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## Energy demand benchmarking of non-domestic buildings in Scotland.

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**Abstract**— Over the years building energy performance has become a predominant concern for owners and real estate managers. The focus is usually on residential buildings but in the last twenty years an interest in non-domestic buildings has emerged in the UK. Benchmarks can generally be found at UK scale, although often restricted to England and Wales. This paper aims to provide benchmarks for the Scottish non-domestic building stock as part of the City of Edinburgh Council estate. In this research, the selected sample includes energy data and calculated carbon emissions of 199 buildings. The deciding parameters were the energy use intensity (kWh/m<sup>2</sup>) and the use and age of buildings. The last two allowed the creation of six clusters in which to group buildings of similar occupancy patterns in four age categories from the 16th to the 21st century. The main findings reveal the predominance of an educational buildings cluster in terms of floor area (72%), number of buildings (70%), carbon emissions (68% of about 42,000 tons of CO<sub>2</sub>), and energy consumption (61% of the 38.4 MWh of electricity consumed, and 73% of the 117.4 MWh of natural gas consumed). These levels of consumption highlight the energy saving potential for schools: 186 kWh/m<sup>2</sup>/year on average, in comparison with the European average of 100 kWh/m<sup>2</sup>/year for thermal end-use energy.

**Index Terms**— Non-domestic; Energy demand; Benchmarking; Scotland;

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### I. INTRODUCTION

**A** GROWING PUBLIC awareness of the need for a more responsible society has been the driving factor for new policies at various levels (European, national and regional), aiming to achieve prolonged sustainable urban development. Since the first release of the European Energy Performance of Buildings Directive (EPBD) in 2002 and its recast in 2010 (EU Parliament, 2010), the construction industry has been under constant pressure to produce more energy-efficient

buildings. In Scotland, the Climate Change Act (Scottish Parliament, 2009) has set a greenhouse gas emissions reduction target of 42% by 2020, and in 2010 the publication of “Conserve and Save: The Energy Efficiency Action Plan for Scotland” set a 12% target reduction of energy (end-use) consumption by 2020 (Scottish Government, 2010). In 2011, Edinburgh City Council demonstrated its commitment to this with the release of “Sustainable Edinburgh 2020”. Ambitious targets for a 40% cut in carbon emissions were set, including a 12 % energy efficiency improvement across all sectors (City of Edinburgh Council, 2011). It is anticipated that part of this cut will come from new building construction. However, a cost-effective way of reducing emissions is to retrofit the existing estate (Bull et al., 2014)

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University and the City of Edinburgh Council (CEC). The project aims to define mid- and long-term strategies and procedures to reduce energy demand and carbon emissions in non-domestic public building across the Council’s estate. CEC is targeting budget reductions and will be continuing to review its estate and the delivery of services over the next few years. Nevertheless, for practical purposes, the project’s output will be a methodology for assessing various buildings: performing economic and life cycle assessment prior to taking adequate measures for refurbishment purposes. Low carbon refurbishment and the development of energy-saving strategies require knowledge of the building stock. This preliminary study informs the systematic data collection by profiling the non-domestic building types and by benchmarking the non-domestic buildings’ fuel consumption. The first part presents the context by going through the literature review, then the methodology is presented, explaining how the council’s estate was investigated and analysed. Subsequently results are presented, first as clusters, then consumption and environmental impacts; these are discussed in the final section. is a template for Microsoft *Word* versions 6.0 or later.

## II. LARGE SCALE BENCHMARKING

Non-domestic buildings in the UK account for about 20% of the energy consumption and carbon emissions (Choudhary, 2012). The wide variety of non-domestic buildings and the heterogeneity of their use raise difficulties for performing large scale benchmark analysis (Tian & Choudhary, 2012). Pérez-Lombard et al. (2008) outlines the lack of a general consensus over building typology. However the authors differentiated commercial buildings by their use as shown in Table 1. This characterisation by use pattern is appropriate to describe building utilisation where energy figures are derived from similar energy demand profiles. Bruhns, Steadman, & Herring (2000) used a primary classification to organise data for a UK-wide non-domestic buildings database, also based on the building use.

Conversely, Gao (2014) explains the danger of ignoring other building features and characteristics, as this may lead to the assessment of non-comparable buildings. The author recommends a ‘K-means’ clustering approach. This method allows the creation of categories taking into account various parameters which have an influence on the energy use intensity (EUI). However this method requires a data refinement level which could not be reached in this study for data availability reasons.

TABLE I  
ENERGY DEMAND OF NON-DOMESTIC PROPERTIES PER BUILDING TYPE

Building Use	UK Energy Use (%)
Retail	22
Offices	17
Hotels and restaurants	16
Schools	10
Hospitals	6

Leisure	6
Others	23

(Pérez-Lombard, Ortiz and Pout, 2008)

In order to assess how a building performs in terms of energy intensity use, it must be compared to similar buildings using a common metric (Thewes et al., 2014). As identified per Aksoezen et al. (2015) top-down and bottom-up models have been largely used in the past to describe building stocks. Hong et al. (2013) explained the differences between top-down and bottom-up approaches. They are both used in engineering to perform system analysis. Bottom-up analysis starts at sub-system level to develop and establish a more general overview. On the other hand top-down analysis captures the system globally and breaks it down to sub-systems to reach the wanted level of accuracy. As for buildings’ energy consumption, the EUI appears to be the common metric employed for top-down approach benchmarks (Hong et al., 2013). Generally used to compare buildings with peers, it also can be used as an incentive for energy efficiency improvement by applying public pressure (Chung, 2011).

## III. METHODOLOGY

### A. Energy Use Intensity & Sample selection

The Council being aware of the requirement to manage and reduce energy effectively, engaged in the KTP project in order to develop a roadmap towards energy efficiency improvements across the estate. The scope of this study aims to evaluate non-domestic buildings’ energy use. However, user’s diversity and building form compose a distinct heterogeneous property type which ought to be considered. Non-domestic buildings are defined as being buildings which accommodate public services, businesses or factories. In comparison with domestic buildings, non-domestic properties belong to the tertiary sector (Mata, Sasic Kalagasidis, & Johnsson, 2014). The primary source of data is a building information database used predominantly by the Council for maintenance and asset management purposes. This data was first analysed using a Microsoft Excel VBA macro application which is a useful tool based on text recognition and identification. It was used to extract and display various building parameters and features, such as floor area, age, energy demand, and the existence of a building management system. In this study the datasets consist mainly of building age, floor areas and EUIs (kWh/m<sup>2</sup>). Floor space was set as gross internal area as this was the most reliable data source. The initial property list contained 535 entries including locations without buildings but part of the urban realm such as street lighting, monuments, parks and clocks. These were subsequently removed from the sample as they do not contribute to the estates EUI. The remaining list includes any non-domestic building still owned by CEC and in use during the year 2013/2014. Additionally, buildings were removed from the sample if the quality of energy data was deemed to be unreliable. Similarly, buildings mainly heated by electricity were not included, as their consumption pattern would require



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a specific analysis. As a result the final sample size consisted of 199 buildings.

## *B. Archetypes*

Following Pérez-Lombard et al. (2008) and Bruhns et al. (2000) approach, this research consisted in categorising buildings by their use, based on a Chartered Institution of Building Services Engineers (CIBSE) refurbishment guide (CIBSE, 2015b). Building use can be determined in most cases by its reference title in the database previously mentioned in this paper. Final selected building types are shown in Table 2.

TABLE II  
BUILDING USE IN CEC SAMPLE

Building Type	No. of Buildings
Offices	12
Factories/warehouses/halls	5
Educational	140
Health care	13
Hotels	3
Others	26

As shown by Aksoezen et al., (2015), there is also a connection between energy performance and building age. Therefore, building age was used to establish best fit characterization archetypes, taking into account historical, architectural and social context. In order to understand non-domestic buildings technical advancements one must analyse the domestic historical building legislation. To begin with, the ‘‘Housing, Town Planning, &c. Act 1919’’ (Addison, 1919) involved local authorities in the construction industry and gave them influence over the building market to balance the public and private sectors in their respective areas, this instigated the creation of the Housing and Town Planning Committee (HTPC) (Edwards & Jenkins (Eds.), 2005). This transition period saw the end of traditional buildings (Barnham, Heath, & Pearson, 2008) and the emergence of new construction systems such as cavity walls (English Heritage, 2012). Edinburgh started to be restructured during the following decade through a vast slum-clearance programme. The development of council housing meant the expansion of the capital city suburbs which absorbed smaller towns, such as Leith during the same period (Edwards & Jenkins (Eds.), 2005). A survey was carried out in 1935 which revealed that about 17,000 houses remained overcrowded but as a consequence of the 1929 economic crisis no money was available for immediate improvement. The war outbreak nearly froze the ongoing development of the city but Edinburgh remained overcrowded. At the same time, the deterioration of economic conditions led to a materials shortage and subsequent price inflation. In the emergency of the situation the government enacted the Housing (Temporary Accommodation) Act in 1944. This brought about the emergence of lightweight prefabricated bungalows, mass-produced by the post-war military industry, with a lifespan of about 10 years (Edwards & Jenkins (Eds.), 2005). From the 1950s to the 1960s Edinburgh has experienced a new episode of re-development, led by Pat Rogan, to improve living conditions across the city. These changes which occurred in the first half of the 20th century were driven by demographic and social issues, and as a result heavily influenced the urban planning of the city. Non-domestic properties such as educational buildings, which are related to urban planning by their catchment areas, were consequently influenced by these building stock and demographic dynamics. The school population increased after World War II and the Education Act of 1944 brought important changes, which implied new

requirements thus new buildings (Bull et al., 2014). The period being economically difficult, construction also needed to be affordable. According to Bett, Hoehnke, Robinson (1993), Scotland adopted a Building Act in 1959 which enabled Building Regulations to be promulgated in 1963, taking effect in 1964. In 1981, the Building Procedures (Scotland) Regulations were made and provided details on application procedures for building construction and for local authorities’ means of enforcement (Bett, Hoehnke, Robinson, 1993). During the second half of the 20th century, construction techniques legislation (CIBSE, 2015b) dealt with more technical aspects of construction methods.

During the second half of the 20th century specific technical issues were introduced into legislation. For instance, as a result of the introduction of energy performance regulations in 1976, cavity walls were no longer a viable construction technique at the end of the decade. The energy crises of 1973 and 1979 led the oil and gas fired boilers to disappear at the beginning of the 1980s and these were gradually replaced by natural gas boilers. At the same time double glazing started to appear on the market.

Based on the above analysis and on the data collected, four main age categories of CEC non-domestic buildings were established to capture the main energy demand evolutions in the building sample, as shown in Table 3.

TABLE III  
AGE CATEGORIES USED TO DESCRIBE CEC’S NON-DOMESTIC ESTATE

No. of buildings per period		
Period I	<1919	54
Period II	1920-1939	22
Period III	1940-1979	75
Period IV	1980-2014	48
Total		199

### C. Carbon contents

According to Bull et al. (2014), 9% of UK building emission is attributed to the public sector. In 2013, carbon dioxide accounted for about 74% of Scotland’s net greenhouse gas emissions or 39.4 MtCO<sub>2</sub> (Scottish Government, 2014). The public sector contributes up to about 0.9 MtCO<sub>2</sub>. This study is interested in the environmental impact of the non-domestic building stock. Therefore, to compare buildings, equivalent CO<sub>2</sub> emissions were computed using the energy consumption and conversion factors method from DECC (2010). Energy consumption figures used throughout this research are from 2013/2014, and the conversion factors were chosen accordingly: 0.5410 kgCO<sub>2</sub>/kWh for natural gas and 0.1836 kgCO<sub>2</sub>/kWh for electricity.

## IV. MAIN RESULTS

### A. City of Edinburgh Council’s estate

Figure 1 and Figure 2 highlight an important cluster of educational properties in the sample, both in terms of the



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number of buildings (70%) and the floor area (72%). Educational buildings, also include community centres (27%) as this typology is often located near or within a school building (73%). The oldest building dates from circa 1590 and the most recent was completed in 2010. Figure 1 shows the impact of the economic crisis which dramatically decreased

construction activity during the inter-war period. On the other hand, relatively high activity is observed during the second half of the 20th century for the above detailed reasons. The post-war period was the time for economic revitalisation which saw the growth and development of the City of Edinburgh.

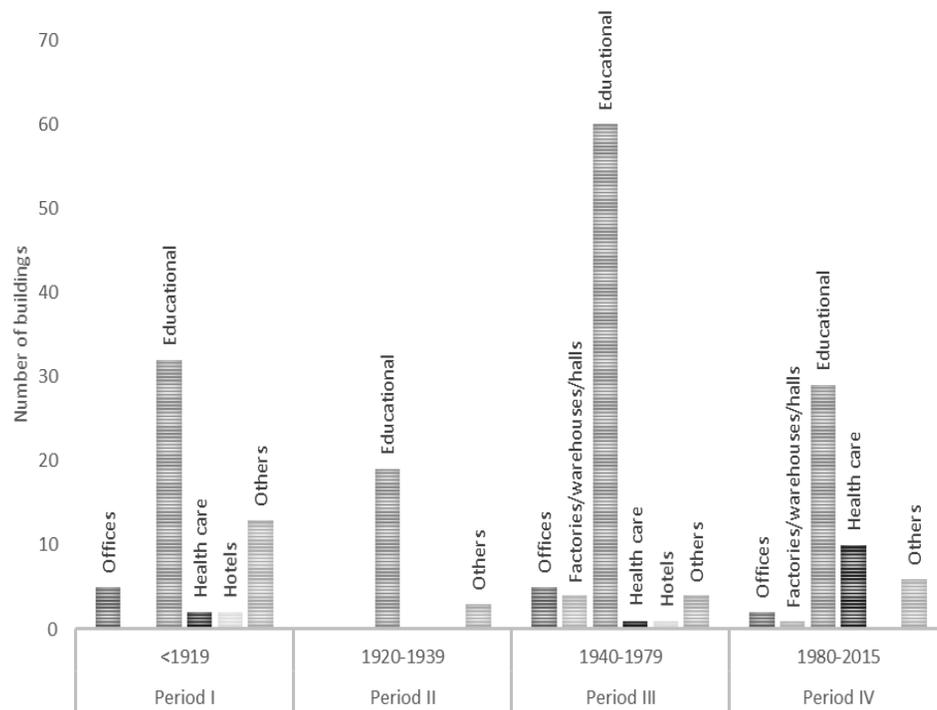


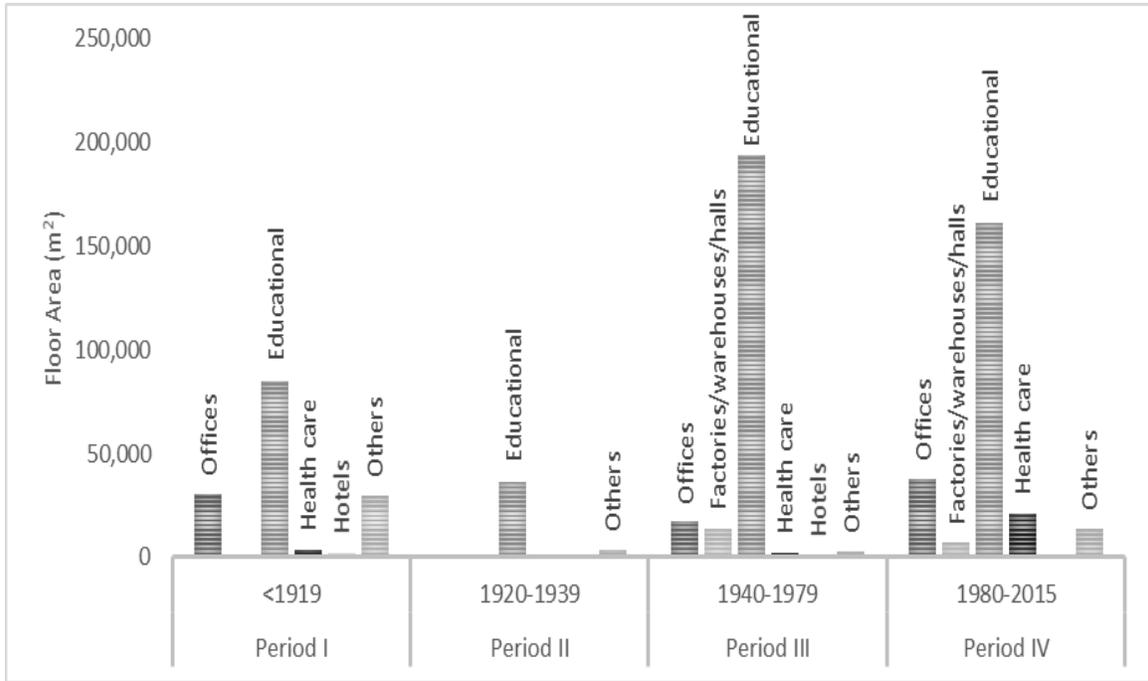
FIGURE I : ESTATE DISTRIBUTION PER NUMBER OF BUILDING

Figure 2 compared to Figure 1 suggests a change in urban planning policy, where larger schools in a catchment area have replaced smaller community schools. While Figure 1 illustrates a decrease in the educational buildings construction rate after 1980 by about 50%, Figure 2 shows a decrease in the floor area of only about 15%. This means fewer buildings were built after 1980, but with an increased building floor area. It could be explained by greater access to public transport, reduced maintenance and better asset strategy. Historically the city of Edinburgh was less extended and covered a smaller area. Over the years it has grown and absorbed small towns, such as Leith, which had their own local schools (Edwards & Jenkins (Eds.), 2005). The various development and restructuring plans during the 20th century have, by changing the residential areas, altered the shape of the schools catchment areas. The main example of these programs is what is commonly referred to as the “slum

clearance programme” initiated in the 30s. The city was overcrowded and suffered from social deprivation (Edwards & Jenkins (Eds.), 2005). Rehabilitation of these area implied a remodelling of urban planning with demolition, reconstruction and city development activities, involving the erection of new schools.

Figure 3 shows the evolution of the built floor area over time. Apart from an exception, built around 1800 with a floor area of approximately 18,500 m<sup>2</sup>, the chart suggests the constructible floor area is capped by a maximum value which increases over time. This could be explained by a demographic change. As Edinburgh grew, public services needs grew too; thus larger buildings were needed. It is also potentially related to the evolution of technology, knowledge, materials and skills, which allowed the conception of larger designs over time. The exception on the chart, built in 1800, is the City Chambers of Edinburgh, which is an atypical

emblematic building. It was extended on several occasions, and still accommodates the City Council. It is therefore not representative in itself of Edinburgh's non-domestic building stock. From the 19th century onwards, more buildings were built annually and most of them were smaller than 5,000 m<sup>2</sup>. After WWII larger buildings emerged, with buildings of a



floor area between 5,000 and 20,000 m<sup>2</sup>.

FIGURE II : ESTATE DISTRIBUTION PER FLOOR AREA

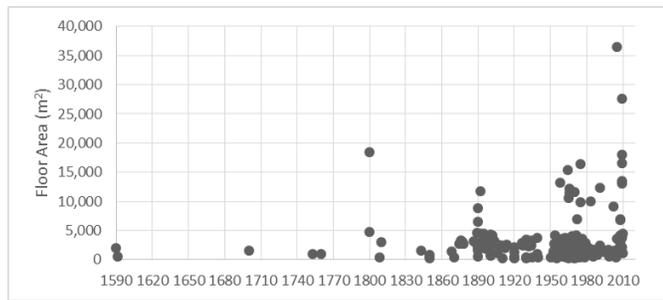


FIGURE III : FLOOR AREA EVOLUTION

Figure 4 and Figure 5 present the energy use in relation to the building age. No obvious trend or relationship could be established for the whole sample. However, almost every building built before 1880 appears to have a thermal end-use energy between 100 kWh/m<sup>2</sup>/year and 300 kWh/m<sup>2</sup>/year.

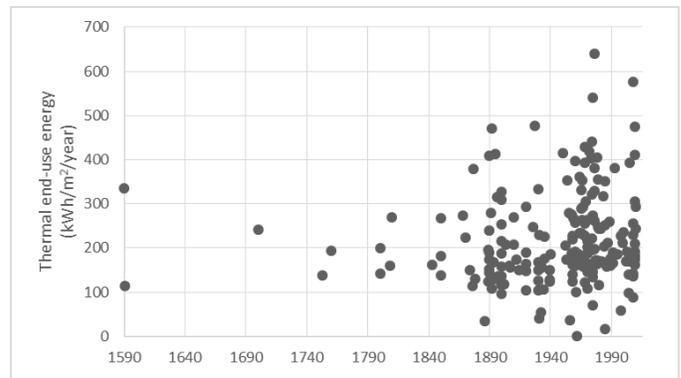


FIGURE IV : THERMAL END-USE ENERGY VS BUILDING AGE



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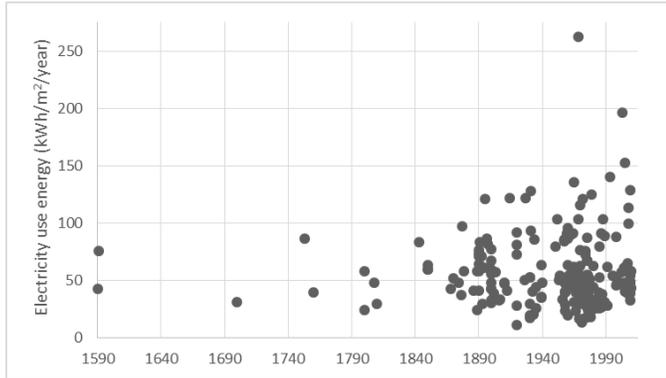


FIGURE V : ELECTRICITY USE ENERGY VS BUILDING AGE

## B. Energy Demand

Table 4 shows the share of the energy demand per building type. Total thermal end-use energy is 117.4 MWh, whereas the total electricity demand is 38.4 MWh. Educational buildings account for 61% and 73% of the electricity and gas consumption respectively. The second cluster consists of offices, it is responsible for 17% of electricity and 8% of gas consumption. This highlights considerable potential for energy savings in the educational sector. In order to go further in terms of energy efficiency, refurbishment options should be considered, as about 25% of the schools were built before 1919 and about 57% were built before 1964 and the first building regulations respectively. Potential interventions and suitable refurbishment scenarios will be the object of a future study.

TABLE IV  
ENERGY USE PER BUILDING TYPE

Building Type	Thermal end-use energy (MWh)				TOTAL	%
	<1919	1920-1939	1940-1979	1980-2015		
Offices	4,857	-	2,539	2,189	9,585	8.2
Factories /warehouses / halls	-	-	1,893	866.4	2,759	2.3
Schools	15,375	6,693	39,417	25,054	86,540	73.7
Health care	657.5	-	651.1	7,464	8,773	7.5
Hotels	416.4	-	90.0	-	506.4	0.4
Others	5,657	504	674	2,415	9,250	7.9
					TOTAL	
					117.4 GWh	
					TOTAL	%
					Electricity use (kWh)	
					TOTAL	%

Offices	2,300	-	1,348	3,017	6,666	17.3
Factories /warehouses/halls	-	-	1,378	330.8	1,709	4.5
Schools	3,269	1,225	9,574	9,667	23,734	61.8
Health care	187.4	-	208.7	2,112	2,508	6.5
Hotels	94.4	-	15.6	-	110	0.3
Others	2,474	125	217	886.5	3,702	9.6
					TOTAL	
					38.4 GWh	

## C. Benchmarks

The sample standard deviation of the thermal end-use energy shown on Figure 6 could be explained by the diverse features affecting energy performance. For instance several high schools have their own swimming pool while others will have extended community use which considerably increases the heating demand. Similarly, buildings such as offices and educational establishments in which catering is provided will have a higher gas demand than buildings in which there is no such provision. Community centres could have long occupancy hours as they accommodate club activities in the evenings. Buildings in constant use, day and night will also have a high energy use intensity. Health care buildings consume 7.5% of the total thermal end-use energy demand. The average is 350.6 kWh/m<sup>2</sup>/year for this typology, higher than the sample average of 219 kWh/m<sup>2</sup>/year. The most intensive use of energy recorded in this category, is in care homes, which are in constant use, day and night, and need to maintain specific comfort settings for the maintenance of the health and quality of life of inmates. The educational cluster was however found to dominate the sample average, with its buildings accounting for 73.5% of the heat demand, with an average of 207.4 kWh/m<sup>2</sup>/year. In Europe, studies show an average for schools of 100 kWh/m<sup>2</sup>/year (Thewes et al., 2014). However, here the educational stock includes nurseries, special needs, primary and high schools. Community centres are also included in this category. The average for the schools only, is 186.6 kWh/m<sup>2</sup>/year. This suggests a considerable potential for energy savings in the educational sector. Hotels and the factories/warehouses consist of categories too small to be meaningful. Office buildings account for 8.2% of thermal end-use energy demand with an average energy consumption of 180.6 kWh/m<sup>2</sup>/year. Finally, the average for the use category "Others", which includes a variety of building size and use, is 217.2 kWh/m<sup>2</sup>/year.

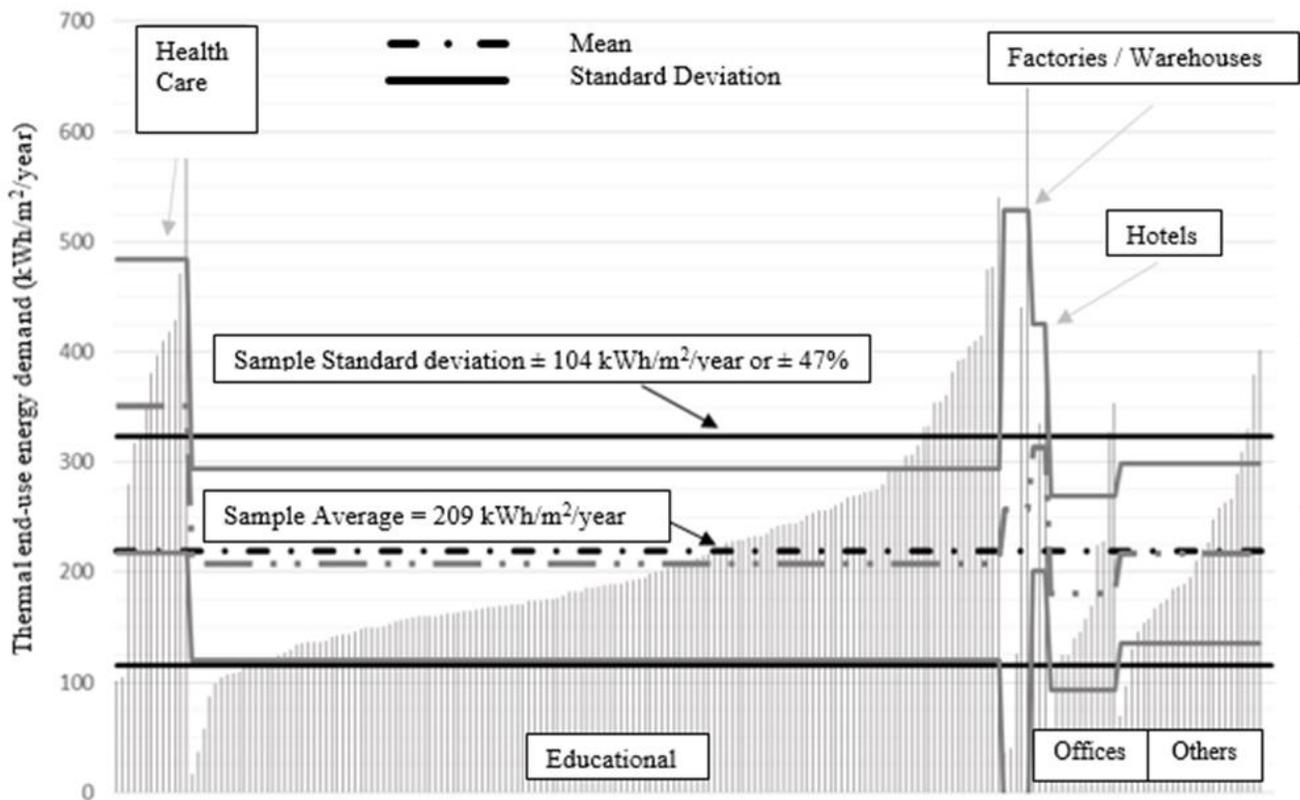


FIGURE VI: THERMAL END-USE ENERGY DEMAND PER BUILDING

Average consumption of electricity per square metre for the sample is 58 kWh/m<sup>2</sup>/year. Standard deviation is relatively high as shown on Figure 7. The main reason is the high energy use intensity in factories and warehouses where machinery creates a significant electric load. Similarly, in offices and health care buildings; lighting levels, computers, printers and other electric equipment contribute to raising the electricity end-use energy demand. However offices and health care buildings consume more electricity in total than factories and warehouses (Table 4). This is a consequence of the shift from

a manufacture-based to a services-based economy over the last 40 years (Backer, Desnoyers-, & Moussiegt, 2015). The emergence of computers from the late 1990s to nowadays and the new information and communication technologies (NICT) have led the buildings to consume more and more electricity. Computer based servers, for example, require a significant amount of electricity both to keep running and for cooling to prevent any overheating. The running of all this equipment causes a considerable rise in the internal temperature of the building, which, if it exceeds 25°C, generally turns on the



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cooling mechanical systems (CIBSE, 2015a). In most cases, if it is an aeraulic fluid circuit, the cooling will consume a significant amount of electricity as it is equipped with fans. As shown in the thermal end-use energy chart (Figure 6), the educational building average (49 kWh/m<sup>2</sup>/year) is relatively close to the sample average. This is due to the over-representation of the educational buildings within the buildings sample.

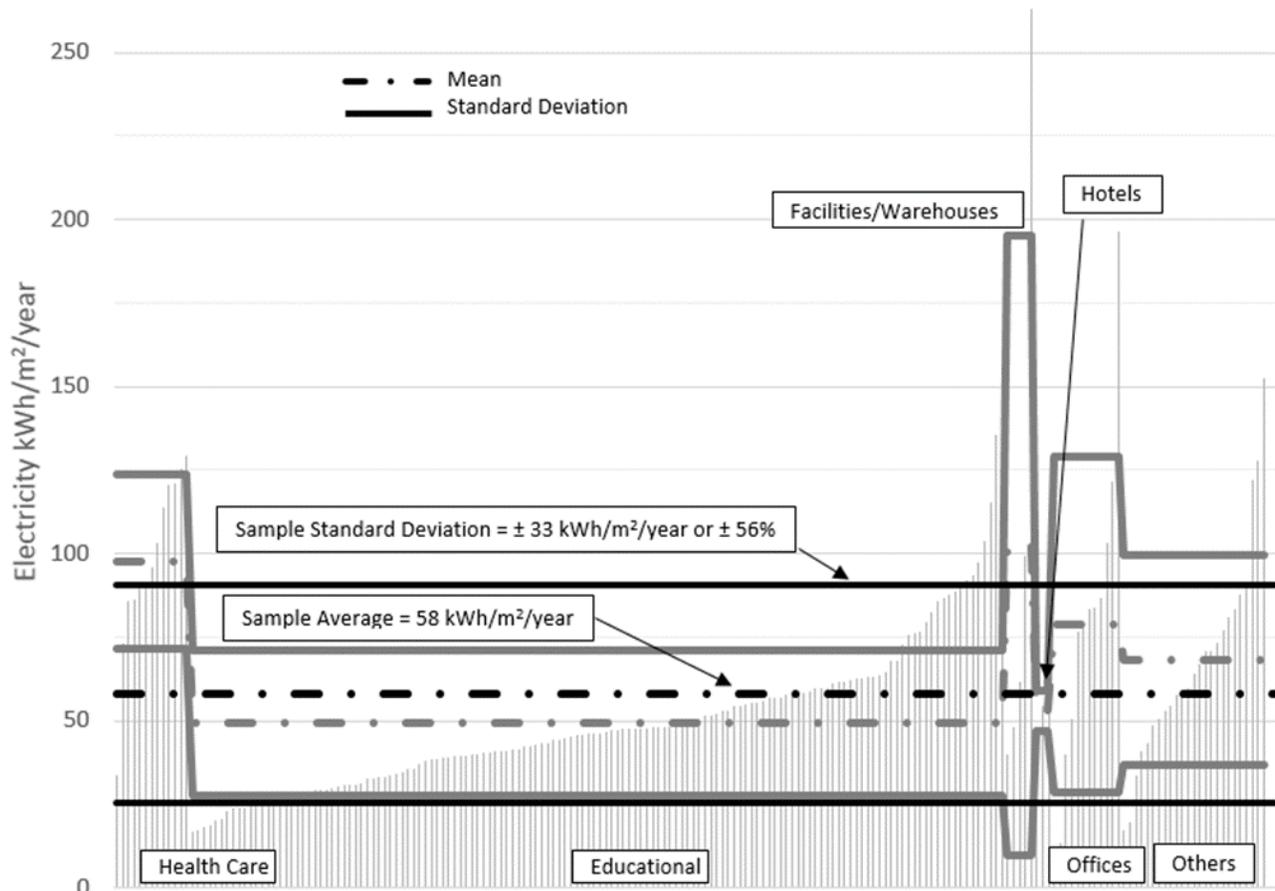


FIGURE VII : ANNUAL ELECTRICITY CONSUPTION PER FLOOR AREA PER BUILDING

#### D. Environmental Impact

Based on the type of fuel used in each building and the actual energy consumption for heating and electricity, the resulting environmental impact is presented in CO<sub>2</sub> equivalent. The selected sample of buildings annually emits about 42,000 tons of CO<sub>2</sub> of which 68% is released in the atmosphere by educational buildings. This predominance is shown in Figure 8, and could be explained by the number of buildings in this cluster along with their floor area compared to the other use categories. The highest emitter is an office building releases just under 2,000 tons CO<sub>2</sub>/year. Office buildings account for about 13% of the total carbon emissions.

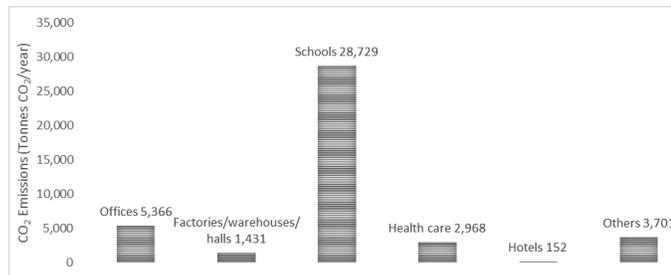


FIGURE VIII : ANNUAL CO<sub>2</sub> EMISSIONS

Table 5 shows the average carbon emissions per building type. Health care buildings have the highest carbon content per meter square. This is explained by the high use intensity of these buildings which contain a large number of appliances and services. These consume electricity which has a higher carbon factor (kgCO<sub>2</sub>/kWh) and consequently are responsible for larger emissions for the given same amount of energy consumption. Factories and warehouses often consist of large undivided spaces with a potential for wasting energy for heating, with the consequent emission of large quantities of CO<sub>2</sub>. In addition, these buildings could be industrial plants with heavy machinery and a high electricity demand. Life-cycle assessment of the buildings would allow the counting of embedded carbon in the fabric.

There is less disparity between building types in the average annual carbon emissions because it accounts for both electricity and gas contributions which can compensate themselves in terms of carbon: a low gas consumption and a high electricity load will be responsible for medium to high carbon emissions because more carbon is associated to a kWh of electricity than to a kWh of gas.



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TABLE V  
 AVERAGE ANNUAL CARBON EMISSIONS PER TYPOLOGY

Carbon Emissions Average	kg CO <sub>2</sub> /m <sup>2</sup> /year	%
Health Care	117.2	22.6 %
Educational buildings	64.7	12.4 %
Factories/warehouses	102.5	19.7 %
Offices	75.8	14.6 %
Hotels	86.0	16.5 %
Others	73.6	14.2 %
<b>TOTAL</b>	<b>519.8</b>	

## V. METHOD LIMITATIONS

This research examined 199 non-domestic buildings. They cater for various uses across the city of Edinburgh, a building characteristic identified by the VBA macro application. Limitations of this process lie in character recognition. The VBA macro application looks for keywords in the properties title to “guess” its use. If in most cases it is sufficient to detect the activity occurring in the building, there is a limited risk for a discrepancy between real building use and study building use. Energy analysis was conducted without taking into account building geospatial information. Further research is required on that matter to develop a city-wide model for Edinburgh, similar to what Choudhary (2012) achieved with the Greater London non-domestic building stock. Furthermore, referring to findings of Aksoezen et al. (2015) about a correlation between the age of a building and its energy consumption, no evidence could be found for the given sample to verify or invalidate this connection. It is possible, considering the sample size (199 buildings) and the restriction to non-domestic building only, that such relationship could be established by including a broader range of buildings across the city of Edinburgh.

Recommendations for developing a systematic data collection involve the creation of a database which contains details on building shapes, elevations, construction materials, number of floors, façade orientation, volume to surface ratio, glazing information and other building characteristics which could impact energy performance. Good practice should gradually implement sub-metering to overcome this. This is even more important when use varies across a building or fluctuates throughout the day.

## VI. CONCLUSION

The built environment contributes up to 40% of the EU

energy consumption and about 35% of its carbon emissions. The City of Edinburgh Council is actively working on the energy performance and the environmental impact of its estate, in which non-domestic building stock plays a major role. In order to achieve a better knowledge of the current stock, it is increasingly important to establish a systematic process to support the data collection and analysis of the energy consumption and carbon emissions of CEC’s building stock.

This study was carried out on a sample which covers a representative range of typical typologies, sizes, constructions, ages and installations. From the data collected, it was established that a large portion of the non-domestic estate is composed of educational buildings, which is reflected in consumptions and CO<sub>2</sub> emissions. Edinburgh schools’ thermal end-use energy consumption average (186 kWh/m<sup>2</sup>/year) is 86% higher than the European average of 100 kWh/m<sup>2</sup>/year. The care homes and health care categories present high energy use compared with the sample average, which is understandable in view of the functions of the buildings. Building age ranges from the late 16th century to the present day but no direct correlation was identified between energy consumption and building age. The intended purpose at the time of construction could be a useful indicator for assessing the performance of a given building and adapting retrofit scenarios to the best fit. Unfortunately this information is rarely available and therefore such consideration is not usually possible. In terms of overall CO<sub>2</sub> emissions, educational buildings are responsible for the majority (68%) of the sample emissions. This is expected given the size of the educational buildings cluster. However in terms of CO<sub>2</sub>/m<sup>2</sup>, the health care cluster is the highest emitter. This is explained by the high intensity use of these buildings and the special health and comfort services they provide by definition. Results show that there is a great variability of energy consumption, indicating that there is a great potential for energy savings, resulting in direct savings in the environmental impact of buildings. Further studies will involve retrofit scenarios looking at life-cycle analysis, life-cycle cost analysis and potential strategies to assess the City of Edinburgh Council’s non-domestic estate.

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