# Mapping Priority Energy Intervention Areas in Birmingham (UK)

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## Abstract

A reduction of energy consumption and efficient clean solutions in buildings are needed to face the climate change. Thus, a sustainable roadmap should be addressed, fostering urban strategies that reduce energy and social inequalities. However, uncertainties to identify and map households' conditions limit this process

Priority Intervention Areas (PEIA) methodology, based on geographic information systems, characterizes energy deprived areas by overlapping of the lowest values of the Index Energy Deprivation (IED) and the Index Multiple Deprivation (IMD). IED, defined to this aim, locates energy vulnerable areas, facing differences between real and theoretical consumptions associated to user´s behavior. Thus, an urban classification based on building properties and age of construction is developed. IMD deal with socioeconomic and environmental aspects. The city of Birmingham and its east corridor is evaluated as case of study. 23 Lower Layer Super Output Areas (LSOA) has located as PEIA, represented mainly by terraced houses. East Birmingham shows lower values of IED and IMD, identifying 6 PEIA with a higher deprivation intensity compared to the whole city. The proposed method fosters detailed, fair and low carbon strategies to tackle the new climate scenarios.

*Keywords: energy poverty, energy performance, socio-economic indices, urban classification, climate change.*

## 1. Introduction

In 2018 the 27% of the final energy consumption in EU belonged to the residential sector, being even superior in the UK reaching the 31% (Eurostat 2018). This fact implies that housing, the second sector with the highest energy consumption after transport, represents one of the crucial areas to face the global warming.

Because of this, positive energy districts and energy retrofitting based on the reduction of energy demands and the use of renewable energy are becoming decisive solutions. To develop these measurements tailored and fair plans are needed. The IPCC report (IPCC 2018) highlights the impact of forecasted extreme climatic events upon vulnerable population. To this end, "green" challenges must consider an energy and a socioeconomic perspective. In that sense, UK government designed the Climate Change Act (CCA 2008). Regionally, the West Midlands area, characterized by a rich industrial heritage, but also for its socioeconomical differences have developed some programs to tackle this situation as the Road Map 2020 (R20 West Midlands)

According to the region forecasts, the Birmingham City Council (BCC) through the Route Zero Taskforce (R20 Taskforce) and BCC´s Green Commission, set out the city´s transition to a future low-carbon roadmap (BCR 2013). It provides a clean framework to reduce total Birmingham´s $CO_2$ emissions by 60% in 2027. To this aim it is developed an innovative energy system putting together public, commercial, academia and communities sectors in order to become the city more prosperous, healthier, fairer, more resource-efficient and better for business (BEI). One of the main plan´s concerns is the energy poverty, defined as a household which needs to spend more than 10% of its income on fuel to maintain an adequate standard of warm.

Tysely Energy Park (TEP) is one of the projects framed in the described energy transition roadmap. It is founded as a collaborative action between the manufacturing business, council-owned energy plant and the Birmingham University to foster the East Birmingham industrial area through the reuse of waste energy (BU

doi:10.18086/eurosun.2020.13.02 Available at http://proceedings.ises.org

2013). One of the potential scenarios is focused the reuse of heat waste coming from the industry to supply the wasted energy to the communities in this zone. The possible prototype could be carried out through a district network, fostering the circular economy and the deprived East Birmingham neighbourhoods.

The city of Birmingham is notably affected by the fuel poverty phenomena, 1 in 5 households is classed as fuel poverty, considerably higher than the national average of 1 to 10, being even worse in the East Birmingham where the 18% of dwellings have problems to afford the fuel costs or they need an amount higher than the national mean (Sub-Regional). Beyond economical and house quality problems, energy poverty triggers other consequences as health problems (Sanz Fernández et al. 2017). In addition, East Birmingham face other socioeconomic challenges as a low economic activity rates, 3% less than the city average, especially amongst women, high levels of public transport congestion or an habitable house shortage (BCC 2015).

In order to reduce inequalities in this area a tailored, fair and clean energy transition should be developed to ensure the habitability conditions in Birmingham´s city, pointing out a particular attention in the East Birmingham. An impactful and innovative action on climate change will be only secured if it is connected to the householders and communities. However, building sector present shortcomings to deal with these considerations due to the diversity of stakeholders, building typologies and final users that are involved.

Hence, this study presents a methodology to map areas where energy intervention effort is needed because of their vulnerable situation (lower social or economic position, poorer dwelling conditions or both energy poverty situations) (Bouzarovski and Petrova 2015). To this end, the planned objectives for this work are: a) The quantification of real energy consumption and a deep analysis of the theoretical energy consumption according to the building characteristics. b) An index to quantify potential differences between real and theoretical energy consumption. c) An evaluation of the socioeconomic situation though different indicators. d) The location of the Priority Energy Intervention Areas for the city of Birmingham.

## 2. Priority Energy Intervention Areas methodology (PEIA)

The energy consumption in dwellings depends on buildings characteristics (surface, materials or typology), but social and economic conditions modify this pattern (IEA 2016). A low energy burden is associated to efficient buildings, but it could also be related to a low income. On the contrary, a high energy burden besides user without problems to pay energy bills, could also mean an inefficient household. This complex combination of factors (energy-housing and social-economic perspectives) implies uncertainties to face the energy poverty situations. Priority Energy Intervention Areas method (PEIA) is focused to solve this situation. PEIA is approached by a novel combination of both energy housing perspective through the Index Energy Deprivation (IED) and socioeconomic perspective over the Index Multiple Deprivation (IMD). The lowest IED and IMD zones will be defined as a PEIA, easing the location of households where gas and electricity bills are low because of their socioeconomic situation.

The methodology is developed firstly, studying the region through different areas according to Lower Layer Super Output Area (LSOA) classification by Geographic Information Systems (GIS). Then, the IED and IMD values are defined for each LSOA. The IED is calculated by the relation between the real and theoretical energy consumption. The IMD considers different potential deprivation levels. Finally, the overlapped areas of both the first IED and IMD decile will be considered as a PEIA. The whole city of Birmingham and the east Birmingham area will be analysed separately in order to know the differences between them.

### 2.1. Birmingham city classification: LSOAs

The city of Birmingham is selected to this study because of its relevance in the UK´s development. After London, it is the largest city and the widest metropolitan economy in United Kingdom. Among its complex urban area diverse cultural, economic and social levels are found, that could be a source of the inequalities. In that sense, the east Birmingham corridor, where is located Tysely Energy Park and the constituencies of Hodge Hill and Yardley, have higher unemployment, lower skills rate and poorer health than other parts of the city.

To quantify and locate these urban differences, the city is studied through LSOAs areas (LSOA), designed for statistical studies in England and Wales. They have been generated with a minimum of 1000 inhabitants and the mean is 1500. The city of Birmingham has 640 LSOAs, which 130 of them belongs to the East Birmingham. They have a mean of 1727 citizens, being the total population of the city 1.1 million inhabitants.

## 2.2. Energy consumption approaches

The energy consumption characterization could be addresses by different perspectives and factors as follows:

### *2.2.1. Real energy consumption*

A top-down approach based on GIS could be an efficiency tool to analyze globally the potential energy deprivation in an area that could be evaluated more precisely later if it is identified as a susceptible zone. Disaggregated energy consumption provided by UK´s statistics is used for this purpose. Although it is assumed that energy data shouldn´t be provided individually (user´s data protection), this analysis presents some weakness. As it is said, construction characteristics and user patters vary the dwelling´s energy consumption.

That´s means that it is hardly to identify the real reason of high or low energy consumption. High amounts could be related to an inadequate construction system, a poor quality of materials or an inefficiency facility, but also with an unconscious behaviour of energy use because a lack of knowledge or commitment. On the other hand, low energy consumption rates could be associated to a good design, high-tech, high construction quality or energy efficiency systems, including the use or renewable energies. Nevertheless, this low quantity could be linked also to an energy deprivation because of difficulties to afford the cost.

### *2.2.2. Energy performance simulation*

Other procedures to know the energy consumption are based on the calculation of theoretical energy consumption, as the energy performance. This estimated value is got by dynamic energy simulation tools. It defines the quantity of energy that household need under habitability and comfort conditions according with their local climate, construction systems, material properties, facilities and a standard of user´s behaviour.

This bottom-up approach could be more precise defining the energy demand by building or dwelling, instead of a generic area. In addition, it can be transformed in a top-down approach though GIS calculations based on the building geometries and a ratio of energy consumption by surface. However, this procedure also presents shortcomings that limit the priority energy areas identification with discrepancies between the real and theoretical energy consumption. Besides the climate data and building properties, an imprecise user´s patterns could be one of the main reasons behind this problem. In the studies focused on the possible energy vulnerabilities identification, the role of the user´s occupancy and their behaviour are crucial.

### *2.2.3. Climate, building and user; energy shapers*

A common method to characterize the local weather conditions is the typical meteorological year (TMY), that must be based on long term weather variables records (at least 10 years), to ensure the natural climate cycles. Depending on the study, there are diverse methodologies to assess the TMY, varying the weight factor of the meteorological variables(Zarzalejo et al. 1995; Soutullo et al. 2017). These climate data files are usually given by the energy simulation tools or provide by a normative standard. One of the widest climate data are the EPW files, developed by ASRAE and used by the Energy+ software (EnergyPlus) . Other files are necessary for an energy certification as the .MET files developed by the Spanish normative (CTE 2015). Some studies point out possible deviations between real and simulated energy consumption due to outdated climate data files that don't consider the climate change or the urban microclimate effect (Soutullo et al. 2020; Sánchez et al. 2020).

Physical properties of the construction materials are need for the calculation of the thermal transmittance of the building envelope. In addition, the type of zones (acclimatized or not acclimatized) and the performance of the facilities need to be known for the calculation of the heat transference. The time-consuming, complex or invasive process of the material identification, areas and facilities characterisation lead to establish some assumptions. Most of these inferences are based on the urban characteristics, like the type of building or the year of construction. These properties gather similar patterns as the occupancy for residential or not residential buildings, the household morphology depending on the urban archetypes or the facilities efficiency and insulation type according to the construction year. The English Housing Survey (EHS) provides ratios of energy consumption according to these characteristics. Moreover, the LandMap project (LandMap 2012) provides mapped information about building type for many conurbations in the UK. Additionally, the Ordnance Survey (OS) facilitates other geographic information as the residential zones or the high of buildings.

Finally, the occupant behavior style has significant influence on the energy used in heating systems in buildings (Sun and Hong 2017). In addition, the building occupancy patterns have changed, as an example in Spain the number of people how live alone has increased, being most of them elderly women (INE 2014). Due to an undetailed or inexistence of a user´s data base, it is generally used standard and normative occupancy parameters for the energy simulation models. However they don't incorporate a variety of socio- economical parameters relating to lifestyle, heath condition or family situation (Cuerda et al. 2019).

#### *2.2.4. Index Energy Deprivation (IED)*

The development of the Index Energy Deprivation (IED), leads with the found weakness. It is defined as the relation between the real and theoretical energy consumption and it gives an idea of how low or high is the amount of the energy consumed compared to the amount of energy that the same building or household should consume according to the standards (comfort minimum values of indoor temperature, humidity, air ventilation, light or equipment and home appliances use). Values lower than 100% mean that energy consumption is less that it should and could present some vulnerabilities as the energy poverty.

### 2.3. Socioeconomic indicators

A low Energy Deprivation Index not necessarily means an energy deprivation household per se. Some false positives could be found as an empty dwelling, second or occasional residence or high energy efficiency. In order to avoid these situations, other aspects as economic, social, urban-environmental or health parameters have been considered. It is assumed that citizens who belongs to low socioeconomic profiles with health problems or live in a depressed area could be also be related to energy deprivation.

In that sense, the Index Multiple Deprivation (IMD) addresses different patterns of deprivation per area. It is based on 39 separate indicators, organised across seven distinct domains of deprivation which are combined and weighted (IoD) . The main attended topics and its corresponding weighted relevance are: Income (22.5%), employment (22.5%), health deprivation and disability (13.5%), education, skills training (13.5%), crime (9.3%), barriers to housing and services (9.3%) and living environment (9.3%). Consequently, through the IMD other concerns as the climate data, the quality of buildings or the user behavior could be approached.

The IMD is calculated for every LSOA in England. Their values are ranked according to their level of deprivation relative to that of other areas. High ranking LSOAs can be referred to as the 'most deprived' or as being 'highly deprived' to aid interpretation, but they are measured on a relative rather than an absolute scale. This fact means that the ranked area as 200th is not twice as deprived as ranked area as 100th, but this number gives an idea of as 100th area should be addressed firstly.

### 2.4. Definition of Priority Energy Intervention Areas (PEIA)

The combination of both low energy deprivation areas and low multiple deprived areas describe zones which: a) Their energy consumption is lower than a building with its same characteristics conditioned in comfortable conditions. b) Their zones are more deprived in terms of economic, social, health and urban-environmental aspects, that limit the achievement of a minimum of habitability conditions. Therefore, in these neighbourhods, strategies to ensure a good quality and wellbeing are a priority.

In that sense, the Priority Energy Intervention Areas (PEIA) are defined as areas which both the Index Energy Deprivation and the Index Multiple Deprivation belongs to the first decile. This condition gathers the overlapped zones of the lowest IED and IMD conditions.

## 3. Applied methodology for the city of Birmingham

The Priority Energy Intervention Areas (PEIA) methodology is applied for the whole city of Birmingham (Bham) and more in detail in the East Birmingham (EBham), where is located the Tyseley Energy Park. Firstly, is mapped the real energy consumption (gas and electricity) through LSOA classification. Secondly, it is estimated and located the theoretical energy consumption aggregated by urban typology and year of construction. Then, the Index Energy Deprivation (IED) and the Index Multiple Deprivation (IMD) is defined by LSOA. Finally, the PEIAs are determined by the overlapping of the lowest IED and IMD decile. The number of LSOAs that are classified as PEIA are compared between Birmingham and its East area.

All the data provide by LSOA is calculated by inhabitants (persons) and year to ease the data comprehension. The most updated files considering all data sources, in order to avoid uncertainties between different period times, has been the year 2017. For the calculations is only used the domestic data. No-residential data and areas with no data are not considered and they are indicated on the maps, as well as the Tyseley Energy Park area.

Results are shown by deciles, dividing the number of values in 10 groups with an equal number of LSOAs. As the city of Birmingham has 640 LSOAs, the first decile (decile 1) belongs to the lowest 64 LSOAs (0-64), continuing the classification to the last decile (decile 10) that gather the 64 highest LSOAs values (576-640). This number could be modified if there are LSOAs with no data that will change the total number of LSOAs.

Some figures include a graph in its bottom-left part that aims to know the variability between LSOAs values differentiating Bham (black dots) and EBham (grey dots). In the X axis are located the deciles for the Bham data set and the Y axis represents the LSOAs values. The mean for the total of LSOA values are also represented for Bham (black line) and EBham (grey line).

## 3.1. Index Energy Deprivation (IED)

For the Index Energy Deprivation (IED) the real and theoretical energy consumption are achieved as follow:

### *3.1.1. Real energy consumption*

The real energy consumption ($EC_{real}$) for domestic use is provided by the UK statistics of electricity and gas consumption at LSOA layer (Sub-national). The sum of gas and electricity consumption is calculated.

The Figure 1 maps the values of real energy consumption. It is observed differences within the city; north and southeast neighbourhoods present the highest energy consumption values, while west and east zones belong to the lowest deciles. This is also revealed by the total energy means calculations, with 6573 kWh/inh per year for Bham and 5695 kWh/inh per year for EBham, that belongs to the decile 6 and decile 4.There is a high variability between Bham points in the first and last deciles, that is less significant for the last decile of EBham.

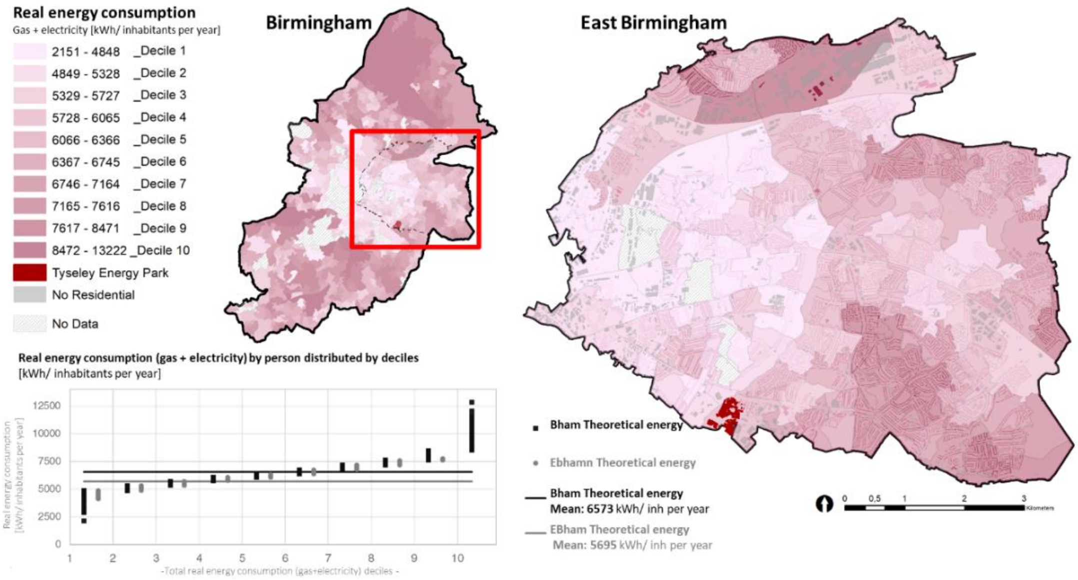


**Figure 1. Real energy consumption (gas and electricity) by Bham´s LSOA [kW/inh per year] gathering by deciles.**

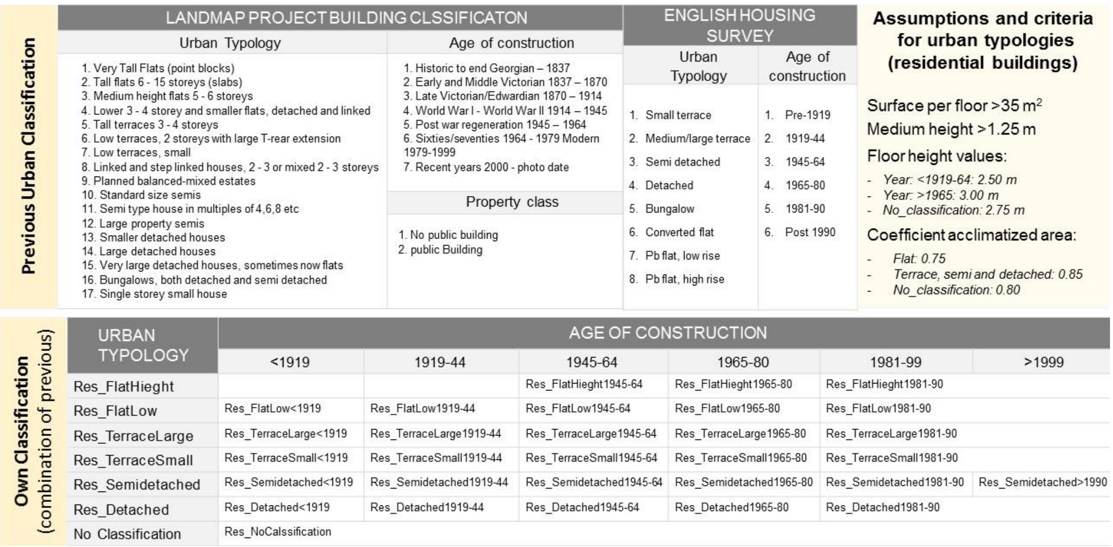
### *3.1.2. Urban properties*

In order to locate and quantify the theoretical energy consumption for each city´s building, firstly it is necessary define the buildings characteristics and their location. The Cities Revealed Building Class´s datasets (LandMap 2012) classify the main residential buildings grouped by their age and building type, with a total of 9 age categories and 19 type categories. The classification is generated primarily by photo interpretation of high resolution digital aerial photography and the evaluation of different elements as shape and size, materials, etc.

This urban classification allows mapping a detailed urban characterization and geometry, however it doesn´t offer an energy consumption estimation. The English Housing Survey datasets (EHS) incorporates an updated and exhaustive dataset of the energy performance for different urban characteristics based the energy performance building certificates. These data file is divided in diverse levels according to dwellings, areas households and heating and insulation characteristics. Within the dwelling level the energy performance is divided by tenure, occupancy status, dwelling age, dwelling type or total usable area floor.

The combination of the LandMap and EHS analysis allows both the estimation of the theoretical energy consumption (kW/m$^2$ per year) by urban typology and age of construction and also the location of this attributes. However, they don´t share the same class groups, because of this an on purpose PEIA classification for this study is done based on both LandMap and EHS categories. Figure 2 shows the urban classifications for LandMap (top-left), EHS (top-center) and PEIA (bottom) categorizations and its assumptions (top-right).

A matrix of selected or combined building typologies and age of construction is done. Conducted typologies are flats (high and low), terraced houses (large and small), semidetached houses and detached houses. On the other hand, the period of construction classes are: before 1919, 1919-1944, 1945-1964, 1965-1980, 1981-1999 and after 1999. The PEIA is classified by a total of 29 building typologies. A no classified typology and a no residential categories are included, despite of the fact that the last one is not considered for further analysis.



**Previous Urban Classification**

LANDMAP PROJECT BUILDING CLSSIFICATON

Urban Typology

1. Very Tall Flats (point blocks)
2. Tall flats 6 - 15 storeys (slabs)
3. Medium height flats 5 - 6 storeys
4. Lower 3 - 4 storey and smaller flats, detached and linked
5. Tall terraces 3 - 4 storeys
6. Low terraces, 2 storeys with large T-rear extension
7. Low terraces, small
8. Linked and step linked houses, 2 - 3 or mixed 2 - 3 storeys
9. Planned balanced-mixed estates
10. Standard size semis
11. Semi type house in multiples of 4,6,8 etc
12. Large property semis
13. Smaller detached houses
14. Large detached houses
15. Very large detached houses, sometimes now flats
16. Bungalows, both detached and semi detached
17. Single storey small house

Age of construction

1. Historic to end Georgian – 1837
2. Early and Middle Victorian 1837 – 1870
3. Late Victorian/Edwardian 1870 – 1914
4. World War I - World War II 1914 – 1945
5. Post war regeneration 1945 – 1964
6. Sixties/seventies 1964 - 1979 Modern 1979-1999
7. Recent years 2000 - photo date

Property class

1. No public building
2. public Building

ENGLISH HOUSING SURVEY

| Urban Typology | Age of construction |
|---|---|
| 1. Small terrace | 1. Pre-1919 |
| 2. Medium/large terrace | 2. 1919-44 |
| 3. Semi detached | 3. 1945-64 |
| 4. Detached | 4. 1965-80 |
| 5. Bungalow | 5. 1981-90 |
| 6. Converted flat | 6. Post 1990 |
| 7. Pb flat, low rise | |
| 8. Pb flat, high rise | |

**Assumptions and criteria for urban typologies (residential buildings)**

Surface per floor >35 m$^2$

Medium height >1.25 m

Floor height values:

- *Year: <1919-64: 2.50 m*
- *Year: >1965: 3.00 m*
- *No_classification: 2.75 m*

Coefficient acclimatized area:

- *Flat: 0.75*
- *Terrace, semi and detached: 0.85*
- *No_classification: 0.80*

**Own Classification** (combination of previous)

| URBAN TYPOLOGY | AGE OF CONSTRUCTION | | | | | |
|---|---|---|---|---|---|---|
| | <1919 | 1919-44 | 1945-64 | 1965-80 | 1981-99 | >1999 |
| Res_FlatHieght | | | Res_FlatHieght1945-64 | Res_FlatHieght1965-80 | Res_FlatHieght1981-90 | |
| Res_FlatLow | Res_FlatLow<1919 | Res_FlatLow1919-44 | Res_FlatLow1945-64 | Res_FlatLow1965-80 | Res_FlatLow1981-90 | |
| Res_TerraceLarge | Res_TerraceLarge<1919 | Res_TerraceLarge1919-44 | Res_TerraceLarge1945-64 | Res_TerraceLarge1965-80 | Res_TerraceLarge1981-90 | |
| Res_TerraceSmall | Res_TerraceSmall<1919 | Res_TerraceSmall1919-44 | Res_TerraceSmall1945-64 | Res_TerraceSmall1965-80 | Res_TerraceSmall1981-90 | |
| Res_Semidetached | Res_Semidetached<1919 | Res_Semidetached1919-44 | Res_Semidetached1945-64 | Res_Semidetached1965-80 | Res_Semidetached1981-90 | Res_Semidetached>1990 |
| Res_Detached | Res_Detached<1919 | Res_Detached1919-44 | Res_Detached1945-64 | Res_Detached1965-80 | Res_Detached1981-90 | |
| No Classification | Res_NoCalssification | | | | | |

**Figure 2. PEIA building classification (bottom) and its assumptions (top-right) based LandMap (top-left) and EHS.**

Figure 3 presents the urban characteristics of the building PEIA classification. Figure 3.a. shows the building typologies (right-top) and the age of construction (righ-bottom) through a georeferenced map. Flats are located in the centre of the city and they are constructed recently. Semidetached and detached houses with a middle-old construction age are sprawled in the suburban neighbourhoods, mainly in the north and south of the city. Finally, terraced houses are located in the west and east areas of Birmingham´s city center. Small-size terraced houses are mainly middle age but most of large-size terraced houses were constructed before 1919.

The PEIA categorization is resembled for the energy performance data provide by the EHS based on dwelling type and age of construction. Then, it is interpolated their values to obtain a value of theoretical energy consumption for each PEIA class. Figure 3.b presents the theoretical energy consumption per surface (left-top and center) and for the whole building and also the representativeness of building typologies (right-bottom)

A notable value of inefficiency is shown for ancient buildings (before 1919 and between 1919 to 1944) and this value is downing along the time (approx. from 290 to 250 kWh/m$^2$ per year). Small terrace and semidetached typologies present the highest values of theoretical energy consumption around 20 kW/m$^2$ per year more than low flats and large terraces. Finally, detached houses energy values are the lowest until the middle of the 20th century, when the high flats flourished, with the best energy efficiency performance.

The typology that have the highest energy consumption per building are flats because of their large surface and height based by multiple apartments, specially the flat-high typology. Although its reduction of energy consumption per surface along the years decreases, this value is inverse for the energy consumption by building (reaching values higher than 40MW/ building per year). It could be explained due to the newest high-rise flats are larger. Similar pattern but in a slight manner have the low-rise flats. All single houses have notably lower energy rates, being approximately 2 to 3 MW/ building per year for the 2nd part of the century.

Finally, the quantity of buildings according their typology, give an idea of how the urban growth of the city was. According to the Figure 3.b. current Birmingham was founded on an urban settlement based basically on large terraced houses constructed before the 20´s (first world war). An urban boom took place after this period between 1919-1944 (between world wars periods) with the construction of more than a 100 thousand of semidetached houses and a little number of detached houses. Then, between the years 1945 to 1980 the growth of the semidetached continued, but in much low and stable manner and decreased from the 80´s. Small-size terraced households' expansion was significant during 1965-1980, approximately 25 thousand were build up. The number of flats is very low compared to the other typologies for all periods, as well as the low number of residential constructions developed from the 21st century.

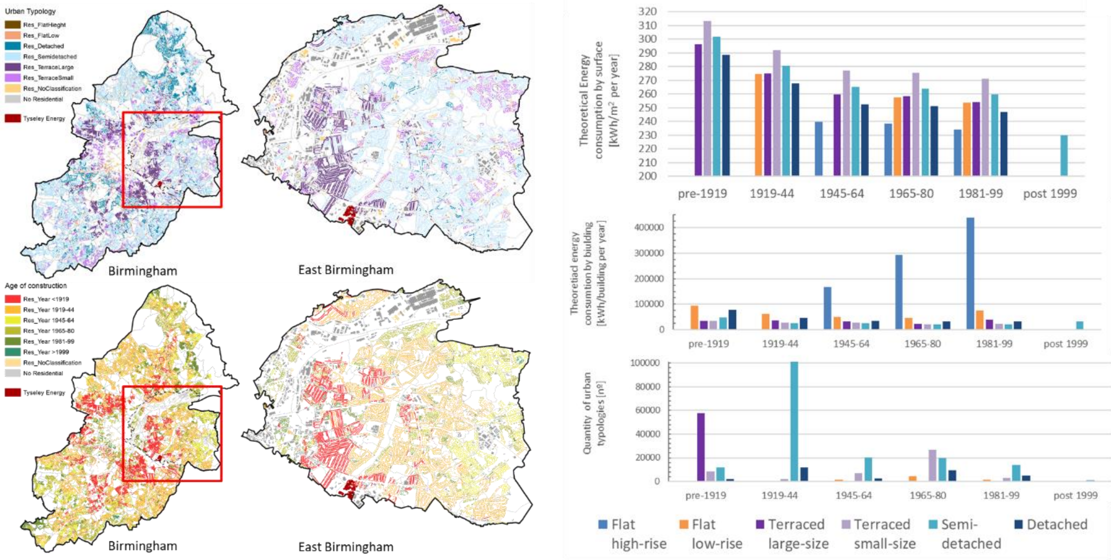


**Figure 3. PEIA urban typology classification: a) Georeferenced map for the urban typologies and the age of construction (left) by LSOA classification. b) Theoretical energy characteristics and representaiveness of building typologies (right)**

### 3.1.3. *Theoretical energy consumption*

The theoretical energy consumption ($EC_{Th}$) it is mapped for the city of Birmingham. This process is developed though the previously calculated theoretical energy consumption per area ($EC_{TH\_Area}$) for each typology and the estimation of the acclimatized surface area per building ($Area_{Acc}$) (eq 1). The assessment of the acclimatized area is addressed by the print area of the building ($Area_{printed}$), provided by georeferenced geometry, the number of floors ($N^o_{floors}$), given by the building height and a coefficient of the acclimatized area ($Coef_{acc}$) (eq 2).

$$EC_{Th} = EC_{Th\_Area} \times Area_{Acc} \text{ [kWh/inh per year]} \qquad \text{(eq 1)}$$

$$Area_{Acc} = Area_{Printed} \times Nº_{floors} \times Coef_{acc} \text{ [m}^2\text{]} \qquad \text{(eq 2)}$$

Some regards are considered in these calculations with the aim of get a better adjustment of the theoretical energy consumption to the reality (Figure 2). Only are considered dwellings with an acclimatized area bigger than 35 $m^2$ and their mean height is upper than 1.25 m. The height of the buildings used to define the number of building´s floor is 2.5 m for buildings constructed before 1919 to 1964 and 3 m for buildings constructed after 1965. Lastly, a coefficient for acclimatized surface is settled to not include buildings' areas which are not heated or cooled as common corridors in flats or garages or storerooms. The acclimatized surface coefficients are 0.75 and 0.85 for flats blocks and single houses.

Figure 4 shows the results of the theoretical energy consumption calculated by the previous criteria gathering the results by LSOAs. Generally, the highest theoretical energy consumption belongs to the north part of the city that corresponds to detached and semidetached houses constructed before 1945. Also, some neighbourhoods located in the southwest, southeast and east of the city center, that are characterized by ancient small terraced houses, show a low efficiency. The north-west and the center buildings of Birmingham have a high ratio of energy efficiency. As it is described previously, the mean theoretical consumption values are lower in EBham than Bham with values of 8316 kW/inh per year and 9196 kW/inh per year respectively, that belongs to the decile 5 and 6 respectively. According to the bottom-left graph, the variability of LSOAs deciles is higher for Bham, especially for the last decile, where there is only a few EBham LSOAs

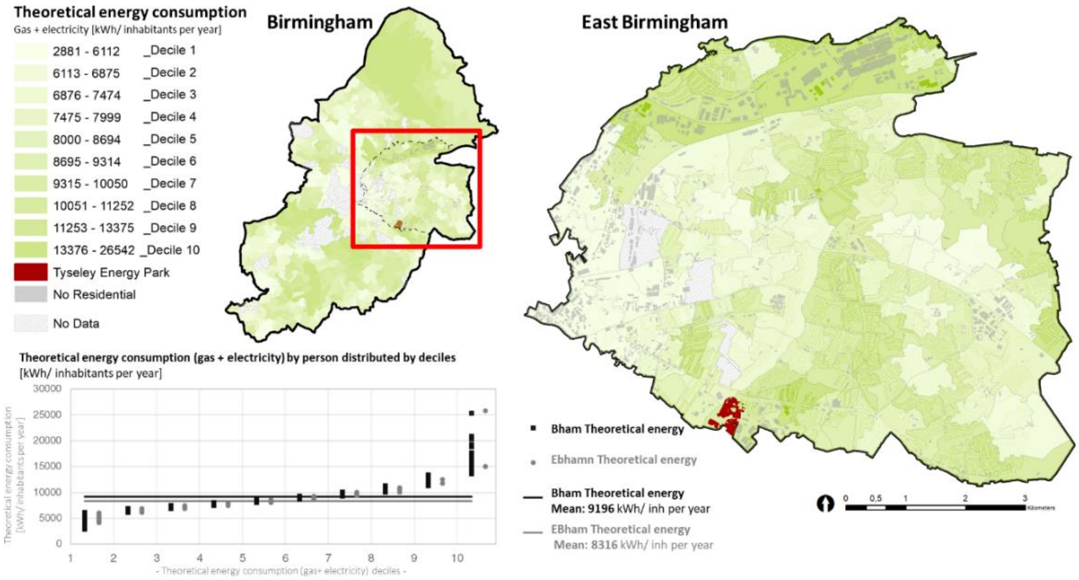


**Figure 4. Theoretical energy consumption by Bham´s LSOA [kW/ Inhabitants-year] gathering by deciles**

### 3.1.4. *Energy consumption comparison*

To know the energy behavior generally, the energy consumptions values for Birmingham city are compared to East Birmingham. The Figure 5 shows the LSOAs´ mean of energy consumption by person per the total (left) and relative value (%) for real gas, real electricity, real total and theoretical energy consumption (right).

Comparing the different energy values according with their origin, the means electricity consumptions are the lowest for all cases, being about three times lower than the mean gas consumption. The means of total real energy consumption sum the values of real consumption of gas and electricity. This quantity is lower than the mean theoretical energy consumption for the studied areas of Birmingham with values of 6573 kWh/inh per year and 9196 kWh/inh per year for real and theoretical energy consumption respectively. The mean of the theoretical energy consumption is lower in the EBham (10%) than Bham and its real energy consumption mean is approximately a 13% lower than the total city, highlighting the energy vulnerability in the east corridor.

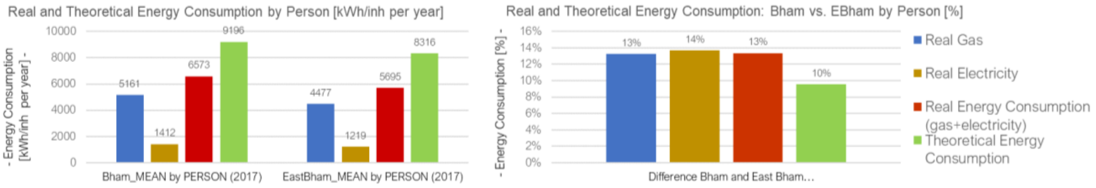


**Figure 5. LSOAs´ means of energy consumption by person per the total (left) and relative value (right)**

### 3.1.5. *Index Energy Deprivation*

The final process for the energy approach is the calculation of the Index Energy Deprivation (IED) (eq 3):

$$IED = \frac{EC_{Real}}{EC_{Th}} x100 \ [\%] \qquad \text{(eq 3)}$$

IED values lower than 100 % mean that consumption is lower than expected, associated to a low energy consumption, but not because the buildings of this area presents a higher efficiency than its typology mean. IED values equal to 100 % consume the same as it is expected. Lastly, IED higher than 100 % belongs to areas where the consumption is higher than expected. They would be related to a high energy burdens, but not because the buildings of this area present a lower efficiency than its typology mean.

Figure 6 reveals that the real energy consumption is less that the expected in most parts of the city (IES < 100%). Only a few LSOAs located in the decile 10 consume the same or more than the theoretical values, reaching a maximum of 197.5. Areas closest to the surrounded city center, west, east and southeast zones present the lowest values, including the proximities of the Tyseley Energy Park with values lower than the 50% of desirable energy consumption and reaching minimum values of 20.9% (decile 1). It should be noted that north areas that before presented high energy consumption values, now have areas that belongs to medium deciles. This fact means that the north LSOAs buildings consume more than their mean theoretical typology.

The mean for Bham LSOA´s neighbourhoods consumes an 81% less than the expected by the standards and belongs to the decile 8, being this value even lower for EBham where, the IED value is 73 %, located in the decile 7. This fact is translated as the mean IED for EBham is a 10% lower than Bham.  A high variability is shown in the first and last decile, but as is graph most of values are between the IED values of 60 to 80%.

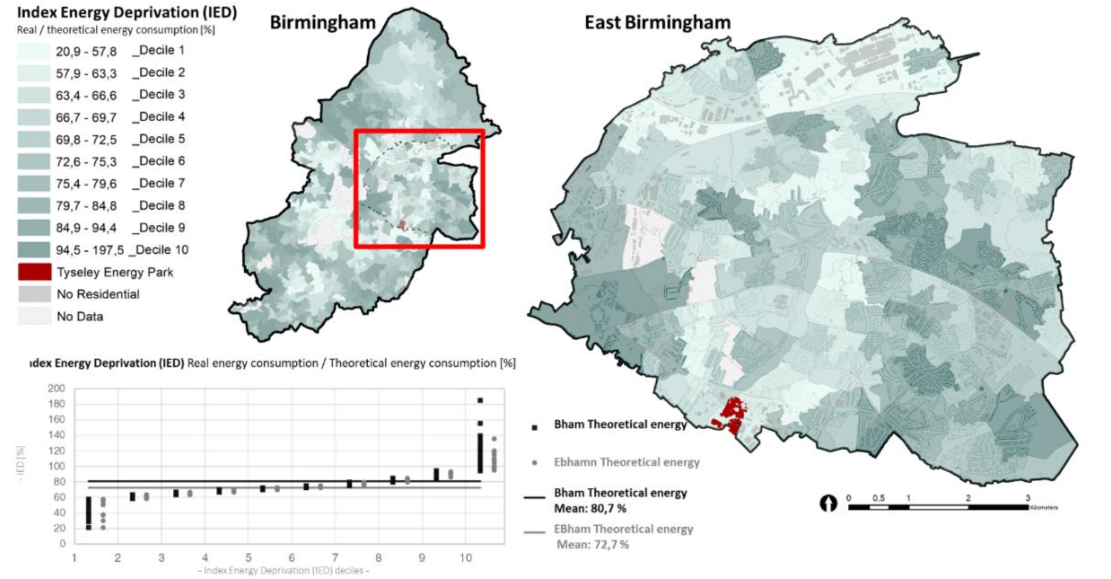


**Figure 6. Index Energy Deprivation (IED) by Bham´s LSOA [%] gathering by deciles**

## 3.2. Index Multiple Deprivation (IMD)

The Index Multiple Deprivation (IMD) provided by the English government (IoD 2017) is used to address socioeconomical factors. IMD is based on a scale from 0 to10 points (most to less deprived respectively) that relativizes England LSOAs. Hence, some deciles share the same values as the results are whole numbers.

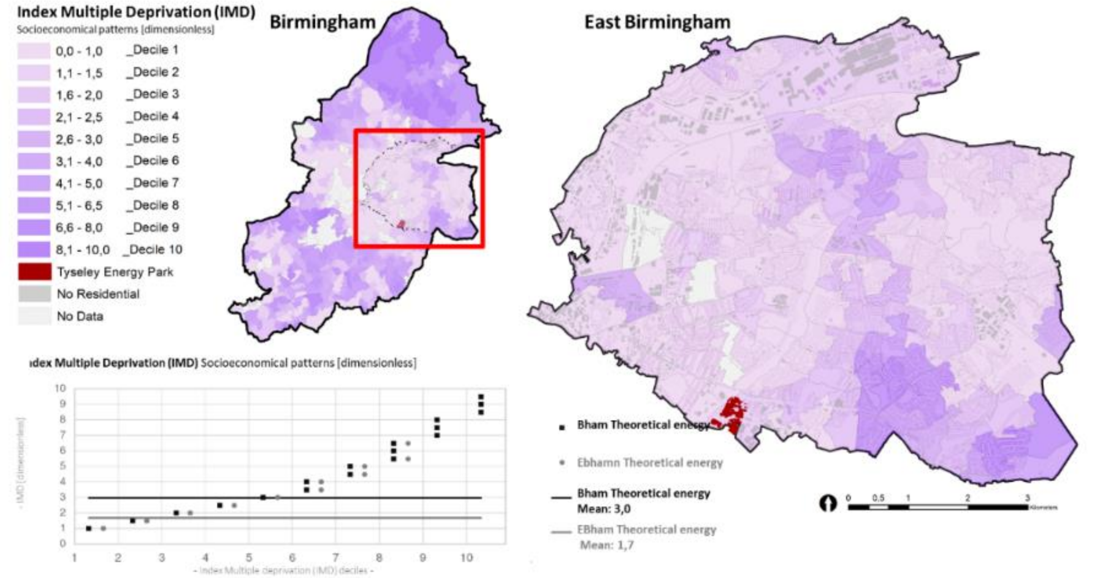


**Figure 7. Index Multiple Deprivation (IMD) by Bham´s LSOA [dimensionless] gathering by deciles**

Figure 7 present the IMD values aggregated by deciles for the city of Bham. It is observed that mainly the north and the south LSOA´s neighbourhoods are characterized by high IMD, on the contrary, the west and essentially the east of the city have the lowest values. Highlighted differences are found between Bham and EBham, with a mean of IMD values a 43 % lower for EBham (1.7) compared to Bham (2.97). IMD mean value of Bham is classified within the decile 6, while the IMD mean value for EBham corresponds to decile 3.

### 3.3. Priority Energy Intervention Areas (PEIA)

Finally, LSOA areas where both, IED and IMD correspond to the lowest decile, will be classified as Priority Energy Intervention Area (PEIA), because of their low energy and socioeconomic characteristics. City´s strategies should be address firstly in PEIAs because of the potential risks related to their deprivation situations.

The IED and IMD lowest deciles are mapped in the Figure 8. Green areas correspond to IED LSOAs located in the first decile (20,9 % to 57,8 %.). On the other hand, purple areas correspond to IMD LSOAs placed in the first decile (0 to 1). The overlap of decile 1 for IED and IMD values, reveal 23 PEIA zones located mainly in the west and east of the city. Six of these PEIA are placed in the east Birmingham corridor and three of them in the surrounding areas of Tysely Energy Park. For both Bham and EBham all IMD belongs to 1 value. The number of PEIA located in EBham is lower than the whole city, however they include a high intensity deprivation (fist decile IED mean for Bham is 52.0 versus the value of 49.3 of EBham)

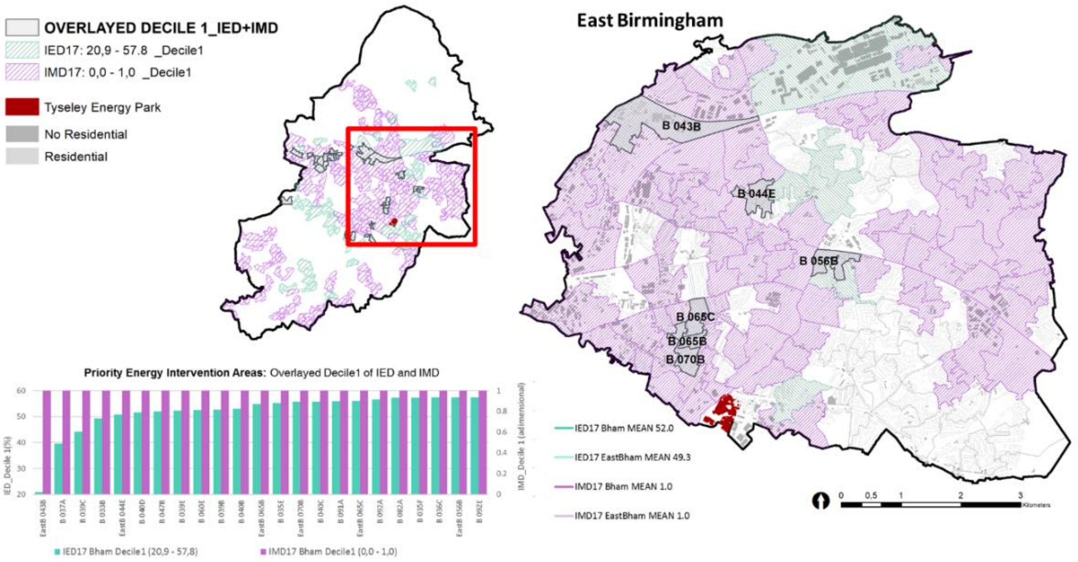


**Figure 8. Priority Energy Intervention Areas (PEIA). Overlapped IED (green) and IMD (purple) LSOA´s areas with decile 1.**

## 4. Conclusions

The Priority Energy Intervention Areas (PEIA) methodology is developed for the dwellings placed in the city of Birmigham, focusing especially in the East Birmigham. This top-down approach is based on GIS tools using the Lower Layer Super Output Area (LSOA) classification. This study aims to reduce uncertainties and time-consuming processes for the location of energy deprived areas. Moreover, it fosters to achieve clean, fair and healthier urban environments in these vulnerable areas though the "green" challenge strategies.

To this end, two indexes are used: The Index Energy Deprivation (IED) and the Index Multiple Deprivation (IMD). IED is a proposed index that compares the real and theoretical energy consumption addressing the differences between consumed and the energy performance associated to the user´s behaviour. Other determinant factors in these variations as the climate data or the household´s quality are approached by the IMD that quantify the socioeconomic, health and environment level of the LSOA´s neighbourhoods. The conducted data have been gathered by deciles, defining the overlapping of lowest IED and IMD as PEIA.

The real energy data is calculated as the sum of real domestic gas and electricity for each LSOA. It should highlight the gas energy consumption, which is approximately three times higher than the electricity consumption, which it reveals an elevated dependency of the gas heating facilities.

An on purpose urban classification is carried out to estimate the theoretical energy consumption. It is based on the building typology and construction´s period considering flats, detached, semidetached and terraced houses.

Flats are located in the city center. Their quantity is not that significant compared with other typologies; however they present notably the highest energy consumption per building, specially the high flats with values higher than 40 MWh/inh per year. This is associate to their increasing surface (larger and higher), besides of having the highest values of efficiency. Both low-rise and high-rise categories represent low values of real and energy demand and medium- high rates of IED and IMD.

Detached houses are in the north and southwest zones and have medium-high levels of efficiency. Their real and theoretical energy consumption is high but have medium- high rates of IED and IMD.

Semidetached houses are placed in all the surroundings neighbourhoods of the city, except of the west zone. They widely belong to the most frequent building typology. From 1919 to 1944 were constructed more than a 10 thousand dwellings and have medium-low energy efficiency. Their real energy consumption is medium-high, while the theoretical one is medium. The IED is medium-high but some west city areas have lower ratios.

Terraced houses are mainly in the west and east city center. Most of them (specially the large-size ones) were built up before 1919, but also other representative amount of small-size terraced houses was constructed in during 1965-1980, presenting the worst energy efficiency values. Their real energy consumption is low but their theoretical values are medium-low generating a low IED areas. IMD is also low.

East Birmingham shows lower energy values compared to the whole city for all cases, being a 13% less for the real energy consumption (gas+electricity) and a 10% inferior for the theoretical energy consumption. The same pattern is shown for the indices. IED is a 10 % lower and IMD has a notable reduction of a 43%. It should highlight that almost the whole city consumes less than expected (from 1 to 9 deciles IED is lower than 100%)

Finally, 23 LSOAs have been characterized as Priority Energy Intervention Areas. Their location belongs mainly to terraced houses neighbourhoods, which reveals the worst IED and IMD values. This situation could explain the low IED and IMD values of the east Birmingham corridor, where are located 6 PEIA associated to an intense deprivation ratio. The wasted energy of Tyseley Energy Park industries, could be reused by households located in the three PEIA closest to this area, fostering the innovative energy challenges proposed in the Birmingham´s Carbon Road Map. The west area of the city should be also considered for further energy interventions because of the high number of PEIA found.

The PEIA methodology is proved as an efficient approach to map and quantify the most deprived neighbourhoods from an energy perspective considering also other influence aspects as socioeconomical and environmental levels. Terraced houses should be considered as a preference within the city´s strategy frameworks. This procedure could help stakeholders to improve these areas though further developments based on sustainable and inclusive projects that should be addressed from a deeper urban perspective.

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