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NOVICE

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Report on typology of buildings suitable for dual energy services

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Description of the related task and the deliverable in the DoA	Task 5.1: Test Cases Identification and Review: In this task typologies of appropriate building types will be developed. This will include a brief literature review and short reports on the main characteristics of the building types (size, end-use, technical features and systems, etc.). The most suitable buildings for NOVICE are large public buildings and commercial buildings (large office buildings, hotels, hospitals, leisure centres, retail). This description will also include recommendations and experiences from DR services documented in literature. Results from WP2 will be considered. Based on that general selection, 2-3 specific buildings that are to be retrofitted will be selected as demonstration sites for the NOVICE dual energy services business model by the consortium from the portfolio of buildings of the NOVICE partners. Specifically, two types of tertiary buildings in the main two categories of open demand response markets (on one hand the more mature markets of Ireland and the UK and on the other hand the less mature markets of Germany, Finland and Austria) will be used as demonstration sites.				
Comments	Non-residential buildings typology and potential for implementation of EE/DR programs				

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1 PUBLISHABLE EXECUTIVE SUMMARY

This report has been developed within the scope of the NOVICE project, and is the first report providing results from WP5, entitled “Revenue Streams Quantification and Monetisation - modelling and simulation of building archetypes and test cases”. The purpose of this task is to compile information and evaluate the suitability of representative non-residential building types, which will be later modelled and simulated in different scenarios of renovation so as to assess the energy and monetary benefits from selected retrofitting scenarios. The deliverable further incorporates the first list of potential demonstrator sites for the NOVICE project.

More specifically, in this report, we initially identify typologies for non-residential buildings in the existing literature. An evaluation of their attributes led to the adoption of the typology as presented in the Annex I of the European Union’s Energy Performance of Buildings Directive. Subsequently, we examine relevant statistics, such as floor area, energy consumption and typical loads, per building typology for the EU and individual countries, when suitable data were available. We then proceed to explore the regulatory and operational constraints of each building type for the deployment of the dual energy efficiency and demand response scheme proposed by NOVICE. Furthermore, we evaluate the potential of different buildings with regards to the adoption of an automated demand-side flexibility strategy, behaviour modification for energy efficiency and demand response purposes and renovation opportunities, taking into further consideration their respective occupancy patterns and relevant stakeholders’ interests.

Based on the knowledge extracted from the aforementioned steps, a qualitative evaluation of the various building types is carried out and suggestions on the appropriate morphology of suitable buildings for dual EE/DR retrofitting programs are presented. Following the general quantitative and qualitative analysis of the European non-residential building stock, a number of potential demonstrator sites have been identified from the portfolio of the respective partners. The information was assimilated to generate a first version of the demonstrators’ site inventory, which will guide the selection the demonstrators for the NOVICE project. The presented work concludes with the identification, analysis, selection and customization of appropriate archetype and reference buildings that will guide the modelling and energy performance simulation stage of the renovation process.

2 INTRODUCTION

2.1 PURPOSE

The purpose of this deliverable is to report on the work performed for the task 5.1 of the project. The goal in T5.1 is the identification of a suitable typology for non-residential buildings, and, based on this typology, an evaluation of their characteristics that will guide, in subsequent steps, the selection of specific buildings that are to be retrofitted based on the NOVICE dual energy services business model.

Results from this step are going to guide the selection of appropriate demonstration sites for the NOVICE dual energy services business model by the consortium from the portfolio of buildings of the NOVICE partners.

2.2 CONTRIBUTION OF PARTNERS

Hypertech(L): Determination of appropriate building typologies for dual energy services and selection of test case buildings and review of their characteristics.

IERC, Tecnalia & e7: Assist in the determination of appropriate building typologies for dual energy services and selection of test case buildings and review of their characteristics.

NLGES, Kiwi & Bilfinger: Provide data of test case buildings from its portfolio.

2.3 BASELINE

For the purposes of Deliverable 2.1, information was extracted primarily from the following sources:

- EU Energy Performance of Buildings Directive and Energy Efficiency Directive.
- EU Building Stock Observatory.
- Previous EU-funded projects, mainly the Zebra2020 and RePublic_ZEB.
- Ecofys Report on the energy status on the non-residential sector in Europe.
- SEDC report on the status of DR in Europe.
- Online sources with detailed characteristics, use cases and examples on EE and DR retrofitting strategies and projects.

This information has been subject to a critical review, and gathered together with a specific focus on categorization and evaluation of the buildings' EE and DR retrofitting potential.

2.4 RELATIONS TO OTHER ACTIVITIES

The task is the first activity performed for WP5. The evaluation of the different building types presented in this report will inform the subsequent tasks of the world package, namely:

- Task 5.2: Modelling of the test cases and baseline determination
- Task 5.3: Scenarios determination for dual services
- Task 5.4: Revenue Stream Quantification from energy savings and demand response
- Task 5.5: Monetisation and feasibility study and risk analysis
- Task 5.6: Preparation of documentation for demonstration projects

3 NON-RESIDENTIAL BUILDING TYPOLOGIES

Eurostat defines buildings as roofed constructions which (i) can be used separately, (ii) have been built for permanent purposes, (iii) can be accessed by persons and (iv) are suitable or intended for protecting persons, animals or objects. Buildings are further subdivided to residential and non-residential, based on their primary use. A residential building is a building at least half of which is used for residential purposes. A non-residential building is a building which is mainly used or intended for non-residential (commercial, services, storage, entertainment etc.) purposes (Eurostat, 2017).

The NOVICE project initially targets private and public non-residential buildings in both mature and emerging energy markets, for the deployment of the dual Energy Efficiency (EE) and Demand Response (DR) Energy Performance Contracting scheme. Non-residential buildings are commonly of significant size and are likely to already possess particular features, such as the presence of comprehensive and IT-based energy management systems that make them more suitable for retrofitting investments under the project's defined objectives.

3.1 SELECTION OF BUILDING TYPOLOGY FOR THE NOVICE DUAL ENERGY SCHEME

An important step towards the comprehensive evaluation of different buildings' potential for EE and DR is the adoption of a classification, a.k.a. typology, of the existing non-residential building stock, on which all subsequent analysis and evaluation is to be based upon. There is limited work and no general consensus on building typologies, especially concerning the commercial and tertiary building sector. The two most prominent standardization efforts and resulting classifications are the building typologies prescribed in the European Union Directive 2010/31/EU and the California Code of Regulations, Title 24, Part 9. Both typologies utilize as their key differentiation attribute the intended use of the buildings. The EU typology is described in detail in the next section, while Title 24 Occupancy Classification is included, for completeness, in the Appendix.

In this work, we adopt the EU building typology. While the Title 24 Occupancy Classification is more concrete and detailed, the surplus information makes the classification less intuitive and counterproductive for our purposes. The EU typology is significantly less elaborate than the Title 24 classification, but the simplicity can be beneficial for the purposes of this project, since it eliminates tedious and unnecessary differentiations. Furthermore, it should be expected that the EU typology is more suited to the building structure and composition of the European continent. In addition, the European Commission and other sources provide further statistical data, based on this classification, which can be utilized to define secondary classification keys for further refinement, calibration and evaluation of the different building types.

3.2 EU DIRECTIVE 2010/31/EU ON THE ENERGY PERFORMANCE OF BUILDINGS - ANNEX I

The European Union (EU) directive on building energy performance includes a categorization of buildings, which must be taken into consideration when energy performance methodologies are developed. The various building types are described below (excluding the Residential category), enriched with information provided by Eurostat (EU, 2010; Radulov & Kaloyanov, 2014):

3.2.1 Offices

Buildings used as places of business, for clerical and administrative purposes, e.g. banks, post offices, municipal offices, government department offices, conference and congress centres, law courts, parliament buildings etc.

3.2.2 Educational buildings

- ***Kindergartens***: Buildings used for pre-primary education.
- ***Schools***: Buildings used for primary and secondary education (e.g. nursery schools, primary schools, secondary schools, colleges, grammar schools, technical schools etc.), formal education schools, vocational training schools.
- ***Universities/High schools***: Buildings used for higher education and research; research laboratories; higher educational establishments.

3.2.3 Health care facilities

- ***Hospitals***: Institutions providing medical and surgical treatment and nursing care for ill or injured people. University hospitals, hospitals of penitentiaries, prisons or armed forces.
- ***Other institutional care buildings***: Sanatoria, long-stay hospitals and nursing homes, psychiatric hospitals, dispensaries, maternity facilities, maternal and child welfare centres. Institutional buildings with combined residential/lodging services and nursing or medical care for the elderly, for handicapped people etc. Buildings used for thermal treatment, therapy, functional rehabilitation, blood transfusion, breast milk collection, veterinary treatment etc.

3.2.4 Hotels and restaurants

- ***Hotels***: Hotels, motels, inns, pensions and similar lodging buildings, with or without restaurants, detached restaurants and bars.
- ***Other short-stay accommodation buildings***: Youth hostels, mountain refuges, children's or family holiday camps, vacation bungalows, holiday and rest homes, other lodging buildings for holiday makers, not elsewhere classified.

3.2.5 Sport facilities

Buildings used for sports (basketball and tennis courts, swimming pools, gymnastic halls, skating or ice-hockey rinks etc.) providing facilities for spectators (stands, terraces etc.) and for participants (shower and changing rooms etc.).

3.2.6 Wholesale and retail trade service buildings

Shopping centres, shopping malls, department stores, detached shops and boutiques, halls used for fairs, auctions and exhibitions, indoor markets, service stations, storage of goods etc.

3.2.7 Other types of energy consuming buildings

- Buildings and installations of civil and military airports, rail stations, bus stations and harbour terminals, cable car and chairlift stations.
- Radio and television broadcast buildings, telephone exchange buildings, telecommunication centres etc.
- Garages (over or underground) and roofed car parks.
- Industrial buildings.
- Cinemas, concert halls, opera houses, theatres etc.
- Meeting halls and multi-purpose halls mainly used for public entertainment.
- Casinos, circuses, music halls, dance-halls and discotheques, bandstands etc.
- Museums, art galleries, libraries and resource centres.
- Farm buildings and storage buildings used for agriculture farming, e.g. cowsheds, stables, pig houses, sheep-folds, studs, kennels, industrial henhouses, granaries, hangars and agricultural outhouses, cellars, wine making plant, wine vats, greenhouses, agricultural silos etc.
- Churches, chapels, mosques, synagogues.
- Historic or protected buildings, of any kind, not used for other purposes.

- Penitentiaries, prisons and remand centres, barracks for armed forces, police or fire services.

4 NON-RESIDENTIAL BUILDING STOCK CHARACTERISTICS IN EUROPE

In this section, we elaborate on the different characteristics of non-residential buildings in Europe and its comprising countries, based on their typological, operational, and energy-related characteristics. The goal of this analysis is to examine the attributes of the various building types and further subcategorize them based on key factors, which can provide further insight into the evaluation of their suitability for the project's objectives. In detail, we first present an analysis on the distribution of floor area on commercial and tertiary buildings in European countries. Subsequently, we examine the age distribution of non-residential building stock. Afterwards, we report on the energy consumption profiles of the buildings, and finally we discuss the characteristics of Energy Performance Certification in EU.

Data was assimilated from the following sources and reports from past projects:

- EU Building Stock Observatory (EU Buildings Database and EU Buildings Factsheets): The EU Building Stock Observatory monitors the energy performance of buildings across Europe. It assesses improvements in the energy efficiency of buildings and the impact of this on the actual energy consumption of the buildings sector overall.
- Zebra2020 project: The Nearly Zero-Energy (nZE) Building Strategy 2020 project was funded by the Intelligent Energy Europe Programme of the European Union, and run from April 2014 to September 2016. It aimed at monitoring the market uptake of nZE buildings across Europe by creating an observatory and thereby generated data and evidence for policy evaluation and optimisation regarding the European building stock.
- Ecofys Report 'Panorama of the European non-residential construction sector': The 2011 report presented a study from the Ecofys consultancy company, aiming to provide background information about the European non-residential building stock, to be used for the assessment of the market potential for building energy technologies.
- RePublic_ZEB project: RePublic_ZEB was a European Commission funded project, completed in 2016, with its objective being to provide the means of reducing energy consumption in public buildings to near zero, in accordance with Article 9 of the EU's Energy Performance of Building Directive. The project's target countries were Bulgaria, Croatia, Former Yugoslav Republic of Macedonia (FYROM), Greece, Hungary, Italy, Portugal, Romania, Slovenia and Spain.

It must be highlighted that for certain characteristics, availability of data is erratic. In all figures, countries for which data are not available, were excluded from the graphs.

4.1 GEOGRAPHICAL CHARACTERIZATION AND CLASSIFICATION

For the purpose of providing a more detailed view on the different energy-related characteristics within the European Union, we adopt here an approximate geographic subdivision of EU states into Central (C), North-East (NE), North-West (NW), South-East (SE) and South-West (SW) regions. The countries we distribute into each of these regions are reported below:

- C: Austria, Belgium, Czech Republic, France, Germany, Hungary, Luxemburg, Netherlands, Poland, Slovakia.
- NE: Denmark, Estonia, Finland, Latvia, Lithuania, Sweden.
- NW: Ireland, UK.
- SE: Bulgaria, Croatia, Cyprus, Greece, Romania.

- SW: Italy, Malta, Portugal, Spain.

We structure each of the subsequent parts are follows: First, statistics and graphs on the various EU countries, and possibly, overall for EU are reported. Afterwards, we zoom in and identify particularities within the different European Union subregions.

4.2 Building Typology and Floor Area Distribution

Figure 1 shows the accumulated non-residential floor area in the EU countries, while Figure 2 presents the relative distribution of residential vs non-residential floor area in EU. Not surprisingly, large countries, such as Germany, France and UK dominate the accumulated non-residential floor area. We further notice that floor area is mostly occupied by residential buildings. While the share varies somewhat depending on the country, non-residential buildings cover on average about 25% on the building stock.

Non-residential buildings consume disproportionally large amounts of energy for their floor area, on average around 35% of the overall energy used in the building sector (see figure in Appendix 14.2). Even more importantly, more than 50% of supplied electricity is used up in the non-residential facilities. For reference, electricity prices in the European countries, and normalized energy consumption profiles for residential vs. non-residential buildings per m^2 of coverage area are also shown in Appendix 14.2. In absolute numbers, the non-residential sector consumes about 250 kWh/m^2, compared to 180 kWh/m^2 in the residential one. This fact further ascertains the project's focus on non-residential buildings. More details on the energy consumption of the buildings are presented in subsection 4.5.

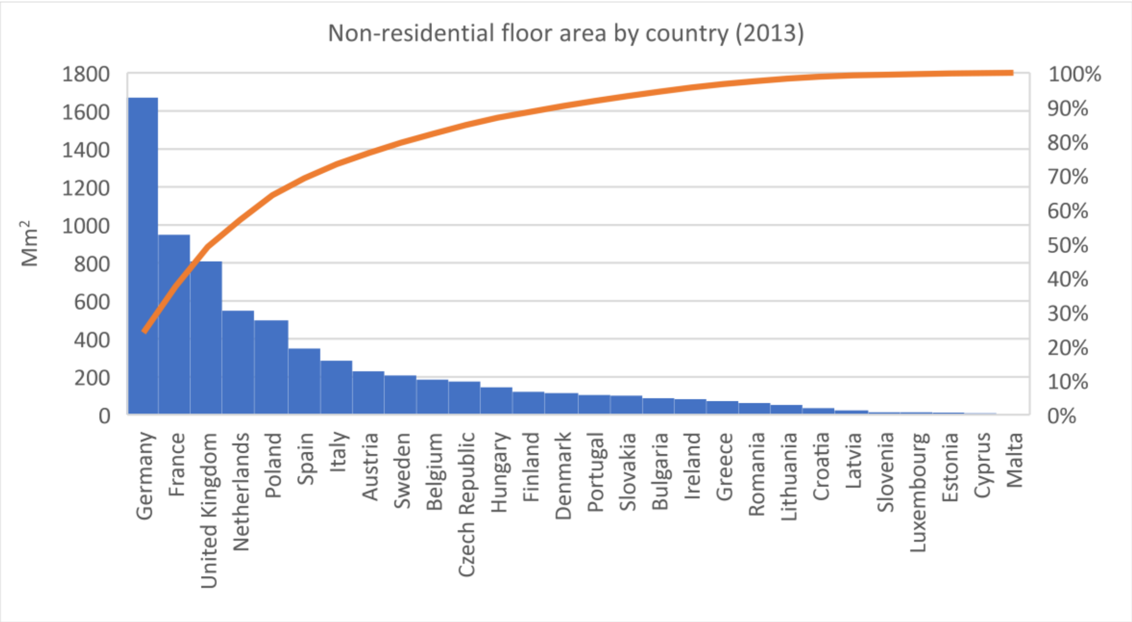

Figure 1. Non-residential Occupied Floor Area by country. Source (EC, 2017)

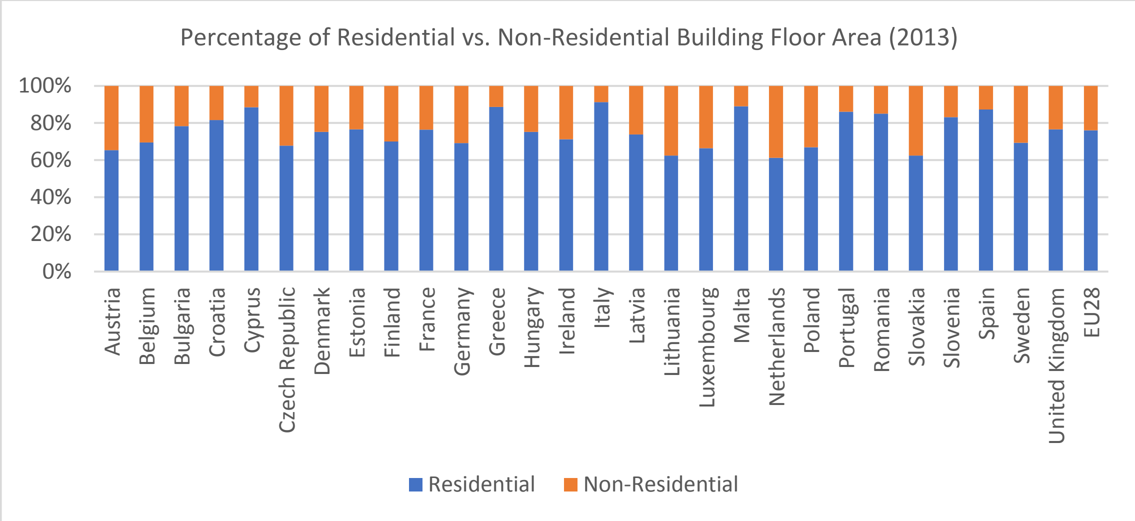

Figure 2. Percentage of Residential vs. Non-Residential Floor Area. Source (EC, 2016)

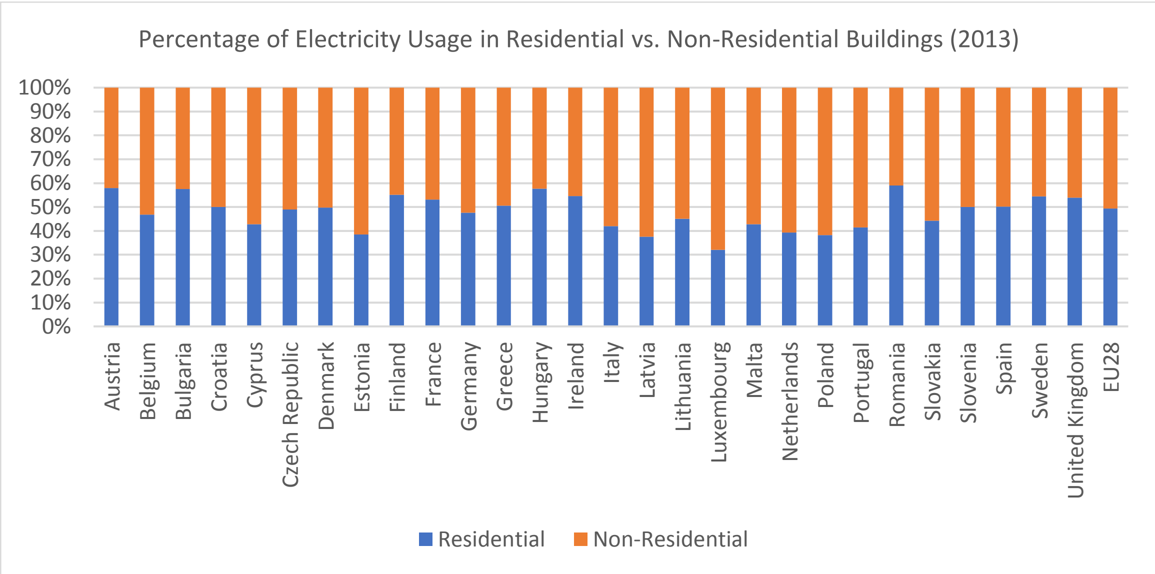

Figure 3. Distribution of Electricity Consumption for Residential and Non-Residential Buildings in Europe. Source (EC, 2017)

On the main subject of different building classes, recorded data show that variability among countries is significant, but on average, two thirds of non-residential floor area (excluding sport facilities and other buildings, for which data were not available) are covered by offices and wholesale/retail businesses, followed, in order, by educational, hotels and restaurants and health care buildings. The distribution of floor area by building type for the EU countries are shown in Figure 4 (Mm^2) and Figure 5 (percentages over total non-residential floor areas).

A common pattern is observed in NW, SE and SW Europe. Hotels, restaurants, retail and wholesale buildings commonly occupy more than 50% of the non-residential floor area, with offices and educational facilities taking up about 40-45% on equal shares. A particularity of importance here is that UK exhibits the largest percentage of retail and wholesale buildings (approximately 45%) of all EU countries.

Central and NE regions have, in general, a more balanced area distribution, with offices and educational buildings accounting for around or even more that 50%. It must be noted that a number of countries in these regions, with prominent examples being France, Estonia and Finland, have more than 5% area coverage attributed to health-care facilities.

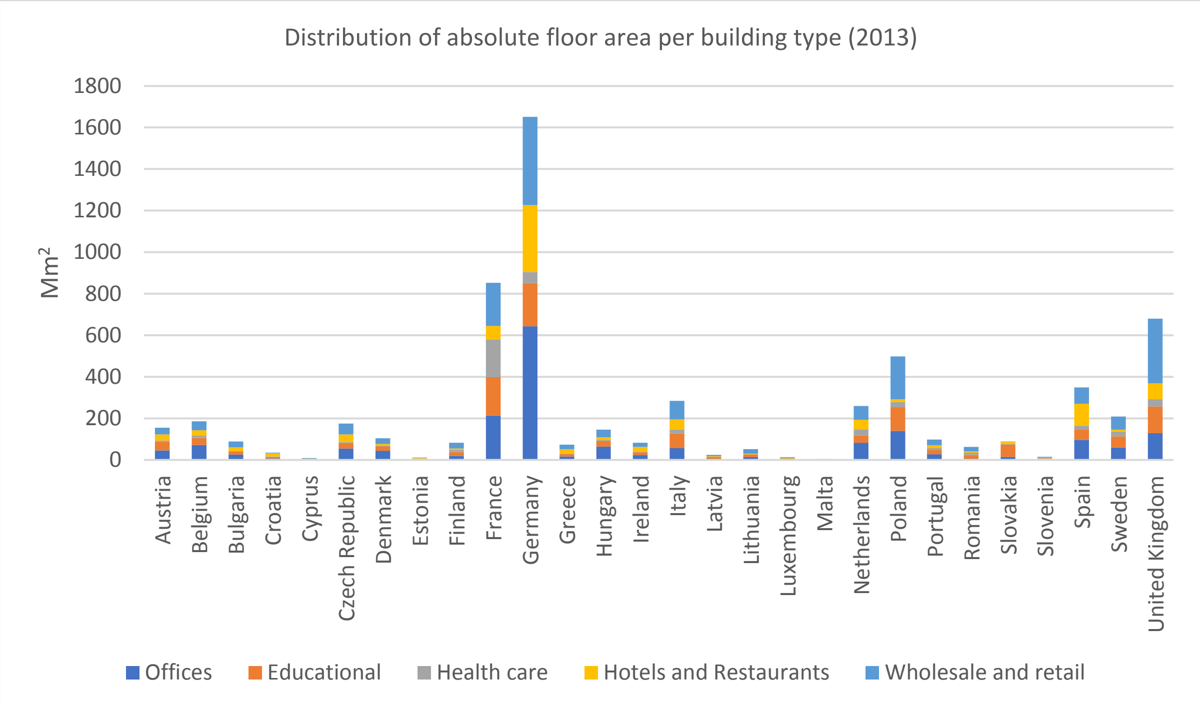

Figure 4. Distribution of floor area (Mm^2) by building type in the EU. Data was not available for Sport Facilities and Other types of buildings. Source (EC, 2017)

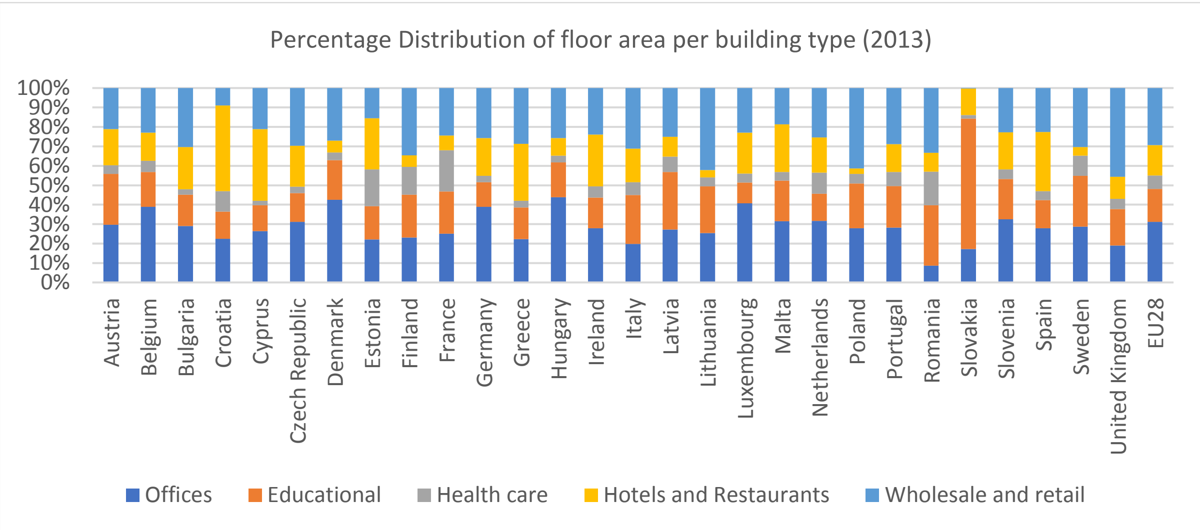

Figure 5. Percentage Distribution of Floor area by building type in the EU. Data was not available for Sport Facilities and Other types of buildings. Source (EC, 2017)

4.3 Building Typology, Number of Buildings and Size

Information on the number and size of non-residential buildings is helpful, particularly for quantifying the average energy consumption per building, for each category. In Figure 6 we include the total numbers for the various non-residential buildings (excluding sport facilities) in the EU countries. In most countries, wholesale and retail facilities are the most plentiful. Some exceptions can be noticed, especially in central and northern Europe (e.g. Netherlands, Belgium, Sweden and Denmark), where offices are more abundant.

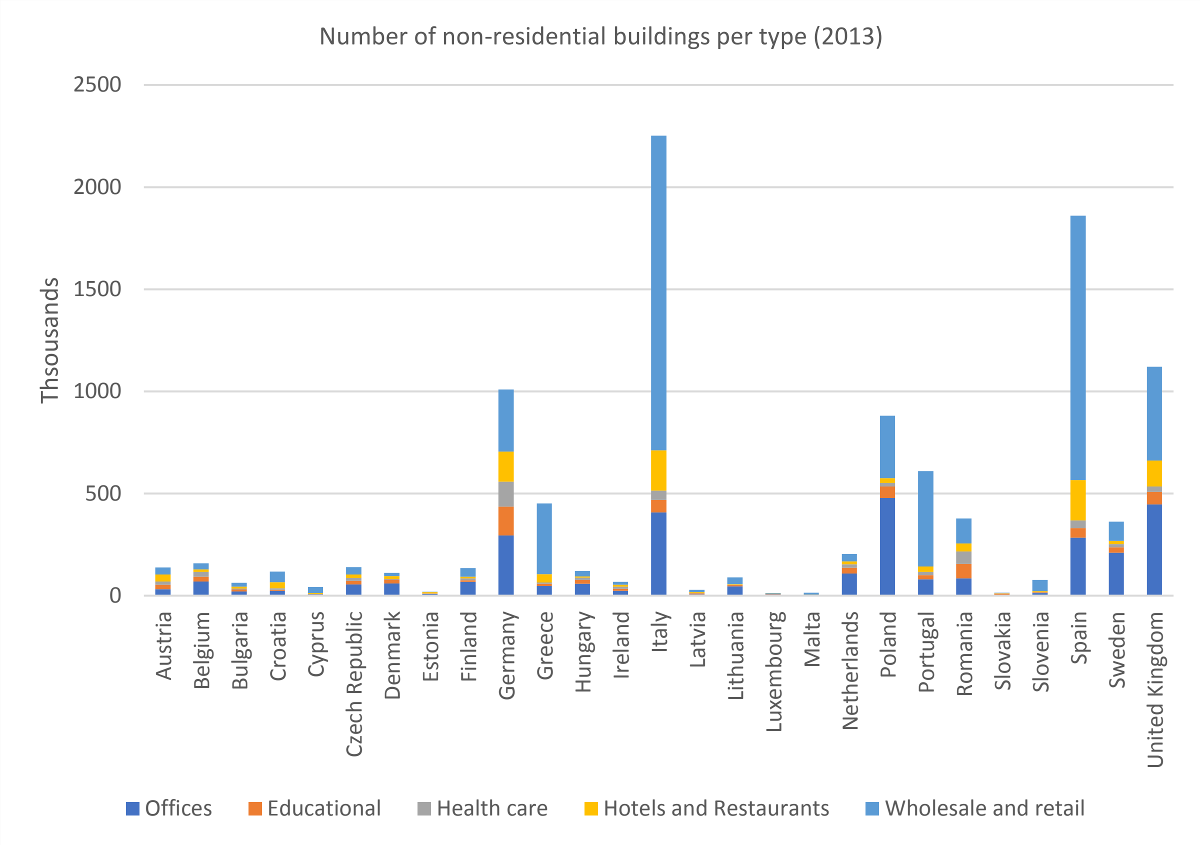

Figure 6. Number of non-residential buildings per type and EU country (in thousands). Source (EC, 2017)

By dividing the total floor areas with the number of buildings, we can acquire the average building sizes, which are shown in Figure 10. The table with detailed values is also included in Appendix 14.2.

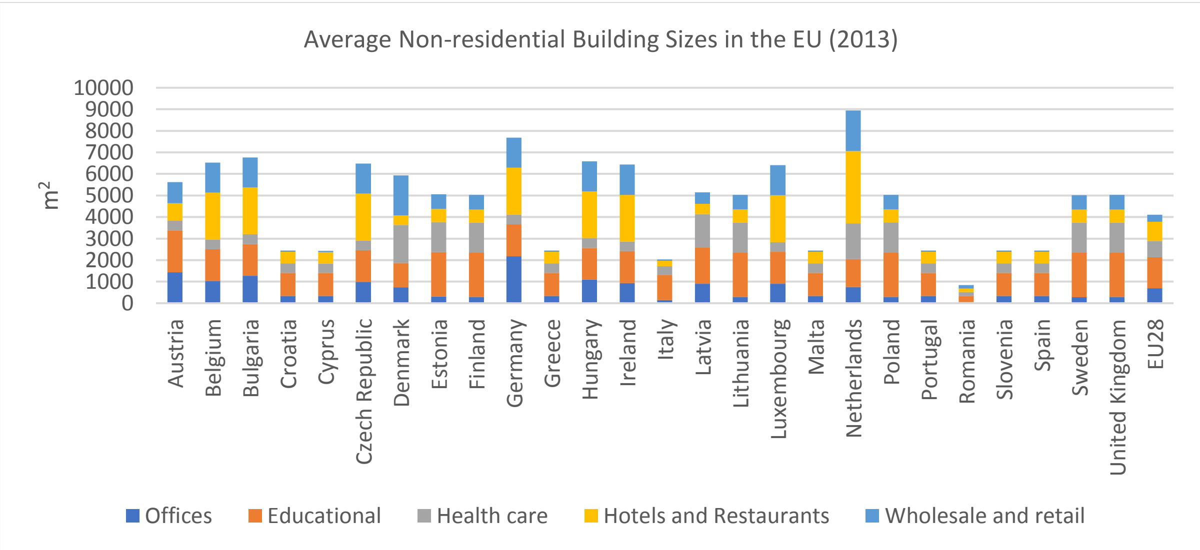

Figure 7. Average size of different buildings in the EU. Source (EC, 2017)

Average sizes across the EU are respectively: Offices - 695 m^2 (std: 482), Education - 1434 m^2 (std: 446), Healthcare - 765 m^2 (std: 512), Hotels and restaurants - 881 m^2 (std: 862), Wholesale and retail - 338 m^2 (std: 611). Educational buildings have the largest average size and the smallest deviation around the mean value, highlighting this category's consistent large size. On the other side, Wholesale and retail facilities occupy the smallest buildings on average. Healthcare, offices and hospitality facilities have very similar mean floor areas per building.

An in-depth analysis regarding the size of different non-residential facilities was also performed from the Building Performance Institute Europe (BPIE). Figure 8 reproduces the results, where, for each building type, a 3-band size distribution is shown (Small: < 200 m^2, Moderate: > 200 m^2 & < 1000 m^2, > 1000 m^2), either as a percentage of the floor area or as a percentage of the number of buildings in that size band.

Offices

Area	< 200 m²	200 - 1 000 m²	> 1 000 m²
BG	60	30	10
UK	26	27	47
NL	12	24	64
IT	5	28	67
SK	1	12	88

Number	< 200 m²	200 - 1 000 m²	> 1 000 m²
IE	95		5
CZ	30	55	15
IT	33	50	17
LT	0	79	21
SE	4.7	25.9	69.4

Hospitals

Area	< 200 m²	200 - 1 000 m²	> 1 000 m²
BG	0	30	70
SK	0	4	96
UK	0	1	99

Number	< 200 m²	200 - 1 000 m²	> 1 000 m²
LT	0	78	22
CZ	0	70	30
SE	4.4	28	67.5
IE	0	0	100

Sport facilities

Area	< 200 m²	200 - 1 000 m²	> 1 000 m²
UK	0	12	88
SK	0	10	90

Wholesale & retail

Area	< 200 m²	200 - 1 000 m²	> 1 000 m²
BG	35	55	10
UK	42	22	36
SK	1	12	86

Number	< 200 m²	200 - 1 000 m²	> 1 000 m²
CZ	25	60	15
SE	3.7	37.4	68.9

Educational buildings

Area	< 200 m²	200 - 1 000 m²	> 1 000 m²
BG	0	40	60
NL	5	4	91
SK	0	6	93
UK	1	5	94

Number	< 200 m²	200 - 1 000 m²	> 1 000 m²
IE	84.5		15.5
CZ	0	55	45
SE	5.3	37.3	57.4

Hotels & Restaurants

Area	< 200 m²	200 - 1 000 m²	> 1 000 m²
BG	10	50	40
UK	27	23	52
SK	0	4	95

Number	< 200 m²	200 - 1 000 m²	> 1 000 m²
CZ	5	65	30
SE	11.2	45	43.9

NOTES

AT: Values based on registered certificates, accounting for 1 007 data sets of non-residential buildings, most of which are office buildings.
CY: Values refer to non-residential building permits issued from 2003-2009 (and % refers to <900 m² and > 900 m² of surface area)
CZ: Estimations based on past official data, extrapolated to present time.
IE: Office values concern buildings under the responsibility of the Office of Public Works. Educational values concern only public primary and secondary schools. Hospital values include publicly owned acute and non-acute hospitals and private nursing homes
SI: The data refer to all real estate units in non-residential use
SE: Values presented are based only on certified non-residential buildings.
UK: All presented values refer only to England and Wales and the categories <200 m² correspond to <250 m² and the categories 200-1 000 m² corresponds to 250-1 000 m². Office values concerns only commercial offices, hospital values exclude health centres and surgeries, and sports facilities include only LA sports centres
BG, EE, LT, NL: Values based on estimations by national experts

Figure 8. Building size distribution per category in EU countries. Source (BPIE, 2011)

Hospitals, educational and sport facilities are predominantly larger than 200 m^2. In more detail, limited data on sport facilities indicate that these buildings most often occupy more than 1000 m^2 per building. In many countries, this is also true for hospitals, although in some central European countries, moderate-sized healthcare facilities have the biggest share. Educational buildings, in general, are better balanced between moderate and large size buildings.

Hotels and restaurants below 200 m^2 are also scarce, although UK poses an exception to that observation, with more than 25% of floor area covered by such small facilities. Otherwise, buildings are about equally distributed between moderate and large size bands.

Wholesale and retail, as well as office buildings are those with the most diverse size profiles, both with respect to size, as well as examined country. States from Central, SW and NE Europe show high percentages of large buildings in both categories. In NW and SE Europe though, moderate-sized, or even small buildings are the most common.

4.4 Building Typology and Construction Period

Retrofitting and renovation potential of buildings is highly correlated with their construction age. In the project's description of work, it is clearly mentioned that 'buildings to be renovated are tertiary buildings that have been built before 2000'. The justification behind this choice is based on the fact that building energy systems are displaying a lifetime of no more than 20-25 years. Hence, all tertiary buildings that were built before 2000, will be eligible for energy upgrades. It is of interest, thus, to examine the distribution of building types based on their construction periods. Data is still somewhat limited on this respect, since relatively few countries have established records with relevant information.

Ecofys has published a report analysis on the building stock for five European countries, namely Germany, Hungary, Poland, Spain and Sweden, and extrapolated the results, based on floor area, for the remaining EU countries (Schimschar et al., 2011). The estimated EU age statistics per building type are presented in Figure 9. We can see that the percentage of buildings build after 2000 ranges between 5 and 20%, with highest percentages belonging to retail, industrial and other buildings, including sport facilities. On the other extreme, pre-1980s buildings comprise around 75% of educational buildings. Public buildings, which, in our typology classification, belong to the Other category, and offices have a more balanced distribution which could translate to a higher renovation potential. They both have considerable percentages of new buildings, hinting at an increased investment interest, as well as a balanced distribution of structures built in other time periods, which, given suitable incentives, can constitute a significant renovation building pool.

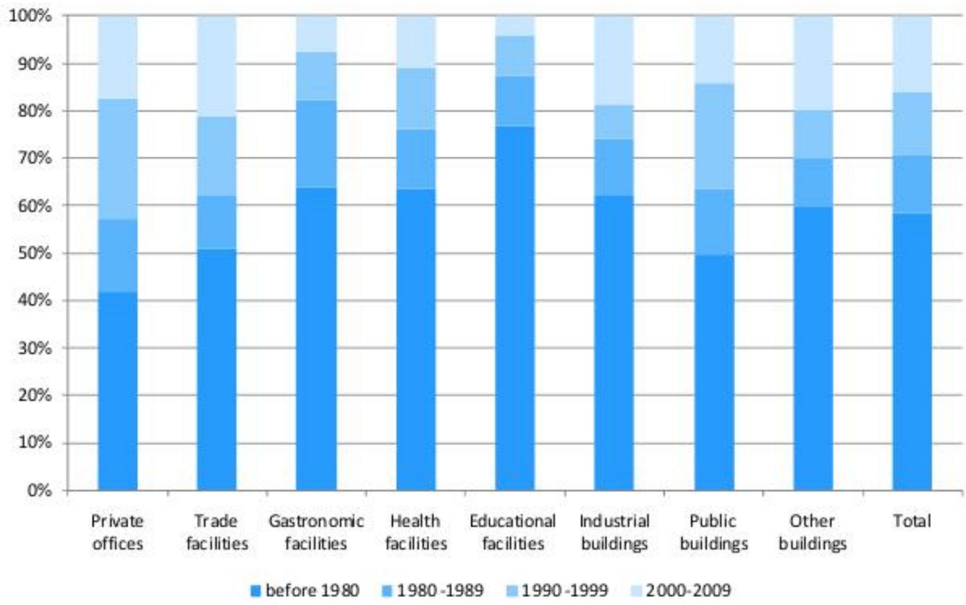

Figure 9. Distribution of EU27 non-residential floor area by building type and construction period. Source (Schimschar et al., 2011)

Detailed age distribution figures for the individual countries examined in the Ecofys report, as well as similar data for Bulgaria, Romania, Portugal and Greece, presented in the RePublic_ZEB project (Radulov & Kaloyanov, 2014), can be found in Appendix 14.3. While some variability is observed in terms of absolute numbers, building age distribution for individual countries follows closely the average European pattern.

Of further interest, is to investigate the interplay between new construction and renovation activities, so as to establish the renovation potential in the non-residential building stock. Prior to the discussion, it should be mentioned that data are sparse, especially regarding the related costs, so the observations made here should not be considered conclusive. The share of annual building stock that undergoes major renovation is generally lower to that of new construction, as seen in Figure 10 and Figure 11. During the past years (2010-2013), we also notice a slight reduction in the number of both new and renovated buildings, probably due to the economic crisis. Average costs for new construction and renovation vary significantly in the different countries (see Figure 12 and Figure 13). The ratio between new construction and renovation costs ranges from around 1.25 (e.g. Spain) up to 4 or even greater (e.g. Poland and Lithuania).

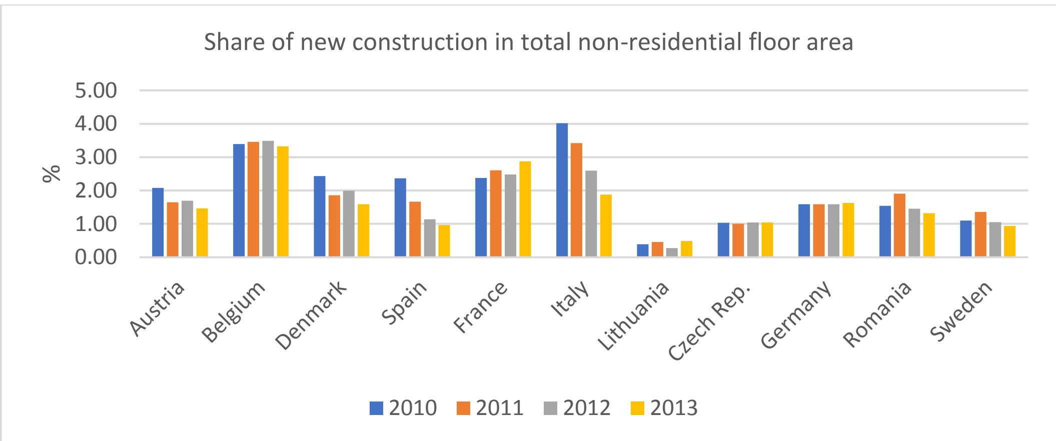

Figure 10. Share of new construction in total non-residential floor area. Source (ZEBRA2020, 2016)

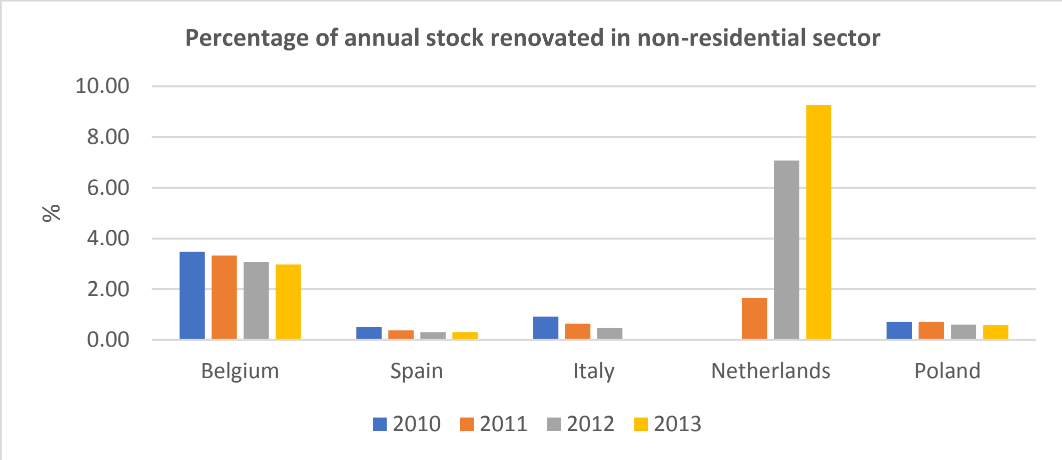

Figure 11. Percentage of annual stock renovated in non-residential sector. Source (ZEBRA2020, 2016)

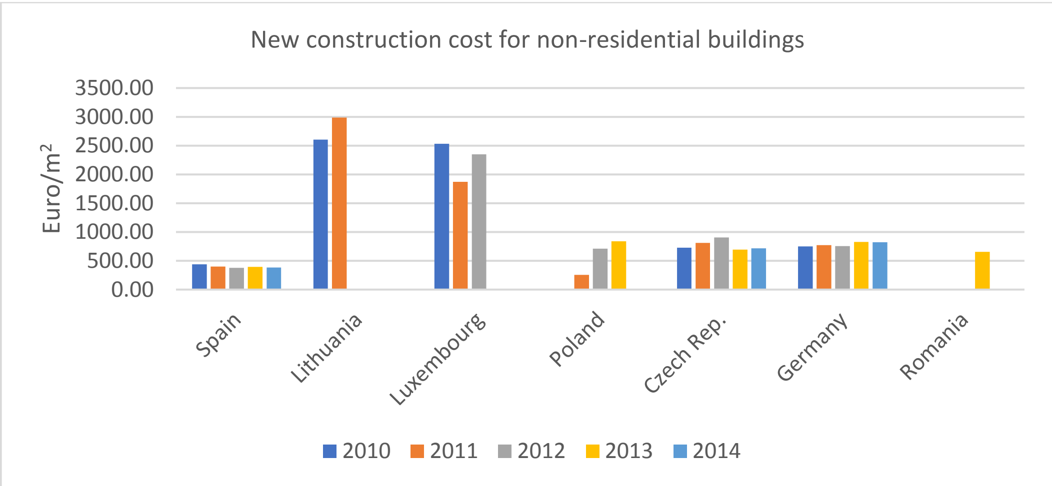

Figure 12. Cost of new construction for non-residential buildings. Source (ZEBRA2020, 2016)

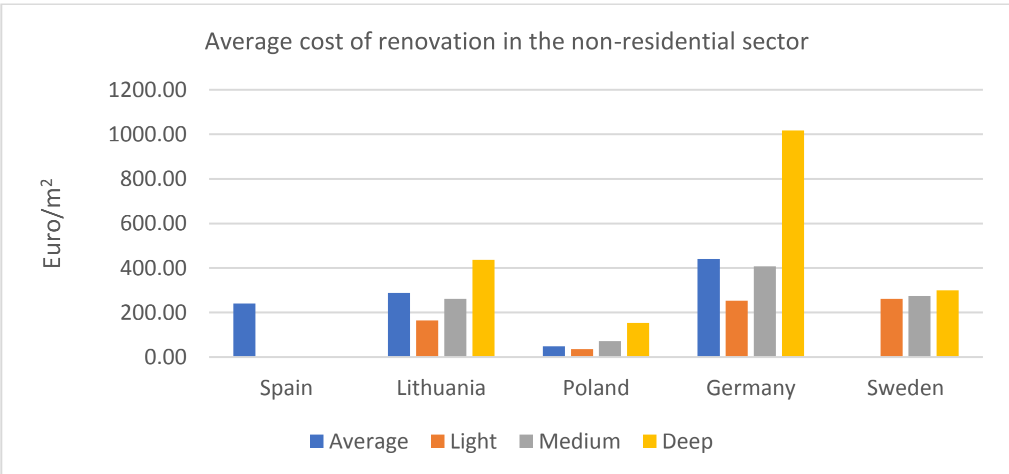

Figure 13. Cost of renovation in the non-residential sector. Source (ZEBRA2020, 2016)

4.5 Building Typology and Energy Consumption

A final, but equally important, area of exploration, regarding the characteristics of the various non-residential buildings, is their energy consumption signatures. As mentioned in a previous subsection, commercial and tertiary buildings are significantly energy hungry, a fact that makes them well suited to the deployment of EE and DR schemes. In terms of absolute energy consumption in the non-residential sector, the results correlate significantly with the overall area covered by buildings, with Germany, France, UK and Italy being the countries with the biggest consumption, as seen in Figure 14. For most countries, energy consumption per m² in the non-residential sector was calculated between 200 and 300 kWh/m².

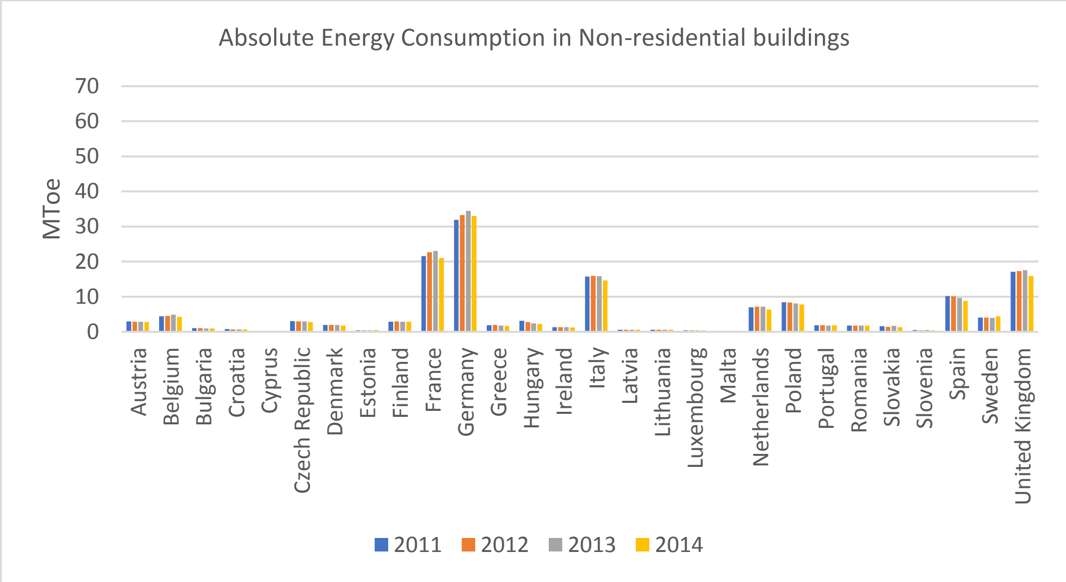

Figure 14. Absolute Energy Consumption for the non-residential sector in the EU countries. Source (EU, 2017a)

Data are limited with respect to energy consumption in the different building categories. For certain countries though, the profile of the typology's consumption is recorded.

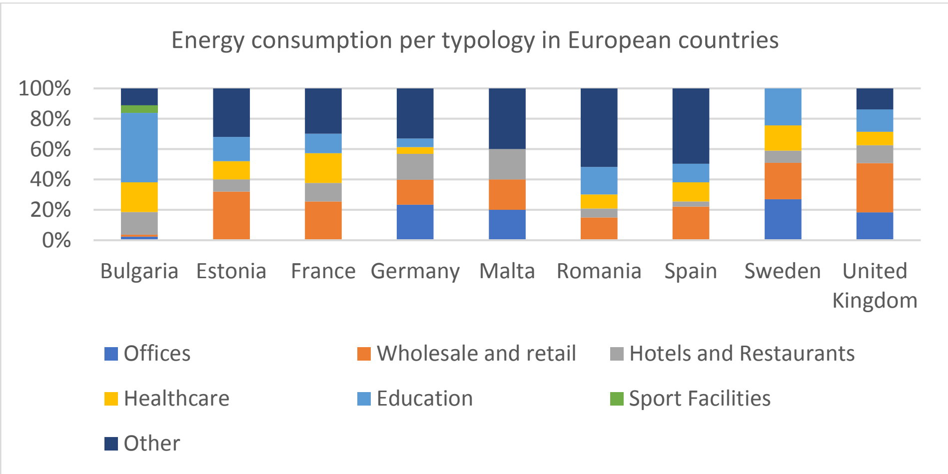

Figure 15. Energy consumption per typology in European countries. Source: (EU, 2016b)

In Figure 15 we report on the percentage of total energy that is consumed in the various non-residential building categories. We notice high heterogeneity among countries. In Bulgaria, for example, about 45% of the energy is consumed in the educational sector, while in the other countries, the same percentage is less than 25%. In Germany, offices, retail and hotel stock share about the same percentage, with only a small part attributed to education and healthcare. The most energy is consumed for other activities, such as industry. UK's energy profile, on the other side, is characterized by the largest consumption in the wholesale and retail sector, while offices, education and hotels are almost equal. Healthcare and other buildings are the least consuming categories.

Of high significance is the absolute energy consumption of non-residential buildings. The total energy consumption per year and building type can be seen in Figure 16, while in Figure 17, we divided consumption by total floor area, to acquire measurements of energy consumption per square meter. In many countries, especially located in Southern Europe, we notice very high consumption per square meter in healthcare facilities. Hospitals appear to be energy thirsty buildings in other European countries as well. In southern Europe, the wholesale and retail sector is also consuming large amounts of energy per m^2. This is different in central and northern Europe, where the second place is taken by hospitality buildings. Offices and educational facilities have similar consumption patterns. The former type does not show any discernible variation pattern associated with geographical region, while educational buildings do appear to have increasing consumption values from north to south.

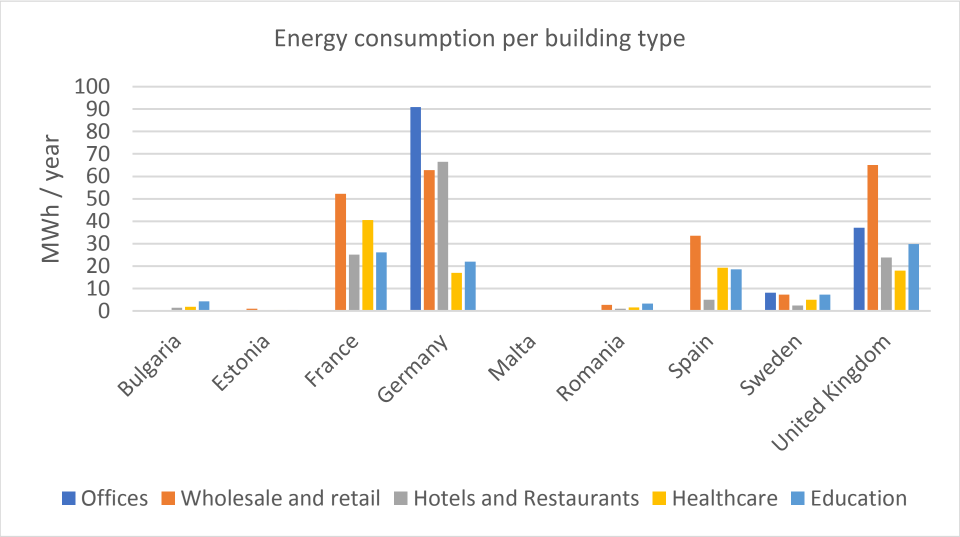

Figure 16. Energy consumption per building type. Source: (EU, 2016b)

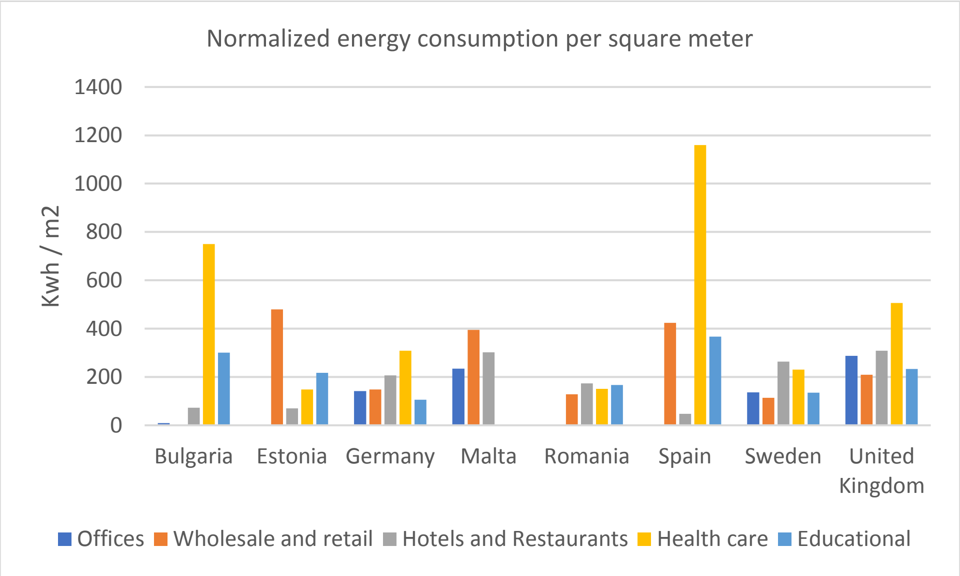

Figure 17. Normalized energy consumption per square meter. Source: (EU, 2016b)

An extra point of interest regards the annual energy consumption per building. By considering the average building sizes, as extracted in section 4.3, we were able to estimate the annual energy consumption of buildings with average floor sizes per country and type (see Figure 18). Healthcare facilities, not surprisingly, have very high consumption per building. Educational facilities also rank very high, especially due to their large average size. Offices, hospitality and retail buildings have diverse profiles per country. In general, though, individual hospitality buildings are bigger energy consumers.

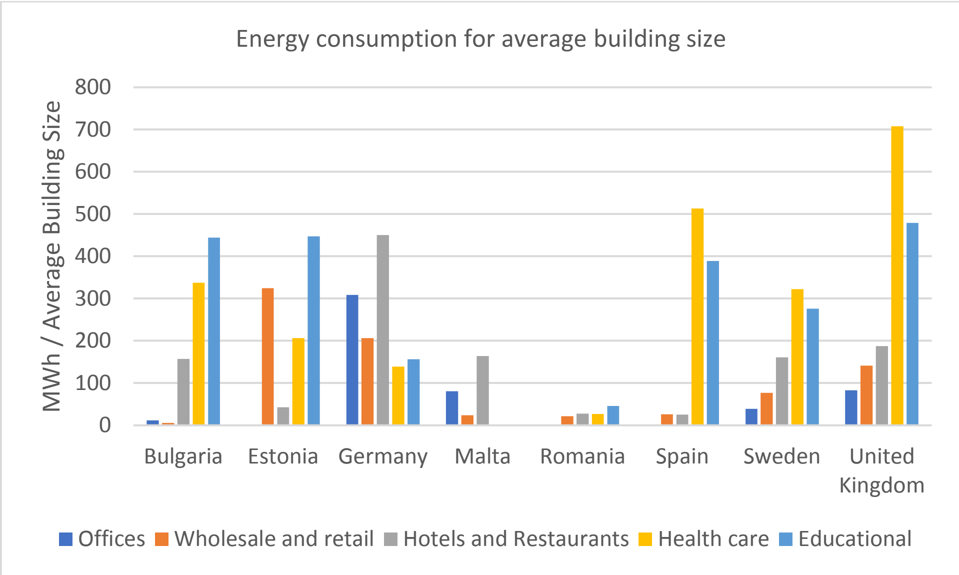

Figure 18. Energy consumption for average building sizes. Source: (EU, 2016b)

Moving forward, we concentrate on the identification of types of load usage on which energy is consumed in the non-residential sector. A general profile per country was extracted from the EU buildings database and is provided in Figure 19.

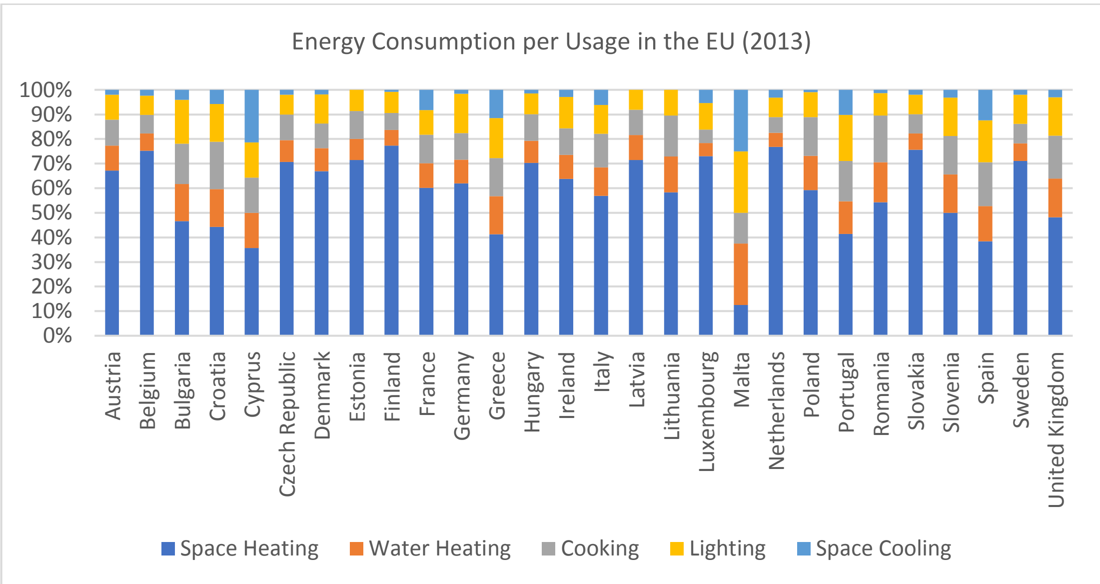

Figure 19. Energy Consumption per Usage in the EU. Source (EU, 2016b)

In the vast majority of countries, the biggest share of energy is used up for heating purposes. Central and northern European countries exhibit heating consumption ratios around 60-75%, very little energy spent for cooling, and the remaining energy used equally on water heating, cooking and lighting. UK, out of these countries, is the only one where energy consumed for heating is less than 50%. Expectedly, southern countries, namely Greece, Malta, Spain, Cyprus, Croatia, Bulgaria and Portugal, have the lowest energy usage percentages for heating, balanced out with a heightened ratio spent for cooling.

A distribution of lighting loads per building type for Central and NW European countries France, Germany and UK, was available in the EU database (Figure 20). From this data we observe that, in France and UK, the wholesale and retail sector is the one with most needs for lighting, while in Germany this position is held by the offices sector.

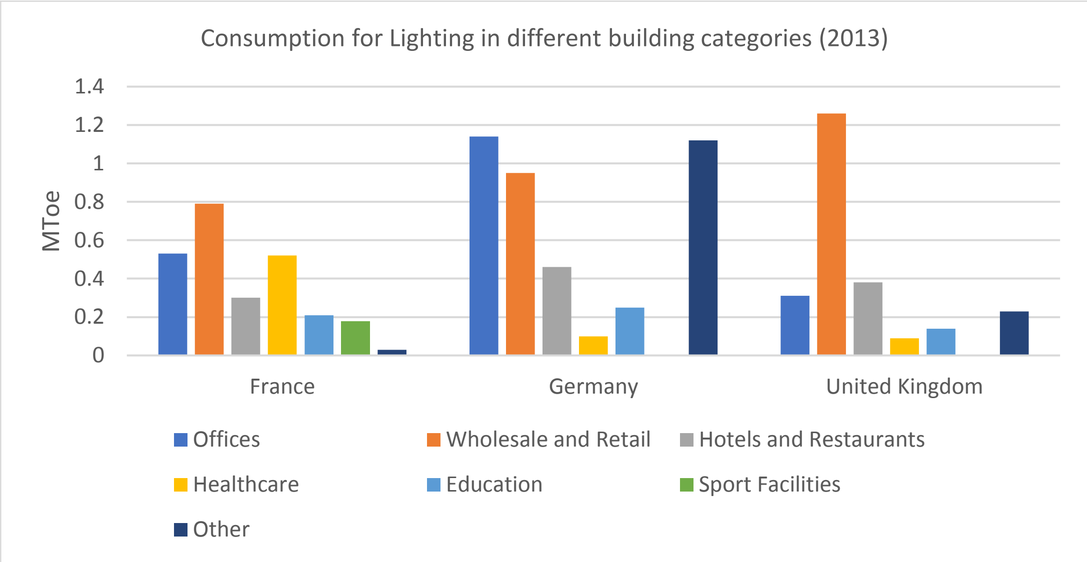

Figure 20. Energy Consumption for Lighting purposes in the non-residential sector of France, Germany and UK. Source (EU, 2016b)

More detailed correlation data between types of loads and buildings was performed for the purposes of the RePublic_ZEB project, and covered a number of southern European states, including Bulgaria, Croatia, Greece, Spain, Romania and Portugal (Radulov & Kaloyanov, 2014). The detailed figures are included in Appendix 14.4.

In most of the examined countries, in the respective RePublic_ZEB report, heating needs dominated the educational and sport sectors. An exception was observed in the southern-most countries of Greece and Portugal, where the demand for heating in the educational buildings was very limited, and the largest share went to cooling and lighting purposes. While heating is prevalent for healthcare and hospitality buildings, important share in these sectors is also taken by water heating, appliances, and lighting. Wholesale and retail buildings had a very balanced distribution of energy consumption, split between heating, cooling and lighting loads.

4.6 Building Typology and Energy Performance Certification

Another important aspect regarding characterization of different buildings in the EU is related to the Energy Performance Certificates (EPCs). EPCs provide a significant push towards the energy performance of buildings through renovation and retrofitting projects. They play a central role in the European Union's Energy Performance for Buildings Directive (EPBD), which asks EU Member States to provide information, during the inspection reports, regarding the buildings; energy performance, their objectives, on cost-effective ways and, where appropriate, on the available financial instruments to improve the energy performance of the building. More details on the EPBD are provided in a subsequent section. With regards to EPCs, though, the EPBD prescribes the following:

- Article 12 (1): EPCs need to be produced for every building and building unit that is newly constructed, undergoes major renovation.
- Article 13: EPCs shall be displayed for buildings with a total floor area of over 250m^2 (from 7th of July 2015) and occupied by a public authority and for those frequently visited by the public. There is no obligation yet to display the recommendations.
- Article 11(1): EPCs shall include the energy performance of a building and its reference values such as the minimum energy performance requirements.
- Article 11 (2): The EPC shall include recommendations for the cost-optimal or cost-effective improvements of the energy performance of a building or building unit, unless there is no reasonable potential for such improvements considering the energy performance requirements in force. The recommendations included in the EPC shall cover: the measures carried out in connection with a major renovation of the building envelope or technical building system(s) and the measures for individual building elements not dependent on a major renovation of the building envelope or technical building system(s).
- Article 17 (1): Member States shall ensure that EPCs are carried out in an independent manner by qualified and/or accredited experts.

While, under the EPBD, it is not compulsory for the EU states to set up a central EPC register, a lot of the Member States have implemented a system to collect EPC data. In 11 out of 28 Member States, issued EPCs must be uploaded to the central database to be officially approved (EC, 2017). Such EPC registers are the primary source of information regarding certified buildings.

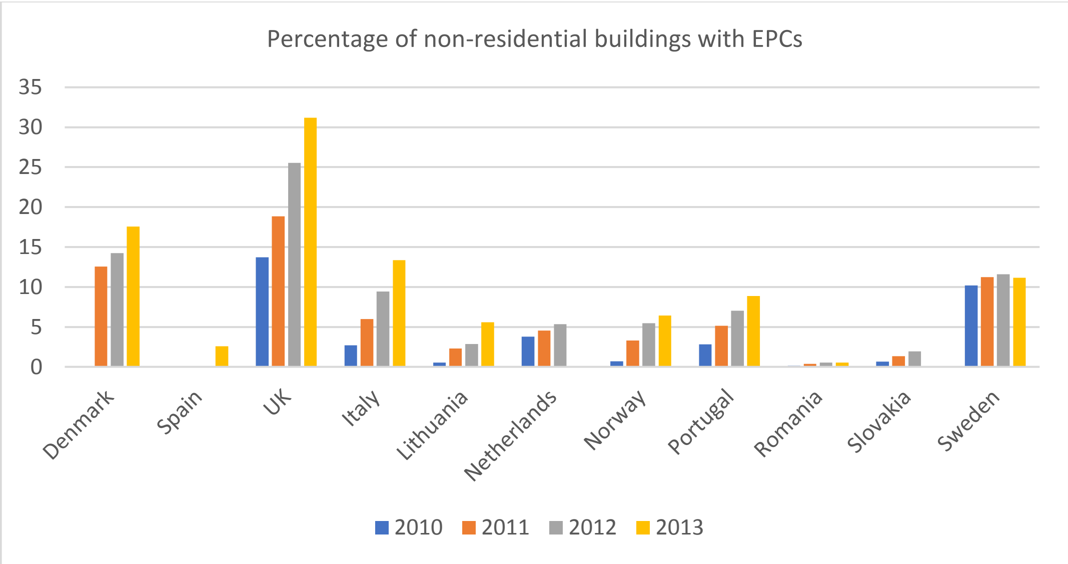

Figure 21. Percentage of non-residential buildings with EPCs for countries in the EU. Source (ZEBRA2020, 2016)

Based on recorded data for a number of EU countries, accumulated under the ZEBRA2020 project, the share of buildings registered in the EPC databases varies somewhat across Europe, ranging from less than 5% up to approximately 30% (see Figure 21). UK at the moment shows the highest EPC percentage, as well as the greatest rate of acquisition during the years 2010-2013, a fact that could be associated with an increased renovation potential.

The exact form of the EPC, the associated performance rating system (i.e. energy level vs. continuous scale) and types of recommendations (i.e. standardised vs. tailor-made) is up to the Member States to decide. Most countries have adopted an energy label scale, typically from A to D or G, although actual efficiency numbers for the same levels can differ significantly among countries (ZEBRA2020, 2016). Figure 22 shows the distribution of different EPC classes for non-residential buildings in various EU countries, while Figure 23 shows the same distribution only for newly constructed buildings. We notice a significant differentiation between newly constructed and existing buildings with EPCs. In the latter category, a significant proportion of the buildings is highly inefficient according to the EPCs, and could indicate a potential for energy efficiency renovation and retrofitting measures.

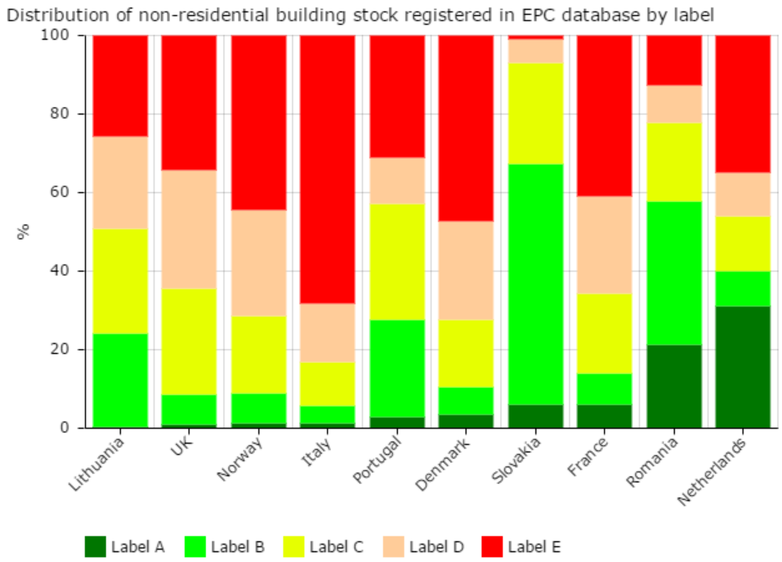

Figure 22. Distribution of EPC classes in the non-residential sector for 2013. Source (ZEBRA2020, 2016)

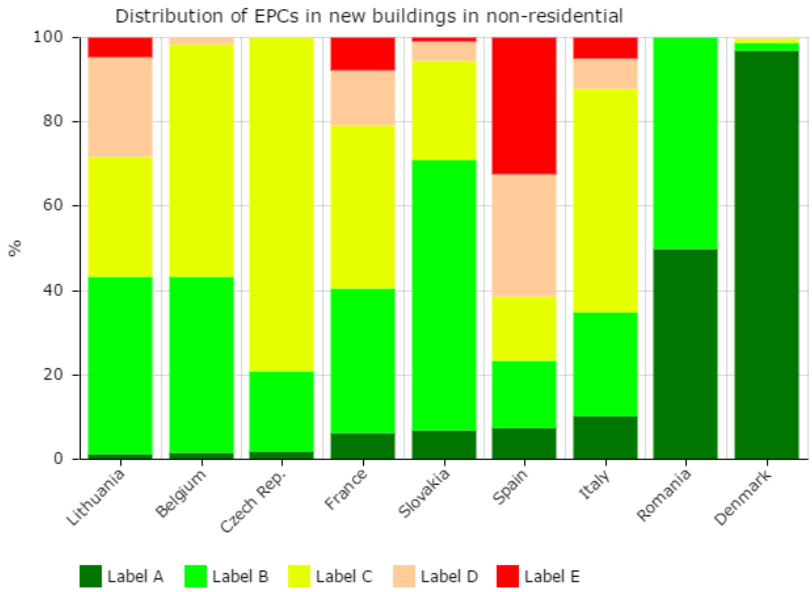

Figure 23. Distribution of EPC classes in the newly constructed non-residential buildings for 2013. Source (ZEBRA2020, 2016)

5 Regulations and Obligations For Energy Efficiency and Demand Response in Europe

In this section, we present an overview of the regulatory status in Europe regarding energy efficiency and demand response in buildings, as well as extracted obligations on EE and DR measures from the respective directives and reports. Such review is vital for the deployment of the proposed dual EE/DR template. EU's main regulatory prescription texts on energy consumption and energy markets are the 2010 Energy Performance of Buildings Directive (EPBD), the 2012 Energy Efficiency Directive (EED) and the 2009 Renewable Energy Directive, along with their respective recasts.

5.1 Energy Performance of Buildings Directive

The Energy Performance of Buildings is European Union's Directive on energy efficiency and characterization of buildings (EPBD, 2010/31/EU). The EPBD introduced the requirement of implementing energy efficiency measures in connection to major renovations to encourage more ambitious renovation activities. The EPBD also asked EU Member States to introduce cost-optimal energy performance requirements for new buildings, as well as for renovation activities, and push for economic support instruments to stimulate the renovation of the existing building stock.

In 2016, the European Commission proposed a recast of the EPBD to help promote the use of smart technology in buildings and to streamline the existing rules, and published the EU Building Stock Observatory database to track the energy performance of buildings across Europe (EC, 2017).

In the following, we describe in more detail the definitions, targets and obligations prescribed in the original EPBD, the 2016 recast and tightly related EU reports.

By 2020, the EU must reduce its greenhouse gas emissions by at least 20%, increase the share of renewable energy to at least 20% of consumption, and achieve energy savings of 20% or more, compared to 1990 levels. By 2030, the targets are adjusted to 40% cut in greenhouse gas emissions 27% share of renewable energy consumption and 27% energy savings. The EPBD directly contributes to the proposed targets of increase in energy efficiency by 2020 and 2030, as well as the goal for 80-95% reduction in greenhouse gas emissions by 2050 (EC, 2011).

In the EPBD recast, it is mentioned that, from the current European building stock, 44% of the stock was constructed between 1945-1980, while 32% after 1980, and 24% before 1945. Owing to advances in technology and more stringent building codes, contemporary new buildings consume half as much energy as buildings from the 1980s. According to current estimates, the average rate of renovations is between 0.5% and 1.2% per year, at which pace only 40% of buildings will be renovated by 2050. This rate is not in accordance to the expected rate required for the attainment of the 2030 and 2050 energy efficiency requirements. As such, EPBD prescribes the increase of renovation rate for the existing stock to at least 2% annually (EPRS, 2016).

In Article 2 of the EPBD, the major renovation of a building is defined as follows: the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated or more than 25% of the surface of the building envelope undergoes renovation; Member States can choose which option to adopt. Furthermore, a NZEB renovation is one that leads to a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from RES, including energy from RES produced on-site or nearby.

A specific obligation of the EPBD is that all new buildings must be nearly zero energy buildings by 31 December 2020 (public buildings by 31 December 2018).

It is helpful to report here associated definitions given by the Building Performance Institute Europe (BPIE), regarding the various renovation types. BPIE provides a more detailed classification, including specific targets on energy savings and cost estimates:

- Minor renovations – 85% of the market: the implementation of 1 or 2 measures (e.g. a new boiler) resulting in a reduction in energy consumption of between 0% and 30% (with average costs of 60 Euro/m^2).
- Moderate renovations – 10%: involving 3-5 improvements (e.g. insulation of relevant parts of the dwelling plus a new boiler) resulting in energy reductions in the range of 30%-60% (with average costs of 140 Euro/m^2).
- Extensive renovations – 5%: in this approach, the renovation is viewed as a package of measures working together leading to an energy reduction of 60% - 90% (with average costs of 330 Euro/m^2).
- Almost Zero-Energy Building renovations - negligible: the replacement or upgrade of all elements which have a bearing on energy use, as well as the installation of renewable energy technologies in order to reduce energy consumption and carbon emission levels to close to zero (with average costs of 580 Euro/m^2).

During the course of the project, NOVICE will primarily focus on moderate retrofit scenarios, with deep renovations considered after the end of the project. Under the EPBD, exact specifications per country are not required for moderate renovations.EU countries must ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements. In Table 1 we present the existing NZEB requirements, both for new and existing buildings, which, by deduction, can give an idea on the expected energy performance benefits for moderate retrofits per country.

While most EU states have established minimum energy consumption requirements for NZEB buildings, the same cannot be said with regards to renovations of existing buildings. From countries that have done so, we observe that retrofitting requirements are either the same or slightly less strict, in comparison to the equivalent constraints for new buildings. It is interesting to notice that a limited number of countries, with Estonia being the primary example, have specified different minimum requirements for new buildings of various non-residential building types. In order of increasing minimum energy consumption, the building types are ranked as follows: schools, offices, public buildings, hotels restaurants and trade centres and finally hospitals.

The EPBD recast in 2016 further specifies that EU countries must establish inspection schemes and recommendations of technical building systems for non-residential buildings with total primary energy use of over 250 MWh. These include, among others, heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements. Furthermore, it is explicitly advised that high-efficiency alternative systems, such as (a) decentralised energy supply systems based on energy from renewable sources; (b) cogeneration; (c) district or block heating or cooling, particularly where it is based entirely or partially on energy from renewable sources and (d) heat pumps, should be considered and taken into account. At the same time, Member States should encourage the introduction of intelligent metering systems whenever a building is constructed or undergoes major renovation.

Finally, in relation to the increased focus on demand response and the move towards flexible resources, such as electric vehicles, EPBD states that Member States shall ensure that in all new non-residential buildings and in all existing non-residential buildings undergoing major renovation with more than ten parking spaces, at least one of every ten is to be equipped with a recharging point.

Table 1. Energy-based requirements defined by EU Member States for NZEB buildings. PE: primary energy; n/a: not available. Source (D'Agostino, Zangheri, & Castellazzi, 2017)

Country	Residential Buildings ($kWh/m^2/y$ or Energy Class)		Non-Residential Buildings ($kWh/m^2/y$ or Energy Class)	
	New	**Existing**	**New**	**Existing**
Austria	160	200	170	250
Belgium	45 (Brussels region) 30 (Flemish region) 60 (Walloon region)	~54	(95–2.5) *(V/S) (Brussels region) 40 (Flemish region) 60 (Walloon region)	~108
Bulgaria	~30–50	~40–60	~30–50	~40–60
Cyprus	100	100	125	125
Czech Republic	75%–80% PE	75%–80% PE	90% PE	90% PE
Germany	40% PE	55% PE	n/a	n/a
Denmark	20	20	25	25
Estonia	50 (detached house)	n/a n/a n/a n/a	100 (office buildings) 130 (hotels, restaurants) 120 (public buildings) 130 (shopping malls)	n/a n/a n/a n/a
	100 (apartment blocks)	n/a n/a n/a	90 (schools) 100 (day care centres) 270 (hospitals)	n/a n/a n/a
France	40–65	80 n/a	70 (offices without AC) 110 (offices with AC)	60% PE n/a
Croatia	33–41	n/a	n/a	n/a
Hungary	50–72	n/a	60–115	n/a
Ireland	45 (Energy load)	75–150	~60% PE	n/a
Italy	Class A1	Class A1	Class A1	Class A1
Latvia	95	95	95	95
Lithuania	Class A++	Class A++	Class A++	Class A++
Luxemburg	Class AAA	n/a	Class AAA	n/a
Malta	40	n/a	60	n/a
Netherlands	0	n/a	0	n/a
Poland	60–75	n/a	45–70–190	n/a
Romania	93–217	n/a	50–192	n/a
Spain	Class A	n/a	Class A	n/a
Sweden	30–75	n/a	30–105	n/a
Slovenia	45–50	70–90	70	100
Slovakia	32 (apartment buildings) 54 (family houses)	n/a n/a	60–96 (offices) 34 (schools)	n/a n/a
UK	~44	n/a	n/a	n/a

5.2 Energy Efficiency Directive

In 2012, the EU adopted Directive 2012/27/EU on Energy Efficiency (EED). This Directive establishes a common framework of measures for the promotion of efficiency measures within the EU, in order to ensure the achievement of the European Union's 2020 20% target on EE and to pave the way for further energy efficiency improvements beyond that date. The EED also prescribes rules designed to remove barriers in the energy market and overcome market failures that impede efficiency in the supply and use of energy. The directive complements the EPBD by encouraging ambitious renovations through the requirement for member states to establish strategies for the renovation of their national building stocks.

In particular, the directive details the following key rules and regulations.

The renovation rate of public buildings in Member States should annually be at least 3% of the total area of "heated and/or cooled buildings owned and occupied by their central government". This was to be applied from 1 January 2014 to buildings with a total useful floor area of more than 500m², and as of July 2015 for more than 250m² (EU, 2017a). In relation to public buildings, EED also states that EU governments should only purchase buildings which are highly energy efficient.

Under the EED, Member States must also ensure that energy suppliers and distributors increase their energy savings by 1.5% per year. The proposal for the amendment of EED in 2016 extends the same requirement beyond 2020, and describes the possibility to use both energy efficiency obligation schemes and alternative measures to achieve this target. Energy suppliers and distributors often achieve their 1.5% savings obligation by implementing energy efficiency measures in the homes of their individual customers.

Another important part of EED is related to Demand Response. In particular, the directive prescribes that member states will be allowed to use alternative means to achieve equivalent energy savings. In addition, Article 15.1 requires that network tariffs and regulations are adapted or changed, if necessary, in order to allow energy efficiency measures and services to be implemented. The above implicitly allows the development of DR participation in the energy market. The directive further prescribes that network tariffs and regulations should not prevent TSOs, DSOs or energy retailers, from offering measures to shift demand from peak to off-peak or measures inducing customers to reduce demand. Moreover, network tariffs must reflect the reductions in network costs brought by DR. Finally, article 15.8 contains dedicated provisions for effective relationships between different stakeholders, allowing for the engagement of the various actors, and enabling the participation of DR flexibility in wholesale and retail markets, alongside primary energy supply. In meeting requirements for balancing and ancillary services, TSOs and DSOs must treat DR providers, including aggregators, in a non-discriminatory way.

5.3 Renewable Energy Directive

The directive 2009/28/EC on the promotion of the use of energy from renewable sources, hereafter referred to as he Renewable Energy Directive (RED), establishes an overall policy for the production and promotion of energy from renewable sources in the EU.

The main goal prescribed in the RED requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020. This objective is to be achieved through the attainment of individual national targets. In particular, the directive included a list with targets for shares of renewable energy for all Member States (see Table 2 for the respective list, updated in 2016), which are further obliged to provide annually reports on these targets and the general course of their renewable energy policy in national renewable energy action plans. The RED also includes a requirement on having at least 10% of their transport fuels come from renewable sources by 2020.

Table 2. National overall targets for the share of energy from renewable sources in gross final consumption of energy in 2020. Source: (EU, 2016a)

	Share of energy from renewable sources in gross final consumption of energy, 2005 (S2005)	Target for share of energy from renewable sources in gross final consumption of energy, 2020 (S2020)
Belgium	2,2 %	**13%**
Bulgaria	9,4 %	**16%**
Czech Republic	6,1 %	**13%**
Denmark	17,0 %	**30%**
Germany	5,8 %	**18%**
Estonia	18,0 %	**25%**
Ireland	3,1 %	**16%**
Greece	6,9 %	**18%**
Spain	8,7 %	**20%**
France	10,3 %	**23%**
Croatia	12,6%	**20%**
Italy	5,2 %	**17%**
Cyprus	2,9 %	**13%**
Latvia	32,6 %	**40%**
Lithuania	15,0 %	**23%**
Luxembourg	0,9 %	**11%**
Hungary	4,3 %	**13%**
Malta	0,0 %	**10%**
Netherlands	2,4 %	**14%**
Austria	23,3 %	**34%**
Poland	7,2 %	**15%**
Portugal	20,5 %	**31%**
Romania	17,8 %	**24%**
Slovenia	16,0 %	**25%**
Slovak Republic	6,7 %	**14%**
Finland	28,5 %	**38%**
Sweden	39,8 %	**49%**
United Kingdom	1,3 %	**15%**

From Table 2 we notice that, in terms of overall RES integration, NE European countries are at the forefront, while on the other side, SW countries lag considerably behind. Central and Eastern Europe presents a more diverse image, with other countries having high integration, and others very low.

Overall, the promotion of energy use from renewable sources have so far been effective, leading to an increase in the share of renewables from 10.4% in 2007 to 17% in 2015 (EU, 2017b). Regarding electricity, in particular, in 2011, renewables generated 21.7% of the EU's electricity; three years later, this figure has reached 27.5% and is expected to go up to 50% by 2030.

Nevertheless, EU energy projections indicate that if no new policies are put in place, only 24.3% of energy will be due to renewable sources in 2030. This level would be below the binding target for at least 27% renewable energy, agreed by the European Council in 2015. As a result, On February 2017, the Commission published a proposal for a revised Renewable Energy Directive so as to ensure that the EU target of at least 27% renewables in the final energy consumption by 2030 will be met. A number of key points and/or obligations mentioned in the revised text are the following:

- The new framework sets out the binding target of at least 27% for the share of renewable energy consumed in the EU in 2030.
- In order to facilitate the penetration of renewable energy in the heating and cooling sector, each Member State shall endeavour to increase the share of renewable energy supplied for heating and cooling by at least 1 percentage point (pp) every year, expressed in terms of national share of final energy consumption.
- With effect from 1 January 2021, Member States shall require fuel suppliers to include a minimum share of energy from advanced biofuels and other biofuels and biogas. The minimum share shall be at least equal to 1.5% in 2021, increasing up to at least 6.8% in 2030.
- Member States shall open support for electricity generated from renewable sources to generators located in other Member States under the conditions.
- RED considers heating and cooling to be key sectors in accelerating the decarbonisation of the energy system. It is projected that around 40% of the renewable energy consumption by 2030 should come from renewable heating and cooling.
- The RED recognizes district heating and cooling systems as having high potential with respect to decarbonisation through increased energy efficiency and renewable energy deployment.

Within the context of renovation projects and NOVICE’s objectives in particular, RED constitutes a useful point of reference with respect to quantifiable energy efficiency targets from renewable sources. Furthermore, it can assist in the identification of suitable retrofits and countries which are more receptive of such measures.

6 ANALYSING THE EUROPEAN ENERGY PERFORMANCE CONTRACTING AND DEMAND RESPONSE MARKETS

6.1 CURRENT MARKET STATUS FOR ENERGY PERFORMANCE CONTRACTING AND DEMAND RESPONSE IN EU

In order to uncover the renovation potential currently existing in European countries, it is important to establish the market status regarding both Energy Performance Contracting, implemented through Energy Service Companies (ESCOs), and demand flexibility. In this section, we elaborate on the above issues and further provide an overview of the economic instruments which are most commonly employed for the funding of building renovation projects in Europe.

6.1.1 Energy Performance Contracting and ESCO Market Status in EU

An Energy Performance Contract is a contractual arrangement between the beneficiary/end-user, and the provider, most commonly an ESCO, of the implementation of an energy efficiency improvement project, for which investments are paid for in relation to an agreed level of energy efficiency improvement. Under such a contract, an ESCO develops, installs maintains and monitors the equipment, and uses the energy cost savings to repay upfront investment costs. Energy Performance Contracting is designed so that the value of the energy savings is split between the customer and the ESCO throughout the contract term. Overall, Energy Performance Contracting offers a holistic approach to renovations, including financing, carrying out the works and energy management.

Two types of contracting models can be identified:

i. Guaranteed savings model, whereby the ESCO guarantees the savings, but the building owner finances the investments.
ii. Shared savings model, whereby the ESCO finances and guarantees the savings, and recoups most of the cost savings in order to repay the upfront costs.

The Energy Performance Contracting models are intuitively attractive because they use the money saved through investments in energy efficiency to pay off the cost of the initial capital investment. Nevertheless, some drawbacks can be observed. It is perceived that to date, ESCOs and Energy Performance Contracts have been mostly applied to improving the energy efficiency of technical systems such as lighting and HVAC systems, and in energy supply solutions such as Combined Heat & Power (CHP), which have relatively short payback periods, compared with building envelope investments, and thus have not been applied to very deep renovation projects. In specific, investment in energy-efficient products is approximately evenly spread across three major categories: appliances, HVAC and lighting. Energy-efficient space cooling, accounts for the largest share of investment in the HVAC category.

Figure 24 shows the size of the market of ESCOs in EU Member States, as recorded in a Joint Research Centre report on ESCO market status (JRC, 2014). There is large diversity in the ESCO markets in Europe. While some countries have many ESCOs (e.g., over 500 in Germany, over 300 in France, 80 in Italy), most have typically less than 20 ESCOs (14 countries each have 10 or less). It is fairly easy to observe, from the map, that most developed markets are in the central and north-west European regions. On average, JRC reports a steady growth of ESCO markets compared to 2010, driven by regulatory frameworks, financial incentives and increasing awareness.

In terms of types of buildings that are included in Energy Performance Contracting projects up to now, it come as no surprise that public buildings, including administration facilities, hospitals and schools in a few countries are at the forefront. Regarding commercial buildings, the ESCO market is mostly developed in buildings such as hotels and large retail facilities. Office buildings have shown decreased potential so far, due to the split incentive problem (Split incentives occur when those responsible for paying energy bills, a.k.a. the tenants, are not the same entity as those making the capital investment decisions, a.k.a. building owner), as well as the 'incompatibility' between the long-term nature of an ESCO project and the more volatile nature of companies that own office buildings.

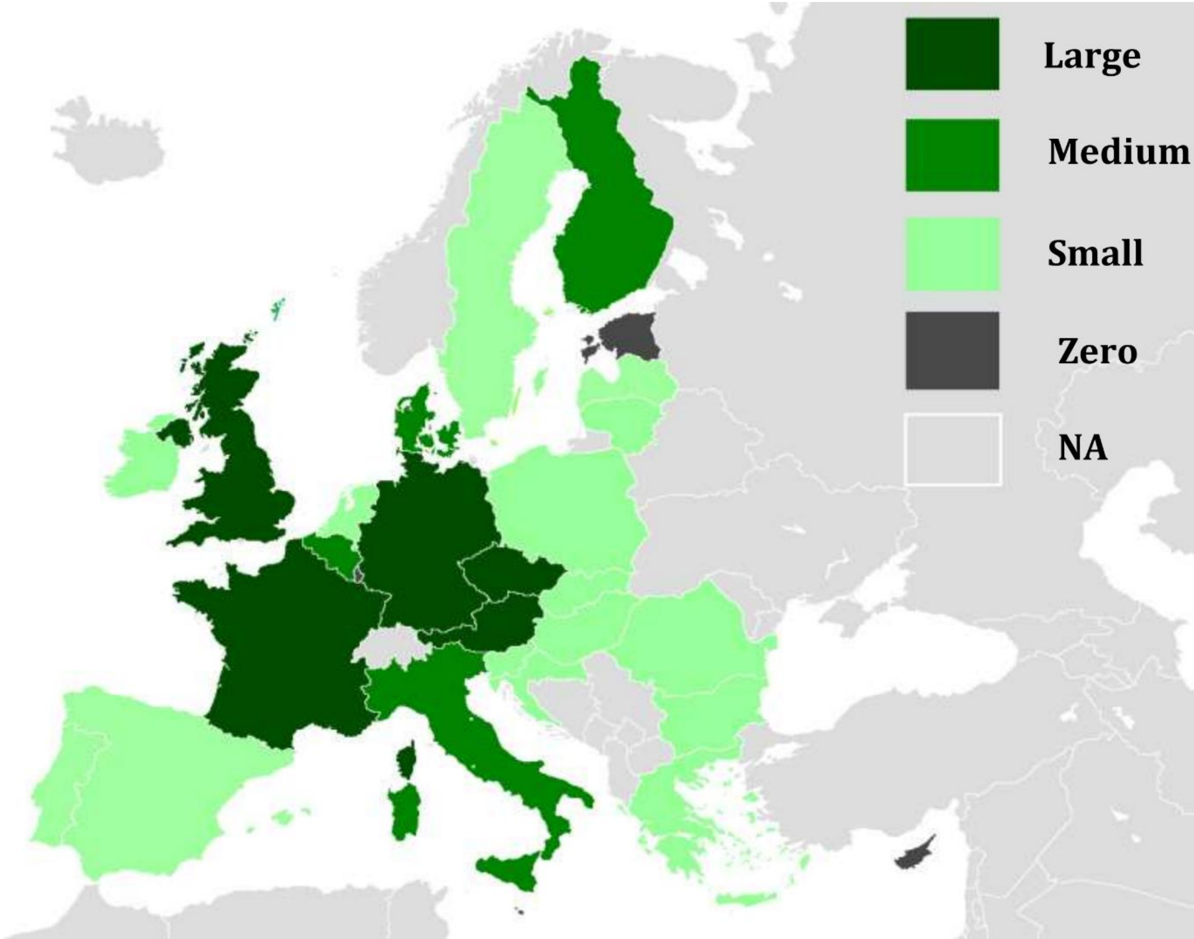

Figure 24. The size of the ESCO market across the EU. Source (JRC, 2014)

6.1.2 Demand Response Status in EU

In continuation of the description regarding the DR enabling regulations imposed by the European Commission, we include here an overview of the current regulatory status in various European countries, based on the work of the Smart Energy Demand Coalition (SEDC).

The level of implementation of the EED directive in the different EU countries, and the inclusion of demand flexibility in the energy markets, is highly varied, both in terms of how many instructions have been implemented, and with respect to technical details. Nevertheless, an overall increase of interest in enabling DR was observed, compared to a previous study by SEDC in 2014, in most of the countries. Figure 25 presents the map of explicit DR development in Europe, according to the most recent SEDC report (SEDC, 2017).

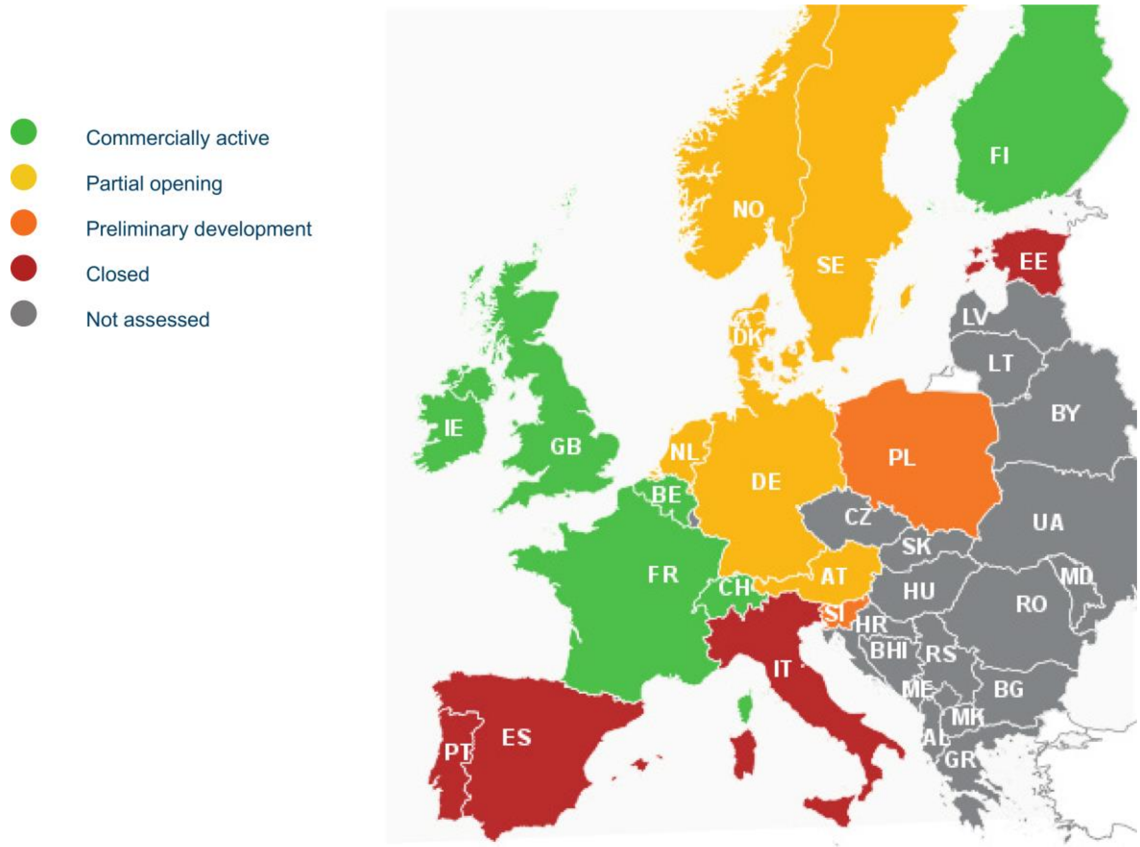

Figure 25. Explicit Demand Response Development Map in Europe. Source (SEDC, 2017)

In more detail, the key findings of the study can be summarized in the following:

- The European countries providing the best conditions for the inclusion of DR flexibility in the markets are Switzerland, France, Belgium, Finland, Great Britain, and Ireland, although issues are still present in these countries as well.
- Switzerland and France have enabled standardized roles for market participants and independent aggregation, but problems persist in terms of the establishment of a baseline methodology.
- Belgium is expected to soon establish the legislation for the independent aggregation of demand flexibility. Issues pertain the measurement and verification procedures.
- In Ireland, within 2018, DR flexibility will be able to participate in a number of energy markets, specifically the balancing and wholesale markets, as well as a new Capacity Remuneration Mechanism.
- United Kingdom allows demand-side participation in a number of energy markets. Furthermore, independent aggregators can now access consumers directly in order to sell aggregated flexibility in the ancillary capacity markets. Problems are again located in measurement and verification procedures.
- Finland has enabled independent aggregation and its participation in ancillary services, and has advanced provisions for measurement and verification.
- Austria, Denmark, Germany, Netherlands, Norway, and Sweden still have certain regulatory barriers which hinder actual participation of demand-side resources in the market. While a number of energy markets are open to DR, technical requirements, lack of clear roles and responsibilities, and unequal competition with traditional supply sources, make participation

extremely difficult. In these countries, efforts are being made to initiate the processes for identifying solutions to the problems.

- Slovenia and Poland have been stagnant during the past years with regard to incorporation of regulatory changes for DR.
- Italy is starting to take measures for enabling DR, but large part of the market is still closed and a complete regulatory framework is still missing.
- Spain, Portugal, and Estonia have not yet allowed demand flexibility to participated as a resource in any of their energy markets or it is not yet viable due to regulation.

In summary, we notice that, from the assessed states, southern countries are the ones lagging mostly behind in opening their energy markets to demand flexibility. NW and SW Europe, as well as parts of the central Europe are more advanced in that respect, although problems still remain. The issue most countries are facing at the moment, in order to proceed with the further integration of DR in the energy markets, is associates with measurement, baselining and verification procedures.

6.2 Financing Instruments for Building Energy Renovations in EU

Article 10 of the EPBD states that "In view of the importance of providing appropriate financing and other instruments to catalyse the energy performance of buildings and the transition to nearly zero-energy buildings, Member States shall take appropriate steps to consider the most relevant instruments in the light of national circumstances". Complementary to that, EED, in its Article 20, mentions "Member States shall facilitate the establishment of financing facilities, or use of existing ones, for energy efficiency improvement measures to maximise the benefits of multiple streams of financing. The Commission shall, where appropriate, directly or via the European financial institutions, assist Member States in setting up financing facilities and technical support schemes with the aim of increasing energy efficiency in different sectors" (EC, 2017).

Within this perspective, a range of financial support programmes have been provided by the EU and national governments to encourage improvements of the energy performance of buildings. The majority of financing for energy efficiency projects in buildings though comes from the private sector and includes building owners, tenants and commercial banks. A recent Joint Research Centre (JRC) report (Economidou and Bertoldi, 2014) provides a detailed view of the types of financing instruments for energy efficiency renovation investments in buildings, which is summarized here.

Overall, four major types of economic instruments were recognized as the primary means of funding for EE renovation projects. These are the following:

- Grants and subsidies:
  Grants and subsidies are generally provided by EU and national governments, in cases that the optimal level of energy efficient investments cannot be supported by the private market alone. Nevertheless, direct investment subsidies rely on limited resources and cannot offer a sustainable solution nor support large market uptake programs.
- Loans:
  Loans are generally a more sustainable means of financing EE projects, in comparison to grant or subsidy schemes, since they provide direct access to capital. This is important, especially considering the high upfront costs associates with deep renovation projects.
- Tax incentives:
  Tax incentives are considered a popular instrument due to the fact that they can be less costly than subsidies or grants. They may work well alongside a taxation scheme, where the tax loss attributed to the tax incentive scheme is offset by revenues from taxation for energy intensive

industries, and their performance is correlated with the rate of tax collection. They can take various forms, such as tax exemptions, income tax or VAT reduction.

- Energy efficiency obligations and white certificates:
  Energy efficiency obligations and white certificates are obligations for EE measures placed to energy companies by governments. Companies are required to prove that they have undertaken activities that promote or fund energy efficiency improvements in the premises of end use customers.

Figure 26 and Figure 27 show the percentage distribution of the different financing instruments for commercial and public buildings respectively in the EU. Grants and subsidies assume by far the largest share not only in the case of public buildings, but also for commercial facilities. Loans are the second most employed way of financing, with higher percentage in the commercial sector. Energy efficiency obligations and tax incentives account for 20% and 10% of the funding in commercial and public sectors respectively.

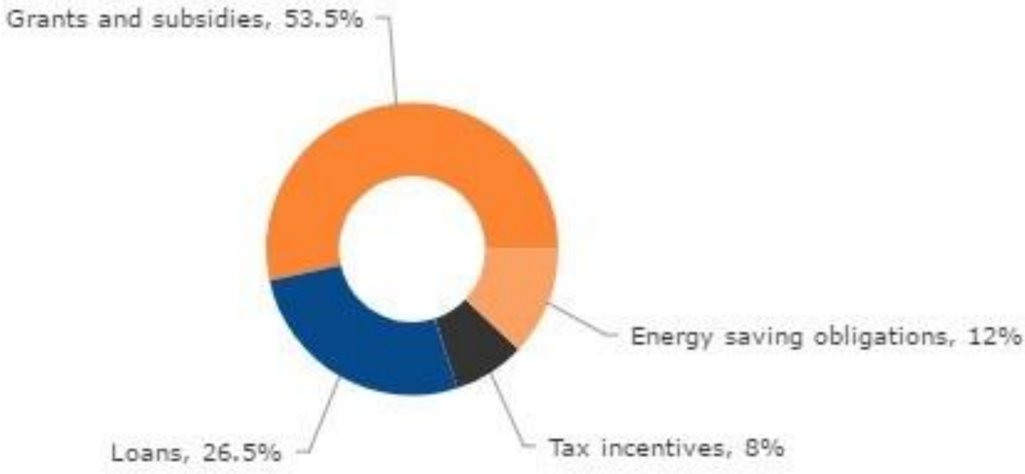

Figure 26. Ratio of economic instruments for EE investments in Commercial Buildings in EU countries. Source (EC, 2017; Economidou & Bertoldi, 2014)

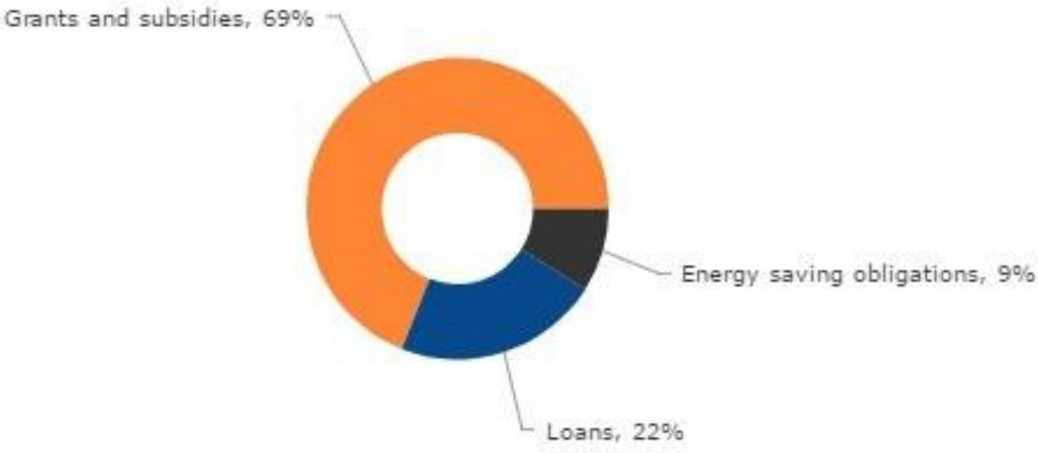

Figure 27. Ratio of economic instruments for EE investments in Public Buildings in EU countries. Source (EC, 2017; Economidou & Bertoldi, 2014)

A large range of stakeholders are targeted by current instruments, highlighting the complex chain of actors involved in building renovation. Figure 28 shows the percentages of different measures that are suitable for different groups. These ranged from households, housing associations to public authorities, commercial companies, ESCOs and many others.

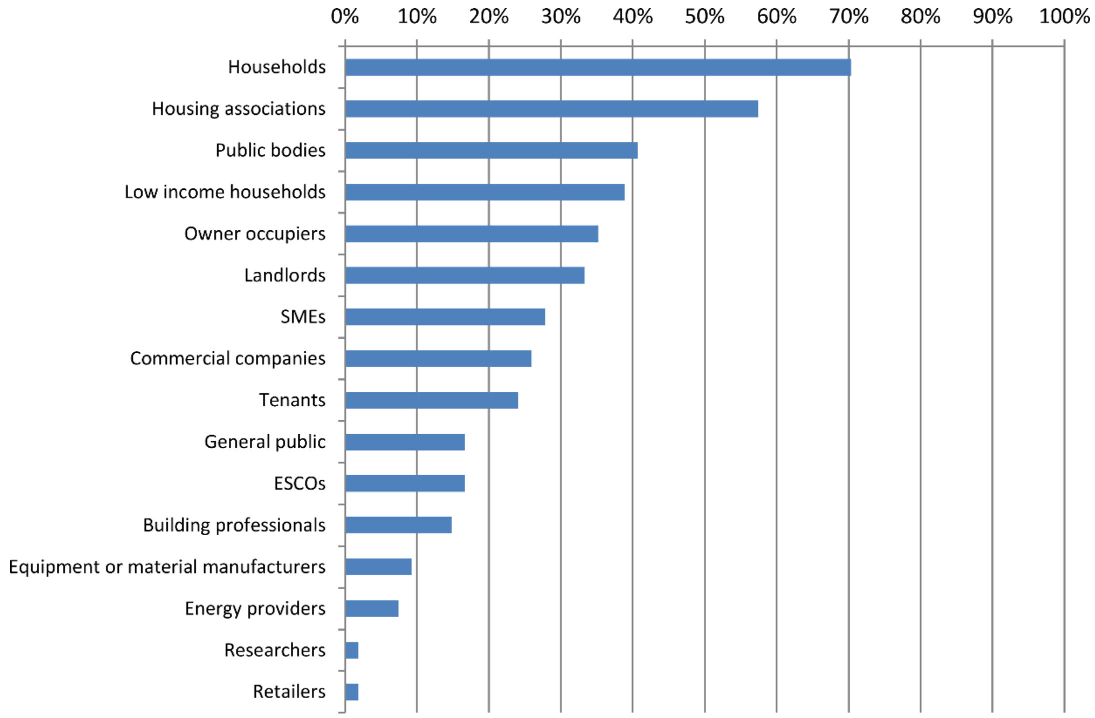

Figure 28. Targeted groups and percentage of financial measures suitable for each stakeholder. Source (Economidou & Bertoldi, 2014)

In terms of individual countries, Figure 29 summarizes the types of financial instruments that were operational in 2013 in each member state. Many countries choose to deploy a combination of different economic instruments. Grants and subsidies are active in the majority of EU countries, followed, in order, by loads, tax incentives and lastly energy efficiency obligations.

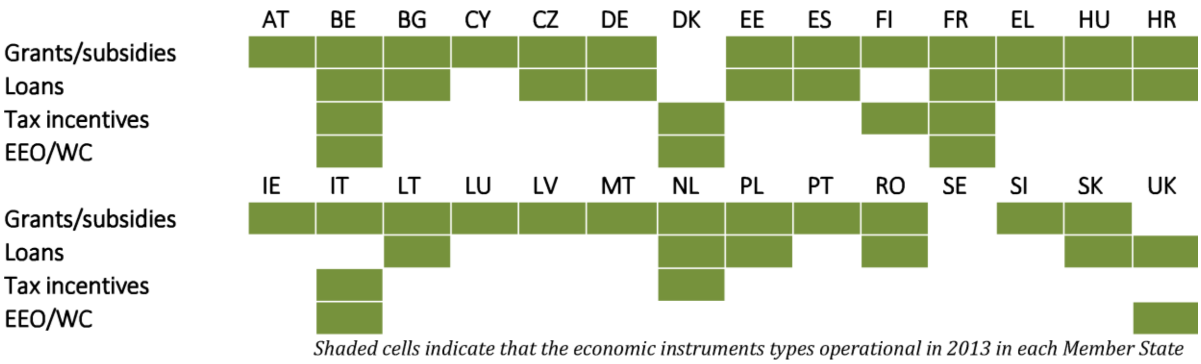

Figure 29. Economic instruments for energy renovations in the EU countries during 2013. Source (Economidou & Bertoldi, 2014)

7 Potential and Operational Constraints for Energy Efficiency and Demand Response in Non-Residential Buildings

Energy savings and active participation in the energy market can be profitable for businesses. Nevertheless, the combined benefits of these two actions are still actively explored (see for example Task 17 of the Demand-Side Management Technology Collaboration Program from the International Energy Association (IEA, 2017a)) and further understanding is needed to take full advantage of them.

A significant aspect relating to the EE and DR potential is the level of automation associated with demand-side flexibility. For large non-residential buildings, such automation can take the form of a centralized control for various loads by the building manager, such as HVAC and lighting, resulting in reduced energy consumption. With the advent of explicit DR, the buildings' demand flexibility can be integrated further with the smart grid, allowing a more centralized control of electricity demand and supply.

The second point of interest regards user behavioural patterns and actions. Behavioural interventions and modifications can be a very efficient and effective source of energy savings. Complementary and additionally to that, user experience, acceptance and behaviour is a cornerstone for enabling and successfully maintaining DR programs.

Thirdly, as outlined in the EED, renovation of buildings should/must be accompanied by certain instrumentation updates, most importantly smart meters, and energy efficiency measures, e.g. in the cooling/heating installation, although alternative means to achieve equivalent energy savings can be adopted, such as demand response. From these observations, it becomes clear that during renovation actions, the objectives of reducing energy consumption and enabling demand-side management can be easily combined to further enhance the buildings energy consumption performance.

In the following, we discuss the potential for EE and DR for different types of buildings, based on the adopted typology, covering various aspects, namely automated demand-side management, behavioural-based interventions and building renovation activities. Additionally, when evaluating integration of demand-side flexibility in commercial and tertiary buildings, it is essential to take into consideration the various operational constraints related with the particular use of the building, so as to provide tailored solutions that are non-intrusive and do not affect the end-user's business. In this subsection, we provide an overview of the operational constraints that are most likely to exist in the different non-residential building types.

7.1 Offices

Office spaces are good candidates both for energy efficiency and demand response programs, although certain characteristics must be taken into consideration, primarily regarding time and type of occupancy. As discussed in detail in section 4.5, energy in offices is used predominantly for the following purposes: space heating and cooling, lighting and office equipment and appliances. One distinctive feature is that, compared to other building types, equipment has a significant proportion of the overall energy consumption. Office buildings can thus participate in load shifting and peak load shedding schemes in many ways, such as by adjusting HVAC set points, reducing lighting, and turning off plug loads.

Automation potential is particularly high for office areas, since most of them make use of centralized control, through a building energy management system (BEMS), for their heating and cooling loads. BEMS can facilitate sensors and controllers to monitor and optimize temperature, pressure, humidity, and flow rates while minimizing the energy use of fans, pumps, Heat, Ventilation and Air-Conditioning (HVAC) equipment and thermostats. Furthermore, special-purpose rooms are commonly in place, such as cafeterias and recreational facilities, in which lighting and plug loads can be curtailed without particular inconvenience. In more detail, automated response to DR events can be handled using several strategies (OUC, 2017a): (i) Adjusting thermostat and HVAC set points. During a DR event, thermostats can be adjusted to decrease electricity demand, (ii) Decreasing ventilation fan speeds. Office buildings often have ventilation systems with variable-frequency drives and fan speeds can be slowed during DR events, (iii) Precooling. Office buildings are good candidates for precooling, a strategy in which the building is over-cooled in advance of a DR event—usually overnight or during the early morning, (iv) Curtailing lighting. Lighting can be turned off in special-purpose rooms such as cafeterias, auditoriums, and recreational facilities, as well as in selected hallways and other areas during DR events. (v) Switching to on-site generation. Large office buildings are also suited to the deployment of renewable energy resources, which can particularly help to alleviate demand during peak demand times.

Behaviour modification can also provide energy benefits in offices. This aspect is mainly related to energy efficiency measures, and not implicit load control, since during working hours, equipment flexibility is usually low. Energy savings can be achieved by adopting a number of habits, such as utilizing only the necessary amount of equipment, and turning appliances off when leaving the office.

On the matter of renovation potential, large office buildings have good potential, since significant trimming of energy costs can be achieved for the owner, whilst boosting the company environmental profile. Nevertheless, as noticed beforehand, the somewhat volatile nature of office businesses has so far led Energy Service Companies to be more tentative with regards to office renovations, compared to other types of buildings.

Regarding operational constraints for DR, occupancy conditions, patterns and load requirements should be taken into consideration, since DR events could inherently affect business operation. Office buildings tend to have highest occupancy from early morning through late evening, with peak electricity demands coinciding with utility peaks on summer afternoons, as HVAC use increases. Indoor air quality and comfort requirements are also in place and must be taken into consideration. Furthermore, office occupants tend to remain in the same location for relatively long periods of time, as such, they are prone to noticing and being inconvenienced by alterations in the environment, such as light dimming and temperature variation. Finally, essential equipment for the office's operation should be excluded from direct load control.

In order to provide a better view on the EE and DR potential for renovation projects in office buildings, we present below a number of example office renovation projects.

Under the Total Concept project, which aims to demonstrate large scale energy performance improvements in existing non-residential buildings, a number of pilot office buildings have been renovated (Concept, n.d.). Lyngby Port in Denmark is an office building in portfolio of property company Nordea Ejendomme. The building was built in 1992 and divided into 3 building segments. The building consisted of cell offices grouped in modules. Total measured energy use before renovations was 124 kWh/m^2 per year (including tenants' electricity). Due to planned tenant adjustments of indoor climate and increase of number of occupants, the energy use of the building was estimated to increase to about 131 kWh/m^2 per year. The latter number was set as a baseline for energy efficiency measures. The proposed action package contained the following energy saving measures:

1. Conversion of natural gas boilers to district heating.
2. Replacing existing cooling machines.
3. Isolating ventilation ducts in the shafts.
4. Replacing fans in ventilation units.
5. Optimization of the BEMS system, including heating, lighting, ventilation and solar shading.
6. Photovoltaic Panels.
7. Replacing existing windows and solar shading.

The renovation was completed in 2015. The estimated energy savings, achieving the set goals, were 20% for heating and 23% for electricity compared to the baseline. The internal rate of return of the action package was approximately 5%.

Another building renovated under the same project is The Högsbo property, in Gothenburg, Sweden, which consists of two office buildings divided into four building sections. Total heated area of the buildings is 14,543m^2. Apart from office areas, the property also included a lunch restaurant and an underground garage. The main objective of the renovation in the Högsbo property was to incorporate energy performance improvements for a general upgrade of the building. Total measured energy use before renovations was 121 kWh/m^2 per year (including tenants' electricity). This rather low energy use, compared to other similar office buildings in Sweden, was justified by the relatively high vacancy level in the buildings and low occupancy rate in the used premises. The energy use of the building was estimated to increase to about 128 kWh/m2 per year. This was set as the baseline for energy efficiency measures, which consisted of:

1. Replacement of air-handling units in two sections of the building.
2. Replacement of thermostats and hydronic balancing of the heating systems in two sections.
3. Installation of new energy efficient pumps with pressure control in the heating system of one section.
4. Replacement of the chiller in two sections with more efficient equipment.
5. Installation of VAV-dampers for two building zones.

The energy savings of performed retrofits, completed in 2015, were approximately 14%, compared to the baseline. The internal rate of return of the action package was 5.5%.

A case study on implementation of a peak reduction DR project is the United Airlines world headquarters office building in Chicago, USA (CUE, 2012). The building is a 50-storey, 960,000 SF office facility. Optimized control sequences were developed, with the goal of providing a solution that would require little capital investment yet achieve cost savings goals for the building.

The developed platform integrated weather forecasts, energy prices, and the building's operational data and applied algorithms to determine how to move load throughout the day. The dynamically calculated zone temperature setpoints were transmitted to the local building automation system, where control sequences were initiated to meet these new setpoints. These setpoints were updated throughout the day to adjust for changes in intra-day weather or energy market forecasts. Although the system was fully automated, building operators maintained the ability to manually adjust zone temperature setpoints, change occupancy schedules, and control all aspects of their HVAC systems.

The technology was reported to meet the predefined objectives of reducing peak demand costs by 30% and reducing daily on-peak energy consumption by up to 30%. Figure 30 illustrates the achieved peak reduction in electricity consumption for September 2010, compared to the same month's consumption in 2009.

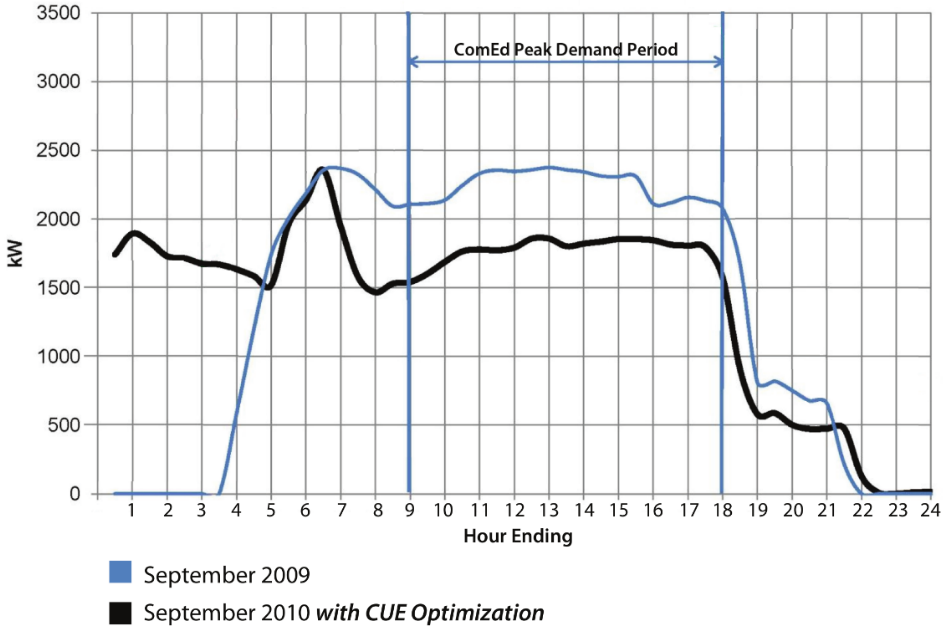

Figure 30. United Building Case Study – Electricity Peak Reduction graph for a period of one month. Source (CUE, 2012)

7.2 Educational Facilities

Educational buildings utilize energy mostly for heating purposes, as highlighted in section 4.5, although the rising role that Information and Communication Technologies (ICT) play in both educational and research activities has resulted in increased energy consumption for appliances in universities over the last few years. Occupancy tends to be higher in the morning times, up to early evening.

Automated demand side flexibility potential in schools and universities can be significant, both because of the current wastage of energy (e.g. computers left open overnight, open lights during the day), as well as due to the fact that educational buildings, even of moderate size, tend to have a building manager on site, that can implement and supervise the system. Due to their size, educational facilities, especially universities, should be good candidates for time-of-use and peak shedding programs.

It is important to mention though that implementation of EE and DR programs in educational premises still seems to be problematic, primarily due to the high bureaucracy and complicated hierarchy of the organizations, which include several administrative layers to deal with, large amounts of students, as well as teaching and research staff. The fact remains that decreasing costs due to energy savings are not felt directly at the faculty level, while, on the other side, external interventions on loads do, resulting in low incentives for abortion of such measures from the end users. Consequently, change towards more sustainable practices, especially when affecting these groups is not always easy.

The same observation can be made with regards to renovation and behavioural modification. A report by the International Energy Agency (IEA, 2017b), describing recent case studies performed in the Utrecht and Cambridge universities further ascertained this fact. Proposed behavioural modifications, aiming at ICT-related energy conservation measures, showed high potential, but faced significant bureaucratic and miscommunication issues, resulting in insufficient adoption of the measures (IEA, 2017b).

Performed operations within educational facilities can be generally divided into either research or teaching activities. In the former case, buildings present very similar load and occupancy profiles to offices, leading to the same operational requirements as mentioned above. For teaching purposes, constraints are mainly identified in the lighting, ventilation and heating systems.

Some examples of educational building renovation projects are detailed below.

In the Total Concept project, a case of renovation was The Pärnu Koidula high school building, in Estonia, which was built in 1978. The school has a total heated area of 8,184 m2, and includes a classroom building, a sports hall, a wrestling hall and a swimming pool. Renovation was targeted towards just the classroom building. Measured energy use was 176 kWh/m² per year, and due to new ventilation rates, the energy use of the building was estimated to increase to about 199 kWh/m² per year, which was set as the baseline consumption. Implemented measures included:

1. Better heat recovery.
2. District heating as a heat source for ventilation.
3. New heating system.
4. Lower Specific Fan Power.
5. Insulation of the building envelope.
6. Energy efficient lighting.

As of today, all of the proposed measures were carried out. Energy consumption measurement showed 46% of total energy savings, compared to the baseline, with actual profitability of the retrofit package being about 6.7%.

Another example of deep retrofit, this time, is the renovation of Aiken Centre at the university of Vermont, USA. The renovation project was kicked off as a national competition, seeking a design that embodied the mission of the school of environment and natural resources to exemplify responsible use of natural resources, develop an interactive living building, and inspire similar future actions. The Aiken Centre houses the University's Rubenstein School of the Environment and Natural Resources (RSENR), including 600 undergraduates, 130 full and part-time Masters and Ph.D. students, 40 full-time faculty members, and 30 research and administrative staff.

The project had a total cost of $8,100,000, with 37,400 Square Feet (SF) renovated and 2,600 SF newly constructed, and was completed in 2013. The main energy efficient measures included the following:

1. A net-metered 71 kW PV system located on U.S. Forest Service land nearby, which produced 110,329kWh in 2012, which is above 25% of the projected building use.
2. The building received a full face-lift, including large windows, which allowed daylight into the previously dark building, offering naturally lit classrooms, offices, and gathering areas.
3. The building envelope was significantly improved with added insulation and moisture control.

The payback period at 2% fuel escalation, was calculated to be 13 years with a 6.6% return on investment. The Aiken project is expected to achieve a 63% reduction in energy consumption over the existing building, reducing the total building load from 89 kBtu/SF per year to 33 kBtu/SF per year, with the addition of air-conditioning. This reduction in energy consumption is attributable to the reconstruction of the building enclosure and a reduction in mechanical equipment size.

Finally, a case study on implementation of DR strategies for peak reduction in the Centre for Information Technology Research in the Interest of Society (CITRIS) Building at the University of California-Berkeley, was published in 2012 (Peffer et al., 2012). The building occupies 141,000 SF, including both private and open plan office space, a few classrooms, light laboratories, café, auditorium and a data centre. DR strategies were considered for the two installed chillers in the facility.

The peak load of the building during mild weather was reported to be approximately 1000 kilowatts. The building had a Siemens Energy Management and Control System (EMCS) and Siemens Apogee Building Automation System (BAS), as well as a lighting system in the open plan offices with tri-level dimming capabilities on a timed schedule. Private offices had Lutron wall switches with dimming ability and occupancy sensors.

Demand response algorithms for the HVAC system were developed from UC Berkeley, LBNL, and the Siemens Corporate Research, and primarily included reduction of minimum ventilation rate by 70% for short periods with air monitoring, turning off lights in daylit zones, dimming lights to 66% and 33% and allow user overrides. While tests were not completed at the time of publication, the authors reported expected peak reductions from the HVAC system of 75- 110kW, 14kW from lighting, 12kW from water heaters, and 12kW, which should be approximately 10% reduction over the peak demand.

7.3 Healthcare Facilities

Healthcare facilities are active 24 hours per day. An important aspect is that backup generators are commonly installed in such buildings, to guarantee the uninterrupted operation of critical loads, such as medical equipment. Energy efficiency can be improved through new technologies in cogeneration units and alternative fuel options. The existence of backup generation can also provide potential for DR services, where the hospital uses its backup generator to shift loads off the grid.

Automation strategies can be fairly straightforward to implement, since constraints are clear within healthcare buildings. Critical loads, including medical equipment, lighting and heating in operation and intensive care units must be guaranteed. Hospitals, though, are generally large facilities and significant load shedding can be offered by cutting back on noncritical loads, such as cafeteria and lounge lighting. Another point of interest, related to DR, is that hospitals need to routinely test their backup generation. Depending on the national legal requirements and framework conditions, testing procedures can be integrated in DR programs.

Behavioural modification in healthcare facilities can be challenging, especially with regards to patients and visitors. Informing the users of the building on the desirable actions, as well as training the personnel that are involved in the operation and maintenance of the building and its infrastructures can have a positive outcome (EPTA, 2007).

Renovation plans for healthcare facilities can be complicated, due to operational, economic and regulatory constraints. Nevertheless, upgrading or replacement of generator units can provide significant potential. Hospitals have one of the highest priorities in the power supply of public buildings, as uninterrupted power supply is essential in these facilities. For this reason, there are different national and international standards that provide the recommended practice for the design and operation of electric systems in healthcare facilities (Guillen-Garcia et al., 2017). Medical requirements necessitate strict control of the thermal environment and indoor air parameters, especially in operating theatres and treatment rooms. Furthermore, specialized medical equipment, sterilization, laundries and food preparation are also services generally inflexible to direct control (Morgenstern, Li, Raslan, Ruyssevelt, & Wright, 2016).

Cases of renovation projects on healthcare facilities from the literature are presented in the following.

An example of a small retrofit project with significant energy savings was reported by the BuildingIQ ESCO company, implemented in one building of the St. Vincent's Hospital, Australia, with area of 38,000m^2, designed for both outpatient and inpatient services (BuildingIQ, n.d.). The target was set to 5% savings of the HVAC energy usage.

The ESCO identified as key issues the overcooling of the facility, due to manual control over the HVAC equipment, and the underutilization of the thermal properties of the building. Adopted measures were thus limited to automation of HVAC control and update of the BEMS system, which were completed in 2013. Final energy consumption during the next year were measured to be 12% larger than the baseline consumption. More details on the achieved energy savings can be seen in Figure 31.

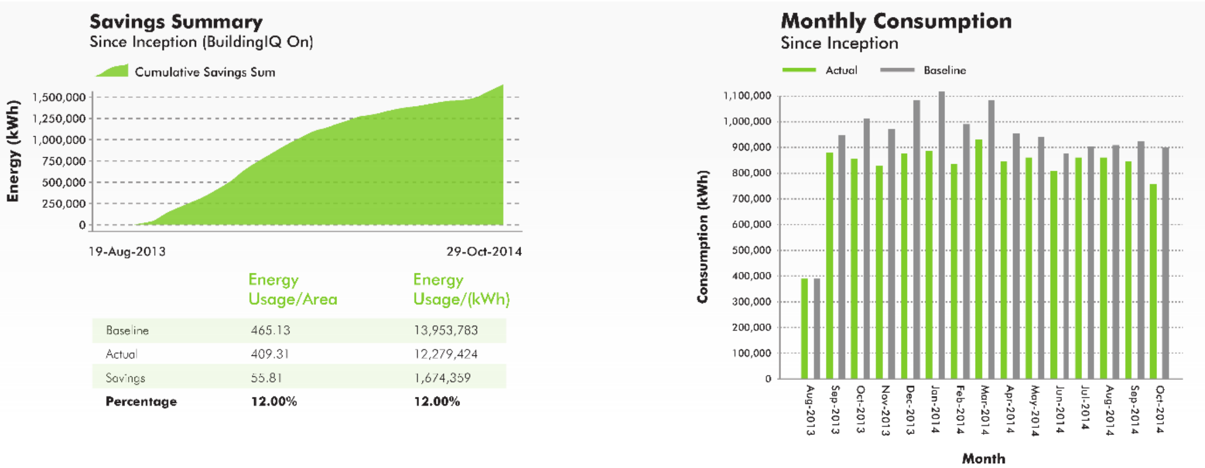

Figure 31. Energy Savings for the St. Vincent's Hospital case, after automation of HVAC control and update of the BEMS system. Source (BuildingIQ, n.d.)

The Colchester Hospital University NHS Foundation Trust in UK, participates in DR programs since 2012 (ADE, n.d.). The hospital has two main sites, Colchester General Hospital and Essex County Hospital. The Trust employs more than 3,400 people, which provide healthcare services to around 370,000 people. Colchester General Hospital opened in 1984. Their care covers 596 inpatient beds, 44 maternity beds and 12 critical care beds (excluding A&E).

The Trust has multiple generation assets, spread across different units. It has an existing parallel agreement with the distribution network to run the generators to offset significant load. This is managed by up to five low voltage diesel units of different capacities spaced around the hospital at key connection points. The Kiwi aggregator company enrolled the hospital into a peak load reduction DR program. The hardware retrofits included instrumentation for remote control of the generators and notification of the relevant members of staff in the event of a demand respond event, as well as real time metering hardware. At the start of the program, 1 MW base load was offered for demand side management, which increased to 1.4 MW after a couple of months. Annual revenues were estimated to be around £100,000.

A final example is the Berkshire Health Systems (BHS), a private, non-profit healthcare organization that operates three separate facilities in Massachusetts, USA (EnerNOC, n.d.). In 2006, BHS was enrolled in a DR program by EnerNOC energy services company. In contrast to the case of Colchester Hospital, BHS participates in an implicit DR scheme. the During a DR event, EnerNOC notifies facility engineers at each via phone and e-mail. The facility managers then reduce loads in their facilities, typically lighting, increase thermostat setpoints, and shut down a portion of the elevators. BHS also operates its backup generation system during DR events. During each event, BHS is able to reduce load by 1.3 megawatts without affecting any of the hospital's critical loads. The organization receives $25,000 in DR incentive payments for participating in the program.

7.4 Wholesale and Retail

Wholesale and retail businesses usually operate from morning into the late afternoon or evening. A major part of electricity demand comes from cooling and lighting purposes. The automated management of energy demand can be challenging, primarily due to concerns from store owners about customer complaints and lost revenue due to DR events. Incentive payments and selective control over non-crucial loads could improve the chances of attracting retail stores to participate in load flexibility programs. Further strategies that could be followed include precooling/preheating, thermal storage or even cogeneration.

Changes in behaviour can be directed towards the working staff, although potential is limited, since the loads such as lighting and cooling are set with the primary objective of offering the best conditions for customers.

Retail facilities offer one of the largest renovation potential. This is due to the fact that owners commonly choose to renovate/alter the store area, in the effort to keep/attract new customers and extend their business.

The operational constraints in retail buildings are associated with their main purpose of selling goods to the costumers. Retail buildings are typically open into the late afternoon and evening and can be particularly busy at times. Retail customers are likely to notice the results of a DR event in a store, such as reduced lighting and air-conditioning. Due to the above, owner-imposed requirements on the intrusiveness of load control, in conjunction with mandatory indoor air quality requirements, that may be in place, are the primary constraints with respect to demand-side flexibility.

Wholesale buildings, on the other side, have on average low levels of human occupancy compared to other commercial and industrial facilities. Electricity consumption is mostly spent for lighting and air conditioning purposes, although this can be highly business dependent. Due to the fact that wholesale businesses store large quantities of goods, indoor comfort is generally not of primary importance. However, where heat-sensitive materials or perishable food products are stored, extra care must be taken to ensure that the integrity of these goods is not sacrificed.

We now concentrate on a number of example trade building renovation projects.

Walmart in 2009 partnered with the U.S. Department of Energy (DOE) to develop and demonstrate energy retrofits for existing buildings. The goal was to reduce energy consumption by at least 30% versus ASHRAE Standard 90.1-2007 or versus pre-retrofit energy consumption as part of DOE's Commercial Building Partnerships (CBP) Program. A specific renovation project, complete in May 2013, focused on energy efficiency retrofits for a Walmart Supercentre, including an auto centre, garden centre, pharmacy, grocery, and a McDonald's (DOE, 2014). The facility occupied 213,000 SF. Important prerequisites were that measures must not interfere with customer experience or sales operations, and that the store must be open 24/7 during the retrofit work.

Implemented efficiency measures were the following:

1. Perimeter light reduction.
2. Lighting upgrade: Canopy, Pharmacy, wall-mounted security, parking lot (Replacement of metal halide fixtures with LED spotlights).
3. Installation of occupancy sensors.

4. Garden centre outside bag goods area and shade cloth area: Turn lights off during daytime (before retrofit the lights were on 24/7).
5. Use waste heat from 2 medium-temperature refrigeration systems to preheat ventilation air for the grocery sales area.
6. Direct evaporative cooling of rooftop unit (RTU) condensers combined with indirect evaporative precooling of ventilation air on 6 of the 8 20-ton sales RTUs.
7. Anti-sweat heater control upgrade: repair and upgrade of existing control panel.
8. Glass doors and LEDs added to medium-temperature dairy, deli, and beer cases, but not horizontal “coffin”-style cases.
9. Replacement of split capacitor evaporator fans with electronically commutated motor fans in all walk-in freezers and coolers.

The renovation project led to electricity savings of 507,800kWh (19% reduction) compared to the pre-retrofit baseline and 2,811,900 kWh (34% reduction) compared to ASHRAE 90.1-2007 baseline. Natural gas savings were 27,800 therms and 3,700 therms against the pre-retrofit and ASHRAE 90.1-2007 baselines respectively. In terms of Energy cost savings, estimated numbers were $66,600 (14%) and $258,500 (37%) against the pre-retrofit and ASHRAE 90.1-2007 baselines. Figure 32 shows the baseline and measured consumption per SF for years 2006 to 2014. Expected simple payback time of retrofit measures is 3-5 years.

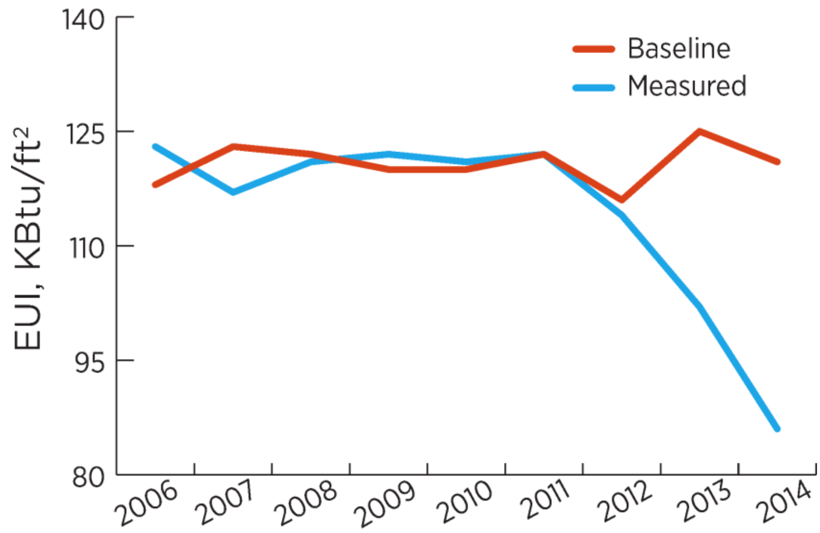

Figure 32. Walmart Case Study - Energy consumption per SF before and after renovation. Source (DOE, 2014)

Another informative example for the EE and DR potential in the wholesale and retail sector is the case of the Sainsbury’s supermarket chain in the UK. According to statistics by the company, investing in more than 100 biomass boilers, 40MW of solar PV, LED lighting, 27 Ground Source Heat Pumps and Green Gas CHP, during the last years, resulted in a lower energy consumption in 2015 than during 2005-06, despite occupying 52% more space during that period. With respect to DR, the company had included their first 150kW generator in an automated DR program, with plans on testing even bigger generators and battery storage, so as to participate in load shedding events (Powerresponsive, 2015).

Finally, in Sønderborg, Denmark, the SuperBrugsen supermarket chain supermarkets have cooperated with Sønderborg District Heating in order to send surplus heat to the district heating networks. Prior to this, the company reported savings of DKK 200,000 annually on gas and reduced CO_2 emissions by 34%, by utilizing the surplus heat from the refrigeration system to heat tap water for cleaning, among other things. The integration with the district heating system is estimated to be able supply 16 so-called standard homes of 130m² annually (Danfoss, n.d.).

7.5 Hotels and Restaurants

Hotels and restaurants are generally occupied all day, although, occupancy tends to be higher during the evening times. EE measures can result in significant energy savings, although participation in DR schemes may be somewhat more challenging to achieve.

Automation measures can be of particular importance for energy efficiency, especially for hotels. Guests are commonly given full control over thermostat settings and individual air conditioning units, which can result in significant and unnecessary energy losses. For example, many rented rooms remain unoccupied for long periods of time while HVAC systems are left running or in stand-by mode. Automated control over such loads, as well as the lighting systems, at least during the occupants' absence, can offer significant energy savings, without affecting comfort (HEL, 2011). For DR, it is important to note that restaurants and hotels are usually less occupied during the usual times of peak demand (for example mid-afternoon). This can enable the participation of such businesses into tailored curtailment programs, that will not affect the quality of their delivered service.

Behaviour modification can be addressed towards costumers and/or staff. Regarding the first group, potential is limited, since it can be difficult to provide adequate incentives to hotel room occupants to pay careful attention to their energy profile. To that end, reducing the level of control given to them may be the most reasonable option. On the other side, significant energy savings can be achieved through staff behaviour, since they can monitor and minimize energy losses in the buildings, e.g. from unoccupied areas and unattended appliances left turned on.

Renovation potential is significant for hotels, as well as restaurants, with the biggest challenge entailing persuasion of owners that the additional costs are justified. In restaurants, energy efficient renovation measures can be limited to refrigerator and cooking appliances with significant results, since they constitute a very large amount of the overall consumption.

Parameters influencing energy consumption in hotels and restaurants revolve around operating schedules for the different functional facilities in the building and occupancy patterns. In hotels, for example, the number of included facilities (e.g. restaurants, kitchens, in-house laundries, swimming pools and sports centres), as well as services offered and fluctuation in occupancy levels can all affect the status of operational constraints for demand-side flexibility. The most significant operation constraint though for such businesses should be associated with customer service and preferences relevant to indoor comfort (HEL, 2011).

Various renovation projects for hospitality facilities were identified in the literature. Some examples are the following.

In the hospitality sector, a recent pilot study including sixteen hotels across seven European countries (Croatia, France, Greece, Italy, Romania, Spain and Sweden) showed that large scale renovations can offer significant benefits. In particular, the aggregated investment of 6.310.297 Euro resulted in a sizable decrease in primary energy use for the hosting areas - Guests' rooms, Reception hall, Offices, Bar, Restaurant, Meeting rooms - from an average of 277 kWh/m^2/y to an average of 102 kWh/m^2/y; a reduction of 63%. The non-hosting functions – Spa, Swimming pools, Saunas, Gym, Kitchen, Laundry, etc. – were shown to be much more energy intensive, therefore extremely important for the overall energy performance of the hotels. The primary energy use for the non-hosting functions was decreased from an average of 727 kWh/m^2/y to an average of 374 kWh/m^2/y; a reduction of 49% (neZEH, 2016). Figure 33 and Figure 34 show the average primary energy consumption patterns before and after the renovation projects, and average savings attributed to the different types of retrofitting measures, while Figure 35 depict energy savings per hospitality facility.

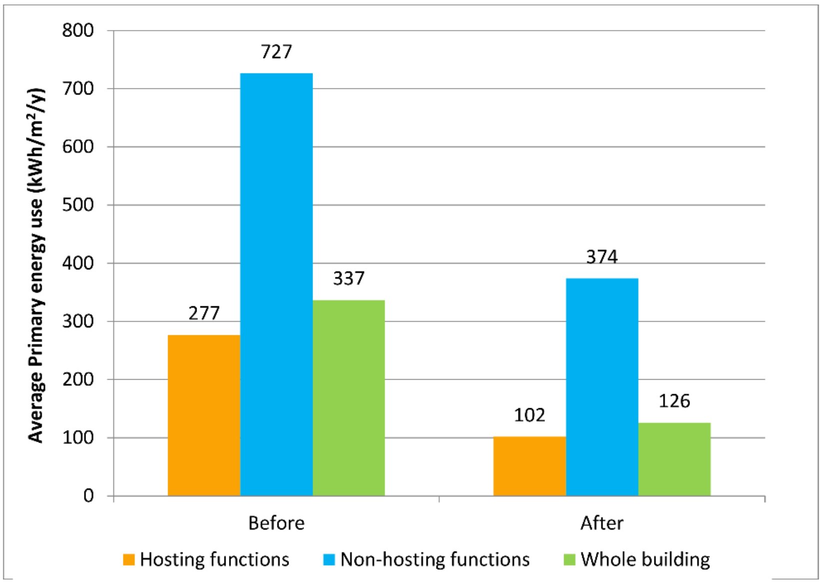

Figure 33. neZEH case study - Average primary energy consumption patterns before and after the renovation projects. Source (neZEH, 2016)

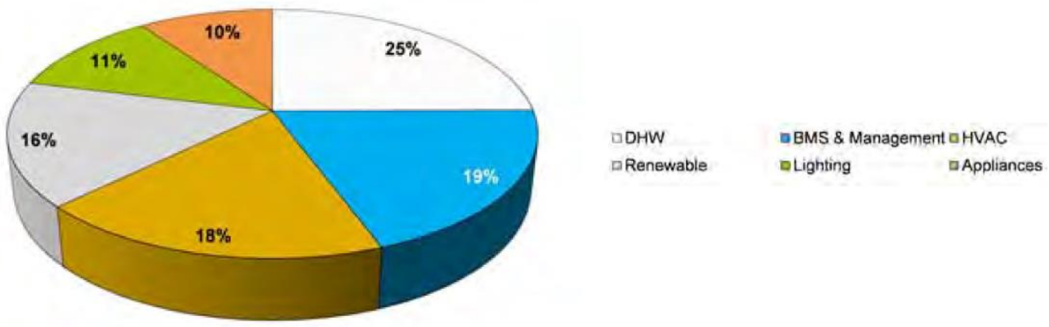

Figure 34. neZEH case study – Percentage of energy savings attributed to different retrofitting measures. Source (neZEH, 2016)

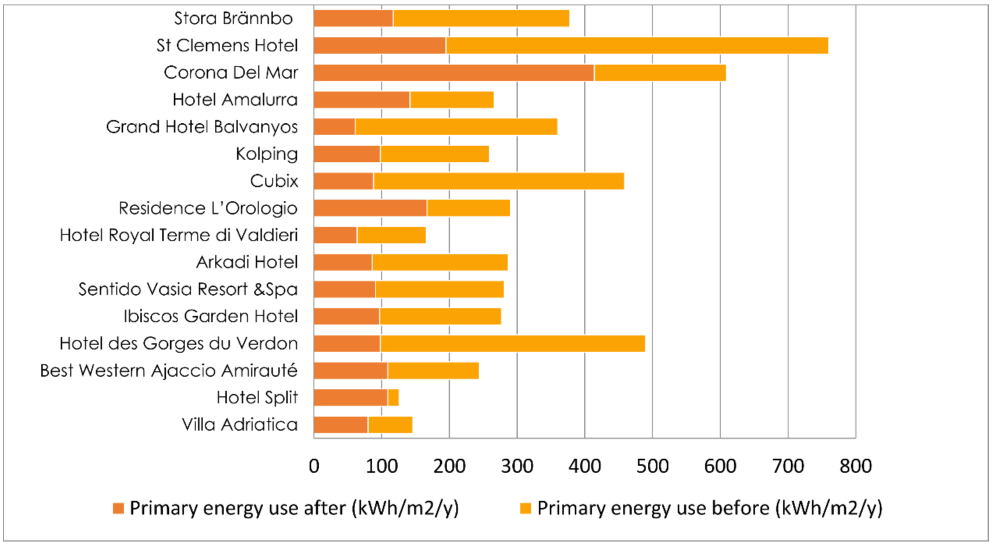

Figure 35. neZEH case study – Energy savings for the 16 pilot hotel facilities included in the study. Source (neZEH, 2016)

A number of hotels are also participating in implicit DR schemes. The Marriott hotel in London, UK, has partnered with the UK-based aggregator Kiwi in order to participate in an automated DR program.

Air conditioning in the lounge, ice coolers in the corridors and fridges in the kitchens can be turned down if the national electricity system requires. It is all triggered via an automated signal to a set top box installed by the aggregator (Guardian, 2015).

In California, USA, A hotel facility with 654 rooms, a kitchen/restaurant, large conference spaces, and a small laundry service is participating in a peak load reduction scheme since 2006. The hotel's peak demand during summer is about 1.7 megawatts. The cooling system, which accounts for around 50%, is the most intensive electricity load, followed by lighting at 30%. Other large electric loads include water heating, office equipment, ventilation, and refrigeration. Load fluctuations throughout the day are tied closely to air conditioning and tend to increase gradually between 11:00 a.m. and 6:00 p.m.

The hotel receives DR notifications one-day prior, and gets a refund based on its actual load reduction during an event. No penalties occur for non-participation. The hotel identified loads that could be turned off without affecting guest comfort. For example, it turns off the large fountain in front of the hotel, bathroom exhaust fans, increases thermostat setpoints by 2°F, and postpones laundry and dishwasher operations. This hotel typically reduces its demand by about 1.2 megawatts (70%) during an event for a direct savings of about $300 per event (OUC, 2017b).

7.6 Sport Facilities

Based on data in section 4.5, the biggest part of energy in sport facilities is used for heating purposes, with the exception of Portugal, from the examined countries, where most energy was consumed for lighting purposes). This difference may be due to the different types of sporting facilities, e.g. indoor vs. outdoor facilities, included in the results. Furthermore, it is important to differentiate between small-sized facilities, such as gyms, and moderate to large establishments, such as stadiums. In the first case, the same principles discussed for retail places are valid here, with one difference concerning the occupancy periods, which for sports facilities, are shifted towards the evening hours. For outdoor facilities, it is reasonable to presume that most energy is consumed in the lighting system. Centralized control and high energy demand, make these places suitable for automated demand response applications. On the points of behavioural training and renovation potential, the same observations presented for trade facilities apply here as well.

Operational constraints are dictated by the activities performed in these buildings, which are commonly of high intensity. Furthermore, in the case of stadiums, any planning should also take into account the mass of spectators. In that respect, sporting infrastructure present similar constraints to teaching facilities. Ventilation and lighting are very important operational aspects and any load control should respect minimum requirements for these loads.

Some examples of renovation projects for sporting facilities follow.

Kirklees Active Leisure (KAL) at Huddersfield, UK, is charitable trust which manages 14 leisure facilities and swimming pools on behalf of Kirklees Council. Up to 2014, approximately £340,000 had been invested, for energy efficiency measures projects across all KAL sites (SustainableClubs, n.d.). KAL initially targeted sites with a high electric and gas consumption, as identified from the daily monitoring of energy that was carried out. The adopted measures included:

1. Induction lighting:
   KAL have installed induction lighting in sports halls and swimming pool areas. Specifically, in the Sports Hall at Dewsbury Sports Centre, 43,400W high pressure sodium lights were replaced with 200W induction lamps at a cost of £11,700. Occupancy and light level sensors were also installed. Savings were conservatively estimated at £7,500 per annum on electricity,

giving a payback of less than 19 months. In the Pool hall at Batley Sports and Tennis Centre, 400kW lamps were replaced also with 200kW induction lamps. Energy use in the pool area halved after installation and payback was approximately 3 years. In the swimming pool at the Stadium Health and Fitness Club, 25,400W high pressure sodium lights were replaced with induction lamps at a cost of £4,500. Estimated savings were £1,600 per annum on electricity, giving a payback of 2.8 years.

2. Overhaul of Combined Heat and Power (CHP) units:
   In 2009 KAL had three CHP units, which were not running correctly, and two units that were not operating at all. All units were overhauled and guaranteed to have correct sizing for the summer heat load and correct heat to power ratio to maximise CHP electrical outputs (which was identified to be around 1.5:1 for the sports centres). The CHP units were integrated into the boiler system, maintained and actively managed through open CHP control protocols. Overall, the five CHP units saved KAL £150,000 per annum, after CHP maintenance is taken into account. At one of the sites, electricity costs were reduced by approximately £4,000 a month through running the CHP, while increases in gas costs were only a fraction of this. The payback on the overhaul of the particular unit was 4.5 months.
3. Electronic commutated motors:
   Electronic commutated motors (ECM), attached to plug fans, were installed in air handling units across KAL sites, replacing older fans and motors. Previous fans were 5kW, while ECM fans were 4.3kW. All ECMs were installed with relevant controls (either humidity or CO2), which allows the speed to be varied on this basis. In one site, the cost of the installation was £4,463. Controls were set to maintain a CO_2 level of 800ppm. The electric consumption was reduced by 33%, saving £4,800 per annum, while gas consumption as reduced by 25%, saving £2,000 per year. Payback of the project was approximately 8 months.
4. Other measures:
   Other measures included installation of LED lighting in some areas throughout the leisure facilities, and variable speed drives installed on the existing pool heating pumps. The combined cost of these jobs was around £3,000, with savings of approximately £1,500 per year and a payback of around 2 years.

Overall, in 2008/09 KAL sites emitted 5,885 tonnes CO_2. This fell to 4,437 tonnes CO2 in 2013/14, a reduction of around 25%. This reduction was achieved in spite of the fact that over the same time period (2009-2014), customer visits to KAL sites have increased from 2 to 3 million, an increase of 50%.

Another example relating to DR potential, this time, is the case study at the Bankstown Sports Club at Sydney, Australia (EEX, n.d.). The club was first approached by a demand side aggregator following pending network capacity problems in the local area and entered an agreement to provide network support, using on site generation. Initial agreement included payment of a standby fee and a dispatch fee for one summer period. The club's 2.6 MW standby generators were used twice under this agreement.

The initial agreement was modified and extended to allow for dispatch by the demand side aggregator during periods of extreme high wholesale market spot prices. The demand-side aggregator installed a remote, automatic start facility for the club's diesel generators and was able to remotely dispatch the generators at very short notice (five minutes) during short periods of extremely high spot prices. However, the club retained control over the generators, which could also be locked out, preventing the remote start function, when required (e.g. for routing maintenance of the generator units or controls).

8 EVALUATION OF NON-RESIDENTIAL BUILDINGS FOR PARTICIPATION IN THE NOVICE DUAL ENERGY SCHEME

An evaluation of the EE/DR retrofitting potential for the different non-residential building types can be performed, based on the data presented above. We first prescribe the key aspects and methodological steps we establish in order to assess the different building types.

8.1 EVALUATION PARAMETERS AND METHODOLOGY

In Table 3, we present the considered building characteristics and parameters and establish their contribution in the evaluation process:

Table 3. Building Evaluation parameters.

	Evaluation Parameter	Description
1	**Energy Consumption per m^2 (EnC/m^2)**	Energy consumption is one of the key criteria for establishing the overall retrofitting potential of buildings, since large consumption should correspond to potentially increased capabilities for energy savings. Due to its significance, we report both on energy consumption per square meter, as well as per typical building unit size. Two tightly associated parameters are floor area coverage and building stock distribution, which must be considered in tandem with EnC.
2	**Energy Consumption per building (EnC/bu)**	
3	**Floor Area (FA)**	Floor area coverage is considered as a positive indicator of renovation potential. Large coverage can mean increased retrofitting opportunities, and/or large-sized facilities, which should offer better profit potential and less investment risks. This variable complements and should be considered alongside EnC/m^2.
4	**Building Stock Distribution (BSD)**	As mentioned above, large numbers of individual facilities per building category can correspond to increased opportunities for renovation actions. In addition, this parameter entails the average values and ranges of typical individual buildings for each category. This variable complements and should be considered alongside EnC/bu.
5	**Energy Efficiency Potential (EEP)**	The potential for implementation of energy efficiency measures in different building classes can be evaluated based on the type and size of equipment in the buildings, in conjunction with patterns of energy usage and occupancy. A tightly associated parameter concerns the various operational constraints.
6	**Demand Response Potential (DRP)**	By taking into account occupancy patterns and automation possibilities, as well as further guidance from the explored case studies on DR renovation projects, we define the Demand Response Potential as a descriptive parameter pertaining the possibilities for adoption of Demand Side Flexibility on the various building classes. As above, DRP should be considered in tandem with relevant operational constraints.
7	**Operational Constraints (OC)**	This parameter entails the various operational obstacles pertaining occupancy, critical loads, ownership-related or otherwise, that have been recognised during this analysis.
8	**Building Age (BA)**	As described in the project's proposal, energy systems are displaying a lifetime of around 20-25 years. Building age is thus a

		deciding factor for consideration of a renovation project on a facility. New buildings, constructed after 2000, have lower renovation potential than older buildings. Overall, a balanced distribution of building ages is deemed preferable, since it shows both the existence of a significant renovation pool, as well as financial soundness for the particular class of businesses.
9	**Regulatory Obligations (RO)**	EU-related regulations, and the status/level of their implementation in the various EU Member States must be taken into consideration for the comprehensive evaluation and identification of possible pilot buildings, particularly with regard to geographical location.
10	**EPC Market Maturity (MME)**	The status of Energy Performance Contracting in the EU can significantly affect the evaluation and selection of suitable buildings in the different countries.
11	**DR Market Maturity (MMD)**	The maturity of Demand Response markets in the EU Countries can play an important role in the evaluation of suitable buildings.
12	**Financial Instruments (FI)**	As with the previous two parameters, financial instruments for renovation projects vary between different countries, and are taken into consideration for establishing overall suitability with respect to geographical localization.

It is important to highlight the differentiation among two types of parameters. On one hand, parameters (1)-(8) can be directly used to characterize and evaluate the renovation possibilities of different building classes.

On the other side, parameters (9)-(12) are not differentiating among types of non-residential buildings, but provide useful information, primarily regarding the potential at different European regions and countries.

Based on this grouping, we also adopt a two-layered classification during the evaluation process, with the first layer being the building type, and the second the geographical division, as detailed in section 4.1. In the following two sections, we present our evaluations for the different European divisions. In the last section of this chapter, we delve into selected countries of interest and report specific evaluations.

8.2 Region-Specific Evaluations

In the following, we first concentrate on the parameters (1)-(8) and present written evaluations for the different building categories.

8.2.1 Offices

Table 4. Written Evaluation for Offices.

Parameter	Written Evaluation
EnC/m2	Energy consumption in offices constitutes about 20% of the overall non-residential demand in countries with recorded data. It varies between about 150 and 300 KWh/m^2. We could not identify significant patterns of variations between different European regions.
FA	Offices occupy about 30% of the European non-residential floor area (excluding sport facilities and other buildings, for which data were not available), which is the largest

	percentage out of all other building classes. Central Europe has in general higher office coverage, with the remaining regions showing similar percentages.
EnC/bu	Energy consumption per building varies a lot among the examined countries. In northern and southern regions, observed values were between 10-100 MWh per year. In central Europe, though, and Germany, in particular, due to the large average size of offices, consumption per average size was more than 300 MWh per year.
BSD	The EU average office size is about 700 m^2. Available data show that in many countries, more than half of office spaces are moderately sized (200-1000 m^2), but small and large office spaces are also common. Central and northern Europe tend to have more and larger offices than southern regions. The most countries, office buildings tend to be the first or the second most plentiful category.
EEP	The potential for Energy Efficiency retrofits in office buildings is high, since significant trimming of energy costs can be achieved for the owner. This observation is further ascertained by the fact the EE renovation case studies encountered in the literature are most often related to office places. Energy is primarily consumed for air-conditioning purposes, with lighting and electrical equipment also taking up significant shares. One issue that has been raised pertains the somewhat volatile nature of the associated businesses. For this reason, most renovation projects target large offices.
DRP	Automation and behavioural control are possible in this building class. Offices should be particularly suited to time-of-use tariff schemes and load shifting procedures, such as preheating and precooling.
OC	Office buildings can have indoor air quality and comfort requirements that must be respected at all times. Furthermore, employee productivity may be affected by sudden interrupts on HVAC and electrical equipment. As such, offices may not be the most ideal candidates for automated DR programs.
BA	Offices exhibit a fairly balanced age distribution, in comparison to other building categories, with approximately 40%, 40% and 20% of the overall stock built before 1980s, between 1980 and 2000, and after 2000 respectively. This spread of building stock between new and old buildings shows good potential in terms of available buildings and renovation interest. The percentage of new buildings is somewhat diminished in the southern Europe, compared to the other regions.

8.2.2 Educational Facilities

Table 5. Written Evaluation for Educational Facilities.

Parameter	**Written Evaluation**
EnC/m2	Energy Consumption varies greatly among countries. It is around 20% of the overall non-residential energy consumption, which is comparable to the consumption of offices. In southern and NW countries, consumption tends to be higher, from 200 up to 300 KWh/m^2, while central and NE countries show consumptions of less than 100 KWh/m^2.
FA	Educational, teaching and research facilities comprise around 20% of the non-residential floor area in Europe, which is the third largest percentage out of the considered classes with recorder data. NE states have consistently higher floor coverage from educational buildings, compares to the EU average. Other regions are diversified, with countries being equally distributed around the mean floor area.
EnC/bu	Energy consumption per educational building tends to be very high, owing mostly to the large size of these facilities. In most examined countries, the value was found to be between 350-450 MWh per year. In NE and central European countries, these values were somewhat lower (between 150-270 MWh per year).

BSN	The EU average educational facility size is about 1400 m^2, which is the biggest average among the examined building categories. Deviation around the mean is small, meaning that size should be fairly consistent within and between the countries. Recorded data show that about half of the building stock is of moderate size (200-1000 m^2), while the other half of large size (>1000 m^2). The number of individual facilities is significantly lower to the respective numbers of offices and retail buildings, and, to a lesser extent, hotels and restaurants.
EEP	Energy efficient retrofits on educational facilities have increased potential, considering, first, that most energy is consumed on HVAC and lighting systems, and second, that this building stock is fairly aged, so currently utilized equipment should be old and inefficient.
DRP	Educational businesses should ideally be perfectly suited to both implicit and explicit DR programs, since centralized control is suited to these facilities, and significant load shedding can be achieved by directly controlling non-critical loads and equipment.
OC	Operational constraints for educational facilities are similar to the ones described for office buildings, since primary use, critical loads and occupancy profiles tend to be the same. An additional issue for educational facilities is the commonly encountered highly bureaucratic organization, with several administrative layers including students and staff. IEA has already acknowledged both the facilities' high potential for DR, and the increased problems during implementation.
BA	Education has the biggest percentage of buildings, out of all other categories, (75%) built prior to 1980, which could point towards a good pool of retrofittable buildings, nevertheless the very small number of new construction is possibly an indicator of reduced interest in this class. Central and SE Europe present a more balanced distribution, and thus are ranked higher in that respect.

8.2.3 Healthcare Facilities

Table 6. Written Evaluation for Healthcare Facilities.

Parameter	Written Evaluation
EnC/m2	Consumption tends to amount for around 10% of the overall non-residential demand, which is significantly lower to the ones in the previously reported building classes. Nevertheless, some countries, especially in central and NE Europe show higher percentages. Due to their functionality, hospitals tend to have high consumption per square meter. Lower values in some central and SE countries are about 150 KWh/m^2, but in many countries around Europe, consumption raises above 400 KWh/m^2.
FA	Healthcare facilities have the lowest percentages of occupied floor area, with the average European percentage being around 5%. NE countries have predominately above average coverage, which is also true for a few countries in Central and SE Europe.
EnC/bu	In many countries, consumption per healthcare building is high, from 300 up to 700 MWh per year, ranking either first or second between the different building categories. This is not true, though, for some central and northern European countries, such as Estonia and Germany, which show low consumption, between 100 and 200 MWh per year.
BSN	Healthcare facilities lie in the middle of the examined categories, in terms of average occupied space per building (765 m^2), as well as deviation from this mean. Northern Europe has significant percentages of large (>1000 m^2) buildings, while most central and southern countries have moderate-sized ones. Healthcare facilities are the scarcest, number-wise.

EEP	Potential on energy efficiency renovation in healthcare facilities is relatively low, compared to other classes. Retrofits can mainly target lighting and HVAC equipment, but also generator units.
DRP	Hospitals are one of the few buildings classes that are commonly equipped with backup generator units, and can thus easily participate in specific DR schemes, such as peak load reduction and variable price tariff. Such programs are already in place for a number of hospitals.
OC	Operational and indoor quality constraints on healthcare facilities are the strictest, compared to the other building typologies. Furthermore, hospitals must remain active all times of the day, as well as all days of the week, as such, any renovation project, as well as demand event must be carefully planned and executed.
BA	Heath facilities show an aging profile, with more than 60% of the stock built before 1980, and only 10% after 2000. This is true for most geographical regions, except SW Europe, where data show a significantly larger number of newly built buildings. Nevertheless, neither case is perceived as ideal.

8.2.4 Wholesale and Retail

Table 7. Written Evaluation for Wholesale and Retail.

Parameter	**Written Evaluation**
EnC/m2	In terms of energy consumption, trade is probably the sector showing the most potential, since recorded data show that it consumes the biggest share of energy out of all building classes. This becomes more obvious in NE Europe. This holds true for many countries as well, when considering normalized consumption, especially in SW and NE Europe, with values around 400 KWh/m^2. Remaining regions present lower numbers, between 100 and 200 KWh/m^2.
FA	The wholesale and retail sector covers second largest proportion (around 30%) of non-residential area, closely following office facilities. Distribution does not show a very strong geographical pattern, although northern countries tend to have somewhat higher percentages, compares to southern ones.
EnC/bu	Energy consumption per building is very diverse across Europe. Southern and some northern countries show very low values, below 50 MWh per year. In the remaining regions though, these numbers go up, from 150 to 350 MWh per year.
BSN	In general, the trade sector occupies the smallest facilities, having an average size of 338 m^2. Nevertheless, standard deviation is high, highlighting the diversity of used buildings. The common pattern of average buildings getting smaller from north to south is observed here as well. Plenty trade facilities are small-sized (<200 m^2).
EEP	Trade facilities are prime candidates for energy efficiency renovation projects, which is both due to the fact that owners are keen to renovate/alter the store areas, in the effort to keep/attract new customers and extend their business, as well as the type of common loads for which retrofitting procedures and corresponding costs/savings are well established. Beside cooling in food retail shops, lighting and air-conditioning are the most important loads in the trade sector. The above is also evident in the literature, with retrofits primarily targeting the lighting and refrigeration systems.
DRP	It was observed that Demand Response potential can be high in particular subclasses of retail shops, with the most obvious example being supermarket chains. This is due to the fact that such places are equipped with large refrigeration and, possibly, cogeneration units, which can be used for participation in load shedding and shifting programs, or even as suppliers of heating energy.
OC	While both EE and DR potential can be high, it is primarily restrained to implicit programs, since automated control can be challenging to implement, primarily due

	to concerns from store owners about customer complaints and lost revenue due to DR events.
BA	Due to the nature of the business, the sector has the biggest percentage of newly constructed buildings (after 2000), while similar ratio corresponds to buildings build between 1980 and 2000. This profile is deemed the most preferable. Geographical variation, with respect to building age, seems to be very small within the EU.

8.2.5 Hotels and Restaurants

Table 8. Written Evaluation for Hotels and Restaurants.

Parameter	Written Evaluation
EnC/m2	The share of consumption attributed to hotels and restaurants varies according to the latitude. In southern countries, it can be the most consuming class, while in northern countries it ranks towards the bottom. Consumption per square meter is diverse, ranging from 50 up to 250 KWh/m^2.
FA	Hospitality and gastronomic facilities occupy around 15% of the European non-residential stock. A strong geographical trend exists in this category, with southern countries showing significantly larger floor area coverage, compared to central and northern ones.
EnC/bu	Consumption per average building size ranges mainly within the 100 to 200 MWh per year, although very small values were observed in some SW and NE European countries.
BSN	Hospitality facilities tend to be relatively large buildings, with an average European size of 881 m^2 (std: 862). Nevertheless, the high deviation points to significant diversity among countries. Central and southern countries have mostly moderate-sized, or even small, facilities, while, in northern countries, buildings are mainly of large sizes.
EEP	Hotels and restaurants, as most commercial buildings with significant energy needs, are good candidates for energy efficiency measures. Most of their energy consumption is spent for lighting, refrigeration and heating/cooking purposes.
DRP	Significant DR potential can be identified, especially in cases of large hospitality facilities, where rescheduling of activities, such as cleaning and preheating, can offer load shifting possibilities.
OC	The constraints on the implementation of EE and DR projects can be mainly attributed to two reasons. First, as in the case or retail shops, owners may be reluctant to adopt measures that may affect their customers' comfort. Secondly, since such facilities are not as often been renovated, justification of the necessary costs may be harder here.
BA	In EU on average, restaurants and hospitality buildings have a rather aged profile, with more than 60% of buildings constructed before 1980, and only around 10% after 2000. This observation translates to a high renovation pool, but may also hint towards a low interest on renovation projects. The above are particularly true in central and northern Europe, while recorded data for southern countries are significantly more balanced.

8.2.6 Sport Facilities

Table 9. Written Evaluation for Sport Facilities.

Parameter	Written Evaluation
EnC/m2	In terms of relative energy consumption, data from only three countries were average consumption being around 5% of the overall demand. Energy consumption per square meter could not be computed, due to lack of available data.

FA	Data on floor area distribution were not available.
EnC/bu	Energy consumption per building could not be computed, due to lack of available data.
BSN	Most sporting facilities are large buildings (>1000 m^2). Energy consumption per building could not be computed, due to lack of available data.
EEP	Sporting facilities combine desirable attributes that have been individually explored in a number of previous classes. In sport facilities, significant loads range, depending on the specific type of building, from heating and ventilation, to lighting. Similar to trade and educational facilities, lighting and heating are the main targets for efficient retrofits.
DRP	It is also common, at least for moderate and large-sized sporting facilities, to be equipped with backup generators, a similar situation observed in hospitals and some retail centres. For this reason, DR case studies found in the literature primarily involved peak load shedding.
OC	Operational constraints relate mostly to health and indoor air quality parameters, since congregation of large number of people is common in such facilities. Ventilation is thus the least flexible type of load. On the other side, lighting and HVAC are not burdened with as high restrictions as in other building types.
BA	Data on building age distribution were not available.

8.2.7 Evaluation Parameters on Geographical Potential

In this subsection, we elaborate on the four parameters that do not differentiate between different building classes, but offer insights on the geographical potential, namely Regulatory Obligations (RO), Market Maturity (MM) and Financial Instruments (FI). The evaluation of these parameters is included in Table 10.

Table 10. Written Evaluation on Regulatory obligations, Market maturity and Financial instruments.

Parameter	Written Evaluation
RO	Regulatory obligations are related predominantly to required minimum levels of renovation rates and energy consumption (equivalently CO_2 emissions) for buildings, as prescribed in the EPBD and EED EU directives. Another regulation targets the required shares of renewable energy resources in the yearly energy consumption of each EU state, which are defined in the RED directive. EU aims to increase the renovation rate from approximately 1% to 3% in the following years. From the limited country-specific data available, renovation rates appear larger in Central European countries. On the matter of energy consumption, countries are individually responsible to define their minimum levels for energy efficiency in new and renovated buildings. Few Central European countries again are in the forefront, having established detailed levels both for new and existing renovated buildings. On the other hand, a lot of EU states have not yet defined specific renovation requirements. Finally, the target level of penetration of renewable energy is significantly higher in the NE and SW Europe, accompanied with a few countries in the Central Europe.
MME	Energy Performance Contracting is a driving factor on the establishment on pilot sites. This evaluation is based predominantly on the size of the various EPC markets in Europe, and the number of active ESCOs. Market size is significant in the more economically advanced EU member states of Central, NW and NE EU, with Italy also showing good attributes. South and eastern Europe is lacking in that respect, although growth is observed.
MMD	Demand Response Markets are overall less mature, compared to the ESCO markets, although the same pattern of development can be observed here. Some southern

	European countries have not yet opened their energy markets to demand side flexibility. The most advanced countries (Switzerland, France, Belgium, Finland, Great Britain, and Ireland) are located in the central and northern Europe. Even there, though, there are still issues that inhibit the complete integration of demand flexibility in the energy markets.
FI	In the previous analysis, we identified four types of financing instruments for renovation projects in the EU, namely, grants and subsidies, loans, tax incentives and energy efficiency obligations. Not all types are operational in all member states. Most countries support up to two financial measures, with Belgium, France, Italy and Netherlands having three of four types operational.

8.3 Region-specific Scoring Table and Prioritization

For the purpose of encapsulating and boiling down the written evaluations, we also adopt a simple scoring system for the evaluation parameters. The scoring levels and justification are provided in the following:

i. Energy Consumption per square meter is classified into one of three layers, with limits for each layer taken to be: High (> 400 KWh/m^2), Medium (> 100 KWh/m^2 and < 400 KWh/m^2), Low (< 100 KWh/m^2).

ii. Floor area coverage is ranked, according to the percentage coverage of each building type, as Very High (> 25%,) High (> 15% and < 25%), Medium (> 7.5% and < 15%) or Low (< 7.5%).

iii. Energy Consumption per building is classified into one of three layers, with limits for each layer taken to be: High (> 300 MWh per year), Medium (> 50 MWh and < 300 MWh per year), Low (< 50 MWh per year).

iv. In particular for building size distribution, we report on the most common class of individual building sizes: Large (>1000m^2), Moderate (>200m^2 and <1000m^2), Small (<200m^2). It must be highlighted that this parameter is not ranked, since each type of size can be appropriate, depending on the desired scenario of the renovation project and the scale of investment.

v. Energy Efficiency Potential for each building class is categorized as High, Moderate or Low The ranking highlights expected energy savings from moderate-size renovation projects, with limits for each level taken to be approximately: Very High (>30%), High (> 20% and < 30%), Moderate (>10% and < 20%), Low (< 10%). The explored case studies were used as guidelines for this classification, and the ranking was further adapted to encompass ease of retrofit implementation.

vi. Demand Response Potential is characterized as High, Medium or Low. The evaluation takes into consideration potential peak energy reductions, with levels corresponding approximately to >30%, > 20% & < 30%, < 10% from the baseline consumption respectively. Scores are further adjusted to take into consideration the existence of suitable loads, that can be easily incorporated into Demand Flexibility schemes.

vii. The status of Operational Constraints is regarded as Good, Moderate or Bad, depending on whether the identified sets of constraints comprise of mostly superfluous, or health-related and officially imposed regulations.

viii. Building Age distribution is reported as Good, Moderate or Bad, primarily depending on the percentage of buildings, within each category, that are built between 1990 and 2000 (main retrofit targets), with level limits set as: > 20%, < 10% & > 20% and < 10%, respectively. The ranking is subsequently adapted to highlight the overall age spread of buildings, since a more uniform distribution is deemed as more favourable, hinting at a healthier business market.

ix. The status of implementation of EU regulatory obligations is deemed as Good, Moderate or Bad, based on whether the EU member states have defined minimum energy efficiency levels for new and retrofit buildings, only for new buildings or for neither. The ranking is further adapted to incorporate size of renewable sources, as prescribed in the Renewable Energy Directive.

x. The ESCO market maturity status is classified as Good, Moderate or Bad, by evaluating the size of the ESCO market (Large, Medium or Small) as described in chapter 6.

xi. Similarly, The DR market maturity is classified as Good, Moderate or Bad, by evaluating the status of DR markets (Active, Opening, Preliminary, Closed), as described in chapter 6.

xii. The status of available Financial instruments is ranked as High, Moderate, Low and None when three or more, two, one and no types of measures are operational respectively.

In Table 11, we present scores on the parameters for each building type/geographical location.

Table 11. Evaluation scoring table of different non-residential buildings in European regions.

Building Type	Geo. Division	EnC /m2	FA	EnC /bu	BSD	EEP	DRP	OC	BA	RO	MME	MMD	FI
Offices	NW	M	H	M	M	H	H	G	G	B	G	G	H
	NE	M	H	L	M	H	H	G	G	M	G	G	M
	Cen	M	VH	H	L	H	H	G	G	M	G	G	H
	SW	M	H	M	M	H	H	G	M	M	M	B	M
	SE	M	H	L	M	H	H	G	M	B	B	B	M
Educational Facilities	NW	M	M	H	L	VH	M	B	B	B	G	G	H
	NE	M	H	H	L	VH	M	B	B	M	G	G	M
	Cen	M	M	M	L	VH	M	B	M	M	G	G	H
	SW	M	M	H	L	VH	M	B	B	M	M	B	M
	SE	M	M	M	L	VH	M	B	M	B	B	B	M
Healthcare Facilities	NW	H	L	H	L	L	M	B	B	B	G	G	H
	NE	M	H	M	L	L	M	B	B	M	G	G	M
	Cen	M	M	M	M	L	M	B	B	M	G	G	H
	SW	H	M	H	M	L	M	B	B	M	M	B	M
	SE	H	L	M	M	L	M	B	B	B	B	B	M
Wholesale and Retail	NW	M	VH	M	M	M	M	G	G	B	G	G	H
	NE	M	VH	M	L	M	M	G	G	M	G	G	M
	Cen	M	H	M	M	M	M	G	G	M	G	G	H
	SW	H	H	M	S	M	M	G	G	M	M	B	M
	SE	M	H	M	S	M	M	G	G	B	B	B	M
Hotels and Restaurants	NW	M	M	M	M	H	H	M	B	B	G	G	H
	NE	M	M	M	L	H	H	M	B	M	G	G	M
	Cen	M	M	H	L	H	H	M	B	M	G	G	H
	SW	M	H	M	M	H	H	M	M	M	M	B	M
	SE	M	VH	M	M	H	H	M	M	B	B	B	M
Sport Facilities	NW	-	-	-	L	M	M	M	-	B	G	G	H
	NE	-	-	-	L	M	M	M	-	M	G	G	M
	Cen	-	-	-	L	M	M	M	-	M	G	G	H
	SW	-	-	-	L	M	M	M	-	M	M	B	M
	SE	-	-	-	L	M	M	M	-	B	B	B	M

Utilizing the written analysis and scoring table, we conclude the section with a prioritization over the different building categories, in terms of their overall potential for demonstration of the project's objectives, given in Table 12.

Table 12. Building Typology Prioritization.

Prioritization	Region	Building Type	Justification
1	NW, Cen	Offices	Office buildings score consistently high in the majority of examined parameters, while their characteristics are relatively stable across Europe. The primary reason for differentiation between regions is consumption per building, which is higher in NW and central Europe.
	NE	Educational Facilities	Educational facilities in NE Europe are very good candidates, showing large energy consumption patterns and very high potential energy savings. Recognized Issues relate to operational constraints and building age distribution.
	SW, SE	Hotels & Restaurants	The hospitality sector in all Europe shows similar performances, with good EE/DR potential, but energy consumption and floor area coverage decline in association to the geographical latitude. In southern Europe, these parameters score high.
2	NW, NE, Cen, SW, SE	Wholesale & Retail	Wholesale and retail businesses have high energy consumption pattern, and occupy significant area. It is important to notice that energy markets in central and northern Europe are more mature.
3	NW, SW, SE	Educational Facilities	See justification above. Floor area coverage is somewhat lower in these areas.
	Cen, NE	Hotels & Restaurants	See justification above. Floor area coverage is moderate in Central and NE Europe.
4	NW	Hotels and Restaurants	See justification above. Floor area coverage is moderate in NW Europe.
	Cen	Educational Facilities	The performance signature of Educational buildings in central and Southern Europe is similar to the North, with the only difference been a somewhat reduced energy consumption.
	NE, SW, SE	Offices	Office spaces rank somewhat low in NE, SW, SE regions, mostly due to low energy consumption per individual building.
5	NW, NE, Cen, SW, SE	Sport Facilities	Sport facilities score moderately in many of the considered parameters. A more limited availability of data, in comparison to the other building categories, especially for energy consumption, but also floor area coverage and building age distribution, results in their low prioritization.
6	NW, NE, Cen, SW, SE	Healthcare Facilities	While Health-care facilities are large energy consumers, they show some significant disadvantages, mainly regarding the required specialized equipment, operational constraints, and limited floor area coverage. These reasons limit their EE and DR potential.

8.4 Country-Specific Evaluations

Following the analysis over wide European regions, we go one level deeper in terms of location, and score the eight more mature and/or largest EU energy markets, namely Austria, Belgium, Finland, France, Germany, Ireland, Italy and UK.

First, we adjust and present scoring tables for the individual countries. For countries where specific information was not available, the respective columns were populated based on data from the closest similar country with recorded data, in the same geographical region. In the tables, this fact is indicated by the use of lowercase lettering.

Table 13. Evaluation scoring table for Austria.

Country	Building Type	EnC /m2	FA	EnC /bu	BSD	EEP	DRP	OB	BA	RO	MME	MMD	FI
Austria	Offices	m	VH	h	L	H	H	G	g	G	G	M	M
	Edu. Facilities	l	VH	m	L	VH	VH	B	b	G	G	M	M
	Health Fac.	h	L	m	M	L	M	B	b	G	G	M	M
	Wh. & Retail	m	H	m	M	M	M	G	g	G	G	M	M
	Hotels & Res.	m	H	h	M	H	H	M	b	G	G	M	M
	Sport Facilities	-	-	-	L	M	M	M	-	G	G	M	M

Table 14. Evaluation scoring table for Belgium.

Country	Building Type	EnC /m2	FA	EnC /bu	BSD	EEP	DRP	OB	BA	RO	MME	MMD	FI
Belgium	Offices	m	VH	h	M	H	H	G	g	G	G	G	VH
	Edu. Facilities	l	H	m	L	VH	VH	B	b	G	G	G	VH
	Health Fac.	h	M	m	M	L	M	B	b	G	G	G	VH
	Wh. & Retail	m	H	m	M	M	M	G	g	G	G	G	VH
	Hotels & Res.	m	M	h	L	H	H	M	b	G	G	G	VH
	Sport Facilities	-	-	-	L	M	M	M	-	G	G	G	VH

Table 15. Evaluation scoring table for Finland.

Country	Building Type	EnC /m2	FA	EnC /bu	BSD	EEP	DRP	OB	BA	RO	MME	MMD	FI
Finland	Offices	m	H	l	M	H	H	G	m	M	G	G	H
	Edu. Facilities	m	H	h	L	VH	VH	B	m	M	G	G	H
	Health Fac.	m	H	h	L	L	M	B	m	M	G	G	H
	Wh. & Retail	l	VH	m	M	M	M	G	g	M	G	G	H
	Hotels & Res.	m	L	m	M	H	H	M	-	M	G	G	H
	Sport Facilities	-	-	-	L	M	M	M	-	M	G	G	H

Table 16. Evaluation scoring table for France.

Country	Building Type	EnC /m2	FA	EnC /bu	BSD	EEP	DRP	OB	BA	RO	MME	MMD	FI
France	Offices	m	H	h	-	H	H	G	g	M	G	G	VH
	Edu. Facilities	l	H	m	-	VH	VH	B	b	M	G	G	VH
	Health Fac.	h	VH	m	-	L	M	B	b	M	G	G	VH

	Wh. & Retail	m	H	m	-	M	M	G	g	M	G	G	VH
	Hotels & Res.	m	M	h	-	H	H	M	b	M	G	G	VH
	Sport Facilities	-	-	-	-	M	M	M	-	M	G	G	VH

Table 17. Evaluation scoring table for Germany.

Country	**Building Type**	**EnC /m2**	**FA**	**EnC /bu**	**BSD**	**EEP**	**DRP**	**OB**	**BA**	**RO**	**MME**	**MMD**	**FI**
Germany	**Offices**	M	VH	H	L	H	H	G	G	B	G	M	H
	Edu. Facilities	L	L	M	L	VH	VH	B	B	B	G	M	H
	Health Fac.	H	L	M	M	L	M	B	B	B	G	M	H
	Wh. & Retail	M	H	M	L	M	M	G	G	B	G	M	H
	Hotels & Res.	M	H	H	L	H	H	M	B	B	G	M	H
	Sport Facilities	-	-	-	L	M	M	M	-	B	G	M	H

Table 18. Evaluation scoring table for Ireland.

Country	**Building Type**	**EnC /m2**	**FA**	**EnC /bu**	**BSD**	**EEP**	**DRP**	**OB**	**BA**	**RO**	**MME**	**MMD**	**FI**
Ireland	**Offices**	h	VH	m	M	H	H	G	-	B	M	G	M
	Edu. Facilities	m	M	h	L	VH	VH	B	-	B	M	G	M
	Health Fac.	h	L	h	M	L	M	B	-	B	M	G	M
	Wh. & Retail	m	H	m	L	M	M	G	-	B	M	G	M
	Hotels & Res.	m	H	m	L	H	H	M	-	B	M	G	M
	Sport Facilities	-	-	-	L	M	M	M	-	B	M	G	M

Table 19. Evaluation scoring table for Italy.

Country	**Building Type**	**EnC /m2**	**FA**	**EnC /bu**	**BSD**	**EEP**	**DRP**	**OB**	**BA**	**RO**	**MME**	**MMD**	**FI**
Italy	**Offices**	-	M	-	S	H	H	G	g	M	G	B	VH
	Edu. Facilities	h	VH	h	L	VH	VH	B	g	M	G	B	VH
	Health Fac.	h	M	h	M	L	M	B	m	M	G	B	VH
	Wh. & Retail	h	VH	l	S	M	M	G	m	M	G	B	VH
	Hotels & Res.	l	M	l	S	H	H	M	-	M	G	B	VH
	Sport Facilities	-	-	-	L	M	M	M	-	M	G	B	VH

Table 20. Evaluation scoring table for UK.

Country	**Building Type**	**EnC /m2**	**FA**	**EnC /bu**	**BSD**	**EEP**	**DRP**	**OB**	**BA**	**RO**	**MME**	**MMD**	**FI**
UK	**Offices**	H	M	M	S	H	H	G	-	B	G	G	H
	Edu. Facilities	M	H	H	L	VH	VH	B	-	B	G	G	H
	Health Fac.	H	M	H	L	L	M	B	-	B	G	G	H
	Wh. & Retail	M	VH	M	M	M	M	G	-	B	G	G	H
	Hotels & Res.	M	M	M	M	H	H	M	-	B	G	G	H
	Sport Facilities	-	-	-	L	M	M	M	-	B	G	G	H

Table 21. Building profiles and prioritization for Austria.

Country	**Rank**	**Building Type**	**Typical Building Profile**				
			Size (m^2)	**EnC/m^2 (KWh)**	**EnC/bu (MWh)**	**Typical Loads/ Equipment**	**Construction Period**
Austria	**1**	**Offices**	1400	*141*	*197*	HVAC, Lighting, Electrical Equipment	*1980-2000*
	2	**Hotels & Res.**	800	*207*	*166*	Refrigeration, Lighting, HVAC	*1970-2000*
	3	**Edu. Facilities**	2000	*105*	*210*	HVAC, Lighting, Electrical Equipment	*1950-1990*
	4	**Wh. & Retail**	1000	*150*	*150*	Refrigeration, Lighting, HVAC, Generator Units	*1985-2005*
	5	**Health Fac.**	450	*300*	*135*	HVAC, Generator Units, Lighting	*1965-1995*

Table 22. Building profiles and prioritization for Belgium.

Country	**Rank**	**Building Type**	**Typical Building Profile**				
			Size (m^2)	**EnC/m^2 (KWh)**	**EnC/bu (MWh)**	**Typical Loads/ Equipment**	**Construction Period**
Belgium	**1**	**Offices**	1000	*141*	*141*	HVAC, Lighting, Electrical Equipment	*1980-2000*
	2	**Hotels & Res.**	2100	*207*	*435*	Refrigeration, Lighting, HVAC	*1970-2000*
	3	**Wh. & Retail**	1400	*150*	*210*	Refrigeration, Lighting, HVAC, Generator Units	*1985-2005*
	4	**Edu. Facilities**	1500	*105*	*158*	HVAC, Lighting, Electrical Equipment	*1950-1990*
	5	**Health Fac.**	450	*300*	*135*	HVAC, Generator Units, Lighting	*1965-1995*

Table 23. Building profiles and prioritization for Finland.

Country	**Rank**	**Building Type**	**Typical Building Profile**				
			Size (m^2)	**EnC/m^2 (KWh)**	**EnC/bu (MWh)**	**Typical Loads/ Equipment**	**Construction Period**
Finland	**1**	**Edu. Facilities**	2000	*130*	*260*	HVAC, Lighting, Electrical Equipment	*1960-1990*
	2	**Health Fac.**	1400	*230*	*322*	HVAC, Generator Units, Lighting	*1965-1995*
	3	**Hotels & Res.**	600	*260*	*156*	Refrigeration, Lighting, HVAC	*1970-2000*
	4	**Wh. & Retail**	700	*120*	*84*	Refrigeration, Lighting, HVAC, Generator Units	*1970-2000*
	5	**Offices**	300	*140*	*42*	HVAC, Lighting, Electrical Equipment	*1970-2000*

Table 24. Building profiles and prioritization for France.

Country	**Rank**	**Building Type**	**Typical Building Profile**				
			Size (m^2)	**EnC/m^2 (KWh)**	**EnC/bu (MWh)**	**Typical Loads/ Equipment**	**Construction Period**
France	**1**	**Offices**	*300*	*141*	*42*	HVAC, Lighting, Electrical Equipment	*1980-2000*
	2	**Hotels & Res.**	*600*	*207*	*538*	Refrigeration, Lighting, HVAC	*1970-2000*
	3	**Health Fac.**	*1400*	*300*	*420*	HVAC, Generator Units, Lighting	*1965-1995*
	4	**Wh. & Retail**	*700*	*150*	*105*	Refrigeration, Lighting, HVAC, Generator Units	*1985-2005*
	5	**Edu. Facilities**	*2000*	*105*	*210*	HVAC, Lighting, Electrical Equipment	*1950-1990*

Table 25. Building profiles and prioritization for Germany.

Country	**Rank**	**Building Type**	**Typical Building Profile**				
			Size (m^2)	**EnC/m^2 (KWh)**	**EnC/bu (MWh)**	**Typical Loads/ Equipment**	**Construction Period**
Germany	**1**	**Offices**	2200	141	310	HVAC, Lighting, Electrical Equipment	1980-2000
	2	**Hotels & Res.**	2200	207	455	Refrigeration, Lighting, HVAC	1970-2000
	3	**Wh. & Retail**	1400	150	210	Refrigeration, Lighting, HVAC, Generator Units	1985-2005
	4	**Health Fac.**	450	300	135	HVAC, Generator Units, Lighting	1965-1995
	5	**Edu. Facilities**	1500	105	158	HVAC, Lighting, Electrical Equipment	1950-1990

Table 26. Building profiles and prioritization for Ireland.

Country	**Rank**	**Building Type**	**Typical Building Profile**				
			Size (m^2)	**EnC/m^2 (KWh)**	**EnC/bu (MWh)**	**Typical Loads/ Equipment**	**Construction Period**
Ireland	**1**	**Edu. Facilities**	1500	*230*	*345*	HVAC, Lighting, Electrical Equipment	*1955-1990*
	2	**Offices**	950	*290*	*276*	HVAC, Lighting, Electrical Equipment	*1975-1995*
	3	**Hotels & Res.**	2200	*310*	*682*	Refrigeration, Lighting, HVAC	*1970-2000*
	4	**Wh. & Retail**	1400	*210*	*294*	Refrigeration, Lighting, HVAC, Generator Units	*1965-1995*
	5	**Health Fac.**	450	*500*	*225*	HVAC, Generator Units, Lighting	*1960-1995*

Table 27. Building profiles and prioritization for Italy.

Country	Rank	Building Type	Typical Building Profile				
			Size (m^2)	EnC/m^2 (KWh)	EnC/bu (MWh)	Typical Loads/ Equipment	Construction Period
Italy	**1**	**Edu. Facilities**	1200	*370*	*444*	HVAC, Lighting, Electrical Equipment	*1960-1990*
	2	**Health Fac.**	400	*1100*	*440*	HVAC, Generator Units, Lighting	*1965-1995*
	3	**Wh. & Retail**	100	*400*	*40*	Refrigeration, Lighting, HVAC, Generator Units	*1970-2000*
	4	**Hotels & Res.**	250	*50*	*12.5*	Refrigeration, Lighting, HVAC	*1970-2000*
	5	**Offices**	140	-	-	HVAC, Lighting, Electrical Equipment	*1980-2000*

Table 28. Building profiles and prioritization for UK.

Country	Rank	Building Type	Typical Building Profile				
			Size (m^2)	EnC/m^2 (KWh)	EnC/bu (MWh)	Typical Loads/ Equipment	Construction Period
UK	**1**	**Edu. Facilities**	2100	230	483	HVAC, Lighting, Electrical Equipment	*1955-1990*
	2	**Wh. & Retail**	700	210	147	Refrigeration, Lighting, HVAC, Generator Units	*1965-1995*
	3	**Offices**	300	290	87	HVAC, Lighting, Electrical Equipment	*1975-1995*
	4	**Hotels & Res.**	600	310	186	Refrigeration, Lighting, HVAC	*1970-2000*
	5	**Health Fac.**	1400	500	700	HVAC, Generator Units, Lighting	*1960-1995*

9 POTENTIAL DEMONSTRATORS' SITE INVENTORY FOR VALIDATION OF THE NOVICE DUAL ENERGY SCHEME

Following the critical analysis and categorization of the European non-residential building stock, the task of identifying suitable demonstrator sites for the NOVICE project is initiated. The first step towards the fulfilment of this goal is the construction of an inventory for potential demonstrator sites from the portfolios of Novice's partners. The process was guided by the previously extracted results.

9.1 DESCRIPTION OF POTENTIAL DEMONSTRATOR SITES

Eight potential demonstrator sites have been identified so far. They comprise the first version of the demonstrators' site inventory, from which suitable retrofitting projects will be selected. Details on the buildings are presented below.

1. Large hotel in Portugal – Respective partner: Joule Assets
   Two commercial buildings from Joule Assets are currently included in the inventory. The first is a large hotel in Portugal, with in-house facility management, and ongoing participation in an EPC program. Primary energy sources for the facility are electricity and diesel, with annual consumptions of 1,340 MWh and 103,745 Litres respectively, and associated costs amounting for € 121,326 and € 99,058. Heating and cooling are provided by hot water boiler and radiators, and air conditioning respectively. A potential renovation plan includes two new installations of air-water electric heat pumps; insulation of an existing hot water system in DWH piping; flow control of a fan (changing Fan Coil's valve); replacement of internal lighting with LED; and installation of a building energy management system to measure electricity and diesel consumption.
2. Sport facility in Portugal – Respective partner: Joule Assets
   The second building identified as potential demonstrator by JA is a fitness centre in Portugal. The facility is managed by an external contractor and participates in an EPC program. Heating and cooling are performed through an HVAC system. Annual electricity consumption is 386 MWh, with corresponding cost of € 62,600. Potential renovation project will include a PV plant of 100kWp capacity will be built on the premises roof. Energy produced by the plant will be directly consumed by the customer. The plant ownership will remain on ESCO for 7 years and the customer will pay a monthly operational lease yearly adjusted according to the actual production of the plant if it's the case.
3. Large multipurpose facility (Offices, Retail, Restaurant, Residential) in Germany – Respective partner: Apleona
   Three multipurpose facilities were drawn by the portfolio of Apleona as suitable for inclusion in the inventory, all managed by external contractors. The first is a large facility, with combined area of 33,958 m^2. Of these, 18,048 m^2 are occupied by offices, 5,426 m^2 by wholesale/retail facilities, 2,977 m^2 by restaurants, with 5,426 m^2 being residential premises. The facility is newly constructed (2008), with primary energy sources being electricity and district heating/cooling. Annual consumption for each source amounts to 4,204 MWh and 3,327 MWh respectively, and electricity expenses are in the order of € 700.000 per annum.
4. Medium-sized multipurpose facility (Offices, Retail, Restaurant, Residential) in Germany – Respective partner: Apleona
   The second potential building is a medium-sized facility, with combined area of 12,281 m^2, with 12,281 m^2 occupied by offices, 4,196 m^2 by wholesale/retail facilities, 3,158 m^2 by restaurants, and 2,154 m^2 being residential premises. The building age showcases greater

renovation potential, since the facility was constructed in 1994. Primary energy sources are again electricity and district heating/cooling, with annual consumption for each source being 256 MWh and 1,209 MWh respectively. Yearly electricity costs are € 41.000.

5. Medium-sized multipurpose facility (Offices, Retail, Restaurant, Other) in Germany – Respective partner: Apleona
The third multipurpose facility is medium-sized as well, with overall area of 10,500 m^2. 7,485 m^2 of these are occupied by offices, 2,254 m^2 by wholesale/retail facilities and 715 m^2 by restaurants, while the facility also houses a train station, and was constructed in 1996. Electricity is again the main energy source, although, in contrast to the previous buildings, additional energy is provided from natural gas boilers. Annual consumptions are respectively 610 MWh and G: 1.403 MWh, while costs amount to € 100.000 and € 45.528 per annum.
6. Brown Thomas Department Store in Ireland – Respective Partner: Noel Lawyer Green Energy Solutions
The Brown Thomas department store is a large retail facility located in Cork, Ireland. The facility building was initially constructed in 1848, but has received numerous renovations, with the most recent being a lighting and heating system upgrade in 2016. The size of the facility is 15,511 m^2, divided in six floors, and is managed by an in-house facility manager. Energy is provided primarily through electricity, but also natural gas, with annual consumptions of 6,597,131 MWh and 965,239 MWh (respective costs: € 792,982, € 54,070). The facility is equipped with a building energy management system and temperature sensing devices. It is heated/cooled through a combination of radiators, hot water coils and air conditioning. Currently, there is no participation in an EPC or DR program. The rated total power of lighting, heating, cooling, ventilation and water heating are respectively 435, 749, 485, 99 and 103 kW respectively.
7. Ballymun Leisure Centre in Ireland – Respective Partner: Noel Lawyer Green Energy Solutions
The Ballymun Leisure Centre, located in Dublin, Ireland, is a multipurpose sport facility, comprising of a pool hall, aerobics rooms, gym, changing rooms, reception, meeting rooms, corridors and canteen store rooms. It was constructed in 2005 and comprises of two floors with total area of 4,508 m^2. New lighting equipment was installed in 2016. The building is managed in-house. Natural gas (yearly consumption 2,400 MWh, € 150,960) and electricity (yearly consumption 800 MWh, € 118,335) are the main energy sources, with rated power of 24, 756 and 62 kW for lighting, heating and ventilation respectively. An Innotech energy management system is installed, along with temperature and humidity sensors, controlling primarily the heating and ventilation system. The facility does participate in an EPC program.
8. Ernest Dence Residential Estate in UK – Respective Partner: KiWi Power
The Ernest Dence Estate (see Figure 36), located in London, UK, is a large residential estate with total area of 5,923 m^2. It was constructed in 1937 and was last renovated in 2000, including installation of double glazing windows. The estate has 5 floors. It comprises of 3 separate buildings: Aylmer House (55 flats), Jennings House (20 Flats) and Gifford House (20 flats, with a total of 259 occupants. A community centre exists in a separate building in the middle of the estate. The facility has two technical rooms for the estate heating and hot water systems, housing three boilers and circulating pumps. It is managed by an external contractor. Main energy sources are natural gas and electricity, with yearly consumptions of 10,662.5 MWh and 376.3 MWh respectively. Heating is performed through a radiator system. The facility does not currently participate in an EPC or DR program. No BEMS is installed, although some lighting loads are equipped with plug meters.
A potential renovation plan includes the deployment of bulk heat meters on the 3 boilers that provide heating and domestic hot water to the estate. In addition, the Heating Interface Units

inside the flats are to be replaced with modern ones equipped with heat meters and smart thermostats. A limited number of flats (10 flat minimum) is also to have clamp on electricity meters deployed.

Figure 36. Ernest Dence Estate.

9.2 Demonstrators' Site Inventory

The above information has been condensed to generate the inventory presented in Table 29. It must be highlighted that the aforementioned list remains an active work-in-progress, subject to enhancements and modifications, mirroring the work and advancements made during the remaining tasks of WP5, as well as WP6, towards the demonstration of NOVICE business model on building retrofitting.

Table 29. Potential Demonstrators' Site Inventory.

Building ID	Type	Country	Constr. or last renov. year	Size (m^2)	Management	Energy Sources	Energy production / storage	Consumption (Annual Average)	Utility Costs (Annual Average)	Loads and Equipment Info	EPC / DR Participation
1	Hotel	Portugal	-	-	In-house FM	Electricity, Diesel	No / -	E: 1,340 MWh D: 103,745 Litres	E: € 121,326 D: € 99,058	Radiators, Air conditioning, Fluorescent Lighting	Yes / No
2	Sport Facility	-	-	-	External Contractor	Electricity	No / -	E: 386 MWh	E: € 62,600	HVAC	Yes / -
3	Multiple: Offices Wholes/Ret Restaurant Residential	Germany	2008	33,958: 18,048 5,426 2,977 5,426	External Contractor	Electricity, District heating/cooling	- / -	E: *4,204* MWh Dis: 3,327 MWh	E: € 700,000	-	- / -
4	Multiple: Offices Wholes/Ret Restaurant Residential	Germany	1994	12,281: 4,196 3,158 2,747 2,154	External Contractor	Electricity, District heating/cooling	- / -	E: *256* MWh Dis: 1,209 MWh	E: € 41,000	-	- / -
5	Multiple: Offices Wholes/Ret Restaurant Other	Germany	1996	*10,500:* *7,485* *2,254* *715*	External Contractor	Electricity, Natural Gas	- / -	E: 610 MWh G: 1,403 MWh	E: € 100,000 G: € 45,528	-	- / -
6	Brown Thomas Store	Ireland	1848/ 2016	*15,511*	In-house FM	Electricity, Natural Gas	No / No	E: 6,597,131 MWh G: 965,239 MWh	E: € 792,982 G: € 54,070	Radiators, Boilers, Air conditioning, Mixed Lighting, BEMS	No / No
7	Ballymun Leisure Centre	Ireland	2005/ 2016	4,508	In-house FM	Electricity, Natural Gas	No / No	E: 800 MWh G: 2,400 MWh	E: € 118,335 G: € 150,960	Radiators, Boilers, Air conditioning, Mixed Lighting, BEMS	Yes / No

8	Ernest Dence Estate	UK	1937/ 2000	5,923	External Contractor	Electricity, Natural Gas	No / No	E: 367.3 MWh G: 10,662.5 MWh	- -	Boilers, Fluorescent Lighting	No / No

Building ID	Short Description	Potential Renovation Plan
1	Large Hotel	HVAC – 2 new installations of air-water electric heat pumps; insulation of an existing hot water system in DWH piping; HVAC – flow control of a fan (changing Fan Coil’s valve); Lighting – replacement of internal lighting with LED; Building Controls – installation of an energy management system (EMS) to measure electricity and diesel consumption; Energy Audit as awareness campaign to educate building staff of advantages of avoiding unnecessary electricity expenses.
2	Fitness centre, wellness and swimming pool inside a mall	SEU (Efficient User System) PV Plant - A PV plant of 100kWp capacity will be built on client premises roof and energy produced by the plant will be directly consumed by the customer. The plant ownership will remain on ESCO for 7 years and the customer will pay a monthly operational lease yearly adjusted according to the actual production of the plant if it's the case. Moreover, the operational lease contract foresees a down payment by the customer and warranties (bonds) on future payments.
8	Ernest Dence Estate	A potential renovation plan includes the deployment of bulk heat meters on the 3 boilers that provide heating and domestic hot water to the estate. In addition, the Heating Interface Units inside the flats are to be replaced with modern ones equipped with heat meters and smart thermostats. A limited number of flats (10 flat minimum) is also to have clamp on electricity meters deployed.

10 Selection of Appropriate Typology Archetypes for Building Modelling and Energy Performance Simulations

The quantification of the benefits the dual energy services business model could bring into building renovation requires very detailed calculations. To perform those calculations, detailed building energy models need to be developed that allow both the assessment of energy savings and demand response services before and after renovations in existing commercial buildings. In addition, those models should be able to represent satisfactory the European commercial buildings stock. The approach that is adopted in studies of similar scope is the use of reference building models (archetypes) that supposedly can represent an adequate percentage of the overall building stock. By performing the required detailed calculations to that limited number of archetypes it can be inferred that the outputs are valid and replicable to a huge number of buildings.

For the purposes of the NOVICE project the required features of any archetypes are:

i. The time resolution of the building models is fine enough to allow calculations with respect to changes in the dynamics of the smart grid (e.g. electricity prices – hourly/subhourly timestep – or even duration of provided ancillary services – minute/subminute timestep).
ii. The description of the HVAC equipment is very detailed to allow control of individual components for the demand response services.
iii. The characterisation of the indoor environment is very detailed to allow the assessment of demand response services (e.g. load curtailment, pre-conditioning) impact on the thermal and visual comfort of occupants.

Those features determine that the archetypes models should be developed in a building simulation environment that allows dynamic calculations.

Developing a portfolio of tertiary building models for the European building stock is not an objective of NOVICE. This is a huge task that lies out of our scope. NOVICE aims to use existing building archetypes to perform detailed calculations with respect to the delivery of energy savings and demand response services that can lead to the determination of a dual energy services business model in building renovation.

In the following paragraphs two sets of commercial reference building models are described. The first one has been delivered from the US Department of Energy and is still the most comprehensive and detailed database of such reference models. The second one is the outcome of the implementation of Article 4 of the recast European Directive on the Energy Performance of Buildings (EU, 2010) from the Member Stated of the European Union. In addition, a short mention to other efforts of developing commercial building archetypes is being made. The chapter concludes with a comparison of the available archetypes using as criteria the NOVICE requirements.

10.1 U.S. Department of Energy Commercial Reference Building Models[1]

The US Department of Energy (DOE), in conjunction with three of its national laboratories (National Renewable Energy Laboratory – NREL, Pacific Northwest National Laboratory – PNNL and Lawrence Berkeley National Laboratory – LBNL), developed 16 commercial reference buildings that represent

[1] https://www.energycodes.gov/development/commercial/prototype_models

approximately 70% of the commercial buildings in the US. Those building models were developed to support research to assess new technologies; optimize designs; analyse advanced controls; develop energy codes and standards; and to conduct lighting, daylighting, ventilation, and indoor air quality studies (Deru et al, 2011).

There were three versions of the reference building models for each building type: new construction, post-1980 construction, and pre-1980 construction. All three versions share the same building form and area and the same operation schedules for all building types. The differences between the three construction periods are reflected in the insulation values, lighting levels, and HVAC equipment types and efficiencies. The new construction models comply with the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2004a), the post-1980 models meet the minimum requirements of Standard 90.1-1989 (ASHRAE 1989), and the pre-1980 models are built to a set of requirements developed from previous standards and other studies of construction practices (DOE, 2017a). ASHRAE Standard 90.1 has been a benchmark for commercial building energy codes in the United States and a key basis for codes and standards around the world and is widely used from building professionals.

Based on the initial reference building models DOE with the help from researchers in PNNL continued to support ANSI/ASHRAE/IES Standard 90.1 and IECC (International Energy Conservation Code), by updating the models to comply with the releases of the newer standards. However, this later iteration, which contains only new constructions, replaced from the original list of 16 commercial building types the Supermarket archetype with a Highrise Apartment one. This change supposedly allowed the coverage of the 80% of the commercial building floor area in the United States for new construction, including both commercial buildings and mid- to high-rise residential buildings. As Standard 90.1 and IECC continue to evolve, PNNL makes modifications to the commercial prototype building models, with extensive input from ASHRAE 90.1 Standing Standards Project Committee members and other building industry experts (DOE, 2017b).

For all iterations of the reference buildings complete descriptions for whole building energy analysis using EnergyPlus simulation software are provided. The EnergyPlus model input files are freely available for all types and versions of the reference buildings.

Table 30 depicts the main features of each building model and the availability of EnergyPlus input files for each version of the ASHRAE Standard 90.1 and IECC building code.

Table 30. DOE commercial prototype building models features and models' availability for ASHRAE Standard 90.1 and IECC versions.

Building Activity	Building Type	Total Floor Area [m^2]	Number of Floors	New Construction			Post-1980	Pre-1980
				90.1-2004	90.1-2007/2010/2013	2006/2009/2012/2015 IECC		
Office	Small Office	511	1	x	x	x	x	x
	Medium Office	4,980	3	x	x	x	x	x
	Large Office	46,321	12	x	x	x	x	x
Retail	Standalone Retail	2,294	1	x	x	x	x	x

	Strip Mall	2,090	1	x	x	x	x	x
Education	Primary School	6,871	1	x	x	x	x	x
	Secondary School	19,593	2	x	x	x	x	x
Healthcare	Outpatient Healthcare	3,804	3	x	x	x	x	x
	Hospital	22,428	5	x	x	x	x	x
Lodging	Small Hotel	4,013	4	x	x	x	x	x
	Large Hotel	11,346	6	x	x	x	x	x
Warehouse	Warehouse	4,598	1	x	x	x	x	x
Food Service	Quick-Service Restaurant	232	1	x	x	x	x	x
	Full-Service Restaurant	511	1	x	x	x	x	x
Apartment	Apartment Highrise	7,837	10	x	x	x		
	Apartment Midrise	3,131	4	x	x	x	x	x
Supermarket	Supermarket	4,181	1	x			x	x

Similarly, Figure 37 shows the shapes and forms of all 17 commercial prototype buildings.

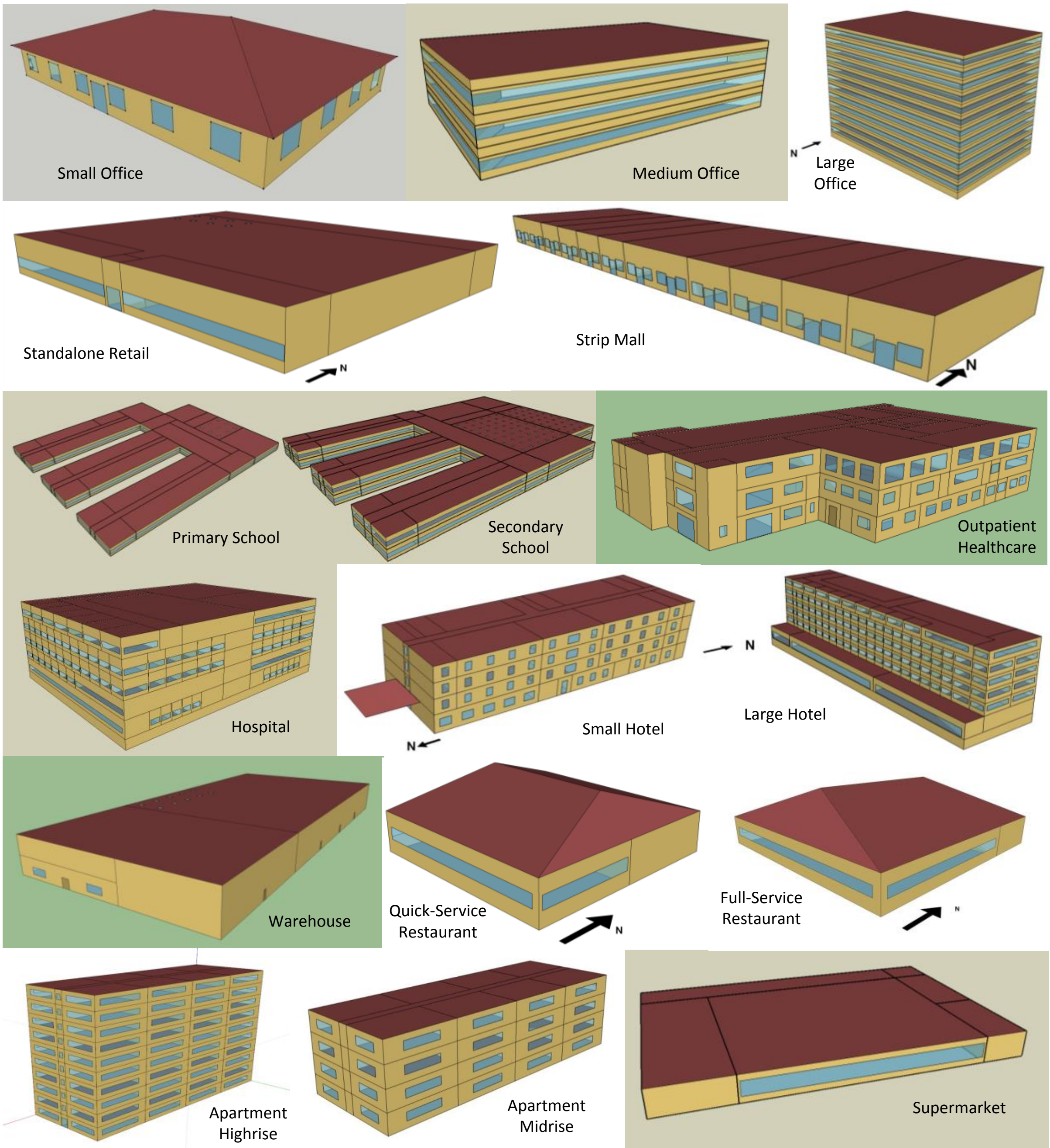

Figure 37. Building forms of DOE commercial prototype building models.

10.2 REFERENCE BUILDINGS OF COST OPTIMAL CALCULATION FOR RECAST EPBD[2]

Article 4 of the European Directive 2010/31/EU (EU, 2010) on the Energy Performance of Buildings (EPBD recast) mandated that Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels. To support that requirement the Commission published delegated Regulation No. 244/2012 (EU, 2012a) supplementing the EPBD and the accompanying associated Guidelines (EU, 2012b). The former was establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements while the latter, although not legally binding, were providing relevant additional

[2] http://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

information and were reflecting accepted principles for the required cost calculations in order to facilitate the application of the Regulation (ECOFYS, 2015).

The cost optimal assessment done by the Member States had as a prerequisite intermediate step the development of reference building to be used in the calculations. Those reference buildings were meant to represent the typical and average building stock in a certain Member State. It was recommended that reference buildings to be established either through selection of a real example representing the most typical building in a specific category or by the creation of a virtual building (archetype) which, for each relevant parameter includes the most commonly used materials and systems.

The categories and number of reference buildings that were required per category for new and renovated buildings were also described in the guidelines and are depicted in Table 31.

Table 31. Number of reference buildings to be developed by each member state per building category.

Type	New	Existing
Single Family	1	2
Apartment Block (multi-family)	1	2
Office Buildings	1	2
Educational Buildings*	1	2
Hospitals*	1	2
Hotels and Restaurants*	1	2
Sports Facilities*	1	2
Wholesale and Retail Trade Services Buildings*	1	2
Other Types of Energy Consuming Buildings*	1	2

** Reference buildings for those other non-residential categories listed in Annex I (5) to Directive 2010/31/EU were should have been developed as long as specific minimum performance requirements existed for them.*

In developing the above reference buildings, the response from Member States was diluted. In many cases they have only produced reference building models for the single family, multi-family and offices categories. In some cases, even the modelling of the multi-family buildings was limited to specific apartment units rather than the whole building. Another point of interest is that most models were developed with national static calculations software tools that are being used for energy regulations compliance and not in dynamic calculations software environments. That resulted in a limited number of input and output data with low granularity for the reference building models.

Table 32 depicts the commercial building categories for which new and existing commercial reference building models have been developed in Ireland, UK, Denmark, Cyprus and Spain.

Table 32. Commercial reference buildings features for selected Member States.

Country	Building Category	Floor Area	New	Existing	
				EE1	EE2
Ireland	Office building (AC)	1,500	x	x	x
	Office building (NV)	1,500	x	x	x
	Primary School (NV)	2,300	x	x	x

	Hotel (AC)	2,500	x	x	x
	Retail (AC)	1,250	x	x	x
UK	Office buildings (AC)	30,000	x		
	Office building (NV)	4,500	x	x	x
	Secondary School	11,500	x	x	x
	Hospital	18,500	x	x	x
	Hotels (AC)	15,200	x	x	x
	Distribution Warehouse	4,900	x	x	x
	Retail Warehouse	4,900	x		
Denmark	Office building	3,283	x	x	x
Cyprus	Office building	1,448		x	x
	Office building	2,515	x		
	Retail	412		x	
Spain	Office building	3,262		x	
	Education building	1,053		x	
	Office	5,064	x		
	Commercial building	5,544	x		
	Cultural activities building	10,237	x		
	Sports facilities	1,219	x		

AC: Air Conditioned

NV: Naturally Ventilated

EE1: Energy Efficiency Level 1

EE2: Energy Efficiency Level 2

10.3 Custom Made Archetypes

Bottom-up physics and engineering based buildings stock reference models have been used extensively to assess energy technologies, strategies and policies on their impact to the energy performance and behaviour of building stocks worldwide. That approach has been used extensively especially for residential building stocks and numerous dwelling archetypes have been developed for several countries (Lim and Zhai, 2017; Kazas et al, 2017). Particularly for the EU region within the TABULA IEE-EU project (Typology Approach for Building Stock Energy Assessment within the European programme Intelligent Energy Europe – IEE) residential building typologies have been created for 20 European countries (Lago et al, 2012).

In the tertiary building sector the development of archetypes has been very limited, less systematic and usually on an ad hoc basis. Some indicative studies that were aiming to deliver detailed building simulation models archetypes were:

- Korolija et al (2013) developed parameterized archetypal simulation models for the UK office building stock.
- Corgnati et al (2013) following the DOE benchmark building models methodology and using data from an Italian survey defined four office building simulation models that can represent the Italian office building stock.
- Similarly, Buso and Corgnati (2017) developed Italian Reference Hotels as archetypes for this building category in Italy.

There are other studies that have used reference buildings to address energy aspects of building stocks but in most cases they haven't resulted in high resolution dynamic building models.

10.4 COMPARISON OF AVAILABLE ARCHETYPES

Although the availability of reference buildings for the residential European building stock is quite high that is not the case for the tertiary buildings. The latter are scarce and even when their archetype models are present they are simplistic in their conceptualisation so as to require essential upgrade and customisation to support assessment of demand response provision from HVAC systems.

By far the most complete and detailed database of archetypes of commercial buildings is the one developed by the US DOE. However, those building models have been developed to represent a large share of the US tertiary building stock. Differences with the large variations of the tertiary building stocks in European countries are inevitable. Of course, similar differences are present even among different European countries. Selecting any archetype to represent a particular typology in a Southern European country most surely will not reflect the particular characteristics and features of the same typology building stock in a Northern European country. Thus, there are strong arguments that justify the use of the DOE reference building models for the purposes of the NOVICE project. Those are:

- The differences in the features of the different typologies of commercial buildings in Europe and US are smoothing out in the newer buildings since the last 30 years the trends in architectural styles and technologies and HVAC systems have been largely globalised and homogenised.
- The DOE archetypes models are so detailed and their input display such high granularity that are the most appropriate to be used in demand response assessment as recent studies have proven (Sehar et al, 2017).

The DOE archetypes variation – both chronological and geographical – allows an easy customisation of the models to the particularities of the European buildings counterparts with respect to their thermal features. Similarly, any other adjustment to European norms and practices (e.g. operational profiles, thermostatic preferences, HVAC systems) can be incorporated in a streamlined and standardised manner.

11 SUMMARY OF WORK

During the course of the first period for the NOVICE project, an important aspect of work pertained the evaluation of the European non-residential building stock, that leads consequently to the identification of NOVICE's demonstrator sites.

In the document, we report on the steps and work performed towards achieving these goals. The typology described in EU Directive 2010/31/EU on the energy performance of buildings was adopted as the basis for this analysis, due to its apparent suitability in terms of geographical relevance and its balanced level of detail offered.

For each building category, quantitative and qualitative analysis on various characteristics ensued, resulting in a concrete characterization of desirable building characteristics, in terms, of energy performance, age, size, EE, DR and retrofitting potential, among other parameters. This analysis was interleaved with the characterization of observed variation and particularities found in different European regions and countries, leading to the creation of region-tailored suggestions on well-suited buildings and associated characteristics, for the demonstration projects.

This examination constituted the basis for the identification of potential demonstrator sites from the portfolios of respective NOVICE partners, presented in the latter sections of this deliverable, which concludes with the description of reference and archetype buildings that are going to be utilized during the subsequent modelling and simulation stages of the project.

12 ACRONYMS

American Society of Heating Refrigeration and Air Conditioning Engineers	ASHRAE
Building Energy Management System	BEMS
Combined Cooling Heat and Power	CCHP
Demand Response	DR
Energy Efficiency	EE
Energy Efficiency Directive	EED
Energy Performance Certificates	EPC
Energy Performance of Buildings Directive	EPBD
European Union	EU
Heat Ventilation and Air-Conditioning	HVAC
International Energy Conservation Code	IECC
Information and Communication Technologies	ICT
Joint Research Centre	JRC
Nearly Zero-Energy Building	NZeB
National Renewable Energy Laboratory	NREL
Lawrence Berkeley National Laboratory	LBNL
Pacific Northwest National Laboratory	PNNL
Department of Energy	DOE

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14 APPENDIX

14.1 CALIFORNIA CODE OF REGULATIONS, TITLE 24, PART 9 - OCCUPANCY CLASSIFICATIONS

In California, USA, non-residential buildings are defined in Part 2 of Title 24 Californian Code of Regulation. Title 24 provides, to our knowledge, the most refined typology list to date. Non-residential buildings are grouped according to their function in one of the following categories, as described in (DSA, 2010; EnergyCodeAce, 2017).

- **Assembly (A) Group**

  Assembly (A) Group occupancy includes, among others, the use of a building or structure, or a portion thereof, for the gathering of persons for purposes such as civic, social or religious functions; recreation, food or drink consumption; or awaiting transportation or Motion Picture and Television Production Studio Sound Stages, Approved Production Facilities and production locations. Subcategories are:

  - A-1 Assembly uses intended for the production and viewing of performing arts or motion pictures including, but not limited to: Motion picture and television production studio sound stages, approved production facilities and production locations, motion picture and live theatres, symphony and concert halls, television and radio studios admitting an audience.
  - A-2 Assembly uses intended for food and/or drink consumption including, but not limited to: banquet halls, night clubs. Restaurants, taverns and bars.
  - A-3 Assembly uses intended for worship, recreation or amusement and other assembly uses not classified elsewhere in Group A, including, but not limited to: amusement arcades, art galleries, bowling alleys, community halls, courtrooms, dance halls (not including food or drink consumption), exhibition halls, funeral parlours, gymnasiums (without spectator seating), indoor swimming pools (without spectator seating), indoor tennis courts (without spectator seating), lecture halls, libraries, museums, places of religious worship, pool and billiard parlours, waiting areas in transportation terminals.
  - A-4 Assembly uses intended for viewing of indoor sporting events and activities with spectator seating including, but not limited to: arenas, skating rinks, swimming pools, tennis courts.
  - A-5 Assembly uses intended for participation in or viewing outdoor activities including, but not limited to: amusement park structures, bleachers, grandstands, stadiums.

- **Business (B) Group**

  Business (B) Group occupancy includes, among others, the use of a building or structure, or a portion thereof, for office, professional or service-type transactions, storage of records and accounts. Business occupancies include, but are not be limited to, the following: airport traffic control towers, ambulatory health-care facilities serving five or fewer patients, animal hospitals, kennels and pounds, banks, barber and beauty shops, car washes, civic administration, clinic-outpatient, dry cleaning and laundries, pick-up and delivery stations, self-service educational occupancies for students above the 12th grade, electronic data processing laboratories including testing, research and instruction, motor vehicle showrooms, post offices, print shops, professional services (architects, attorneys, dentists, physicians, engineers, etc.), radio and television stations, telephone exchanges, training and skill development not within a school or academic program.

- **Educational (E) Group**

  Educational (E) Group occupancy includes, among others, the use of a building or structure, or a portion thereof, by more than six persons at any one time for educational purposes through the 12th grade.

- **Factory Industrial (F) Group**

Factory Industrial (F) Group occupancy includes, among others, the use of a building or structure, or a portion thereof, for assembling, disassembling, fabricating, finishing, manufacturing, packaging, repair or processing operations that are not classified as a Group H (High-Hazard) or Group S (Storage) occupancy. Subcategories are:

- F-1 Moderate-Hazard occupancy. Factory industrial uses which are not classified as Factory Industrial F-2 Low Hazard shall be classified as F-1 Moderate Hazard and shall include, but not be limited to, the following: aircraft (manufacturing, not to include repair), appliances, athletic equipment, automobiles and other motor vehicles, bakeries, beverages over 16-percent alcohol content, bicycles, boats, brooms or brushes, business machines, cameras and photo equipment, canvas or similar fabric carpets and rugs (includes cleaning), clothing construction and agricultural machinery, disinfectants, dry cleaning and dyeing, electric generation plants, electronics engines (including rebuilding), food processing, furniture, hemp products, jute products, laundries, leather products, machinery, metals, millwork (sash and door), motion picture and television production studio, sound stages, approved production facilities and production locations (without live audiences), musical instruments, optical goods, paper mills or products, photographic film, plastic products, printing or publishing, refuse incineration, shoes, soaps and detergents, textiles, tobacco, trailers, upholstering, wood distillation, woodworking (cabinet).
- F-2 Low-hazard Occupancy. Factory industrial uses involving the fabrication or manufacturing of non-combustible materials which, during finishing, packaging or processing do not involve a significant fire hazard, shall be classified as Group F-2 occupancies and shall include, but not be limited to, the following: beverages up to and including 16-percent alcohol content, brick and masonry, ceramic products, foundries, glass products, gypsum, ice, metal products (fabrication and assembly).

- **High-Hazard (H) Group**

High-Hazard (H) Group occupancy includes, among others, the use of a building or structure, or a portion thereof that involves the manufacturing, processing, generation or storage of materials that constitute a physical or health hazard in quantities in excess of those allowed in control areas complying with Title 24 section 2703.8.3. Hazardous materials stored or used on top of roofs or canopies are classified as outdoor storage or use and comply with this code. Subcategories are:

- H-1 Group: Buildings and structures containing materials that pose a detonation hazard. Such materials shall include, but not be limited to, the following: Detonable pyrophoric materials Explosives, organic peroxides, other unclassified detonable.
- H-2 Group: Buildings and structures containing materials that pose a deflagration hazard or a hazard from accelerated burning. Such materials shall include, but not be limited to, the following: Class I, II or IIIA flammable or combustible liquids or oxidizers which are used or stored in normally open containers or systems, or in closed containers or systems pressurized at more than 15 pounds per square inch, combustible dusts, cryogenic fluids, flammable gases, non-detonable pyrophoric liquids, solids and gases, non-detonable unstable (reactive) materials, water-reactive material.
- H-3 Group: Buildings and structures containing materials that readily support combustion or that pose a physical hazard. Such materials shall include, but not be limited to, the following: Class I, II or IIIA flammable or combustible liquids that are used or stored in normally closed containers or systems pressurized at 15 pounds per square inch or less, combustible fibres, consumer fireworks, oxidizing cryogenic fluids, flammable solids, class II and III organic peroxides.

- H-4 Group: Buildings and structures which contain materials that are health hazards. Such materials shall include, but not be limited to, the following: corrosives, toxic and highly toxic materials.
- H-5 Group. Semiconductor fabrication facilities and comparable research and development areas in which hazardous production materials are used and the aggregate quantity of materials is in excess of those listed in Title 24 Tables 2703.1.1(1) and 2703.1.1(2).

❖ **Institutional (I) Group**

Institutional (I) Group occupancy includes, among others, the use of a building or structure, or a portion thereof, in which people are cared for or live in a supervised environment, having physical limitations because of health or age, are harboured for medical treatment or other care or treatment, or in which people are detained for penal or correctional purposes or in which the liberty of the occupants is restricted. Institutional occupancies shall be classified as Group I-2, I-3 or I-4 (Restraint shall not be permitted in any building except in Group I-3 occupancies constructed for such use):

- I-1 Group: Not used.
- I-2 Group: This occupancy shall include buildings and structures used for medical, surgical, psychiatric, nursing or custodial care for persons who are not capable of self-preservation or classified as non-ambulatory or bedridden. This group shall include, but not be limited to, the following: child care facilities, detoxification facilities, hospitals, mental hospitals, nursing homes.
- I-2.1 Group: Ambulatory healthcare facility. A healthcare facility that receives persons for outpatient medical care that may render the patient incapable of unassisted self-preservation and where each tenant space accommodates more than five such patients.
- I-3 Group: This occupancy shall include buildings or portions of buildings and structures which are inhabited by one or more persons who are under restraint. An I-3 facility is occupied by persons who are restrained. This group shall include, but not be limited to, the following: correctional centres, detention centres, jails, juvenile halls, prisons, reformatories.
- I-4 Group: Day-care facilities. This group shall include buildings and structures occupied by persons of any age who receive custodial care for less than 24 hours by individuals other than parents or guardians, relatives by blood, marriage, or adoption, and in a place other than the home of the person cared for. A facility such as the above with six or fewer clients shall be classified as Residential. Places of worship during religious functions are not included.

❖ **Mercantile (M) Group**

Mercantile (M) Group occupancy includes, among others, the use of a building or structure or a portion thereof, for the display and sale of merchandise, and involves stocks of goods, wares or merchandise incidental to such purposes and accessible to the public. Mercantile occupancies shall include, but not be limited to, the following: department stores, drug stores, markets, motor fuel-dispensing facilities, retail or wholesale stores, sales rooms.

❖ **Storage (S) Group**

Storage (S) Group S occupancy includes, among others, the use of a building or structure, or a portion thereof, for storage that is not classified as a hazardous occupancy. Subcategories are:

- S-1 Moderate-hazard storage: Buildings occupied for storage uses that are not classified as Group S-2, including, but not limited to, storage of the following: aerosols, cloth, burlap and paper bags, bamboos and rattan baskets, belting, books and paper in rolls or packs, boots and shoes, buttons, including cloth covered, pearl or bone, cardboard and cardboard boxes, woollen clothing, wearing apparel, cordage, furniture, furs, glues, grains, horns and combs, leather, linoleum, lumber, photo engravings, resilient flooring, silks, soaps, sugar, tires, bulk storage of tobacco, cigars, cigarettes and snuff, upholstery and mattresses, wax, candles.

- S-2 Low-hazard storage: S-2 includes, among others, buildings used for the storage of non-combustible materials such as products on wood pallets or in paper cartons with or without single thickness divisions; or in paper wrappings. Such products are permitted to have a negligible amount of plastic trim, such as knobs, handles or film wrapping. Storage uses shall include, but not be limited to, storage of the following: asbestos, beverages up to and including 16-percent alcohol, metal, glass or ceramic containers, cement in bags, chalk and crayons, dairy products in non-waxed coated paper containers, dry cell batteries, electrical coils, electrical motors, empty cans, food products, foods in non-combustible containers, fresh fruits and vegetables in non-plastic trays or containers. frozen foods, glass, ivory, meats, metal cabinets metal desks, mirrors, porcelain and pottery, stoves, talc, stones, washers and dryers.

- **Miscellaneous (U) Group**

  Miscellaneous (U) Group buildings and structures of an accessory character and miscellaneous structures not classified in any specific occupancy are to be constructed, equipped and maintained to conform to the requirements of the code commensurate with the fire and life hazard incidental to their occupancy. Group U shall include, but not be limited to, the following: agricultural buildings, aircraft hangars, accessory to a one- or two-family residence, barns, carports, fences, high grain silos, greenhouses, livestock shelters, private garages, retaining walls, sheds, stables tanks, towers.

14.2 Building Stock Characteristics – Supplementary Figures

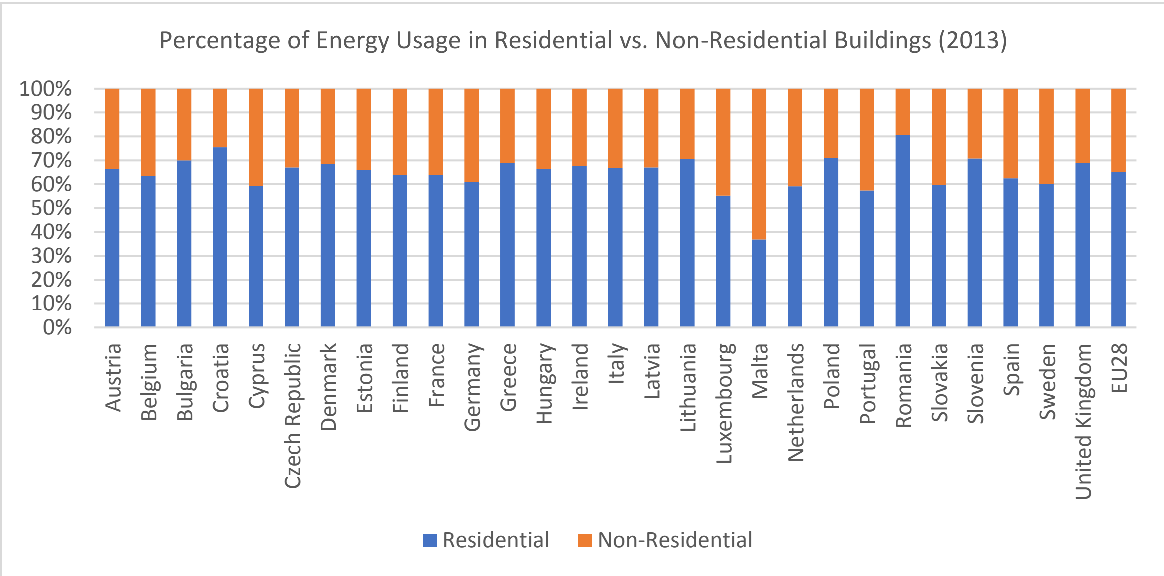

Figure 38. Distribution of Energy Consumption for Residential and Non-Residential Buildings in Europe. Source (EC, 2017)

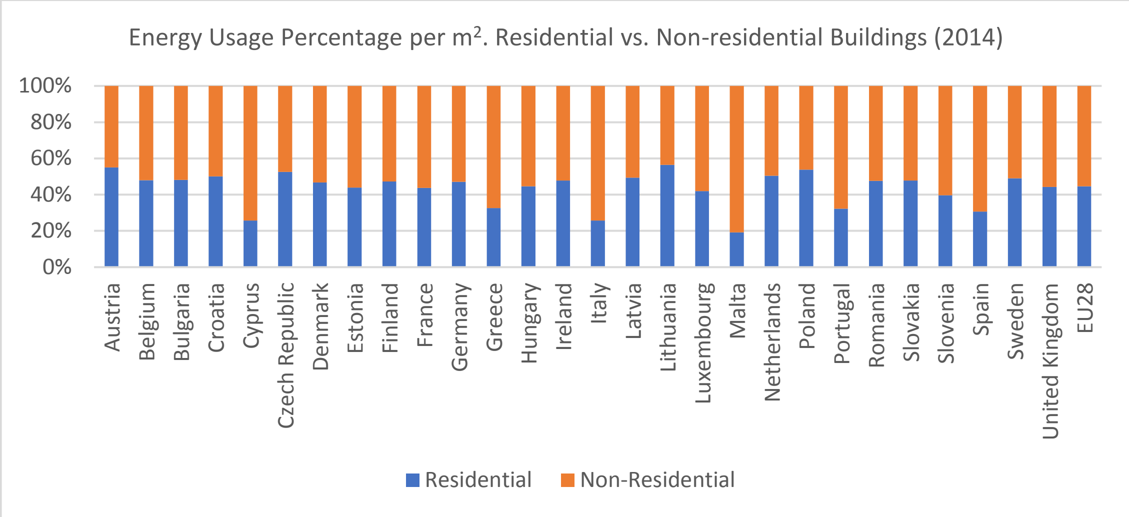

Figure 39. Residential vs. Non-residential energy usage percentage per m². Source (EU 2016b)

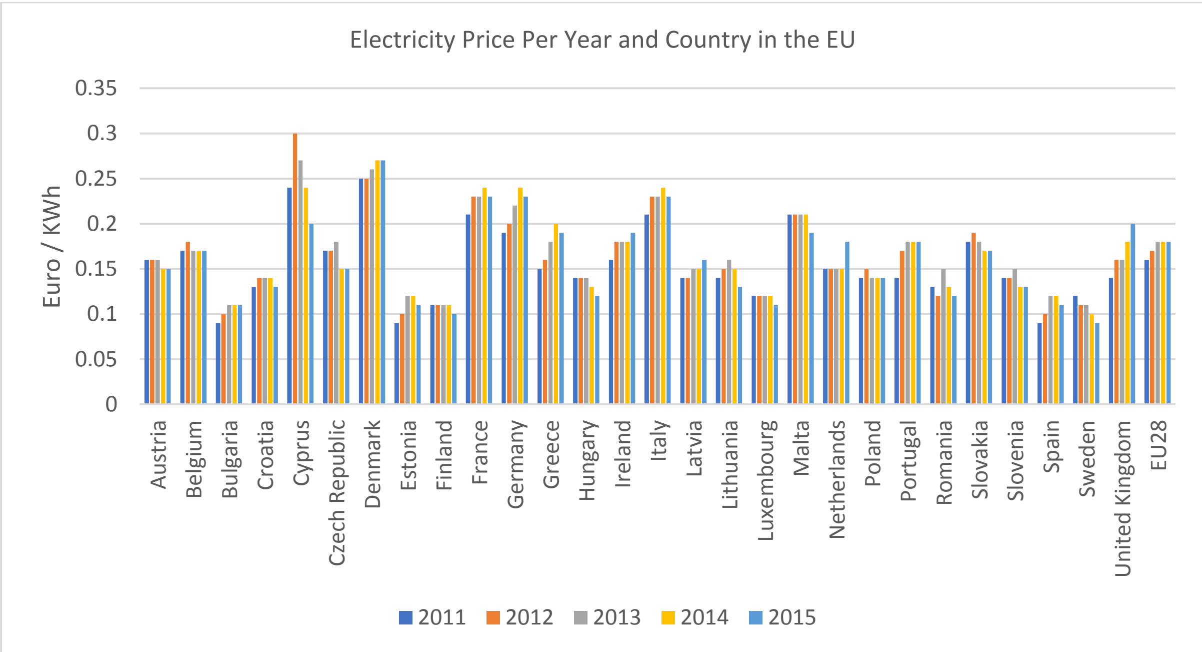

Figure 40. Electricity Price Per Year and Country in the EU. Source (EU 2016b)

Table 33. Average building sizes per type and country in the EU. Source (EC, 2017).

Country	Offices	Educational	Health care	Hotels and Restaurants	Wholesale and retail
Austria	1429.813665	1951.079137	448.9795918	814.3459916	979.3783622
Belgium	1028.579594	1478.879502	449.3355482	2171.938362	1397.305291
Bulgaria	1268.015795	1479.338843	449.2753623	2173.61894	1396.99014
Croatia	343.0531732	1061.052632	442.9928741	538.723985	61.02212052
Cyprus	343.2601881	1057.142857	431.8181818	537.9188713	60.85753804
Czech Republic	984.3440705	1478.905359	449.197861	2172.861357	1397.212544
Denmark	733.366435	1128.929142	1773.504274	444.0583739	1845.800525
Estonia	315.4897494	2057.692308	1396.449704	609.2592593	675.9581882
Finland	287.8652355	2055.11811	1397.887324	608.7484812	674.2388759
Germany	2181.660782	1478.743068	449.2729946	2172.294782	1397.428731
Greece	343.0305567	1059.608541	442.1768707	538.7509406	60.95661205
Hungary	1088.620514	1478.777589	449.339207	2172.240803	1397.326402
Ireland	935.075541	1478.409091	449.1129785	2171.968191	1397.590361
Italy	137.8693147	1172.779136	406.9997799	249.0619613	57.7621079
Latvia	903.4965035	1693.975904	1541.666667	479.2079208	534.4673232
Lithuania	288.4657474	2056.198347	1398.843931	611.2852665	674.0467405
Luxembourg	901.8691589	1480.769231	448.9795918	2173.913043	1399.141631
Malta	342.5605536	1064.516129	437.5	542.2535211	61.39438085
Netherlands	756.8609454	1283.145275	1661.980082	3359.285714	1889.428571
Poland	290.9895986	2055.297065	1398.137369	608.7142247	674.2233692
Portugal	343.1287813	1059.505799	442.8746929	538.961039	60.96985808
Romania	63.2569077	275.2047444	176.4899031	157.7163712	168.9512531
Slovenia	343.1952663	1060.498221	443.75	538.7673956	60.97333582
Spain	343.1092289	1059.899117	442.7501338	538.7819373	60.96374753
Sweden	283.7408023	2055.05279	1397.551546	609.4674556	674.1632914
United Kingdom	289.6917839	2055.18018	1398.023715	609.0415059	674.2185633
EU28	695.0685414	1433.809281	765.4977872	880.9142661	338.1838482

14.3 Building typology and Construction Period distribution in Individual European countries

The following figures present age-related characteristics of the different non-residential building types for various European countries extracted from an ECOFYS report (Schimschar et al. 2011) and the RePublic_ZEB project (Radulov & Kaloyanov 2014).

1. Hungary

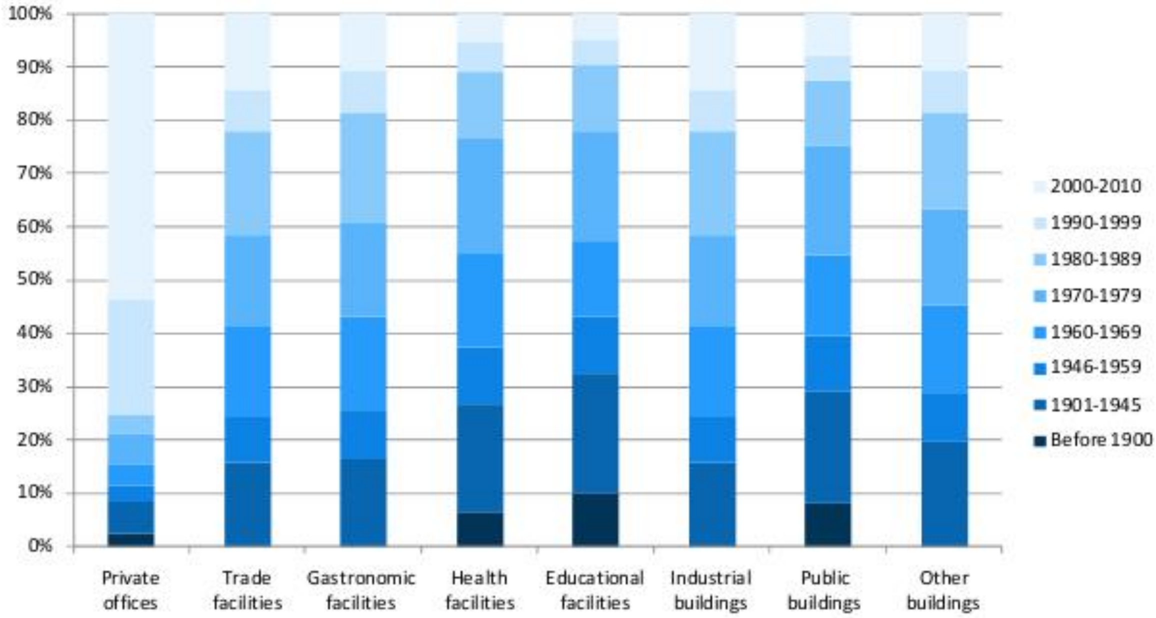

Figure 41. Distribution of non-residential floor area by building type and construction period in Hungary. Source (Schimschar et al. 2011)

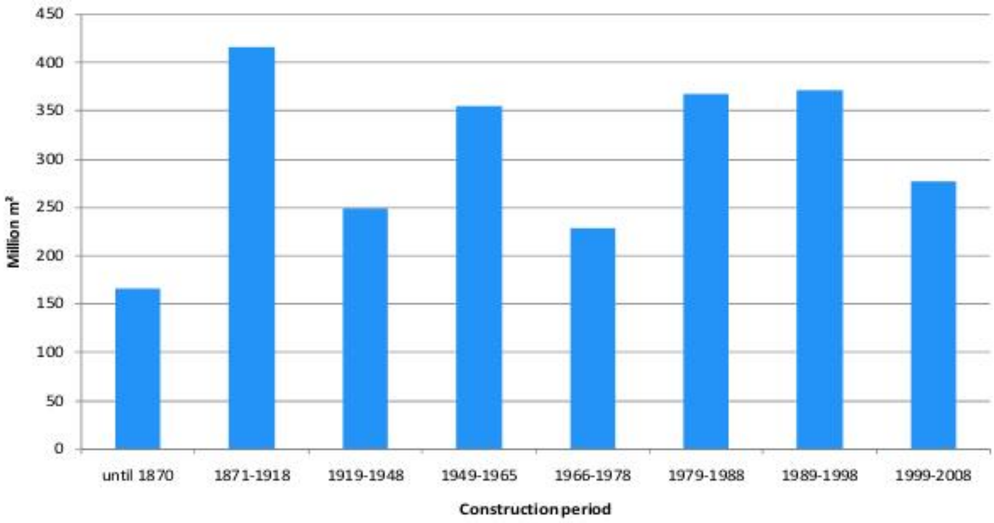

Figure 42. Total non-residential floor area by construction period in Hungary. Source (Schimschar et al. 2011)

2. Poland

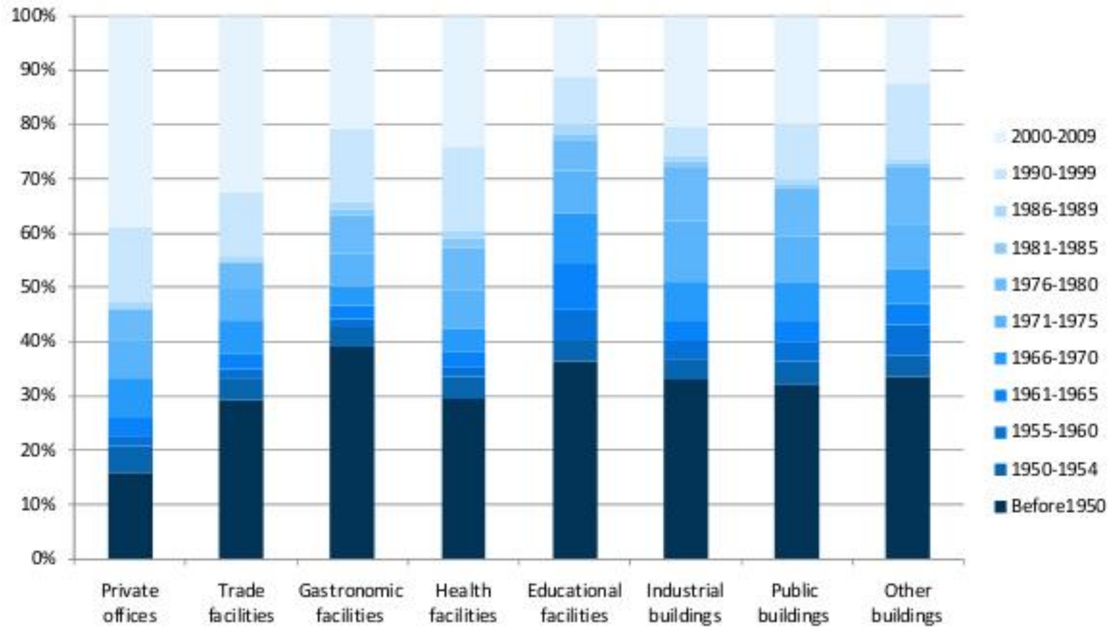

Figure 43. Distribution of non-residential floor area by building type and construction period in Poland. Source (Schimschar et al. 2011)

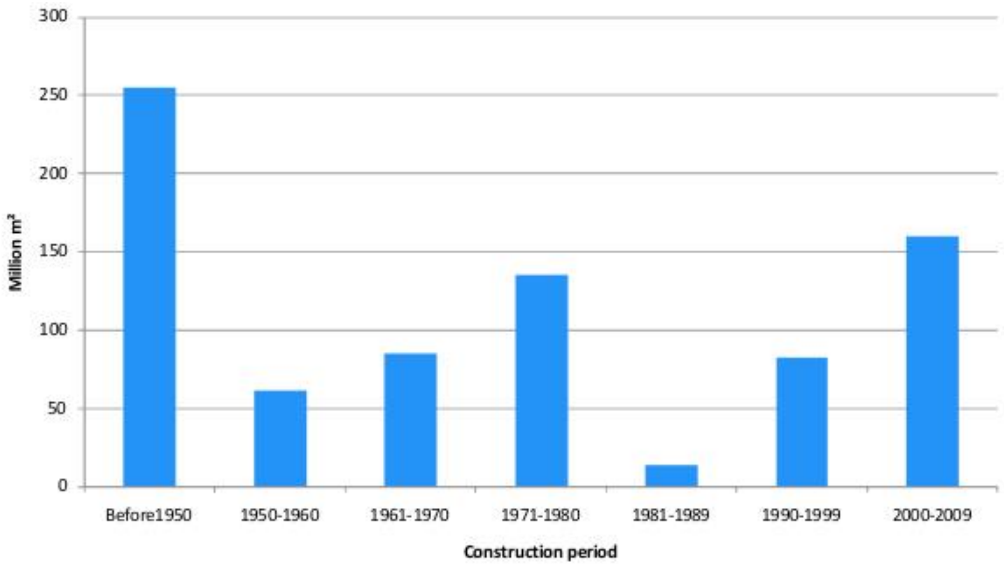

Figure 44. Total non-residential floor area by construction period in Poland. Source (Schimschar et al. 2011)

3. Spain

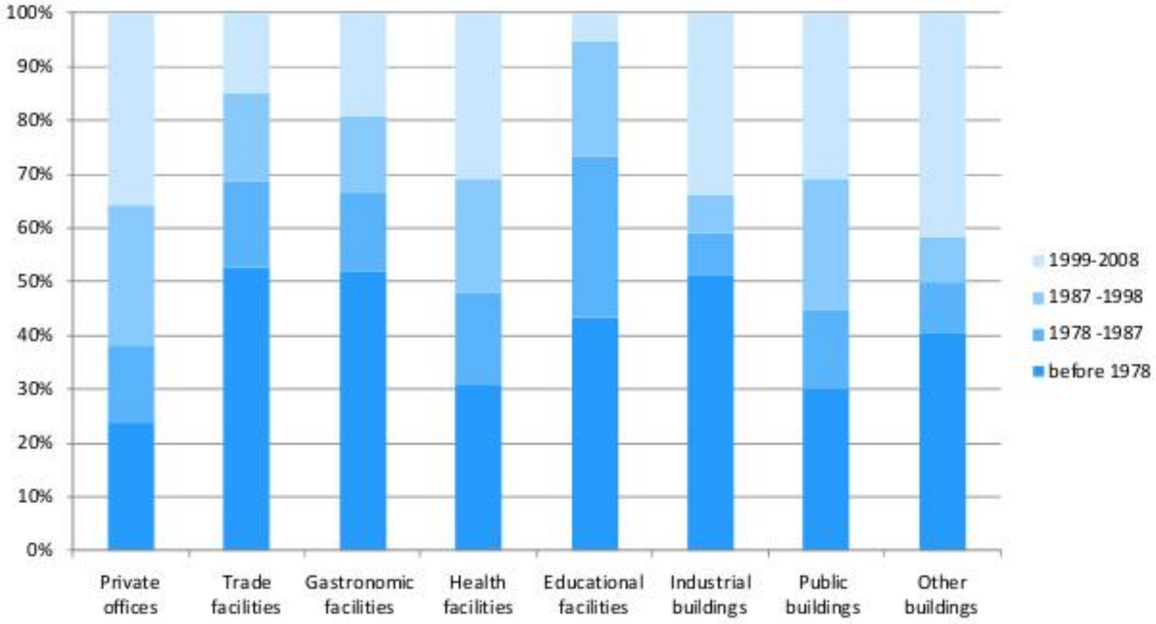

Figure 45. Distribution of non-residential floor area by building type and construction period in Spain. Source (Schimschar et al. 2011)

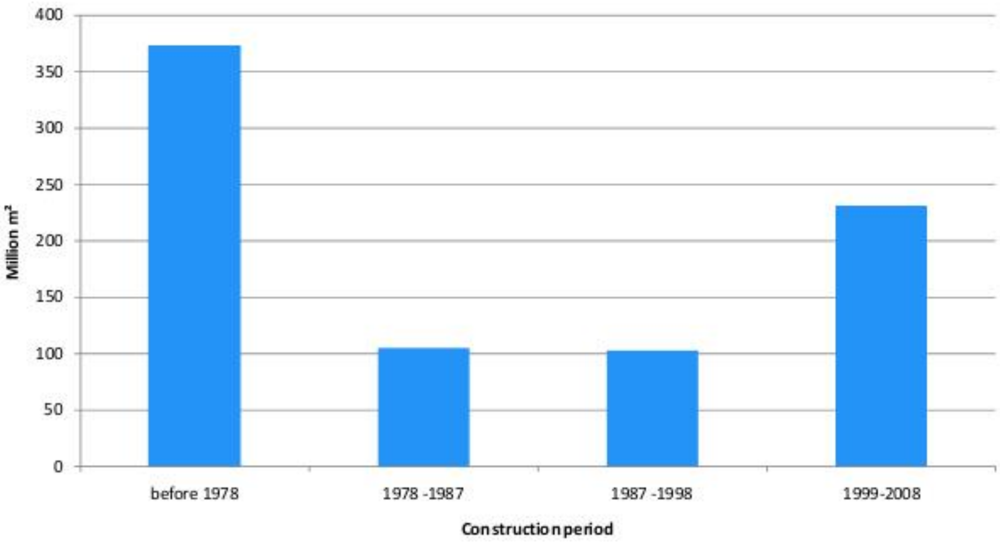

Figure 46. Total non-residential floor area by construction period in Spain. Source (Schimschar et al. 2011)

4. Sweden

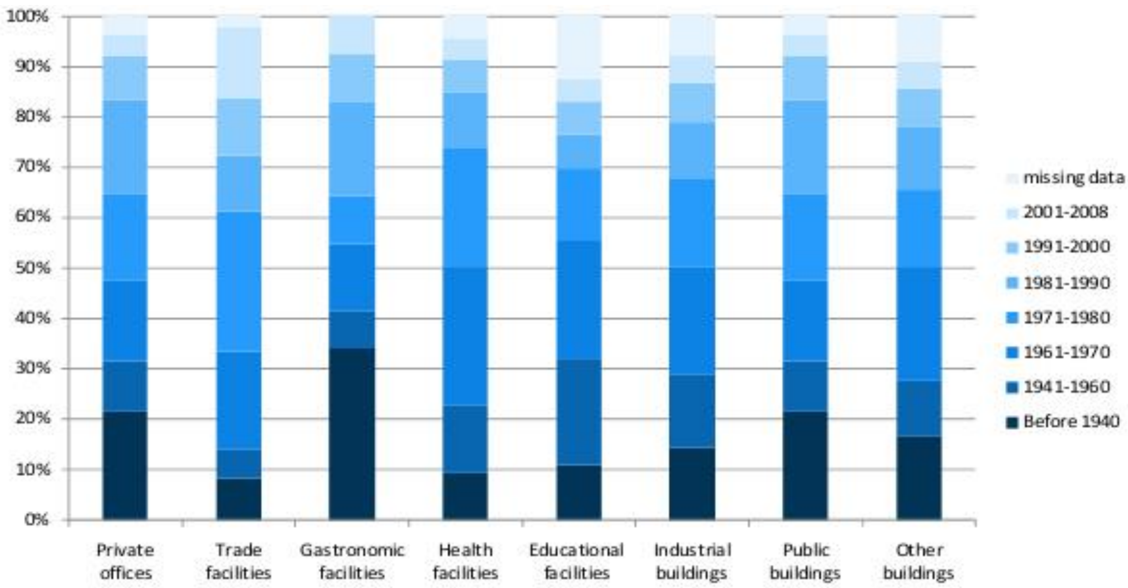

Figure 47. Distribution of non-residential floor area by building type and construction period in Sweden. Source (Schimschar et al. 2011)

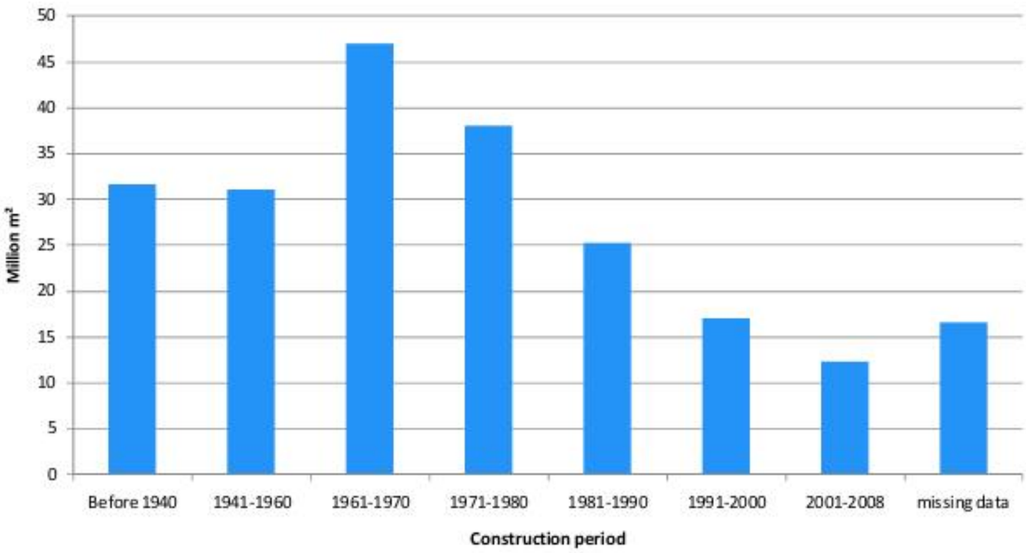

Figure 48. Total non-residential floor area by construction period in Sweden. Source (Schimschar et al. 2011)

5. Germany

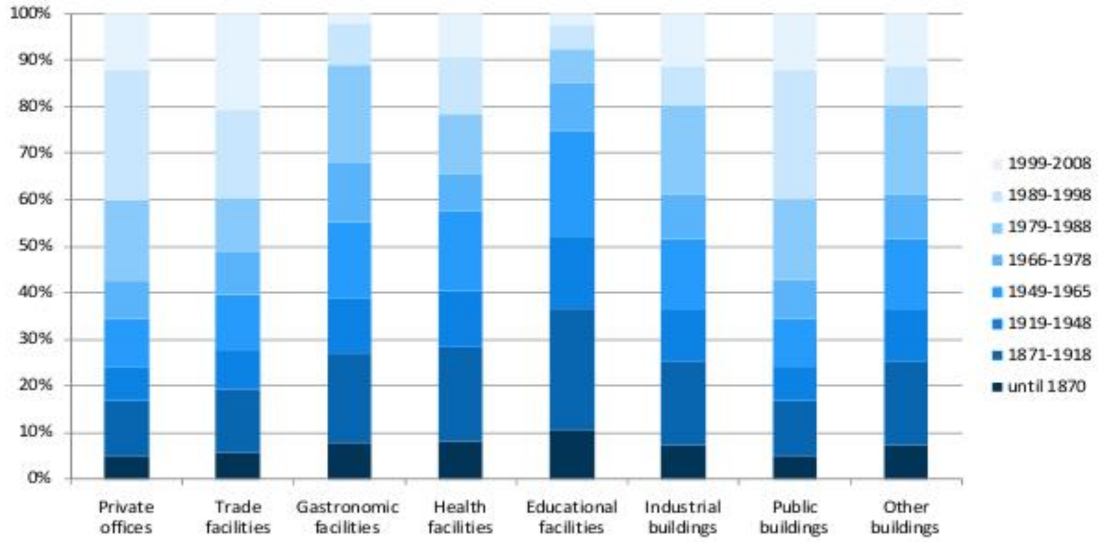

Figure 49. Distribution of non-residential floor area by building type and construction period in Germany. Source (Schimschar et al. 2011)

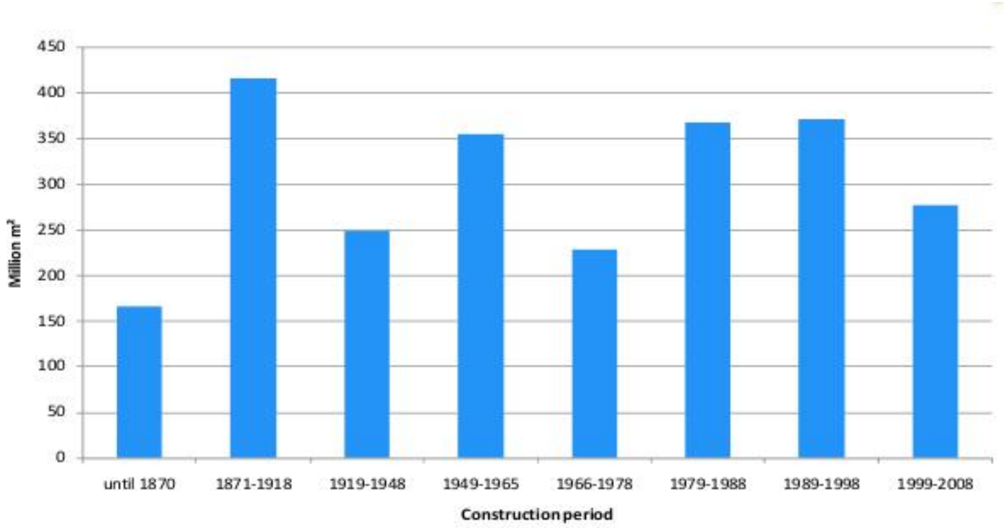

Figure 50. Total non-residential floor area by construction period in Germany. Source (Schimschar et al. 2011)

6. Romania

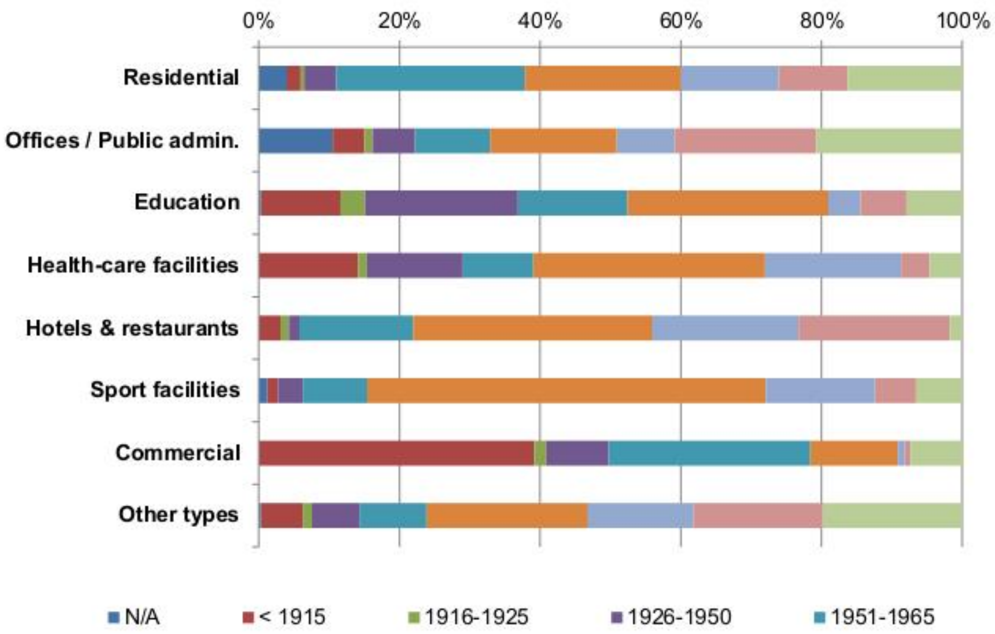

Figure 51. Distribution of non-residential floor area by building type and construction period in Romania. Source (Radulov & Kaloyanov 2014)

7. Greece

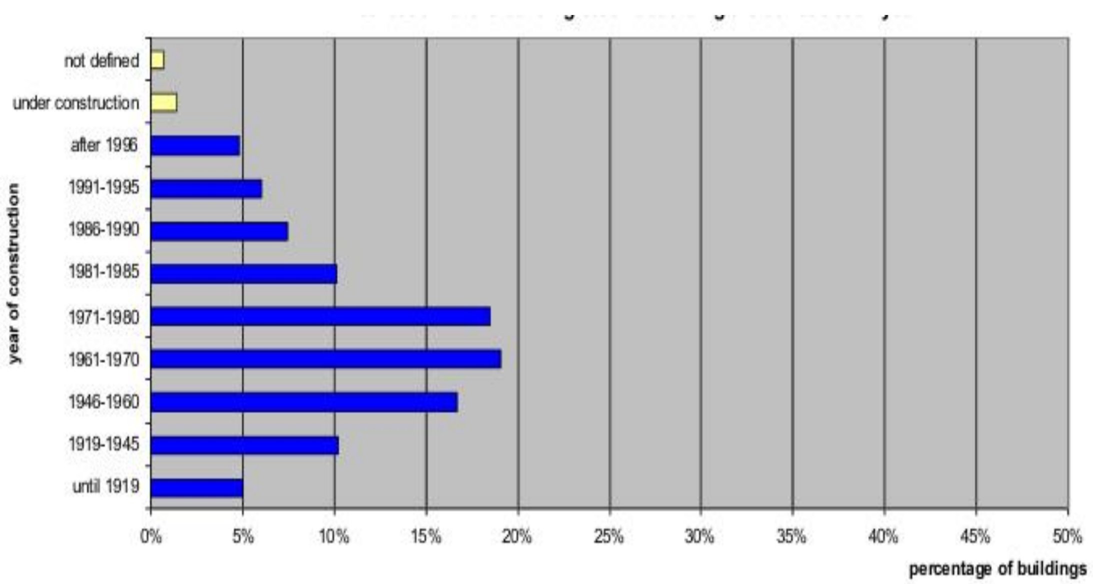

Figure 52. Distribution of non-residential floor area by building type and construction period in Greece. Source (Radulov & Kaloyanov 2014)

8. Portugal

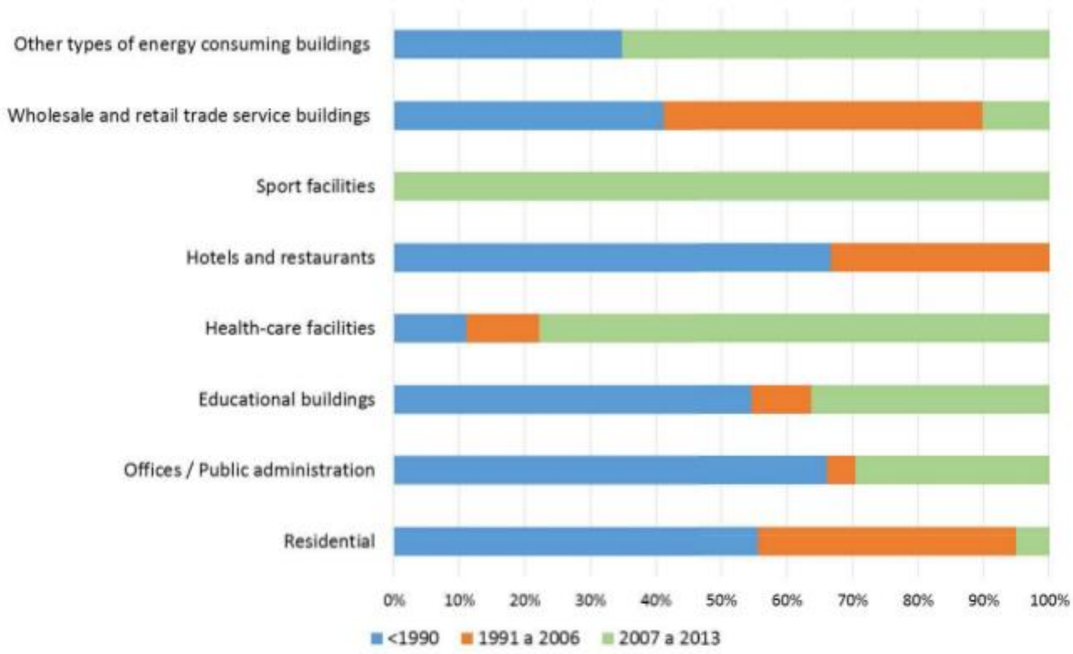

Figure 53. Distribution of non-residential floor area by building type and construction period in Portugal. Source (Radulov & Kaloyanov 2014)

9. Bulgaria

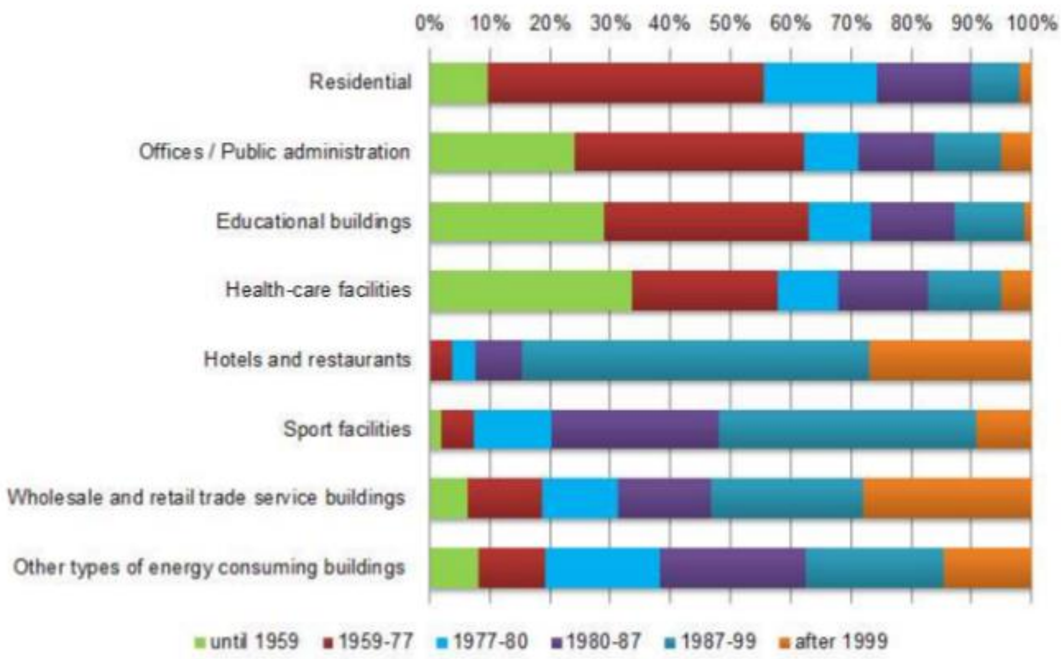

Figure 54. Distribution of non-residential floor area by building type and construction period in Bulgaria. Source (Radulov & Kaloyanov 2014)

14.4 Building typology and Energy Consumption Purposes For Southern European countries

1. Bulgaria

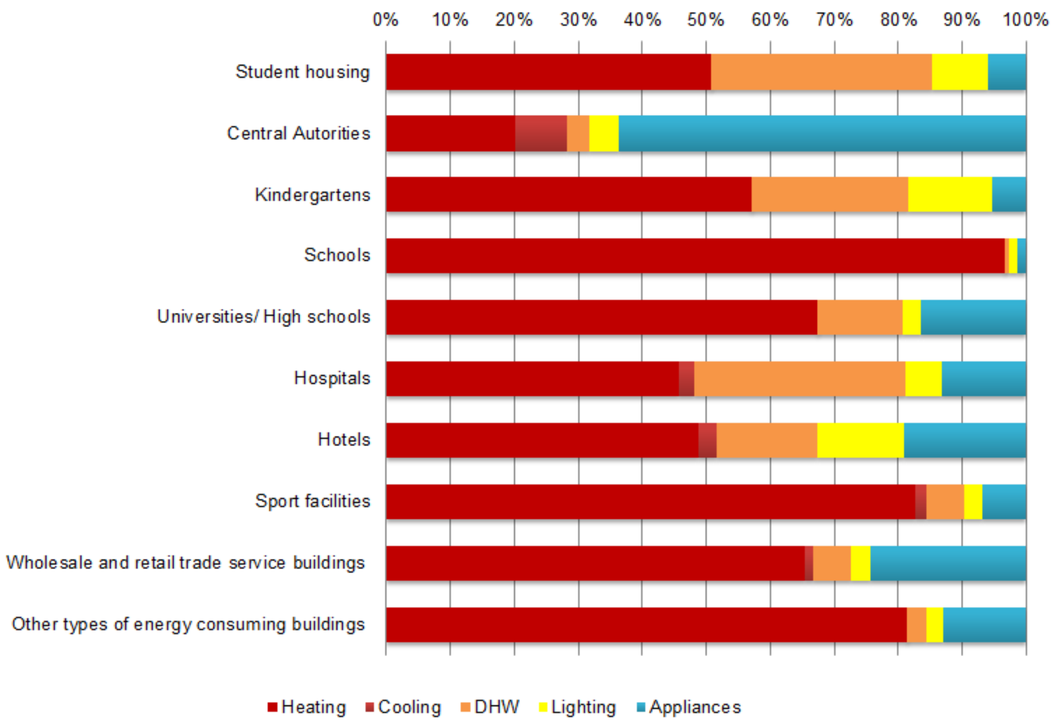

Figure 55. Share of the energy consumption for different building types and energy purposes in Bulgaria. Source (Radulov & Kaloyanov 2014)

2. Croatia

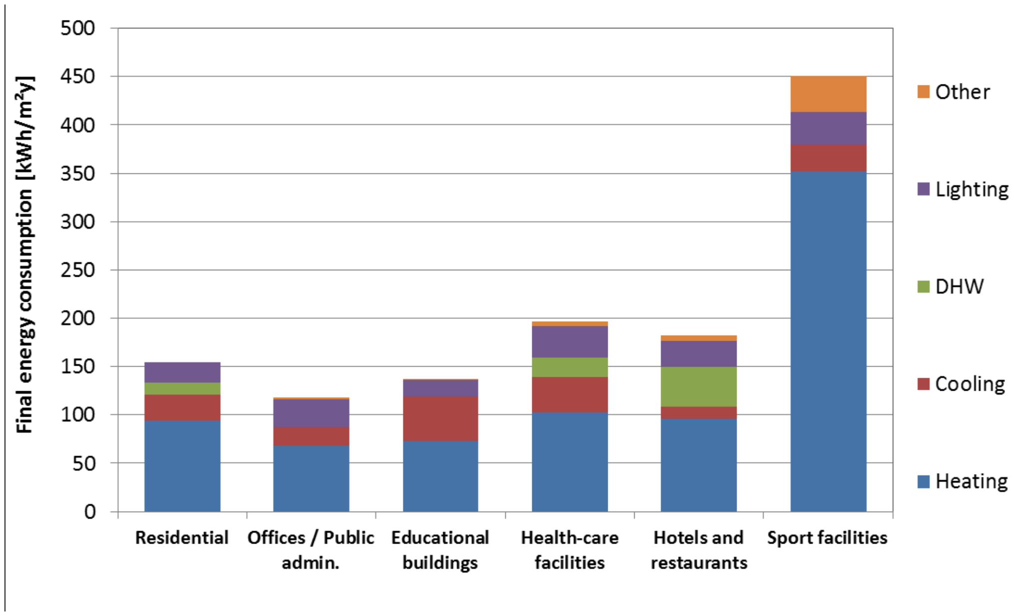

Figure 56. Share of the energy consumption for different building types and energy purposes in Croatia. Source (Radulov & Kaloyanov 2014)

3. Romania

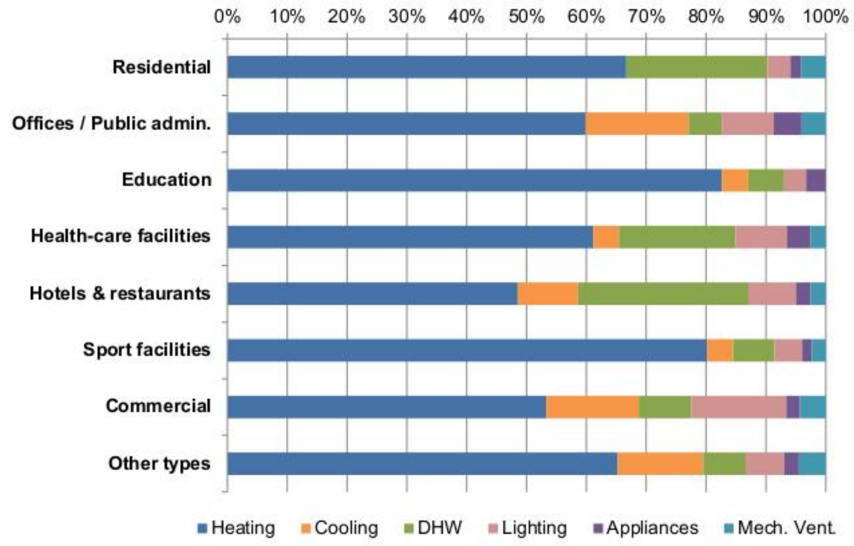

Figure 57. Share of the energy consumption for different building types and energy purposes in Romania. Source (Radulov & Kaloyanov 2014)

4. Spain

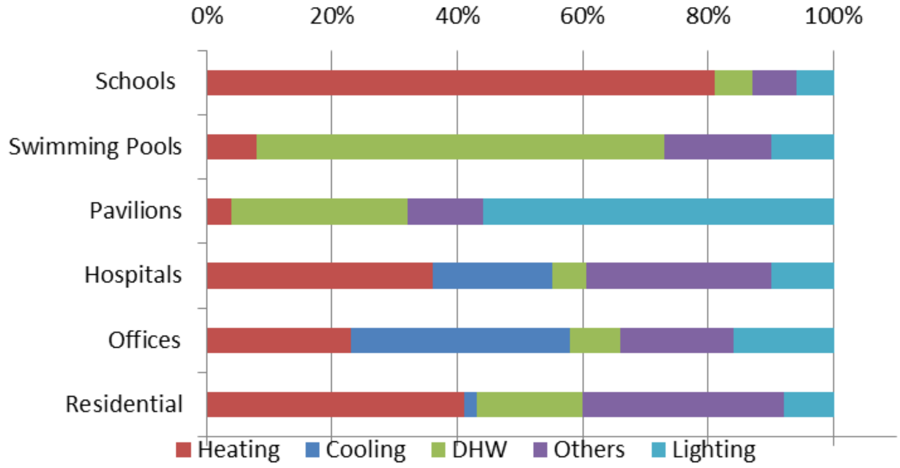

Figure 58. Share of the energy consumption for different building types and energy purposes in Spain. Source (Radulov & Kaloyanov 2014)

5. Greece

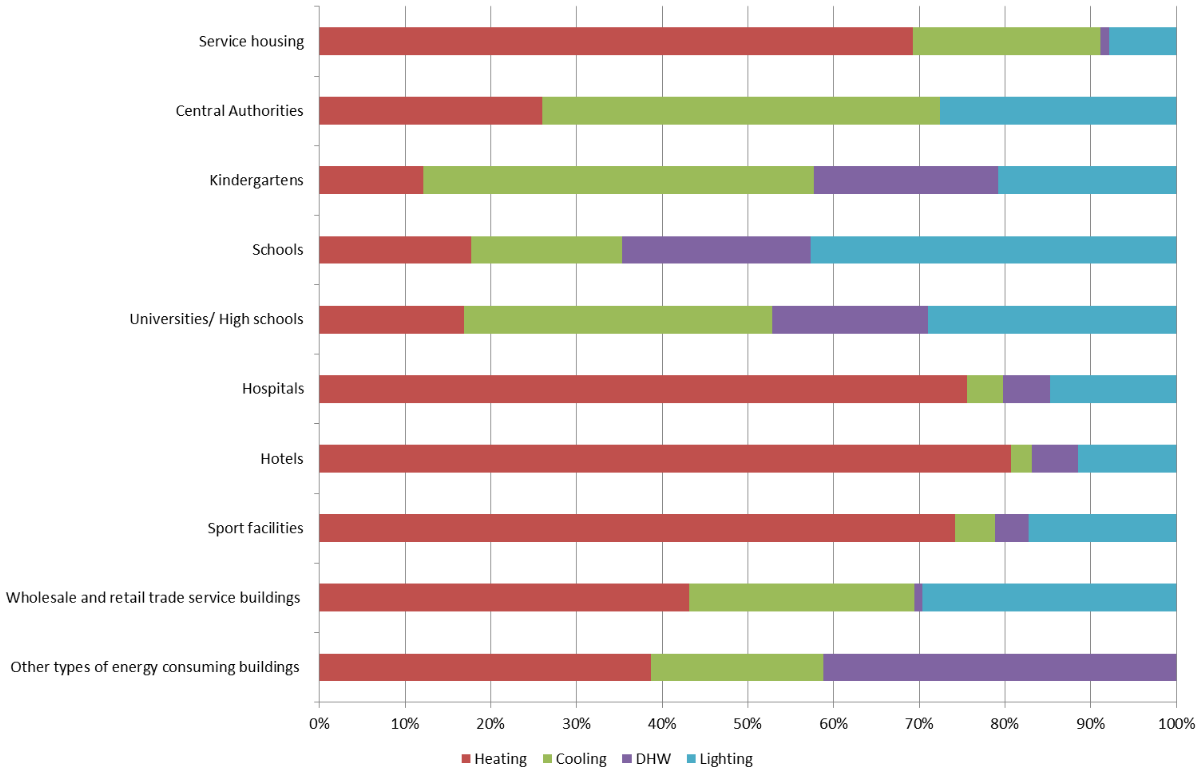

Figure 59. Share of the energy consumption for different building types and energy purposes in Greece. Source (Radulov & Kaloyanov 2014)

6. Portugal

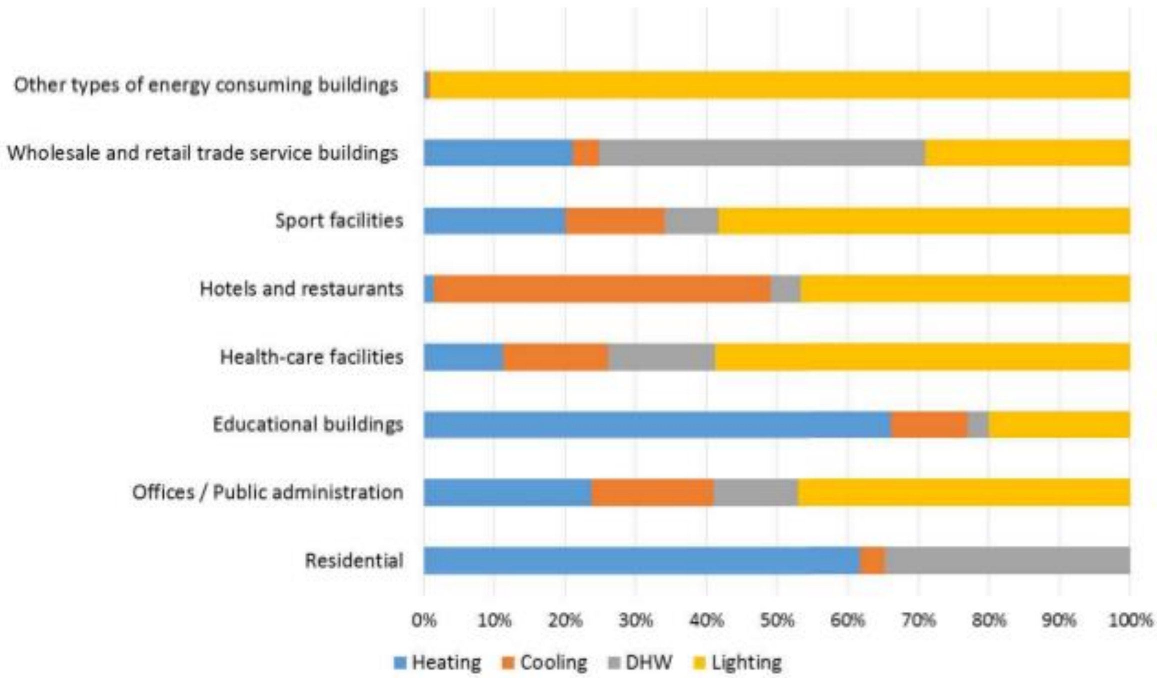

Figure 60. Share of the energy consumption for different building types and energy purposes in Portugal. Source (Radulov & Kaloyanov 2014)