices in service sector buildings for various locations or countries. These values are represented by the diagonal green squares in Figure 5. Twenty-seven of these values have been cited from (INSPIRE, 2014) and consider country averages. These values have also smaller diagonal black squares. The average green line represents the best linear fit to these fifty-three values.

Energy efficiency ratio (EER) is the performance indicator for cooling devices expressing the ratio between the output cooling energy from the evaporator and the input electricity to the compressor. The average seasonal ERR (SEER) can be estimated from Figure 5 by the ratio between the slopes for the two average lines. This SEER estimate amounts to 3.1 and this is a very plausible value. Hence, the two average lines in Figure 5 support each other. Hereby, the average red line in Figure 5 can be used to estimate the European cooling demands in service sector buildings.

The corresponding detailed information about specific cooling demands is currently not available for residential buildings in Europe. In both (Dalin et al., 2005) and (Tvärne et al., 2014), the residential cooling demands were assumed to be 45% of the service sector cooling demands. The same estimation of 45% was also obtained when comparing residential and office buildings in (INSPIRE, 2014). Therefore, the same ratio of 45% will also be used here in the Stratego project.

1.2.3.2 National building spaces

Areas of residential building spaces are rather well accessible from various national statistical authorities. They have gathered them for many years, since this information have had substantial political and governmental interests. The same has not been valid for service sector building areas, giving a considerable unavailability of information about these buildings.

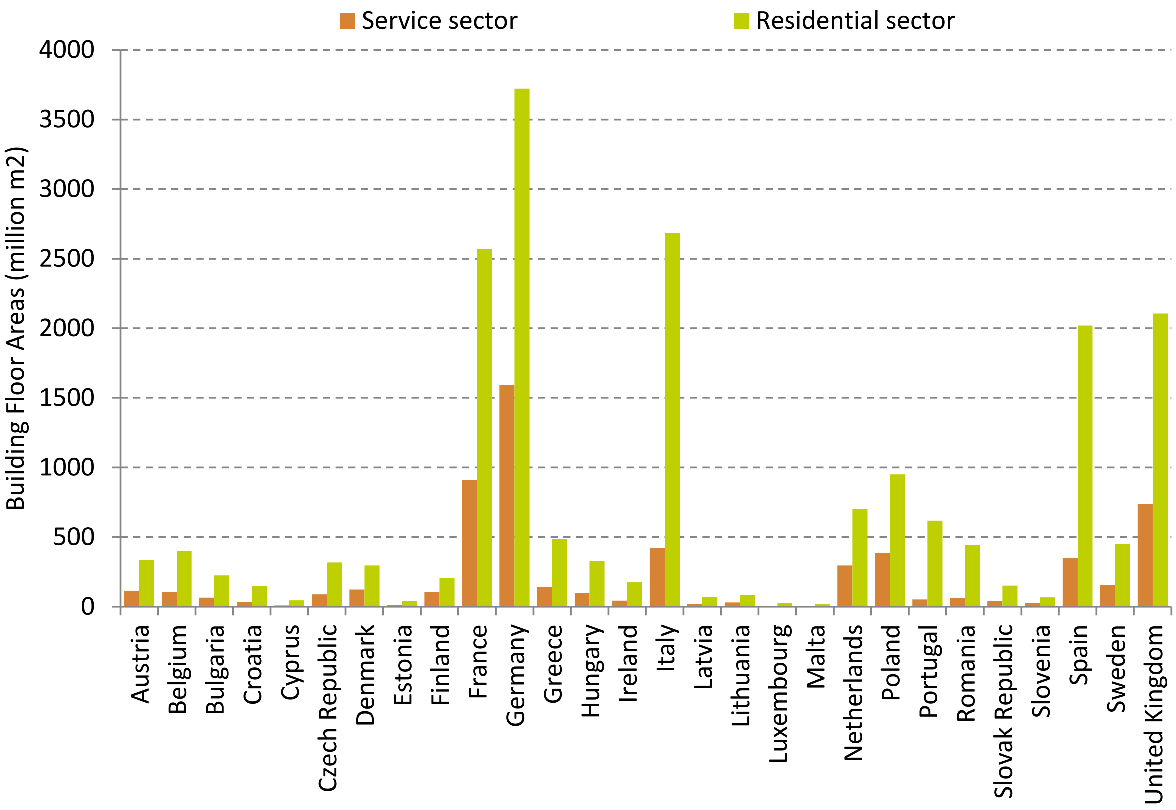

Figure 6. Estimated building space areas in residential and service sector buildings in the EU28 member states.

However, the European Energy Performance for Buildings Directive and the Ecodesign Directive has created a research demand for more information about the European buildings, including the service sector buildings. This has given a better supply of information about the European buildings from EU institutions, projects, and clusters as JRC, INSPIRE, BPIE, ENTRANZE, ODYSSEE, and EPISCOPE (formerly TABULA). However, the INSPIRE project did only review residential and office buildings, so the whole service sector was not reviewed. The quality of this new information is sometimes very low with no references to original information sources. Different sources are also quoting each other, giving some circulation of low quality information. Another problem is that the national rules and standards for calculating building space areas are different from country to country.

Estimated building floor areas are presented in Figure 6. The service sector areas have been estimated as the averages from six different groups of estimations, while the residential areas have been estimated as the averages from eight different groups of estimations.

1.2.3.3 National saturation rates

Gathered saturation rates are presented in Figure 7. Values for service sector buildings have been estimated as the averages from four different groups of estimations. Ten percent was assumed as a default value when no information was available at all for a specific country. Values for residential buildings have been estimated from averages of seven different groups of estimations.

Several of these estimations can be questioned and this reveals the low quality level for current saturation rates. This is also the explanation for many literature sources to only provide estimations of the European cooling demands on an aggregated European level, as in (Tvärne et al., 2014).

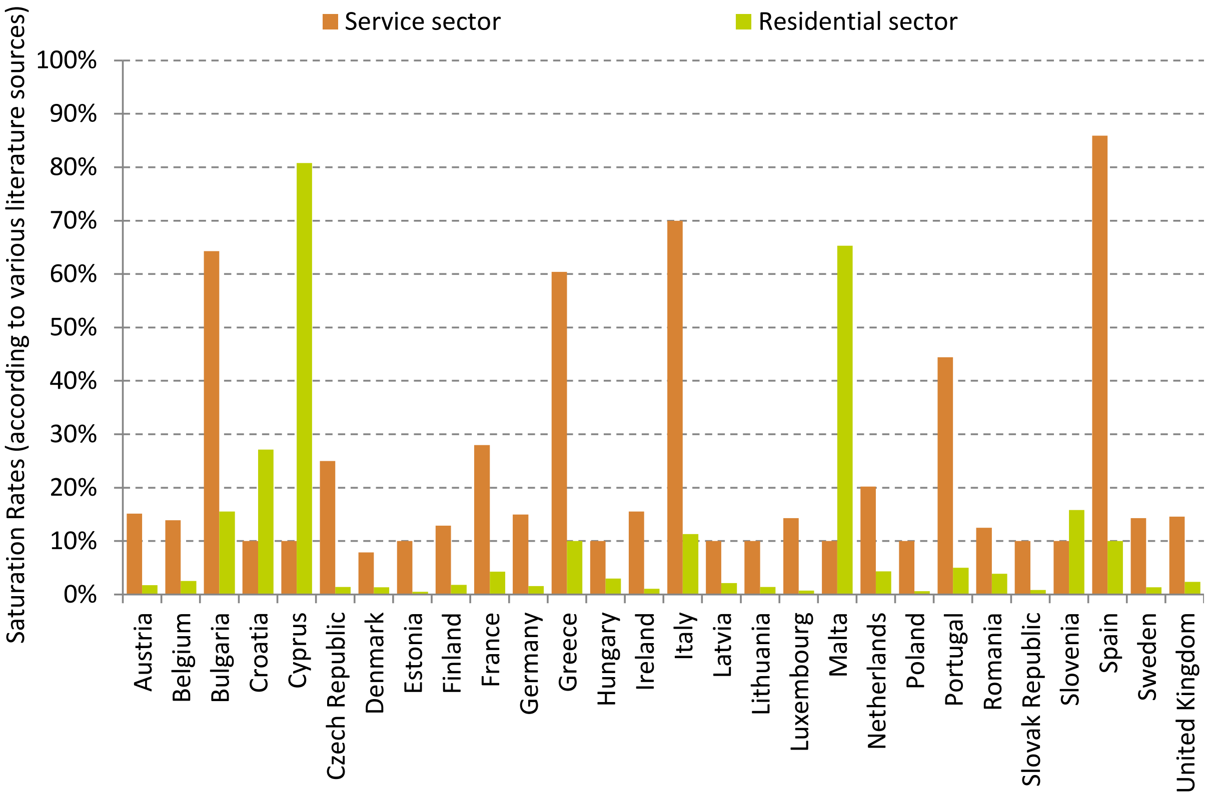

Figure 7. Estimated saturation rates for cooling supply to residential and service sector buildings in the EU28 member states.

1.2.4 Results

Country estimations of total floor areas, European cooling index, specific cooling demands, cooled areas, and the current cooling supplies are summarised inTable 4. The aggregated values for EU28 reveal that 10% of all building areas are cooled and that these cooling supplies cover 16% of the total cooling demand. The latter proportion is higher than the former since cooling supplies are more common when the cooling demands are high.

Table 4. Country estimations of total floor areas, European cooling index (ECI), specific cooling demands, cooled floor areas and current cooling demands by country. Each national ECI estimation considers the estimation for each capital city.

	Total floor areas				Specific cooling demands			Cooled floor areas			Current cooling supplies		
Country	Service sector	Residen-tial	Total	ECI	Service sector	Residen-tial	Average	Service sector	Residenti al	Total	Service sector	Residen-tial	Total
	Mm2	Mm2	Mm2		kWh/m2	kWh/m2	kWh/m2	Mm2	Mm2	Mm2	TWh	TWh	TWh
Austria	114	338	452	106	83	38	49	17	6	23	1	0	2
Belgium	105	402	507	77	50	23	28	15	10	25	1	0	1
Bulgaria	64	225	288	116	95	43	54	41	35	76	4	1	5
Croatia	32	149	181	85	59	27	32	3	40	44	0	1	1
Cyprus	8	44	52	160	145	65	77	1	36	37	0	2	2
Czech Republic	89	316	405	89	64	29	37	22	4	27	1	0	2
Denmark	122	295	418	59	30	13	18	10	4	14	0	0	0
Estonia	12	38	50	65	37	16	21	1	0	1	0	0	0
Finland	104	206	310	72	45	20	28	13	4	17	1	0	1
France	911	2571	3482	95	71	32	42	255	110	365	18	4	22
Germany	1594	3723	5317	98	74	33	46	239	58	297	18	2	20
Greece	141	486	627	161	146	66	84	85	49	134	12	3	16
Hungary	99	327	426	123	103	46	59	10	10	20	1	0	1
Ireland	43	174	216	32	0	0	0	7	2	8	0	0	0
Italy	421	2686	3107	133	114	51	60	295	304	599	34	16	49
Latvia	17	68	85	79	53	24	29	2	1	3	0	0	0
Lithuania	30	84	114	85	59	27	35	3	1	4	0	0	0
Luxembourg	5	27	32	81	55	25	29	1	0	1	0	0	0
Malta	4	17	21	143	126	57	70	0	11	11	0	1	1
Netherlands	295	702	997	65	37	16	22	60	30	90	2	0	3
Poland	385	951	1336	95	71	32	43	39	6	44	3	0	3
Portugal	52	619	671	104	81	36	40	23	31	54	2	1	3
Romania	59	442	501	137	119	53	61	7	17	24	1	1	2
Slovak Republic	38	150	188	117	96	43	54	4	1	5	0	0	0
Slovenia	28	67	95	116	95	43	58	3	11	13	0	0	1
Spain	349	2019	2368	147	130	59	69	299	202	501	39	12	51
Sweden	155	451	606	73	46	21	27	22	6	28	1	0	1
United Kingdom	736	2107	2843	74	47	21	28	107	50	157	5	1	6
EU28	6011	19684	25695	103	74	37	45	1584	1039	2623	145	47	192
								26%	5%	10%	33%	7%	16%

1.2.4.1 European cooling demand map

The information from Figure 5 about the correlation between the average specific cooling demands for service sector buildings and the European cooling index (ECI) makes it possible to generate a European map from locations with known estimations of ECI. This map is provided in Figure 8 based on 80 locations in Europe. It is important to understand that this map only presents average demands and that individual demands vary from these average demands. The highest demands of 140 kWh/m^2 are found in southeast Europe, while near zero demands are found in northwest Europe. Ireland should have no cooling demands, while the demands in the Nordic countries are around 30-40 kWh/m^2, explaining the basic conditions for the large district cooling systems in Stockholm and Helsinki.

The information from Figure 8 will be used to identify high agglomerations of cooling demands giving high cold densities in European cities in order to investigate the possibilities for extended and new district cooling systems.

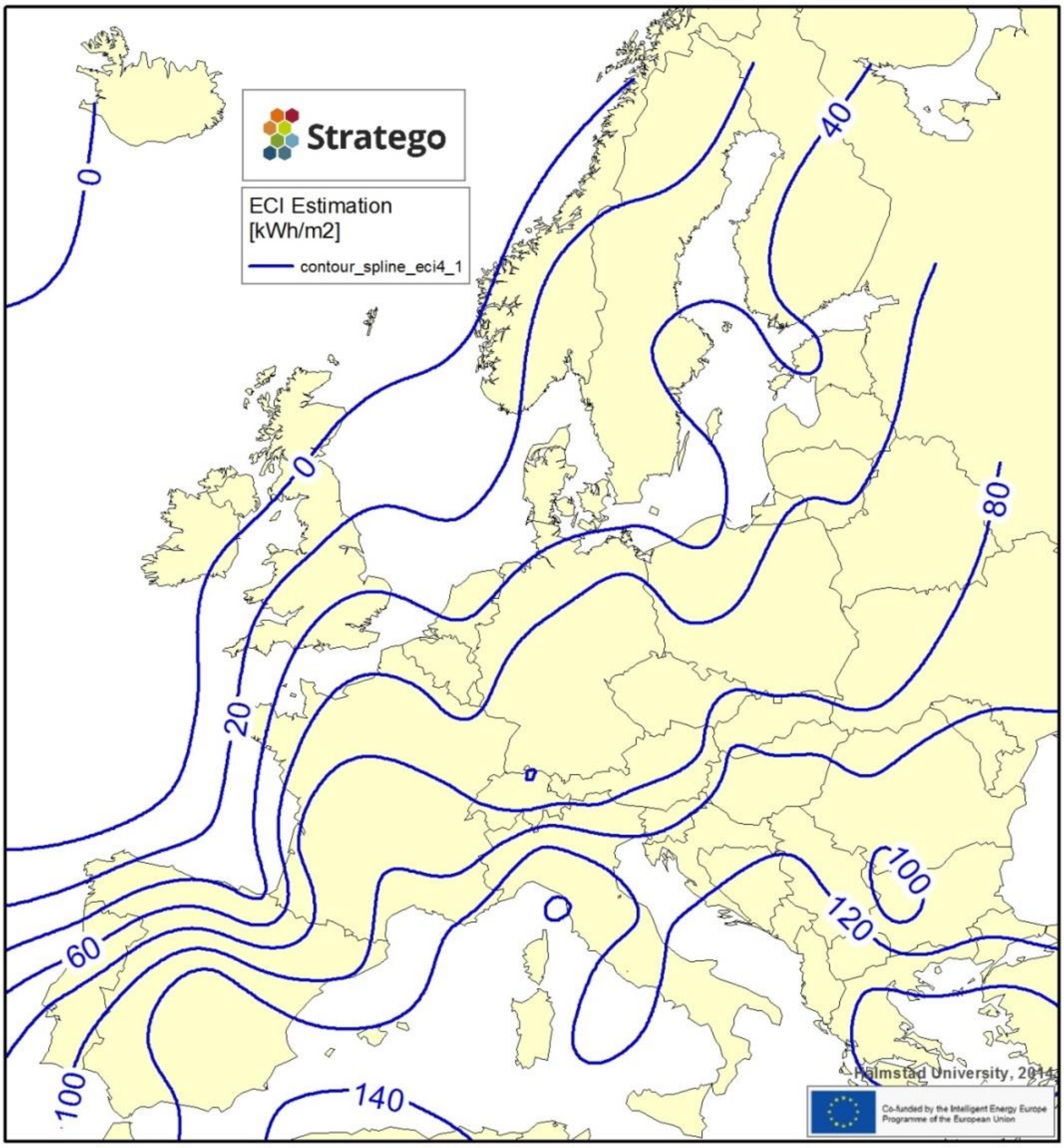

Figure 8. The average specific cooling demands in kWh/m² for service sector buildings for various locations in Europe. The map has been generated by using the red average line in Figure 5 together with estimated ECI for 80 different locations according to (Dalin et al., 2005).

1.2.4.2 Average annual specific cooling demands

The average annual specific demands estimated here in Stratego are benchmarked in Figure 9 with two other sources: (EURAC, 2014) and (Tvärne et al., 2014). The average specific demands from (EURAC, 2014) was estimated by multiplying the electricity inputs from that study (64 TWh/year for service sector buildings and 18 TWh/year for residential buildings) with the SEER estimate of 3.1 in this study and by dividing with the building floor spaces estimated in this study. The conclusion from the comparison in Figure 9 becomes that the Stratego estimations will be somewhat lower than in the two other studies.

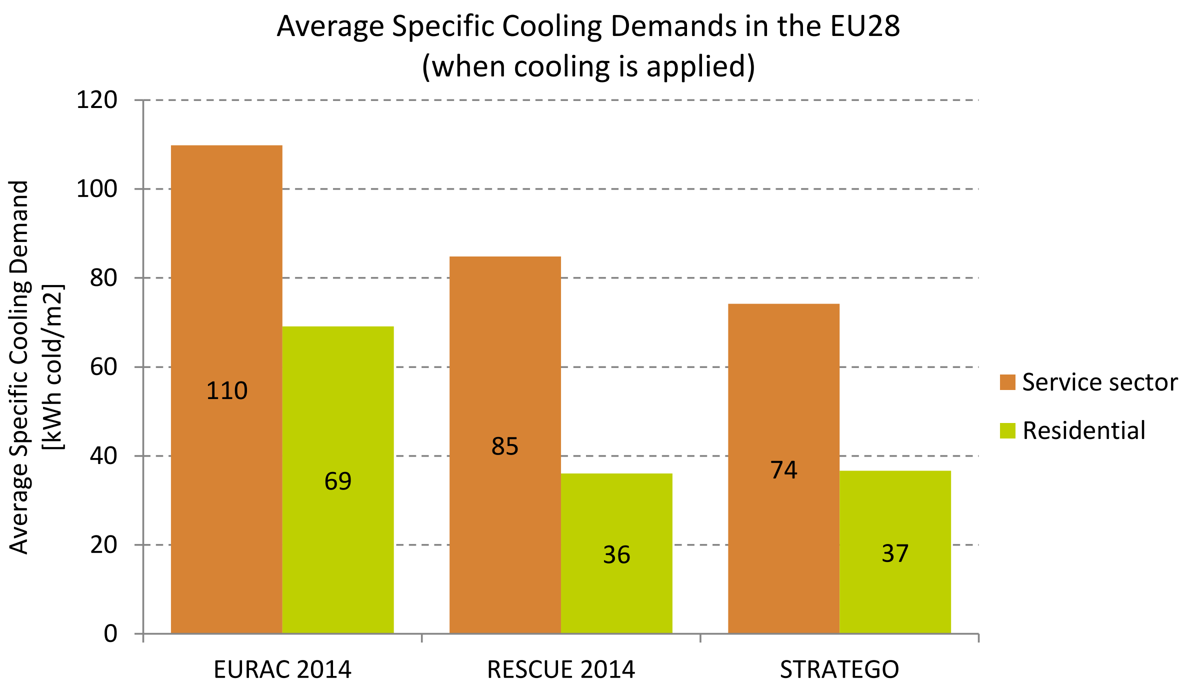

Figure 9. Three different estimations of the average annual specific cooling demands in EU28, when cooling is applied, from two external sources and this Stratego estimation.

1.2.4.3 Current annual European cooling supplies

The current annual European cooling supplies estimated here in Stratego are benchmarked in Figure 10 with four other sources: (EURAC, 2014; Kemna, 2014; Pardo et al., 2012 ; Tvärne et al., 2014). The conclusion from Figure 10 becomes that the Stratego estimations will be the lowest, somewhat lower than three other estimations, while (Pardo et al., 2012) have provided the highest estimations.

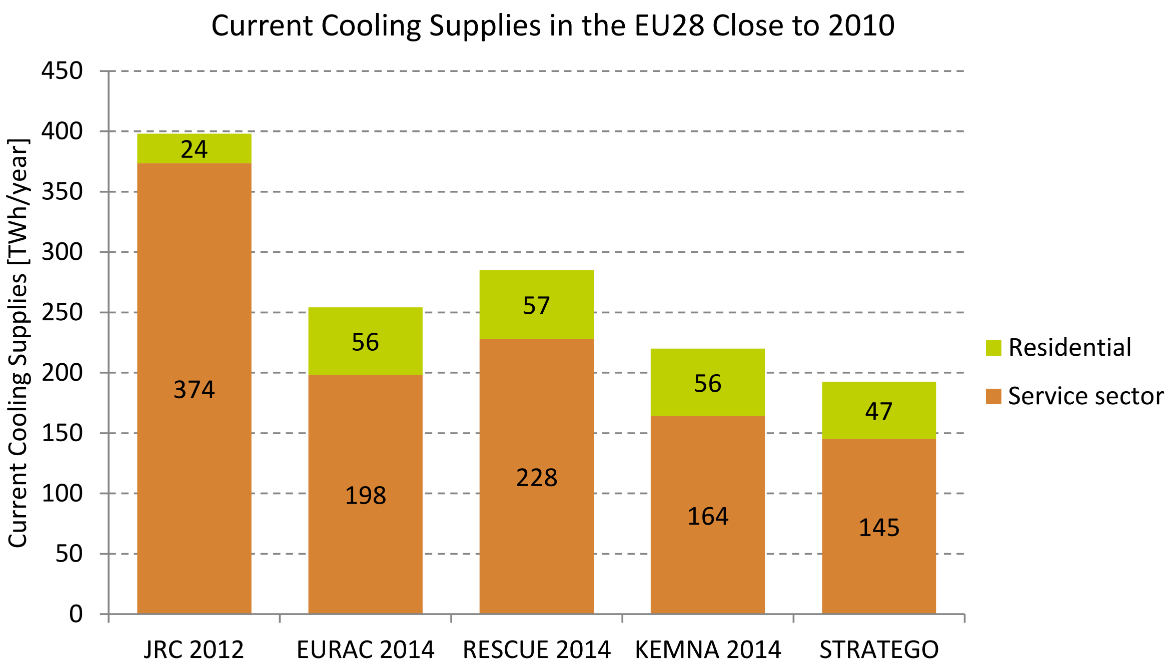

Figure 10. Five different estimations of the current cooling supplies in EU28 close to 2010 from four external sources and this Stratego estimation.

1.2.4.4 Annual full European cooling demands

The annual full European cooling demands estimated here in Stratego are benchmarked in Figure 11 with two other sources: (EURAC, 2014; Tvärne et al., 2014). The conclusion from Figure 11 becomes that the Stratego estimations will be about the same as the estimations as in (Tvärne et al., 2014), while (EURAC, 2014) have provided much higher estimations.

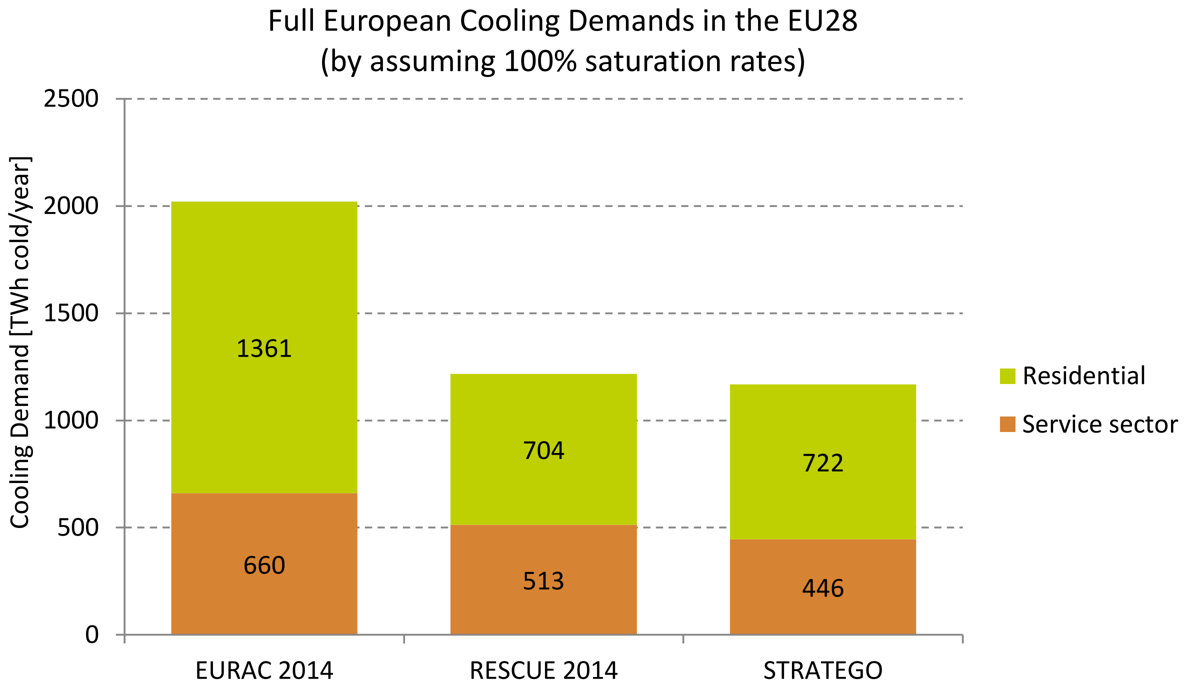

Figure 11. Three different estimations of full European cooling demands in EU28, by assuming all saturation rates to be 100%, from two external sources and this Stratego estimation.

1.2.5 Some conclusions

The four major conclusions from these Stratego estimations of European cooling demands become then:

1. Information about individual and aggregated cold deliveries in several European district cooling systems has made it possible to estimate the average annual cooling demands in Europe.
2. These estimations can for the first time ever provide cooling demands by countries and by locations in Europe.
3. The obtained estimations by locations can also be used to identify urban areas with high cold densities as input for studies of the possibilities for extended and new district cooling systems in Europe.
4. Benchmarking with other recent studies of aggregated European cooling demands reveals that the Stratego estimations will be somewhat lower than estimations obtained in other studies.

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Appendix

Table 5. Stratego assessment of the EU28 residential and service sector building heat market in 2010, by Member States and fuel supply sources and energy carriers. All values in PJ

Member States	**Coal &Coal Products**	**Peat**	**Crude/NGL feedstocks**	**Oil Products**	**Natural Gas**	**Geothermal**	**Solar/Wind Other**	**Biofuels & Waste**	**Heat**	**Electricity**	**Total Heat Market**
Austria	1.6	0.005	-	53.8	74.1	0.3	6.6	48.2	67.0	29.7	281
Belgium	3.6	-	-	137.8	207.1	-	0.5	7.1	4.9	23.4	384
Bulgaria	5.3	-	-	2.3	4.6	1.4	0.4	19.6	19.6	14.1	67
Croatia	0.3	-	-	11.0	26.7	0.3	0.2	8.8	8.3	6.8	63
Cyprus	0.003	-	-	5.6	-	0.03	2.5	0.3	-	4.1	13
Czech Republic	16.2	-	-	1.1	136.0	-	0.4	33.3	68.5	34.9	290
Denmark	0.3	-	-	18.4	34.8	-	0.5	27.0	112.0	13.9	207
Estonia	0.2	0.1	-	1.3	3.0	-	-	12.0	20.4	2.8	40
Finland	0.02	0.3	-	42.1	2.7	-	0.04	41.9	120.3	58.0	265
France	10.7	-	-	402.9	794.0	3.5	2.4	232.4	147.5	285.4	1879
Germany	29.6	-	-	739.5	1204.7	2.2	20.3	213.6	325.7	282.2	2818
Greece	0.1	-	-	74.4	14.0	0.5	7.7	16.5	1.9	19.9	135
Hungary	4.1	-	-	5.1	177.0	3.3	0.2	21.2	33.0	14.2	258
Ireland	6.3	6.4	-	57.5	40.8	-	0.3	1.2	-	9.2	122
Italy	0.1	-	-	143.5	971.7	3.2	5.3	94.1	8.4	117.3	1344
Latvia	1.3	0.01	-	3.1	8.5	-	-	22.2	23.3	2.0	60
Lithuania	2.5	0.5	-	1.9	8.0	-	-	16.5	30.7	2.2	62
Luxembourg	0.0	-	-	8.3	13.6	-	0.04	0.5	2.6	2.1	27
Malta	-	-	-	0.8	-	-	0.04	0.0	-	3.2	4
Netherlands	0.2	-	-	16.6	513.9	-	1.0	9.5	36.3	43.7	621
Poland	217.9	-	-	47.9	197.0	0.6	0.4	79.1	231.6	40.2	815
Portugal	-	-	-	31.8	17.6	0.04	2.0	19.4	0.8	24.8	97
Romania	0.3	0.005	-	13.0	111.8	0.8	0.0	99.3	56.5	8.3	290
Slovak Republic	9.0	-	-	1.1	77.4	0.05	0.2	1.8	31.0	8.9	129
Slovenia	-	-	-	17.7	4.9	0.7	0.3	11.5	5.8	2.5	43
Spain	5.8	-	-	159.6	225.9	0.5	7.6	68.7	-	184.9	653
Sweden	0.3	-	-	22.9	6.4	-	0.4	19.8	196.1	152.5	398
United Kingdom	18.5	-	-	136.5	1338.6	-	4.1	11.6	18.6	209.8	1738
EU28 Total	**334**	**7**	**0**	**2157**	**6215**	**17**	**63**	**1137**	**1571**	**1601**	**13104**
Shares [%]	3	0	0	16	47	0	0	9	12	12	100

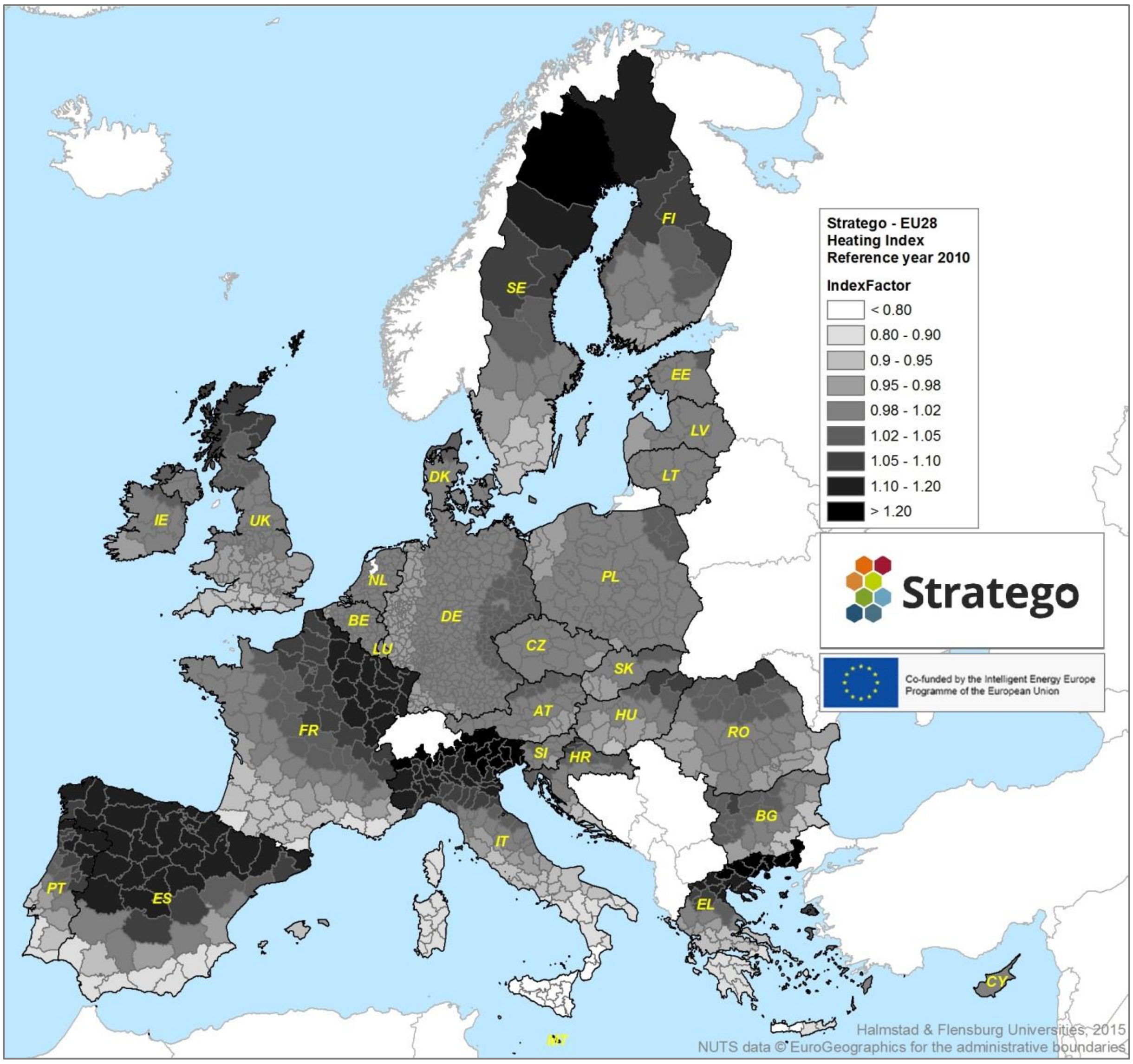

Figure 12. Regional climate index factors by NUTS3 regions in EU28 Member States. Based on the European Heating Index (EHI).

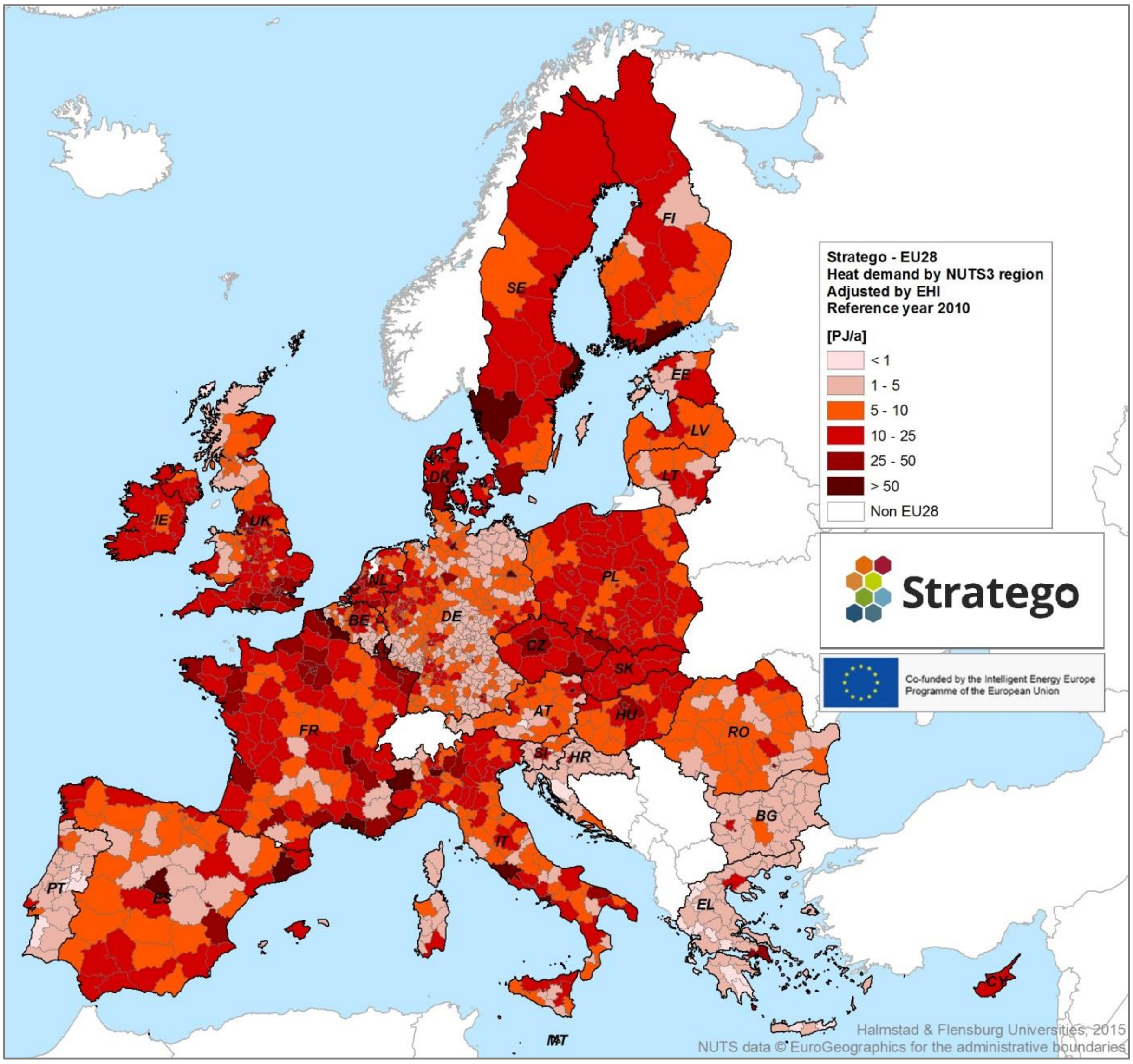

Figure 13. End use heat demands for space heating and domestic hot water preparation in residential and service sectors, by EU28 NUTS3 regions. Heat demands adjusted to local conditions by adaption of regional climate index factors based on the European Heating Index (EHI).