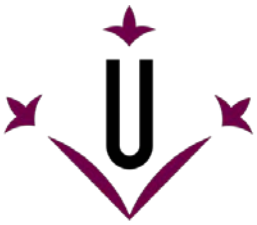

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Heating and cooling energy trends and drivers in Europe

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Abstract

This paper aims to complete and complement the information available on the past trends of thermal energy consumption in residential buildings and its drivers for Europe, as a continent and for the different countries. This paper follows the drivers identified in a previous one for the heating and cooling energy consumption, decomposing this energy demand into key drivers based on a Kaya identity approach: number of households, persons per household, floor space per capita and specific energy consumption for residential heating and cooling. Results show that all drivers did follow a consistent trend at global, regional and country level during the studied period of time, but the heating and cooling energy consumption did not follow the same trend if it was considered at global, regional or country level, showing that the energy consumption is very much influenced by all its drivers and does not follow the same trend as the specific energy consumption. Moreover, similar trends for each indicator can be found when evaluated at country or regional level, therefore as expected when aggregating data trends can be seen but details and particularities (both for the different countries and for the different studied years) are lost.

Keywords – buildings, thermal energy use, drivers, trends, Europe

1. Introduction

Trends in heating and cooling energy consumption and their drivers in Europe cannot be found in the literature. But there are other related studies in energy trends as for example, that of Li et al. [1] that presented a study of the energy consumed and its drivers in high-performance office buildings in USA, Europe, China, and other parts of Asia. The drivers considered were the impact of climate, the impact of building size, the impact of building technologies (lighting-related, envelope, and HVAC technologies related to space cooling and heating). The paper also lists other driven factors, such as operation hours, the number of occupants, and the building functions (space use type: mixed use, data centres, commercial, cooking), highlighting the lack of data of those factors (or drivers).

Streimikiene [2] analysed theoretical issues of the main drivers of residential energy consumption, the residential energy consumption trends in Lithuania, comparing these trends with other EU member states, defined the main drivers of residential energy consumption by applying a correlation analysis, and analysed policies aiming to reduce energy consumption in residential buildings and their impacts on GHG emission reduction. Results from 2001 to 2009 showed that the residential energy consumption per capita in Lithuania is significantly lower than in old EU member states because of the lower income per capita and lower living standards. The drivers used in this paper are distinguished between economic factors (income) and non-economic factors, such as technological, policy and others (cultural, psychological and institutional).

Authors also found some studies where the energy consumption of buildings and its main drivers were studied in a specific country, like in Da Rosa et al. [3] where authors calculated the heating and cooling degree days for several Italian cities for the period 1978-2013 based on daily meteorological data. Their analysis was based on historical climatic data and the methodology followed in their calculations was based in a literature review of the methods adopted by different researchers to calculate degree-days. Jones and Lomas 2015 [4] focused their research in determining socio-economic and dwelling factors that contribute to electrical energy demand in UK residential buildings. Authors highlight some socio-economic factors as key elements that affect the energy consumption in buildings being higher in households that have more children and teenagers and in households with high annual incomes. On the other hand, floor areas higher than 100 m^2, the use of electricity as the main source in space and water heating are dwelling factors that strongly affect the electrical energy consumption. Jia and Lee 2016 [5] identify the factors and drivers responsible for the increase in cooling energy consumption in residential buildings between 2004 and 2013 examining 64 dwellings in Hong

Kong. Authors found the increase of population as a key element. However, the increase of the energy consumption for cooling space conditioning was moderate due to the positive role of using more efficient unit and smaller window-to-wall ratios.

A recent publication by Ürge-Vorsatz et al. [6] presented not only complete past, present and future trends of the heating and cooling energy consumption in buildings, both residential and commercial, and on a global and regional basis, but also defined the drivers of heating and cooling energy consumption based on a Kaya identity approach. The drivers identified were number of households, persons per household, floor space per capita, and specific energy consumption for residential heating and cooling; and GDP, floor space per GDP, and specific energy consumption for commercial buildings. The biggest problem when carrying out the work was that the data on floor area (m^2) for the past was not available for most of the world areas. Moreover, another recent review by Nejat et al. [7] reviews the status and current trends of energy consumption, CO_2 emissions, and energy policies in the residential sector globally for the world, and for the top ten CO_2 emitting countries (China, USA, India, Russia, Japan, Germany, South Korea, Canada, Iran, and UK). Authors found that global residential energy consumption grew 14% from 2000 to 2010, which are consistent with results presented in Ürge-Vorsatz et al. [6]. Nejat et al. [7] conclude that most of this increase has occurred in developing countries, where population, urbanization and economic growth have been the main driving factors.

Worldwide data regarding heating and cooling energy consumption in buildings has been analysed from global, regional basis and in the highest CO_2 emitting countries [6,7]. However, a complete and detailed set of data is not available in the literature for residential buildings in Europe in order to deeply assess the trends of heating and cooling energy consumption in each country, region and from a European global basis. This is why, this paper presents for the first time the trends in heating and cooling residential energy consumption for the past and its drivers for Europe in a complete data set, to serve as a useful source and to shed light on the longer term perspective in order to enable more informed modelling and planning of heating and cooling energy use. Authors would want to highlight that the purpose of the present study is to serve as a source of data. Therefore, understand in detail the trends of the different drivers would be the purpose of further research.

2. Methodology

2.1. Drivers decomposition

The decomposition followed in this paper is the same as in a previous one [6] and is based on the Kaya decomposition. In this type of decomposition, the factors commonly used are CO_2 intensity, energy intensity, structural changes, and economic activity, or the IPAT approach (Income–Population–Affluence–Technology approach) (Figure 1) [8-11]. This concept has been used by the authors in order to define the heating and cooling energy trends by identifying the activity drivers (A), use intensity drivers (TEI – technological energy intensity), and energy intensity drivers (SEI – structural/systemic energy intensity). It should be highlighted that carbon intensity (CI) driver is not considered in the present study. Authors consider as mandatory the evaluation of GHG emissions so as to properly and deeply assess energy efficiency of buildings. For this reason, authors point out that energy efficiency analysis is not addressed in the present study.

Heating and cooling and domestic hot water energy consumption, from now on heating and cooling energy consumption, in residential buildings can be decomposed in several drivers following the Kaya identity methodology, as shown in Eq. 1:

$$E_{resid}[kWh] = h \cdot \frac{p}{h} \cdot \frac{A}{p} \cdot \frac{E}{A} \qquad \text{Eq. 1}$$

where:

E_{resid}	is the energy consumption for heating and cooling in residential buildings,
h	is the number of households,
p/h	is the number of persons living in each household, also called household size,
A/p	is the floor area [m^2] per person, and
E/A	is the energy [kWh] consumed for heating and cooling in each unit of floor area [m^2], also called *specific energy consumption*.

2.2. Regional distribution

All results are presented either globally for Europe, for the different regions grouped by United Nations, or for each country. Considered regions are:

- Western Europe: Austria, Belgium, France, Germany, Luxembourg, Netherlands, and Switzerland.
- Eastern Europe: Belarus, Bulgaria, Czech Republic, Hungary, Poland, Republic of Moldova, Romania, Slovakia, and Ukraine.
- Southern Europe: Albania, Bosnia and Herzegovina, Croatia, Greece, Italy, Malta, Portugal, Serbia, Slovenia, Spain, and TFYR Macedonia.
- Northern Europe: Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, and United Kingdom.

Gibraltar, Channel Islands, Faeroe Islands, Isle of man, Andorra, Holy See, Montenegro, San Marino, Liechtenstein and Monaco have been discarded due to lack of information.

2.3. Data sources

Population (p) from 1990 to 2010 of each country was obtained from United Nations, Department of Economic and Social Affairs [12]. The number of households (h) was obtained from the United Nations [13]. This document gives data for every 15 years in the period 1985-2010, and estimates the growth in each period. Data presented in this paper has been calculated for the period 1990-2010 in 10 years periods. The data on residential floor area (m^2) from 1990 to 2010 as well as the heating and cooling energy consumption (kWh) of each country was obtained from Odyssee Database [14]. Note that Odyssee Database contains data only from the 28 EU member states. The total energy consumption in buildings was available in two sources: Odyssee [14] and the IAE statistics [15]. Because of no significant differences were found between the data provided by each source once checked, the selected one was the IEA database because it is more complete. The data on Gross Domestic Product (GDP) was obtained from the IEA statistics [15] in 2005 US$. Table 1 shows all the data provided in this study.

3. Results

3.1. Global analysis of the trends and drivers in Europe

Table 2 shows data of residential heating and cooling energy consumption drivers in Europe from 1990 to 2010. It can be seen that the persons per household slightly decrease (8.4%) while the number of households increase (12.8%). The floor area in Europe in the period under study

and the population increase 22.6% and 5.4%, respectively, therefore, the floor area per person also increases (18.1%). Finally, the specific energy consumption decreases 21.3% (from 1990 to 2010), although the heating and cooling and total residential building energy consumption increases 6.1% and 10.3%, respectively. The trends of the drivers are illustrated in Figure 2.

3.2. Analysis of the trends in the drivers in European regions

Figure 3 shows the trends in the drivers of the heating and cooling residential buildings energy consumption between 1990 and 2010 for the four regions considered in Europe. In Northern, Eastern and Western Europe, heating and cooling residential buildings energy consumption almost stagnate, increasing by 7.9% and 2.1% in Northern and Eastern Europe, respectively, and decreasing 7.2% in Western Europe. On the other hand, Southern Europe shows the strongest variation in the heating and cooling energy consumption, increasing 36.1% in the considered period. Trends of each driver are very similar between them in Northern, Eastern and Western Europe (the number of households and the floor area per person grow constantly, while the number of persons living in each household and the specific energy consumption decrease). On the other hand, in Southern Europe the number of persons living in each household decreased until 2000 and stagnated after then, while all other drivers were still growing in 2010.

3.3. Per capita and per GDP regional heating and cooling energy consumption in the EU member regions

As specified in Section 2.3, data of heating and cooling energy consumption was obtained from Odyssee Database [14], therefore, only the analysis of the 28 EU member states are included in this section.

Figure 4 shows heating and cooling energy consumption per capita. It can be seen that all regions follow, approximately, the same trend within small differences as follows, Eastern and Northern Europe regions almost stagnate when comparing 1990 and 2010, Western slightly decreases and Southern increases:

- Western Europe: from 7443 kWh/p in 1990 to 6442 kWh/p in 2010
- Southern Europe: from 2576 kWh/p in 1990 to 3716 kWh/p in 2010
- Northern Europe: from 6226 kWh/p in 1990 to 6316 kWh/p in 2010
- Eastern Europe: from 2346 kWh/p in 1990 to 2561 kWh/p in 2010

Western and Northern European regions show the highest heating and cooling energy consumption per capita (between 6000 and 8000 kWh per capita). Meanwhile, in Southern and Eastern regions this indicator is half (between 2000 and 4000 kWh per capita).

Figure 5 presents that heating and cooling energy consumption per GDP decreases in Northern and Western Europe regions while in Southern Europe increases, achieving almost the same values in the three regions in 2010, on the other hand, this indicator is notably higher in Eastern Europe than in the other regions although strongly decreases in the period studied:

- Western Europe: from 0.26 kWh/GDP to 0.17 kWh/GDP
- Southern Europe: from 0.14 kWh/GDP to 0.16 kWh/GDP
- Northern Europe: from 0.24 kWh/GDP to 0.16 kWh/GDP
- Eastern Europe: from 0.56 kWh/GDP to 0.41 kWh/GDP

Figure 6 shows that the floor area per capita increases in all European regions in general, however, in Eastern Europe this indicator is approximately a third compared to Northern Europe that shows the highest values:

- Western Europe: from 31 m^2/p in 1990 to 37 m^2/p in 2010
- Southern Europe: from 24 m^2/p in 1990 to 28 m^2/p in 2010
- Northern Europe: from 31 m^2/p in 1990 to 41 m^2/p in 2010
- Eastern Europe: from 10 m^2/p in 1990 to 16 m^2/p in 2010

When comparing heating and cooling energy consumption per capita (Figure 4) and per GDP (Figure 5) in EU member regions, very different relationships between the two indicators are found, i.e. while in Western Europe the energy consumption per capita and per GDP decreased in the period considered, in Eastern Europe the energy consumption per capita increased and the energy consumption per GDP decreased notably, but overall it can be seen that in Europe the residential heating and cooling energy consumption per GDP decreased more than that per capita.

Similarly, when the heating and cooling energy consumption per capita (Figure 4) is compared to the floor area per capita (Figure 6) differences between regions are seen, i.e. in Southern Europe the energy consumption per capita increased more than the floor area per capita, and in Northern Europe the energy consumption per capita stagnated while the floor area per capita increased a lot; but overall the floor area per capita increased more than the energy consumption per capita.

3.4. Analysis of the trends in the drivers in European countries

Figure 7 and Table 3 show the heating and cooling energy consumption and its drivers for each country in Europe. In Northern Europe, all countries show a decrease in the number of persons

living in each household, with variation from 41% in Lithuania to 5.9% in Denmark. The floor area per person in this region increases in all countries that have data, from 23.6% in Ireland to 5.5% in Sweden in the period 1990 to 2010. Similarly, all countries show a steep increase in the number of households during the period studied, but for this driver countries that stand out are Ireland and Iceland, with increases of 39.4% and 41.4%, respectively. Finally, the heating and cooling building energy consumption show an increase in the period studied in Finland, while in UK, Denmark, Ireland, and Estonia stagnated; on the other hand, Sweden, Lithuania and Latvia show an important decrease in the heating and cooling energy consumption. Similar trends can be seen in the countries of the other regions.

3.5. Analysis of the trends in specific drivers in European countries

Figure 8 shows the heating and cooling energy consumption in residential buildings per capita. It can be noticed that this indicator is slightly decreasing in Western and Eastern Europe, even though values are between different ranges: from 6,000 to 10,000 kWh per capita in Western Europe and from 2,000 to 10,000 kWh per capita in Eastern Europe. On the other hand, these values almost stagnate in the period studied in Northern and Southern European regions, showing higher values in Northern Europe (4,000 – 10,000 kWh per capita) than in Southern Europe (less than 1,000 to 6,500 kWh per capita).

Figure 9 shows the heating and cooling energy consumption per GDP in each European country. This indicator decreases in all countries in Western Europe, going from 0.26-0.31 in 1990 to 0.07-0.20 in 2010, while stagnates in almost all countries in Southern Europe except in Croatia and Slovenia (0.03-0.47 in 1990 and 0.05-0.54 in 2010). In Northern Europe, this indicator decreases in all countries (except Finland). Two groups can be seen, one with high values of this indicator that has strongly decreased in the last two decades (Latvia, Estonia and Lithuania), and another with Sweden, UK, Denmark and Ireland, that follow a slight decreasing trend (between 0.24-0.33 in 1990 and 0.14-0.17 in 2010), having notably lower values. Finally, in Eastern Europe, heating and cooling energy consumption per GDP decreases in all countries.

Figure 10 shows the floor area per capita in each country. In Eastern, Western and Northern Europe an increasing trend can be seen in all countries, while in Southern Europe the floor area per capita almost stagnated (from 24-38 m^2/p in 1990 to 25-39 m^2/p in 2010). But it is interesting to see that Western Europe and some countries in Northern Europe show the highest floor area per capita values.

Figure 8 and Figure 9 show that the residential heating and cooling energy consumption per capita and per GDP stagnated or decreased in all countries (or almost all) within the period studied, but the energy consumption per GDP decreased more than that per capita. If the energy consumption per capita in European countries is compared to the floor area per capita, it should be highlighted that while the floor area increased, the energy consumption stagnated or decreased (more or less depending in the country).

4. Conclusions

In this paper, a complete data set to evaluate residential heating and cooling energy consumption trends and drivers for Europe is presented and assessed. The Kaya identity approach was followed, identifying that the residential energy use (kWh) has two activity drivers, the number of households and persons per household, one use intensity driver, the floor area per person (m^2/p), and one energy intensity driver, the energy intensity (kWh/m^2).

All drivers did follow a consistent trend at global, regional and country level during the studied period of time. Within the activity drivers, the number of households increased at all levels while the persons per household decreased; the use intensity driver, the floor area per person, increased; and the energy intensity driver, the specific energy consumption, decreased. But the heating and cooling energy consumption does not follow the same trend if it is considered at global, regional or country level, showing that the energy consumption is very much influenced by all its drivers and does not follow the same trend as the specific energy consumption.

The indicators studied and their trends show that European inhabitants live in bigger houses but spend less in energy per capita and even less when their income is higher. This decreasing trend could be because they have access to more efficient housing and appliances, improving energy efficiency [16 - 18]. However, energy consumed per capita is affected by several and different factors [19] that are not assessed. For this reason, authors cannot provide a strong conclusion regarding the trends of this indicator in the last decades.

Finally, when comparing Figure 4 and Figure 5 to Figure 8 and Figure 9, and Figure 4 and Figure 6 to Figure 8 and Figure 10, similar trends in energy consumption and its drivers can be found, therefore we corroborate the feeling that aggregating data the trends can be seen but details and particularities (both for the different countries and for the different studied years) are lost.

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References

1. Li C, Hong T, Yan D. An insight into actual energy use and its drivers in high-performance buildings. Applied Energy 131 (2014) 394–410.
2. Streimikiene D. Residential energy consumption trends, main drivers and policies in Lithuania. Renewable and Sustainable Energy Reviews 35 (2014) 285–293.
3. Da Rosa M, Bianco V, Scarpa F, Tagliafico LA. Historical trends and current state of heating and cooling degree days in Italy. Energy Conversion and Management 90 (2015) 323-335.
4. Jones RV and Lomas KJ. Determinants of high electrical energy demand in UK homes: Socio-economic and dwelling characteristics. Energy and Buildings 101 (2015) 34-34.
5. Jia J and Lee WL. Drivers of moderate increase in cooling energy use in residential buildings in Hong Kong. Energy and Buildings 125 (2016) 19-26.
6. Ürge-Vorsatz D, Cabeza LF, Serrano S, Barreneche C, Petrichenko K. Heating and cooling energy trends and drivers in buildings. Renewable and Sustainable Energy Reviews 41 (2015) 85–98.
7. Nejat P, Jomehzadeh F, Taheri MM, Gohari M, Majid MZA. A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renewable and Sustainable Energy Reviews 43 (2015) 843–862.
8. MacKellar FL, Lutz W, Prinz C, Goujon A. Population, households and CO2 emissions. International Institute for Applied Systems Analysis, Laxenburg, Austria (1995).
9. Isaac M, Van Vuuren DP. Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. Energy Policy, 37 (2009) 507–521.
10. M. Zhang, H. Mu, Y. Ning, Y. Song. Decomposition of energy-related CO2 emission over 1991–2006 in China. Ecol. Econ., 68 (2009) 2122–2128.
11. T. O'Mahony, P. Zhou, J. Sweeney. The driving forces of change in energy-related CO2 emissions in Ireland: A multi-sectoral decomposition from 1990 to 2007. Energy Policy, 44 (2012) 256–267.
12. United Nations, Department of Economic and Social Affairs, Population Division (2011). World Population Prospects: The 2010 Revision, CD-ROM Edition

13. United Nations, Centre for Human Settlements. Cities in a globalizing world. Global Report on Human Settlements 2001. Earthscan Publications, London, 2001.

14. Odyssee database - Enerdata - http://www.indicators.odyssee-mure.eu/energy-efficiency-database.html (accessed January 2015).

15. On-line data services, International Energy Agency - http://data.iea.org/ieastore/default.asp (accessed December 2012).

16. Ma J, Cheng JCP. Identifying the influential features on the regional energy use intensity of residential buildings based on Random Forests. Applied Energy 183 (2016) 193–201.

17. Zhang C, Zhao W. Panel estimation for income inequality and CO2 emissions: a regional analysis in China. Applied Energy 136 (2014) 382–392.

18. Langevin J, Gurian PL, Wen J. Reducing energy consumption in low income public housing: interviewing residents about energy behaviors. Applied Energy 102 (2013) 1358–1370

19. Freire-González J, Font Vivanco D, Puig-Ventosa I. Economic structure and energy savings from energy efficiency in households. Ecological Economics 131 (2017) 12–20.

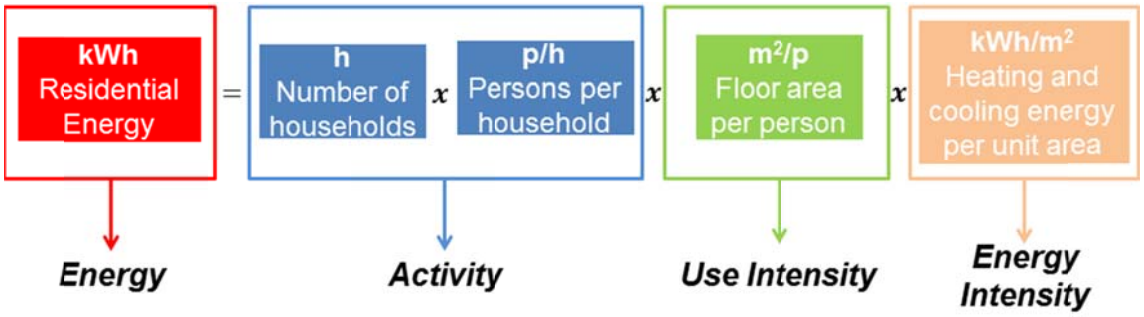

Figure 1. Kaya identity methodology scheme

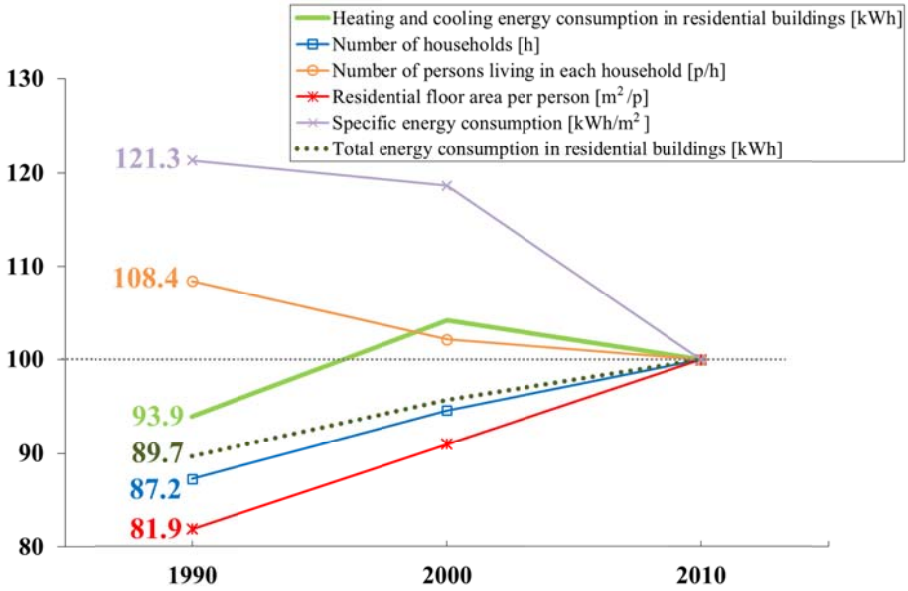

Figure 2. Trends in the different drivers of heating and cooling energy consumption in residential buildings in Europe 1990-2010. Data from [15, 12-14] expressed as % of 2010 values.

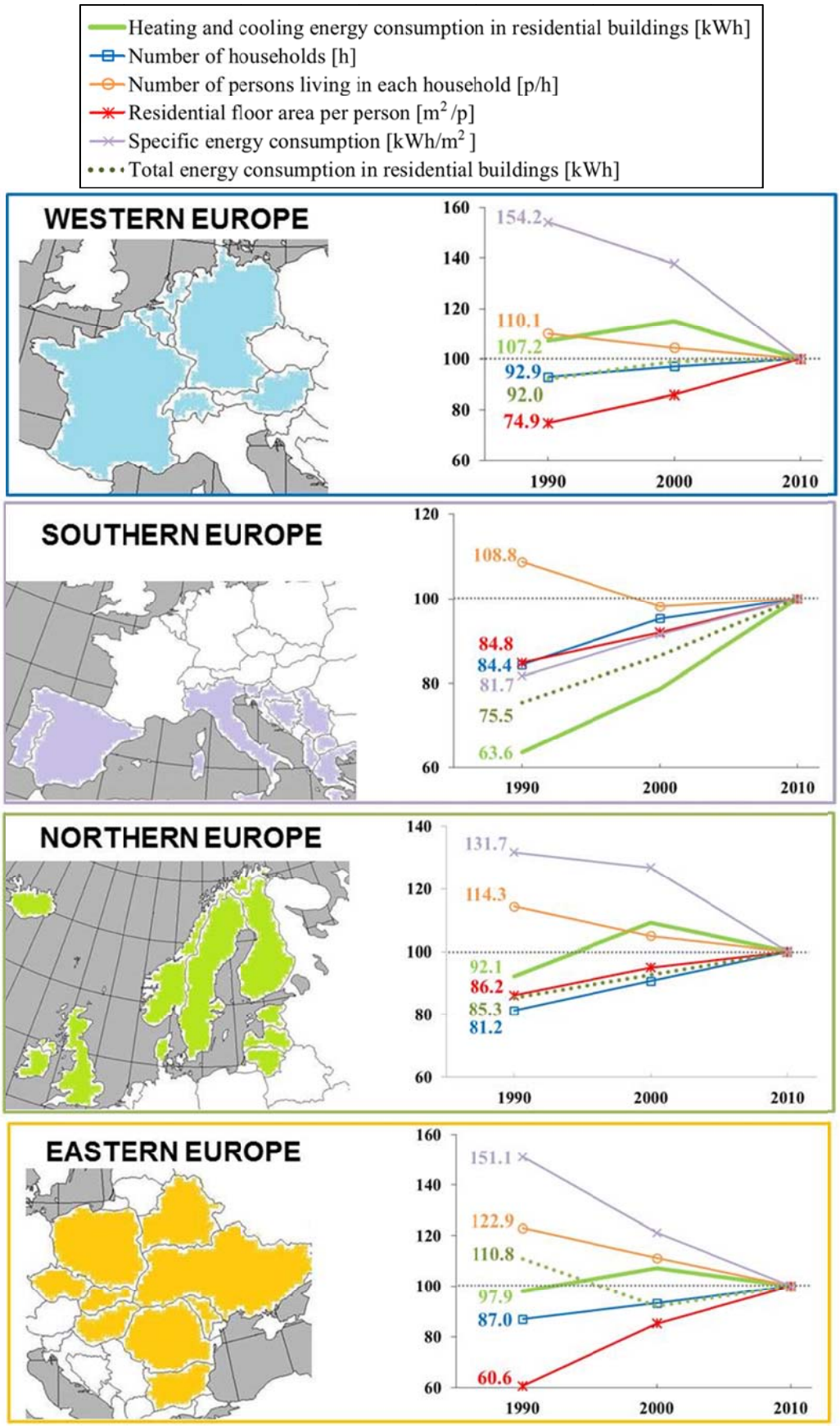

Figure 3. Trends in the drivers of heating and cooling energy consumption in residential buildings by key European regions 1990-2010. Data from [15,12-14] expressed as % of 2010 values.

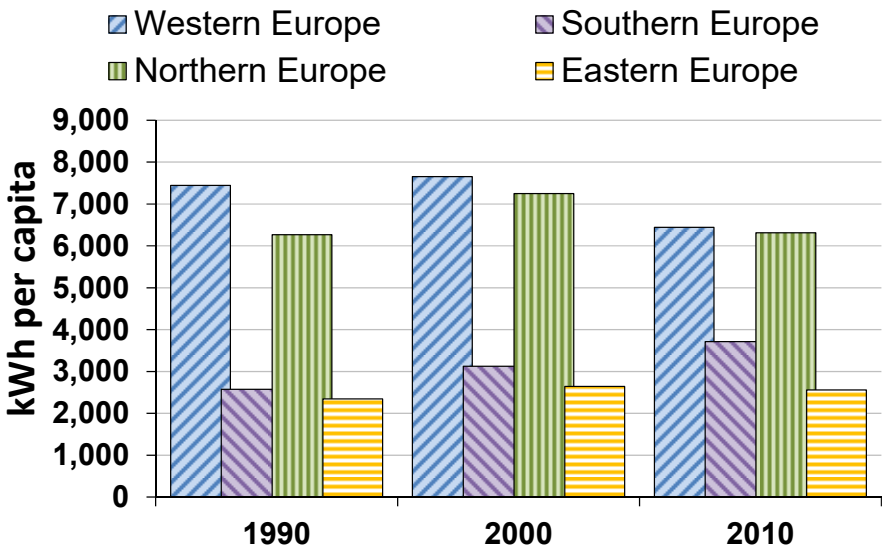

Figure 4. Heating and cooling energy consumption per capita in each EU member regions. Data from [12,14]. Note: Data missing from WEU (Luxembourg (1990-2000)), SEU (Slovenia (1990) and Portugal (1990)), NEU (Estonia (1990), Finland (1990), Ireland (1990) and Latvia (1990) and EEU (Romania (1990)).

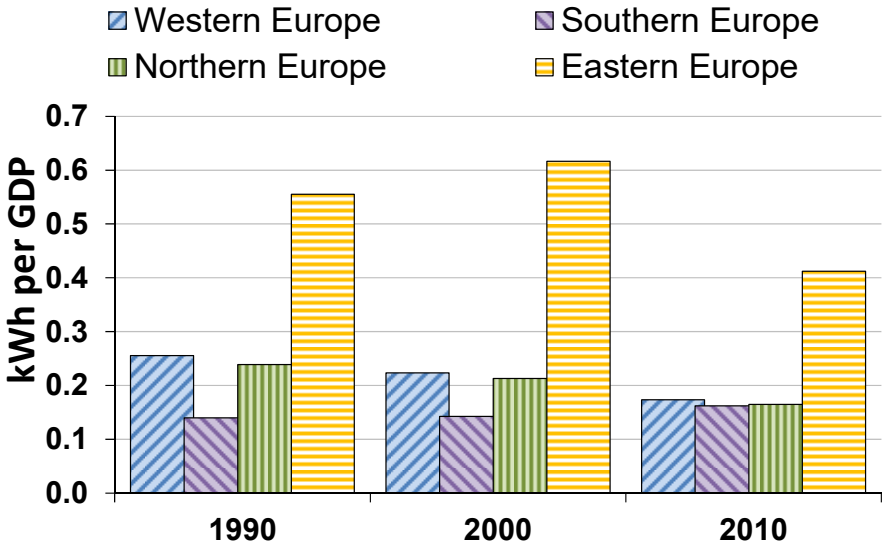

Figure 5. Heating and cooling energy consumption per GDP in each EU member region. Data from [15, 14].Note: Data missing from WEU (Luxembourg (1990-2000)), SEU (Slovenia (1990) and Portugal (1990)), NEU (Estonia (1990), Finland (1990), Ireland (1990) and Latvia (1990)) and EEU (Romania (1990)).

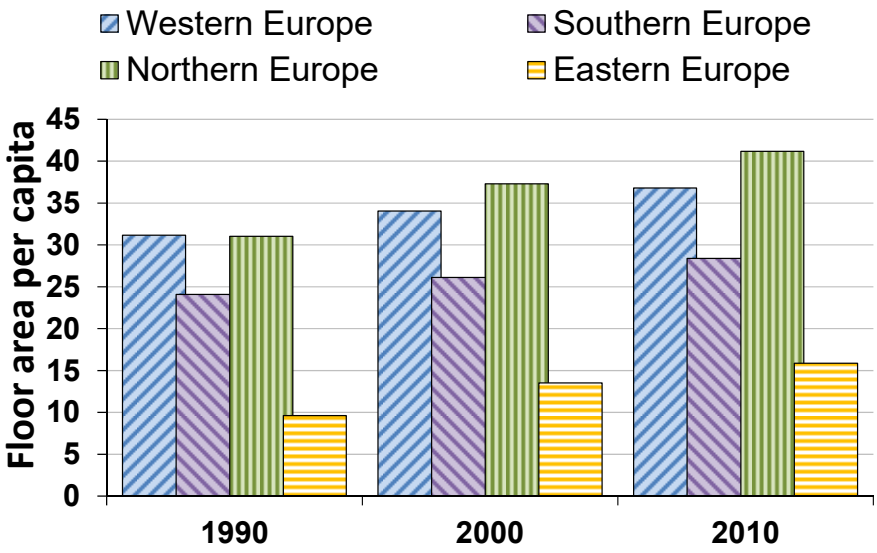

Figure 6. Per capita floor area in each EU member region. Data from [12, 14]. Note: Data missing from WEU (Belgium and Luxembourg (1990-2000)), SEU (Malta (1990-2000), Portugal (1990-2000) and Slovenia (1990)), NEU (Estonia (1990), Finland (1990), Latvia (1990) and Lithuania (1990)) and EEU (Romania (1990)).

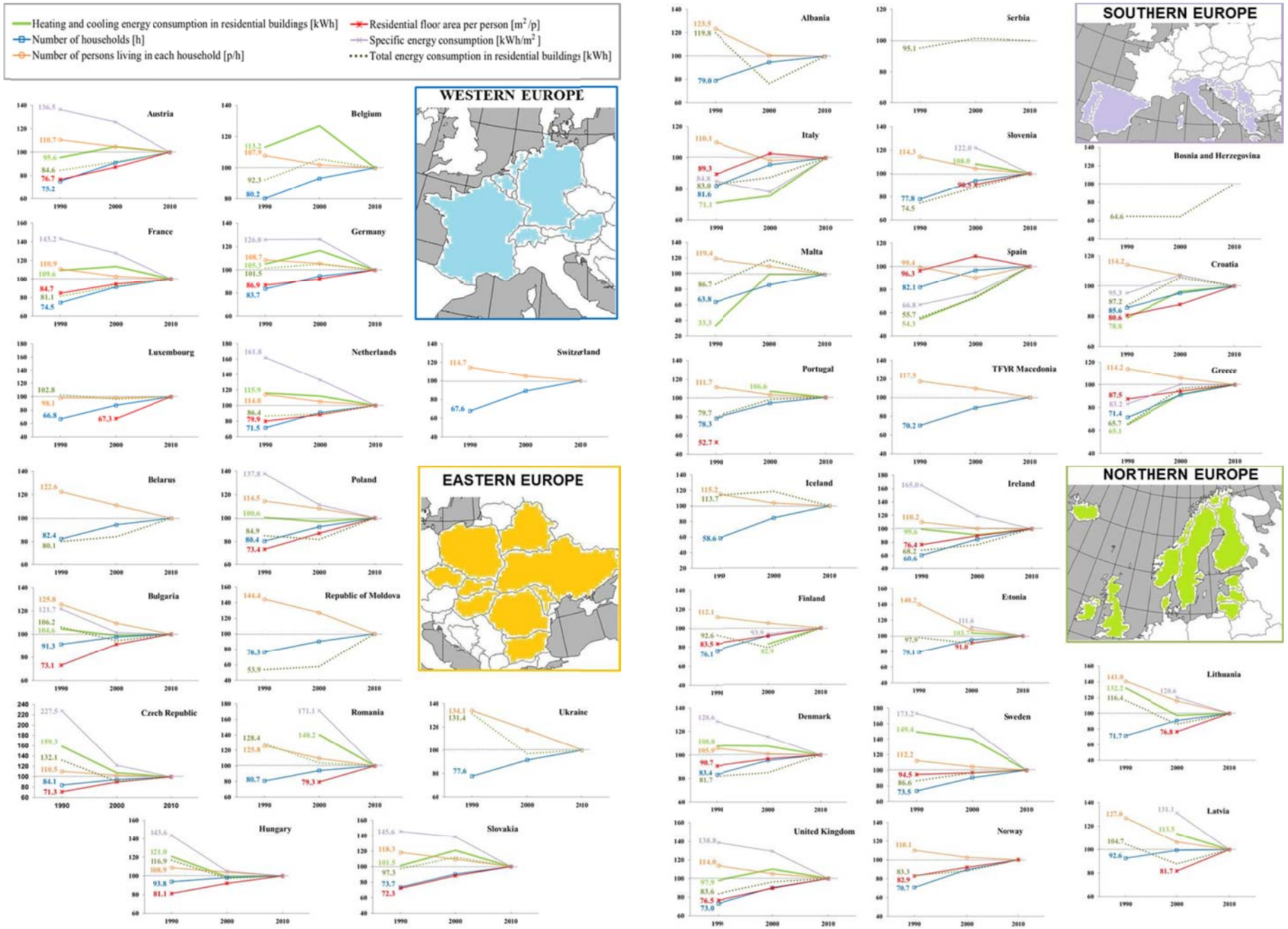

Figure 7. Trends in the drivers of heating and cooling energy consumption in residential buildings by European countries 1990-2010. Data from [15, 12-14] expressed as % of 2010 values.

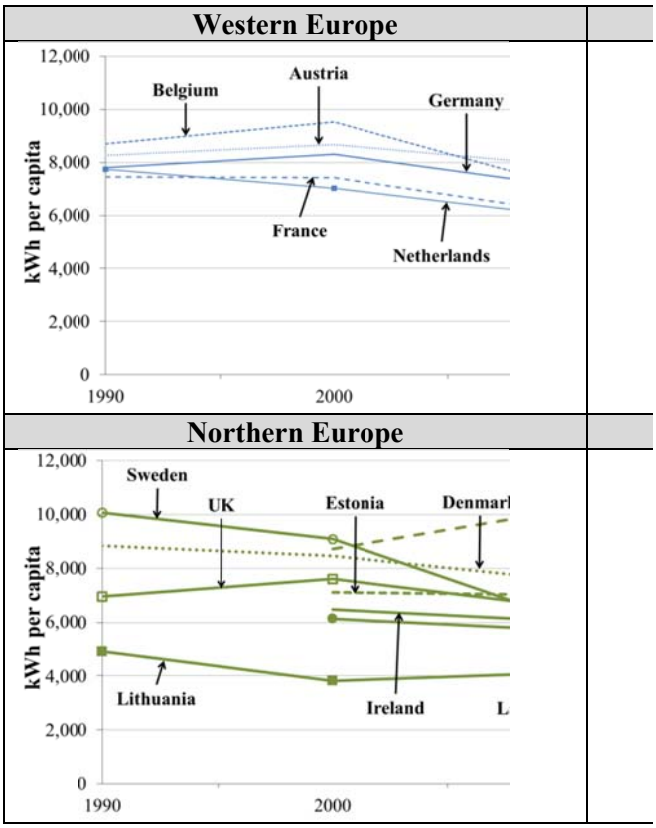

Figure 8. Heating and cooling energy consumption i
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