UNIVERSITY COLLEGE LONDON
FACULTY OF THE BUILT ENVIRONMENT
BARTLETT SCHOOL OF PLANNING

Effects of the urban green and blue spaces on residential energy consumption: a case study on London

Li Huang, MSc.

Student number: 19041189

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Li Huang

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Abstract

The residential sector has accounted for about 40% of the total energy consumption in the UK for a long time. Under the requirement of sustainable development, it is necessary to study which factors affect this part of energy consumption. Social and economic conditions, household behaviours and energy usage attitudes, dwelling features and the natural and built environment are four generally identified aspects that have an influence on residential energy consumption in the existing studies. There is abundant literature having explored the first three aspects, but relatively little literature has studied the natural and built environment, especially the built environment. The urban green and blue spaces as elements of the built environment have been proved affecting the urban surface temperature, which is critical to residential energy usage. However, their relationship with residential energy consumption has not been fully explored.

This dissertation takes residential energy consumption in London as the research object, exploring whether the difference in its spatial distribution is directly related to the urban green and blue spaces at the scale of Lower Layer Super Output Area (LSOA). After the control of other significant influence factors, multiple linear regression is applied to examine the relationship between study variables and normalised residential energy consumption. The study results show that some variables are significantly correlated to the domestic gas/electricity consumption, including variables about land occupation, distance and spatial distribution characteristics. However, their effects are not always consistent in different situations. The results of this dissertation not only can inspire future studies in this area but also provide some advice on the urban ecosystem planning and design.

1. Introduction

1.1. Study background

As the energy demand has increased worldwide, energy crisis and climate change that mainly caused by carbon dioxide emission have been critical concerns for many countries, including the UK (Bickerstaff et al., 2008; Lindberg, 1977; Solomon, 2009). The White Paper on Energy acknowledged that energy is crucial to our lives and economic success, and that involves two long-term challenges: mitigating climate change by reducing emissions and ensuring secure, clean and affordable energy (Department of Trade and Industry, 2007). It also claimed that saving energy is the starting point of energy policy.

Sustainable energy usage is an essential aspect of sustainable development for a country (Vera and Langlois, 2007). As an essential part of daily life, the domestic sector maintains a considerable part of total energy consumption, which can be observed in Fig.1. Excluding transport sector, domestic energy consumption accounts for 50% of all in 2018 (Department for Business, Energy & Industrial Strategy, 2019). Therefore, if this part of energy consumption can be reduced, it will be significant to the sustainable development goal in terms of mitigating energy crisis and climate change. Also, decreasing residential energy use could benefit economic development, as it could limit the availability of energy by other productive sectors (Miranda and Assis, 2013).

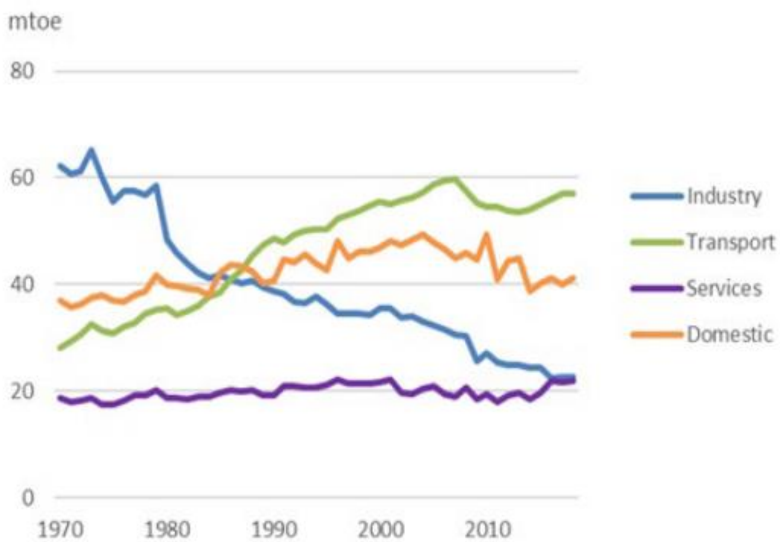


Fig. 1. Change in energy consumption in the UK by sector 1970 to 2018.

Source: Department for Business, Energy & Industrial Strategy (2019).

Therefore, many have studied the influence factors of domestic energy consumption for the reason of making a more precise prediction and giving advice for policymakers on energy reduction, thus influencing occupants to conduct energy-saving behaviour actively or passively (Abrahamse and Steg, 2009, 2011; Baker and Rylatt, 2008; Belaïd, 2017; Bhattacharjee and Reichard, 2011; Brandon and Lewis, 1999; Brounen et al., 2012; Guerin et al., 2000; Sanquist et al., 2012; Steemers and Yun, 2009). Some are related to the conditions of occupants, and some are related to the living environment. The latter has aroused the attention of the planning sector since some belief of environmental determinism, even though this part of influence factors, especially those about the external living environment, have not been well studied and verified. There is some research evidence showing that the built environment such as urban form and urban ecosystem can affect the local climate like temperature and humidity which can further influence the energy consumption (Moon et al., 2018; Santamouris et al., 2001). The urban ecosystem includes all green and blue spaces in urban areas, which provides 'service' like urban temperature regulation to benefit the living environment (Gómez-Baggethun and Barton, 2013). Some have recognised its contribution to energy saving due to its cooling effect, even though these studies are mainly in areas where cold appliances are often used (Zhang et al., 2014). Thus, whether it also works on other areas with different energy use characteristics needs more studies.

In the UK, gas and electricity are the two primary forms of household energy. Heating energy which mostly uses gas, has been the most substantial part of UK domestic energy consumption, accounting for 60-70 per cent (Jason and Ian, 2013). Therefore, the factors influencing heating demand are likely to have a considerable impact on household energy consumption in this country. Besides, like many other regions, electricity is used mainly for cooking, lighting, cold appliances, audiovisual, washing/drying and others (Zimmermann et al., 2012).

Although there are some studies of domestic energy consumption based on the situation of UK, they always have limits on the geographic scale and the data size, and the influence factors of green and blue spaces are not fully identified. Previous researches in the UK were mainly carried out either on a regional scale or on a small number of buildings. Small-scale studies have many details but may have restrictions on a broader application, while large-scale studies can consider different urban environments but may neglect details. Thus, Baker and Rylatt (2008) suggest having Meso-level studies which suit the urban form of many

British cities. At the same time, open high-resolution data now offer a chance to improve this situation. Many statistics in England which are often based on small to mesoscale areas can be conducive to studies on such level.

1.2. Research aim and objectives

This dissertation focuses on the differences in the spatial distribution of household energy consumption, including electricity and gas, aiming to explore whether it is affected by the green and blue spaces in London, as well as specific influence factors. However, there are many other factors, which perhaps have a more significant influence than green and blue spaces, influencing energy usage. This study will recognise the influence of target factors with the control of other major factors, exploring the extent to which they can explain energy consumption after normalisation.

In order to meet the aim, the four following objectives are set.

(1) Review the previous studies on residential energy consumption critically and determine the study factors and appropriate methodology.

(2) Control the influence of factors that have no relation with green and spaces but have obvious influence on household energy consumption.

(3) Explain the effect of all variables of green and blue spaces on residential energy consumption in London, and compare with the results of other studies.

(4) Provide implications and suggestions for urban (green and blue spaces) planning on helping reduce domestic energy consumption.

1.3. Structure of this dissertation

Chapter 2 will review the literature on residential energy consumption, summarise the existing research results and methods, and discuss the research gap. The research methodology will be presented in chapter 3, explaining the study area, the research design, data sources, and how the data will be processed and analysed. The analysis results will be demonstrated in chapter 4. The key findings and some implications for urban planning will be discussed in chapter 5, as well as some limitation of this study. In the end, the conclusion will be presented in chapter 6.

2. Literature review

2.1. Influence factors of residential energy consumption

The influence factors of residential energy consumption are complex. There are many studies in this field, but different conclusions are often drawn due to the different spatial and temporal scales. Also, differences in specific target issues and available data always lead to different results. Some researchers study factors that influence energy consumption changes over a period, such as Halvorsen and Larsen (2001) who has identified the effects from household size, equipment used, income, dwelling size and energy price. In comparison, others do not focus on time changes but focus on the determinants of energy consumption differences between households, such as Sanquist et al. (2012). The research of this paper is more similar to the latter, so the research literature is mainly in such part.

In general, the influence factors of residential energy consumption include four aspects: household social and economic conditions, household behaviours and energy usage attitudes, dwelling characteristics, and the natural and built environment (Ye et al., 2013; Azevedo et al., 2016; Santamouris et al., 2007; Guerin et al., 2000; Belaïd, 2017). The first two aspects represent the occupants while the last two reflect the living environment. Bhattacharjee and Reichard (2011) reviewed more than fifty literature about energy consumption factors and found that many factors fall into more than one aspect.

2.1.1. Factors of occupants

(1)Social and economic conditions

Many pieces of literature have proved that there is a close relationship between social and economic conditions and residential energy consumption. Income is recognised as a strong determinant by many researchers, but no one factor alone can explain household energy consumption, including it (Druckman and Jackson, 2008). Guerin et al. (2000) have reviewed the research in energy studies since 1975 and conclude that age, income, home ownership, and education are the most frequent predictors of energy behaviour and energy consumption that related to occupant characteristics. Others like family size, dwelling size and the number of wage-earners in the family are also indicated in many studies (Bhattacharjee and Reichard, 2011).

Household attributes can directly affect energy behaviours, but more importantly, they have indirect effects on energy use by affecting housing choices (Belaïd, 2017; Steemers and Yun, 2009). For example, income is a factor that almost every research is mentioned since it is directly related to the availability of energy. Santamouris et al. (2007) claim that, on the one hand, low-income families can hardly afford relatively high energy costs, which is regarded as fuel poverty; on the other hand, low-income people are more likely to live in buildings with poor conditions, often leading to higher energy costs and less energy availability.

Many researchers recognise that household size and dwelling size are the most influential factor in their research (Bhattacharjee and Reichard, 2011). In general, the more people live in one home, or the bigger the dwelling, the more energy it consumes. However, there seems to be a minimum annual energy consumption irrespective of the number of occupants and floor area (Jason and Ian, 2013). Therefore, it may not be a simple linear relationship between these two and total residential energy consumption. In terms of heating energy, the physical size of dwellings is more strongly correlated to it than household size (Jason and Ian, 2013), which may be more relevant to the energy consumption of London where most families have a heating system but no air conditioner. Besides, as for the energy consumption per capita, Lenzen et al. (2006) argue that it decreases as the household size increases, which is because occupants are simply sharing consumer items.

The age structure of the household is also mentioned in a substantial body of literature as a background influence factor. Bhattacharjee and Reichard (2011) have summarised some literature, arguing the per capita energy consumption increases with age because older people tend to lack knowledge about energy conservation, have stronger inertia for change, and need to derive their well-being from health and comfort. Also, Urban and Ščasný (2012) find the positive relationship between the presence of children in a household and the probability of installing thermal insulation.

(2)Household behaviour and energy usage attitudes

Although household socio-economic attributes can affect energy consumption, the household behaviours and energy usage attitudes also play a role in it. Sanquist et al. (2012) claim that lifestyle factors reflecting social and behavioural modes can explain electricity consumption more than income. Brandon and Lewis (1999) find that even though income and demographic characteristics can predict historical energy consumption, compared to the feedback mechanism and environmental attitudes, they can hardly change the consumption during the study period. However, energy behaviour is also affected by many social and economic variables such as income, age, education and home ownership (Guerin et al., 2000). Therefore, this aspect is often discussed together with socio-economic factors.

For example, education level of household is often mentioned in conjunction with energy attitudes and energy behaviour, but its influence on energy consumption is controversial. Some have observed that higher education levels of occupants lead to lower energy consumption, possibly because they tend to have more knowledge of energy usage and its consequences and are more likely to adopt energy conservation measures (Bhattacharjee and Reichard, 2011). However, Abrahamse et al. (2005) notice that information enables higher knowledge levels of individuals but not necessarily energy-saving behaviour. The level of formal education seems only has an apparent positive effect on the environmental concern of the occupants but has no decisive influence on energy conservation activities (Urban and Ščasný, 2012).

Household behaviour refers to the occupant's activities in the house, including the use of various household equipment and space. The household habits like the temperature set for the air conditioner and the 'standby' modes of appliances have effects on the energy consumption, but many people cannot realise it (Guerin et al., 2000; Jason and Ian, 2013). Moreover, Baker and Rylatt (2008) through the analysis of survey data point out that, compared with the previous studies, the number of bedrooms and homeworking become important for the energy consumption difference, which may be related to the changes in households as technology and appliances become more available. Thus, not only the energy usage but also its influence factors will change as residents' living habits change.

Furthermore, some focus interventions in terms of the social and environmental psychology that causes voluntary behaviour change instead of contextual factors that influence household energy behaviour. These interventions often intend to change occupants' attitudes toward energy use, such as antecedent strategies like commitment and consequence strategies like feedback (Abrahamse et al., 2005). For example, some research indicates that making energy consumption visible is vital to change the behaviour of residents because it can raise their concern (Brandon and Lewis, 1999). The attitudes of occupants like how they feel about comfort in homes, their perception of the 'cost' of saving energy and their responsibility of environment can affect energy usage (Barr et al., 2005). Also, Guerin et al. (2000) find that desire for comfort, health concerns, incentives and folk knowledge, which are related to user attitudes, are frequently proved predictors for energy behaviour.

2.1.2. Factors of the living environment

(1) Dwelling characteristics

In addition to the factors of occupants, the living environment is also crucial to energy consumption by households since it is the external condition that affects energy use. Cheng and Steemers (2011) claim that over 85% of the variance in energy consumption is explained by dwelling type and the socio-economic class of households. Compared to the residential electricity consumption is mainly related to household characteristics, Brounen et al. (2012) indicate that residential gas consumption is principally determined by dwelling characteristics. Dwelling characteristics denote the features of building itself and its interior. There are two significant factors of dwelling that influence its energy performance, type (detached, semi-detached, terraced house or flat, for example) and the level of energy-saving measures installed (Druckman and Jackson, 2008).

The building conditions of the building itself and their components like doors, windows and insulation layer influence energy consumption. Housing types are considered affecting energy use because heating/cooling energy is related to external wall area and window area, which are often different for different housing types like flats and detached houses (Jason and Ian, 2013). Also, different housing design leads to different degrees of wind and sunlight exposure, which can directly affect energy end use (Bhattacharjee and Reichard, 2011). The age of housing usually affects energy consumption, not only because the older homes tend to be in worse conditions, but also the building regulation after 21st century require developers build homes more energy efficient (Jason and Ian, 2013; Tiwari et al., 2000).

Then improving the energy efficiency of houses through building energy-saving technology may help with reducing energy consumption. For instance, the insulation of the façade or double glazing is likely to reduce energy consumption, especially for heating (Guerra Santin et al., 2009). However, the research result from Brounen et al. (2012) suggests that the impact of home insulation on household energy use is not significant in the Netherlands. Besides, the measures applied also vary according to local climate and energy use purposes (Huo et al., 2017). For example, some regions in tropics concern the ventilation technology instead of insulation. Therefore, the impact of dwelling characteristics on energy consumption and its influence factors may have considerable differences in diverse regions.

(2) The natural and built environment

The natural environment is a natural system, including elements that are not artificial such as climate, air, water and rocks (Johnson et al., 1997). In urbanised areas, where most places are affected by human activities, such an environment can be called the built environment. The elements of the natural environment related to the research on energy consumption are mainly the climate. Atmospheric temperature, humidity, wind flow and numbers of sunny days are the weather-related factors that affect residential energy consumption, and dwelling microclimate which refers to the local temperature around a dwelling can also have an additional influence (Bhattacharjee and Reichard, 2011). In urban space, this kind of small-scale climate pattern is influenced by the built environment such as urban forms, topography, water bodies and vegetation.

Some researches through climatic measurements to identify the urban heat island and its relationship with energy use. For example, Santamouris et al. (2001) identify the cooling and heating load is affected by the urban climate, which has a high value in the city centre. Besides, some researchers like Steemers and Yun (2009) based on survey data of households, including climate, building characteristics, occupant behaviour and socio-economic factors. They argue that the most significant variable determining energy use among those four categories is the climate. However, Azevedo et al. (2016) detect that there are apparent differences in urban heat and vegetation distribution across Birmingham, but the dominant factor affecting electricity consumption is not climate but income. Their research is based on open data online and is conducted at Middle Layer Super Output Area (MSOA) scale with a mean population of 7,200. They also admit that the results can change when the method is conducted based on higher resolution.

Because the wide acknowledge of the ecosystem services like climate regulation and air purification, some literature tries to prove that urban ecosystem can influence the urban climate and therefore achieve energy and emission reduction. For example, Zhang et al. (2014) examine such mechanism of green spaces in Beijing, and they also claim that the plant structural type (i.e. tree, shrub, grass and their combination) and size largely determine the effect. However, the research is conducted at a citywide scale, and the energy saved from the cooling effect is estimated based on the transformation coefficient rather than actual energy reduction. Moreover, Ye et al. (2013) examine that green space and water bodies can help reduce home energy usage carbon emissions at the town scale. Zhou et al. (2011) find out not only land cover composition but also its spatial configuration can influence land surface temperature that dispersed distribution of green space can mitigate the urban heat island effect and reduce energy consumption. Similarly, Ye et al. (2015) prove their point and also argue that, compared with green space and water bodies with large area but far away from the residences, those closer to the residences are more likely to have effects on energy reduction. Also, some indices about spatial layouts like patch density and edge density are beneficial for UHI mitigation (Li et al., 2013).

Overall, the exploration of the specific influence factors of green and blue spaces is insufficient. Some studies have not controlled other influence factors well, and some research scales are either too macro or too micro, affecting the results. Although there is considerable literature linking the variables of green and blue spaces to land surface temperature or carbon emission, very little is directly related to residential energy consumption. Furthermore, since the energy consumption in the UK is mainly for heating, the cooling effect of the ecosystem might adversely affect total domestic energy consumption. Therefore, it is necessary to conduct a more specific study on the impact of urban ecosystem on residential energy consumption in the UK.

2.2. Research methods

Regression analysis is the most commonly used method to explore the relationship between things, and it is widely used in geography (Ferguson, 1977). However, according to different research purposes and data characteristics, specific methods are often different. For instance, Ye et al. (2013) specifically used ordinary least squares method for regression. Sanquist et al. (2012) applied multiple regression analysis after factor analysis to explore the relationship between lifestyle factors and residential electricity consumption. Steemers and Yun (2009) employed the general linear model and path analysis to verify the influence of the parameters of occupants and their interrelationship. Baker and Rylatt (2008) first adopted simple regression in the exploratory phase. They then used multiple regression to analyse the full sample by adding variables one by one, so as to detect the most statistically-significant relationship. Thus, it can be seen that most researchers choose linear regression. Nevertheless, Belaïd (2017) believes that linear regression cannot reveal the driving factors behind residential energy use, so he chose the method of nonlinear regression to identify the direct and indirect effects of household attributes.

Except for regression, there are also other methods to analyse the relationship between factors and domestic energy consumption. For example, Azevedo et al. (2016) used direct Pearson correlation to explore the relationship between normalised energy consumption and the aggregated LST and NDVI. However, this method has certain requirements on data, not all data is applicable, and causality cannot be confirmed. Structural equation modelling is used by Urban and Ščasný (2012) to explore the role of environmental concern and household characteristics on residential energy use since this method is suitable for identifying latent variables.

Therefore, different methods suit different situations, and every method has its flaws. The determination of the analysis method should base on the characteristics of research data and research purpose.

3. Methodology

In this part, the study area, research design and the data collection and analysis methods will be demonstrated, as well as their justifications. This research will use quantitative research methods to reveal the relationship between the elements of urban green and blue spaces and residential energy consumption. All initial data used in this dissertation are available for application online, and they are mainly processed and analysed in ArcGIS and SPSS.

3.1. Study area

Greater London is the study area of this dissertation, covering an area of 1,569 square kilometres, with a population of about 8.908 million in 2018. It is a representative big city with a temperate oceanic climate. The mild summers and cool winters in this city have long led to more heating energy use rather than cooling one. However, data have shown that summers are getting hotter, and the demand for air-cooling systems in buildings are increasing these years (Nickson, A. et al., 2011).

Furthermore, this research will be conducted at LSOA (Lower Layer Super Output Area) level. There are 4,835 LSOAs in the Greater London area. It is a geospatial statistical unit created by the Office for National Statistics to facilitate with the statistics of small areas, which has a mean population of 1,500 (NHS, 2020). According to the data from census 2011, each LSOA has an average of 676 households. Besides, the average geographic area of an LSOA is about 32.5 hectares and usually consists of several blocks (see Fig.2). Therefore, LSOA can be considered a mesoscale urban area.

Fig. 2. The spatial relationship between LSOAs and buildings.

3.2. Research design

According to the literature review in chapter 2, the relationship between residential energy consumption and the major influence factors is shown in Fig.3. The socio-economic conditions of occupants will influence household energy consumption directly. Also, more importantly, such characteristics will affect household energy consumption indirectly by affecting their 'choice' of dwellings with specific architectural and environmental characteristics and, to some extent, their attitudes toward energy use. Then under the influence of different attitudes and residential and environmental characteristics, household behaviour will also be different, resulting in different energy consumption. The built environment is thought to influence the occupants' energy use by influencing the climate, and this paper will try to link its variables with residential energy consumption directly.

Specifically, this dissertation aims to test whether urban green and blue spaces affect household energy consumption in London. Thus, the effects from other critical effects, as shown in the dotted box in Fig.3, need to be controlled to demonstrate that the urban ecosystem has an additional critical role in household energy consumption through the quantitative analysis. Also, this research plan to determine which relative characteristics actually pose an impact on energy consumption, and then provide some suggestions for blue and green system planning and developers.

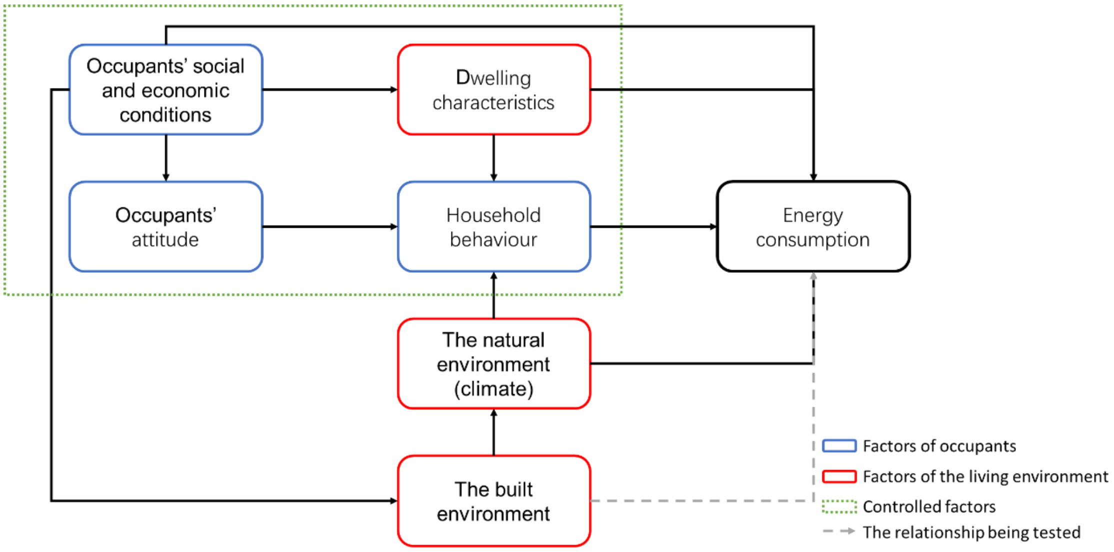


Fig. 3. The relationship between residential energy consumption and essential factors.

3.3. Data collection and analysis

3.3.1. Household energy consumption data

The domestic energy consumption data of London, including electricity and gas, is from National Statistics (2020a; 2020b), collected by Department for Business, Energy & Industrial Strategy. This dataset records real data on total domestic electricity/gas consumption, the number of meters, mean and median consumption for LSOA regions. The total domestic gas and electricity consumption (kWh) will be used in this dissertation.

After synthesising the information of all the required data, the study year is determined as 2016, because the data for this year is relatively new and comprehensive.

3.3.2. Control the effects of dwelling characteristics

The first step is to control the influence of dwelling characteristics, which will be accomplished by using the data of Energy Performance Certificate (EPC). An EPC is primarily used to certify the energy efficiency of the property being evaluated. The rating of EPC is divided based on the current energy efficiency score through the examination of key items related to the energy use of properties such as windows, range from A to G where A is very efficient, and G is inefficient (Department for Communities and Local Government, 2017). Therefore, this scoring system can represent the building characteristics of the home in terms of energy performance.

The dataset is downloaded from the Ministry of Housing, Communities & Local Government (2020). Since 2007, EPC has been required by the government that most of the domestic and non-domestic buildings must have one when constructed, sold or let in England and Wales (MHCLG, 2014). As a result, it does not show the entire building stock but a representative portion of it. Based on the raw data, London had 2,924,217 effective records, with more than 30% each at Grade C and D, and nearly 15% each at Grade B and E (see Fig.4). In this study, records with missing values or errors are cleaned before analysing, leaving 2,908,898 pieces of data.

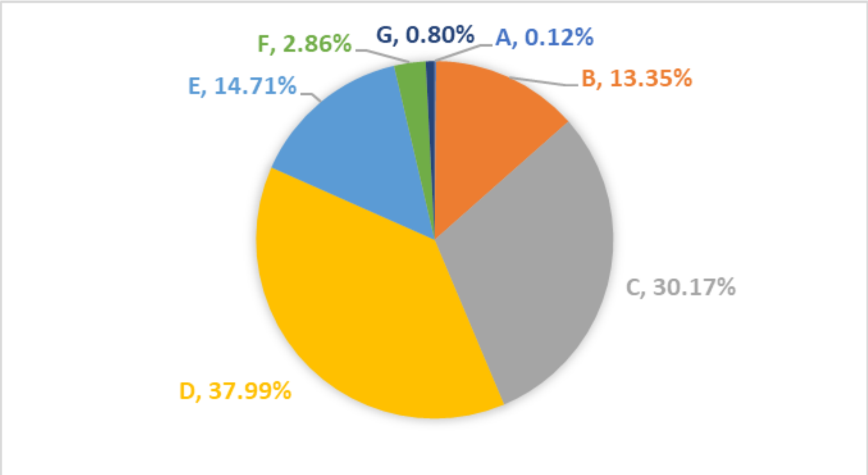


Fig. 4. Chart for the Rating of Residential Energy Performance in London.

In order to get a general picture of each LSOA, this dissertation evaluates each LSOA by its average current energy efficiency score. It then bases on the EPC rating criteria (see Table 1) to classify.

Table 1: EPC rating criteria.

Source: SAP (2009)

Rating	Score
A	92-100
B	81-91
C	69-80
D	55-68
E	39-54
F	21-38
G	1-20

3.3.3. Control the effects of social and economic conditions

The way to control the effects of social and economic conditions on residential energy consumption is to normalise energy consumption by essential social and economic factors. The average household size, the average floor area, the average age and the household income, which are believed can well construct a family in terms of energy consumption (Ye et al., 2013). Firstly, the total energy consumption of each LSOA in 2016 is divided by the total population to get the average electricity/gas consumption per person. Then divide it by the average housing area, the average age and the household income.

In the absence of satisfactory actual survey data, the average age and household income data at the LSOA level in this dissertation are estimated. The population of each LSOA in 2016 was estimated by the Office for National Statistics (2019) based on the 2011 census. This dataset also contains a specific number of people between 0 and 90 years old and over 90 years old, which can be used to calculate the average age of each area. Calculated from the estimates data of the very old, including centenarians of the UK, the average age of people over 90 in the UK of 2016 is about 90 (Office for National Statistics, 2017). Thus, people over 90 are counted as 90 in the calculation. In fact, the number of people over the age of 90 accounts for a tiny proportion of the total population in every LSOA, and the average age of each LSOA is the same when the age of this group is recorded as any years of age from 90 – 98. Besides, GLA (2015) estimated the data of the household income at LSOA level. Although its latest data is from 2012, this study only uses this variable to control the impact of the differences in economic factors among different areas. We assume that the differences do not change much over four years.

Besides, the raw data for the average floor area is from EPC. In addition to the information about energy efficiency, the certificate contains many property details such as postcode, property type, and the total floor area. Hence, in order to obtain the average resident area of each LSOA, the gross floor area data for each household needs to be connected to its LSOA code based on postcode before calculation.

3.3.4. Control the effect of household behaviour and attitudes

Based on the literature review, household behaviour and attitudes of occupants are related closely with some social and economic factors. These socio-economic factors have been considered in the previous section. Therefore, this research does not use specific variables to control household behaviour and attitudes and assumes that residents in London will not change their habits by moving location.

3.3.5. Determine the research variables and data acquisition for the urban blue-green spaces

Based on the literature review, the characteristics of the green and blue space that will be examined in this study are the area, the percent cover of green spaces (GS)/blue spaces (BS, i.e. water bodies), spatial patch density and distance. The overall variables are shown in Table 2. The area factor includes the total area, which can reflect the total amount of urban ecosystem within a study unit, and the per capita area since LSOA is divided based on population rather than geographical area. Besides, some LSOAs in this study have a significant difference in the area, which may make the percent cover of GS/BS more practical. The calculation of these three variables will be conducted for GS and BS, respectively, and their sum. In terms of spatial distribution characteristics, patch density (PD), the number of GS and BS divided by their total area, is one of the main spatial characteristics of the ecosystem and is considered to be related to UHI (Li et al., 2013). This dissertation will directly relate these variables to energy consumption and examine the relationship between them.

Table 2: Research variables and their meanings.

Variable name	Meaning	Unit
Y	The normalised residential energy consumption, denoting the amount of residential energy consumed by a person of the same age, housing area and income.	10^6kWh/(person*age*m^2*￡)
X_{BA}	The total area of blue spaces.	ha (0.01km^2)
X_{GA}	The total area of green spaces.	ha
X_{BGA}	The total area of blue and green spaces.	ha
X_{BP}	The per capita area of blue spaces.	ha per capita
X_{GP}	The per capita area of green spaces.	ha per capita
X_{BGP}	The per capita area of blue and green spaces.	ha per capita
X_B	The ratio of blue spaces to the total area of a unit.	-
X_G	The ratio of green spaces to the total area of a unit.	-
X_{BG}	The ratio of blue and green spaces to the total area of a unit.	-
X_{PD}	Patch density, including blue and green patch.	patch per km^2
X_{D_5G}	The distance from the unit centre point to its nearest green space of over 5 hectares.	km
X_{D_50G}	The distance from the unit centre point to its nearest green space of over 50 hectares.	km
X_{D_100G}	The distance from the unit centre point to its nearest green space of over 100 hectares.	km

Moreover, since some LSOAs are relatively small, irregularly shaped or elongated, the environment outside the boundary may also have some impact on the normalised household energy consumption of these areas. Every LSOA is detected to have green covers, which may be only two trees, but not all of them have relatively intact green spaces. In order to examine the influence of natural space with a certain scale, the distance from the unit centre point to its nearest green space of over 5, 50 and 100 hectares will be included in this study as independent variables. The preliminary visualisation of urban natural environment and household energy data shows that the household energy consumption does not appear to increase or decrease outward along rivers and water bodies. Therefore, this dissertation does not take the distance from the nearest water body as a separate variable for subsequent regression analysis.

The geospatial dataset of GS and BS are from the Greater London Authority (2019), which has combined classified near-infrared aerial imagery (NDVI) captured during 2016 with land use datasets to identify the green and blue infrastructure more accurately. This dissertation will use the data of NDVI 0.05 threshold due to its higher accuracy compared with the NDVI 0.1 threshold one. However, in the calculation of PD and distance, the data is simplified on 5m x 5m grids in order to facilitate computer calculation. The calculation of the variables of GS and BS is mainly based on the ArcGIS platform.

3.3.6. Explore the relationship between urban green and blue spaces and household energy consumption

Since this dissertation aims to acknowledge the direct relationship between green and blue spaces variables and household energy consumption, multiple linear regression analysis will be employed. After the integration of various data sets, a total of 4,768 LSOAs have met the above requirements with complete information. Stepwise regression will be applied to these sample data based on SPSS. When the P-value of a variable is less than 0.05, it enters the regression equation; when the P-value of a variable is bigger than 0.1, it is eliminated.

3.4. Ethical issues

This research will abide by the principles related to ethical considerations and the stipulations imposed by the data providers. This research is based on secondary data from the Internet, including statistical and spatial data. All used data has been desensitised before being illustrated.

4. Results

4.1. Energy efficiency classification for LSOA

The classification result shows that LSOA with Grade C, D and E has 689, 4021 and 103, respectively. Grade B only contains 20 areas, not enough to make it a separate sample so that it will be ignored in the following study. Fig.5 illustrates their spatial distribution, where LSOA with Grade C and E are scattered all over the city. However, a significant proportion of the former is clustered in the area along the Thames to the east of central London, while the latter is mainly scattered around the suburban ring near the green belt.

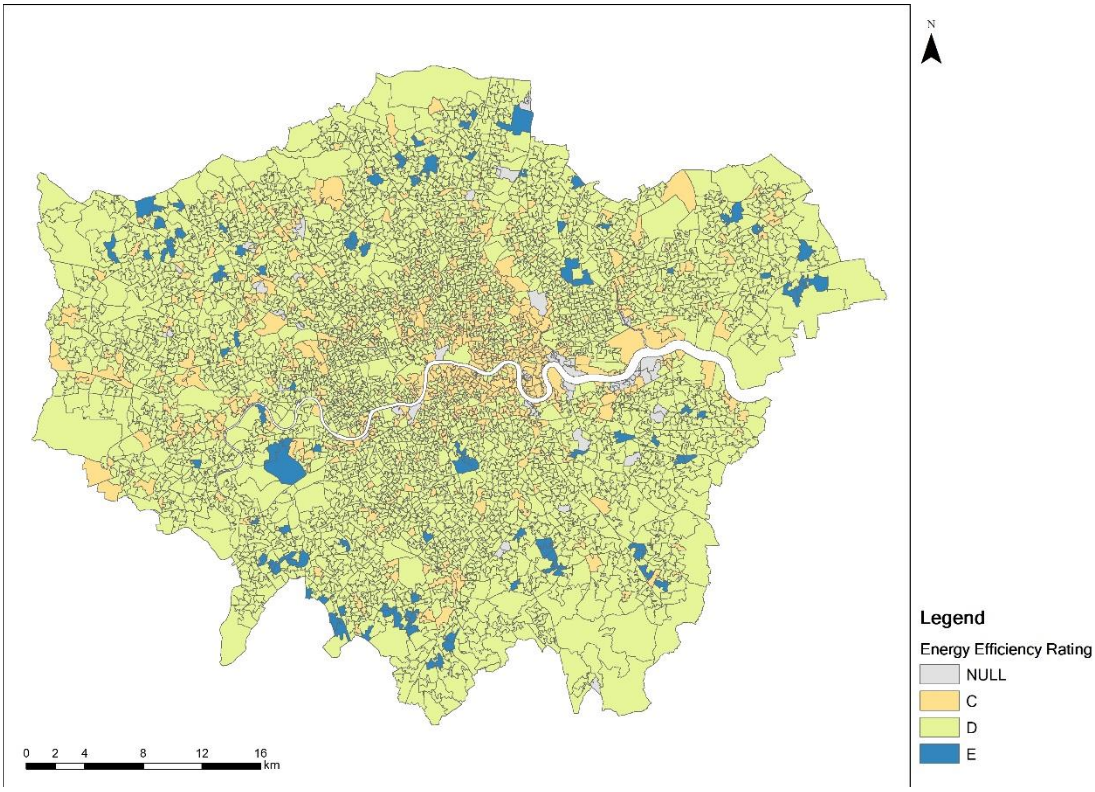


Fig. 5. Distribution of Energy efficiency classification for study units.

4.2. Spatial distribution of residential energy consumption

The spatial distribution of residential consumption of gas and electricity is similar to some extent, see Fig.6 (a)&(c). The grading is based on the method of Natural Breaks. Area ① to ③ are three places where high-value areas are relatively concentrated. However, the consumption of household gas and electricity are not the same everywhere. For example, in area ⑤ (Newham), gas consumption is not as high as electricity consumption relative to other areas.

From Fig.6, we also can observe almost opposite characteristics between household energy consumption distribution and the normalised one. Most of the areas with high value have changed become relatively lower than others after normalisation with socio-economic variables, such as areas around Hyde Park and Hampstead Heath (in ②). Most low-energy areas tend to become relatively high-value areas after normalisation. However, the extent of change of every LSOA is not the same, and some LOSAs like the city of London (④) still have high values in the citywide comparisons.

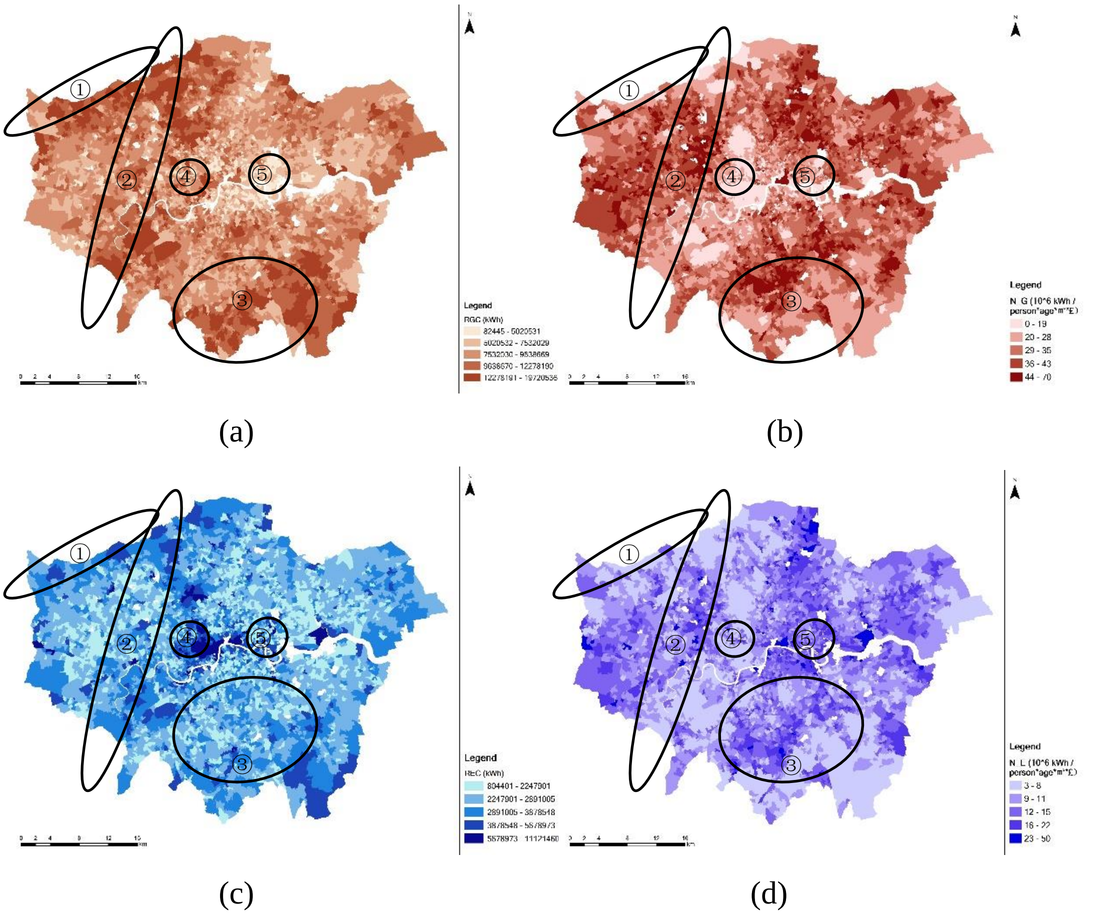
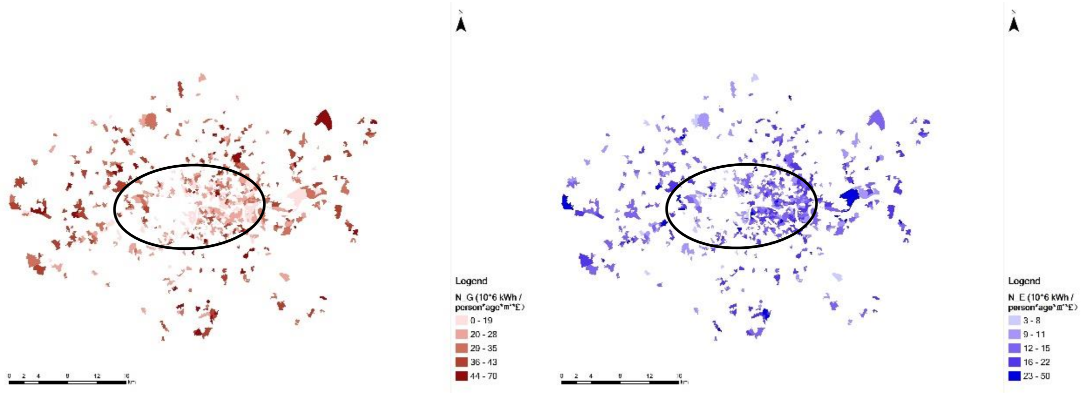
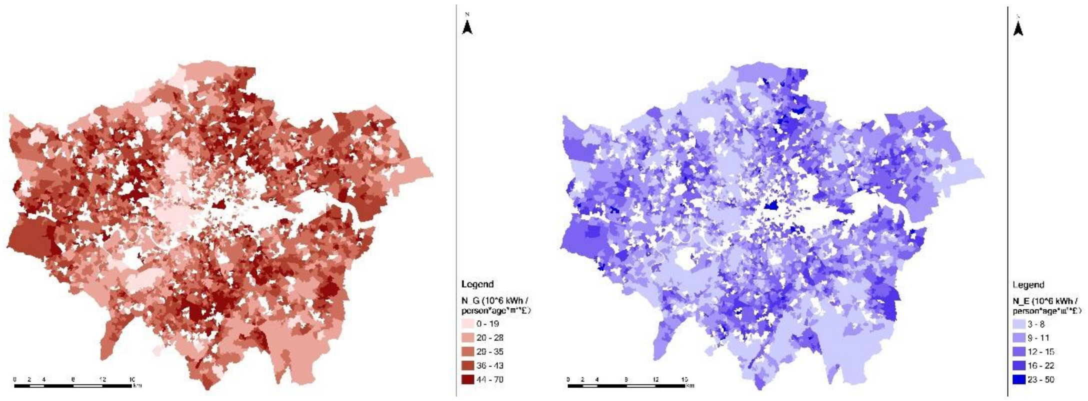


Fig. 6. Residential energy consumption of 2016 in London. (a): residential gas consumption distribution; (b): normalised residential gas consumption distribution; (c): residential electricity consumption distribution; (d): normalised residential electricity consumption distribution.

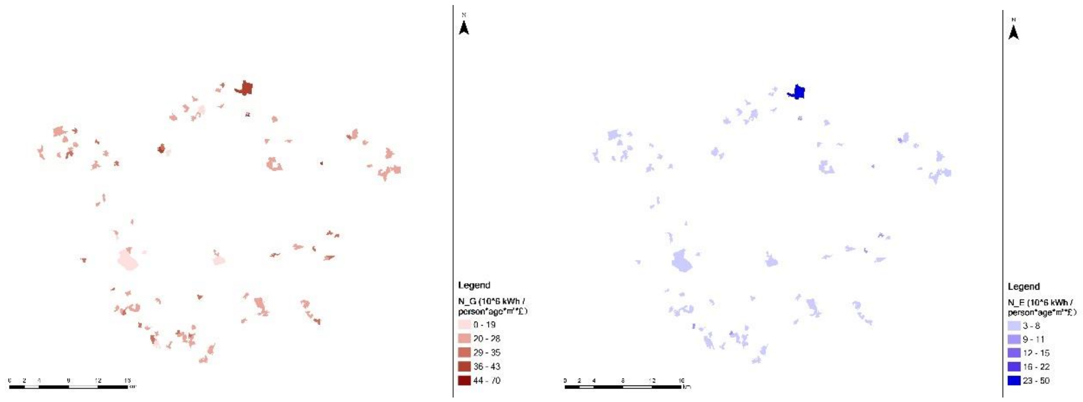
Fig.7 shows the detailed normalised energy spatial distribution of each test group. As can be seen from the figure, the distribution of NRGC and NREC in Group D and Group E has similar characteristics, while there are apparent differences in Group C. In Group D and E, places with high normalised electricity consumption also tend to have high normalised gas consumption. When it comes to Group C, such a relationship is uncertain. The circled area in Fig.7, located to the east of central London, is a low-value NRGC area and also a high-value NREC area. It is because, after the process of normalisation, the residential gas consumption of these LSOAs has not changed in the opposite direction as others and has remained low in value (see Fig. 6).



(a)



(b)



(c)

Fig. 7. The distribution of normalised residential energy consumption of different groups. (a): Group C; (b): Group D; (c): Group E.

Statistics based on energy efficiency grouping show that there are different characteristics between and within groups. Group D (i.e. LSOAs with Grade D) has the highest value of mean normalised residential gas consumption (NRGC) with 32.73 * 10^6kWh/(person*age*m^2*￡), and Group C has the highest value of mean normalised residential electricity consumption (NREC) with 13.40 * 10^6kWh/(person*age*m^2* £). As shown in the Fig.8, the normalised residential energy consumption performance of these three groups are not as the energy efficiency grading expected that high-grade ones tend to have less energy consumption. As for the data within groups, they are all different to some degree. The NREC of Group E has the minimum of standard deviation (i.e. 2.19), and the NRGC differences within Group C are the most obvious. Overall, the differences within Group E are smaller than those within Group D, which are smaller than those within Group C. Under similar building construction situation, the differences of NRGC are larger than that of NREC.

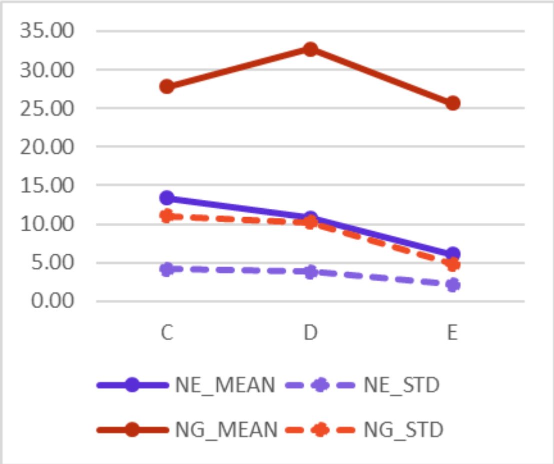


Fig. 8. The mean and standard deviation of normalised electricity and gas consumption.

4.3. Urban blue and green system of London

Fig.9 shows the urban blue and green system of London and its spatial relation with LSOA energy efficiency groups. In comparison with Fig.6, although we can find that the normalised household energy consumption values around large parks always tend to be lower, it is difficult to tell the exact impacts of urban blue-green space on normalised household energy consumption. In addition to fewer blue-green spaces in the city centre and the airports and more in the green belt area in the outer ring of the city, the configuration of blue-green spaces in other places is similar. Compared with other regions, area ① to ③ have several large natural open spaces, but their spatial configurations are not unique in the city.

However, on the LSOA scale, different variables of the blue-green spaces have various characteristics. Blue Spaces in cities vary greatly in spatial configuration, and less than half of LSOAs have blue spaces. The GS area of each LSOA also varies considerably since some contain large areas of urban green space while some are mainly residential or working area. Besides, although the land cover percentage of GS varied among groups, there was little change within each group. Group C, D and E has an average of 29.8%, 18.4% and 50.8% respectively, and the standard deviation of them is 0.15, 0.05 and 0.17.

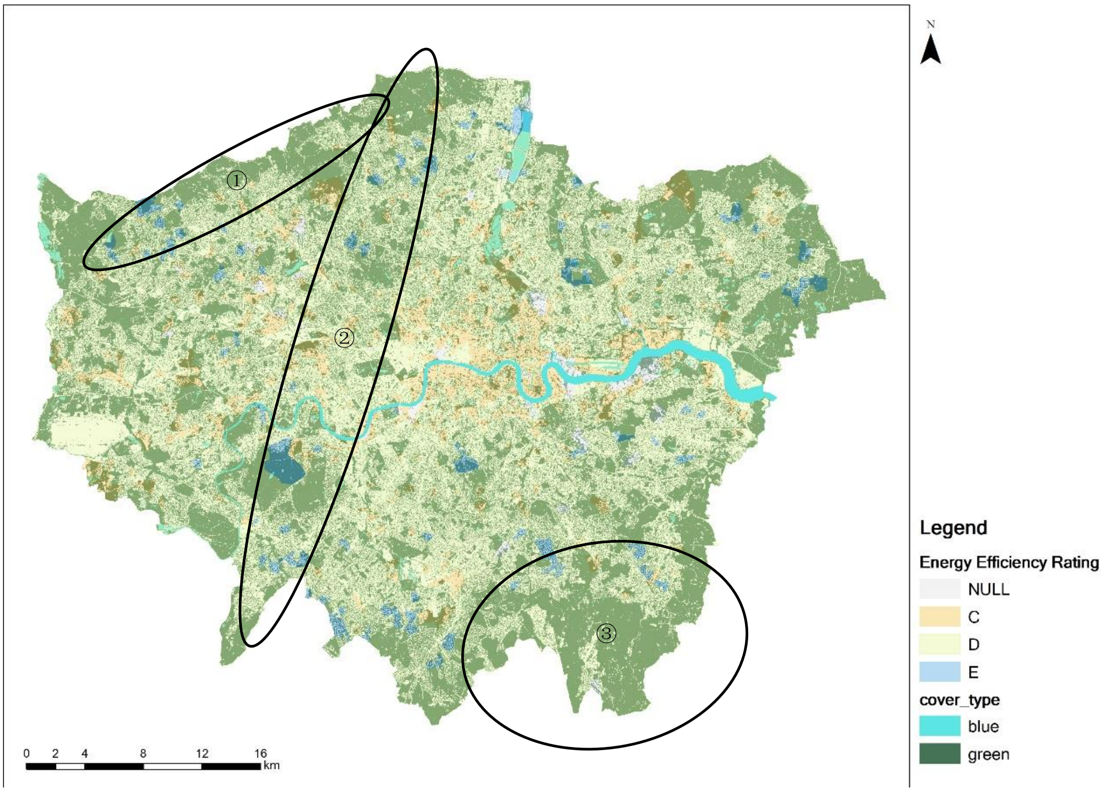


Fig. 9. Urban blue and green system of London.

4.4. Multiple linear regression

Multiple linear regression is used to exam the relationship between normalised residential energy consumption and urban blue and green space characteristics. Table 3 shows the regression equations, related adjusted R^2 and the significance probability value of each correlated variable. During the analysis progress, some correlative variables have been removed in order to avoid multicollinearity. Many variables are correlated; for example, X_{BGA} and X_{GA} may be very similar in some cases because of the lack of BS. The results in Table 3 all passed the regression tests.

Table 3: Regression results.

Group	Dependent Variable	Equation	Adjusted R^2	Correlated variable	Standardised coefficient	Sig. (<0.05)
C	NREC	$Y = -6.571X_G + 0.313X_{BA} - 1.684X_{D\_5G} + 0.357X_{D\_50G} + 15.366$	0.064	X_G	-0.239	0.000
				X_{BA}	0.160	0.000
				X_{D_5G}	-0.149	0.003
				X_{D_50G}	0.093	0.039
	NRGC	$Y = -1.526X_{D\_50G} - 58.606X_B + 10.478X_G - 2.996X_{D\_5G} + 29.017$	0.145	X_{D_50G}	-0.151	0.000
				X_B	-0.216	0.000
				X_G	0.145	0.001
				X_{D_5G}	-0.101	0.034
D	NREC	$Y = 0.538X_{D\_50G} + 8.625X_B - 1.926X_G + 0.217X_{D\_100G} + 10.272$	0.056	X_{D_50G}	0.110	0.000
				X_B	0.100	0.000
				X_G	-0.090	0.000
				X_{D_100G}	0.075	0.000
	NRGC	$Y = -22.110X_{GP} + 0.003X_{PD} - 3.333X_{D\_5G} + 0.869X_{D\_50G} + 0.076X_{BA} +31.297$	0.025	X_{GP}	-0.086	0.000
				X_{PD}	0.090	0.000
				X_{D_5G}	-0.091	0.000
				X_{D_50G}	0.075	0.000
				X_{BA}	0.046	0.005
E	NREC	$Y = 0.201X_{BA} + 2.505X_{D\_5} - 14.031X_{GP} + 5.696$	0.687	X_{BA}	0.803	0.000
				X_{D_5G}	0.173	0.005
				X_{GP}	-0.168	0.007
	NRGC	$Y = -67.059X_{GP} + 39.825X_B$	0.176	X_{GP}	-0.363	0.000
				X_B	0.292	0.002

*NREC means normalised residential electricity consumption.

NRGS means normalised residential gas consumption.

As a whole, the adjusted R^2 of the above equations are small except the one of NREC in Group E, which means the natural environment variables in this study cannot explain the normalised household energy consumption change thoroughly. In addition to the considered factors in this dissertation, there still are other factors influencing residential energy consumption in London.

However, the blue and green spaces are examined to have an influence on normalised residential energy consumption in London, and some characteristics are significantly correlated with it. The correlated variables of NREC are XB, XBA, XD_100G, XD_50G, XD_5G, XG and XGP; XB, XBA, XD_50G, XD_5G, XG, XGP and XPD are identified to influence NRGC. It seems those four factors (i.e. area, percent cover, distance and patch density) all have an influence of different extent on the normalised residential energy consumption. The distance from the unit centre to its nearest green space of a certain scale generally affects NREC and NRGC, except the NRGC of Group E. Especially for Group C and D, the distance to green spaces over 50ha have an influence on both NREC and NRGC. Other correlated green indicators are the ratio of green cover and the per capita green space area instead of the total area. By contrast, the total area of blue spaces and its cover percentage is identified. The patch density only detected to be related to NRGC in Group D, meaning that its impact on normalised residential energy consumption is not widespread.

The variables concerning the occupation of land are concerned with all dependent variables in this study. Those about green space (i.e. XG and XGP) are usually negatively correlated with either NREC or NRGC. In contrast, variables about blue space (i.e. XB and XBA) are usually positively correlated with them. This relationship is only reversed in the NRGC of Group C.

In addition, XD_50G has a positive correlation with the NREC and NRGC of Group D as well as the NREC of Group C. It is negatively correlated with the NREC of Group C. XD_5G has a negative relation with the NREC of Group C and the NRGC of Group C and D but has a positive relationship with the NREC of Group E. XD_100G only affects the NREC of Group D significantly with the coefficient of 0.217. It seems that all variables of the urban green and blue spaces in this study do not have a consistent relationship with NREC or NRGC, which may concern with other influence factors.

In terms of NREC, the percent cover of green spaces is the most influential factor of Group C. When all other variables are constant, the NREC of Group C decreases by about 0.066 units as X_G increases by 0.01 (i.e. 1% of land cover). X_{D_50G} has the most significant effect on the NREC in Group D, although the other identified variables were also significantly associated with it. When other variables remain unchanged, X_{D_50G} increases by 1km and NREC increases 0.538 units. The total area of blue spaces is the most significant variable for Group E, which can make NREC increase by 0.201 units if it increases one hectare with other variables unchanged.

As for NRGC, X_B, X_{D_5G} and X_{GP} are the variables with the greatest influence in Group C, D and E respectively. With the ratio of blue cover increasing by 0.01 and other variables remaining unchanged, the NRGC of Group C decreases 0.58 units. In Group D, the coefficient of X_{D_5G} is -3.333, which is the regression coefficient with the largest absolute value of this variable in each regression equation. In Group E, when other variables remain unchanged, increasing one hectare per capita of green space can reduce about 67 standard units of gas consumption.

5. Discussion

5.1. Influence factors of green and blue spaces on normalised residential energy consumption

In the previous chapter, Fig.7 shows that the normalised residential gas/electricity consumption after controlling for major socio-economic factors does not behave as predicted by the rating that the higher the rating, the lower the energy consumption. This means the energy consumption values are also affected by other factors. When the energy efficiency scoring system applied at the LSOA level, the grading cannot represent the actual energy consumption behaviour. However, the research object of this dissertation is not the influence factors concerning the differences between energy efficiency groups, but the ones involved differences within groups.

The regression results show that the ratio of green cover and the per capita green space area rather than the total area, which is identified by many studies, are significantly correlated with normalised energy consumption. For example, Ye et al. (2013) argue that the size of GS has a significant influence on reducing domestic energy usage carbon emissions, and Li et al.

(2013) claim that increasing patch area can mitigate UHI. These different arguments may attribute to the division of research units. LSOA is divided according to a similar population, which means that the more non-residential land, such as green spaces, the larger the total area of LSOA. Such a relationship does not exist in the research units of the examples mentioned above. Therefore, the results in this dissertation show that the ratio of GS or the per capita area can better represent the quality of the natural environment of every LSOA and the normalised household energy consumption.

Compared with GS, the spatial distribution of BS in London is more heterogeneous and relatively scarce, and the total area of a considerable amount of BS is small. Thus, the total area of BS is less closely related to the total area of the LSOA in which it is located. The total area of BS and its cover ratio is sufficient to represent the environmental characteristics of the region and correlated with normalised energy consumption at the LSOA scale.

In most cases, the residential gas and electricity consumption for a person generally tends to decrease with the increase of X_{GP} or X_G, or with the decrease of X_B or X_{BA}, under the same age, income and housing conditions. It proves that GS can not only alleviate UHI as many pieces of literature have shown (Zhang et al., 2014; Moon et al., 2018), but also directly related to household energy consumption. Besides, GS does not increase household gas consumption due to cooling effects in such climate condition of London. In contrast with it, BS in London is examined to the disadvantage of residential consumption both of electricity and gas in most cases. Some studies based on the climate characteristics of London or areas similar to London have found that some water bodies increase rather than decrease UHI effect, which is related to the urban morphology (Gunawardena et al., 2017; Steeneveld et al., 2014). It may be why, in general, BS has the opposite effect on residential energy consumption than GS, since they may also have different effects on urban temperatures.

However, the results show that the NRGC of Group C increases as X_G increases or X_B decreases, which is a particular case among all. As the circled area in Fig.7 is 'abnormal' compared with others, the regression coefficients of the NRGC in Group C appears in the opposite situation. It indicates that the influence of blue-green space on normalised energy consumption value is not constant in different geographic areas. Gunawardena et al. (2017) have proved not all blue space can mitigate UHI while Hathway and Sharples (2012) have found a river in Sheffield can help cooling the urban temperature, and this was influenced by the urban form on the river bank. Also, Shashua-Bar and Hoffman (2000) claim that the layout of green space and the urban form also affect its cooling effects. Therefore, the effects of different blue and green spaces on the microclimate are not changeless, which is related to the built environment that they are located. Similarly, the effects of blue and green spaces on normalised energy consumption may be affected by other factors like building layout, which need further study to prove.

The general relationship between X_{D_50G} and X_{D_100G} and normalised residential energy consumption has verified the intuitive finding in Section 4.2 that the proximity of large GS makes the normalised energy consumption of LSOAs in area ① to ③ are relatively less than other areas. However, the results also show that, except for NREC in group E, the proximity of GS over 5 ha is not conducive to the normalised domestic energy consumption reduction. This means that in most cases in London when all other variables are constant, proximity to large GS usually can help to reduce residential energy consumption, but not to all scales of GS. When the threshold of the GS area is set to 5 ha, their effects on normalised energy consumption may be reversed. Therefore, if medium-scale GS is close to the centre of an LSOA, and the LSOA is far from large GS, in most cases, it has high normalised domestic energy consumption. This is somewhat different from the findings of Ye et al. (2015) who claims that GS closer to residences generally has more effects on urban household energy use carbon emission reduction, no matter how small they are, and the green spaces far away from residents are associated with fewer effects even though they have large areas. The results of this dissertation, however, demonstrate that for normalised household energy consumption, not only does the distance from GS affect it, but the impact also varies with the size of the corresponding GS, which was not present in their study. Nonetheless, similar to their study, this dissertation has not confirmed the threshold for change.

Besides, only X_{D_5G} is identified among the variables about distance in Group E, and it is significantly correlated with the NREC. In this group, big-scale natural spaces are contained in or around most of the LSOAs, while in Group C and D, this is not general (see Fig.9). In this case, the result shows that the closer from the unit centre to the nearest GS over 5 ha the less normalised residential electricity is consumed. This indicates that the surrounding environment or other factors may change the threshold of GS area with a positive effect of distance on NREC.

The patch density, which is an important feature of spatial configuration representing the fragmentation of GS (Zhou et al., 2011), only significantly correlated positively with the NRGC of Group D. The relationship identified in this dissertation is contrary to the finding of Ye et al. (2015). They argue that fragmentary GS and BS are better for energy use carbon emission reduction. However, the results from Li et al. (2013) indicate that decreasing patch density of GS can further mitigate UHI, and they also acknowledge that the relationship between land surface temperature and spatial form is not consistent. Thus, the result of this dissertation only can indicate the relationship between patch density and the normalised energy consumption in London.

5.2. Implications for urban planning on helping reduce domestic energy consumption

Sustainable development has long attracted the attention of urban planning and city design domain that many concepts are related such as eco-city, low-carbon city and recently smart energy city (Mosannenzadeh et al., 2017; Kenworthy, 2006; Roseland, 1997; Phdungsilp, 2010). Energy is considered widely to be closely related to sustainable development and the environment, and cities are the key of energy consumption (Dincer and Rosen, 1999; Phdungsilp, 2010; Vera and Langlois, 2007). From the perspective of the effects of urban green and blue system on residential energy consumption, this dissertation aims to propose some suggestions for urban planning and design on energy reduction and environment improvement, so as to facilitate sustainable development further.

First of all, in a given area, it is useful to increase the GS ratio and reduce the BS ratio for the energy consumption reduction in groups D and E. In terms of green space construction, more attention should be paid to increasing per capita area rather than total area. Therefore, the overall coordination between the residential and green space environment configuration is required. However, in urban developments, except for parks, blue-green space cannot grow to a high occupation ratio of land cover in order to guarantee certain living space and other essential functions as well as the profits for developers. Hence, the spatial layout of the urban ecosystem is vital in an urban context.

The pattern in Fig.10 denotes, for most cases of London (i.e. the Group D and the NREC of Group C), the layout of blue-green spaces in an area with low/high normalised residential energy consumption. The left and right sides have the same land area, population and green and blue spaces. The area of each LSOA in it is the average size (about 32.5 ha), which means each unit cannot contain the entire green space over 50 ha. According to the regression results, it is better to have a big-size green space in the middle of several units, and small ones are set around the units, rather than dividing the green space into many small ones distributed near the centre of each unit. It is because the latter tend to decrease the distance from the unit centre to green space over 5 ha, and also increase the patch density in that area, generally increasing normalised energy consumption. Likewise, planning for other situations also can be based on the relationship detected in the results of this dissertation.

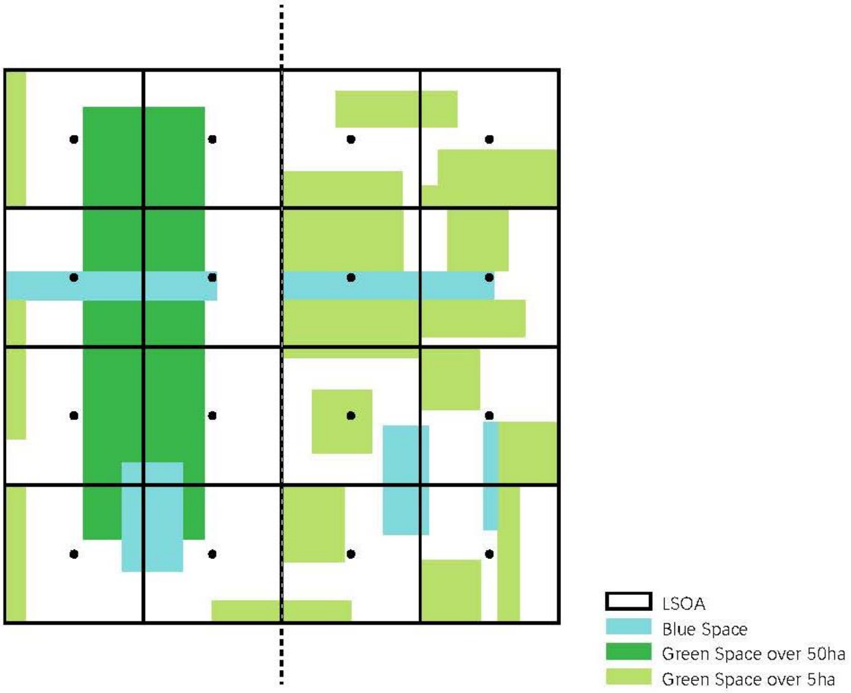


Fig. 10. A simple green and blue spaces layout pattern with low normalised residential energy consumption (left half) and high normalised residential energy consumption (right half).

Generally speaking, different planning strategies should be adopted for energy reduction in different regions since the relationship between green and blue spaces and the residential energy consumption is not constant. Also, the development strategy of different areas in a city is often different, such as the central district and rural areas. The model mentioned only based on the theory and research findings. Other elements need to be brought into consideration all together in the actual planning and development process.

5.3. Limitations of the study

There are limitations of the applied data, some of which are estimated, including the population, age and household income, and the EPC data concerning the building construction condition does not cover the whole property in London. Although the estimated data is produced by government agencies based on reliable methodologies and real data, the research results cannot fully represent reality.

The results above indicate that the characteristics of each location have influenced them, so they do not represent energy consumption influence factors of the corresponding energy efficiency level area of other regions. The results can only reflect the situation of greater London. However, the distribution of energy groups and the spatial configuration of the ecosystem in most cities are similar. Usually, the energy-efficient buildings or energy-efficient blocks concentrated in the central area where the green and water resources are less and broken, and high energy consumption buildings are mainly in the suburbs of the city where are often more abundant ecological resources. Even so, the results show the effects of the green and blue spaces variables are not always consistent in different groups. Therefore, although the results of this dissertation may be applicable in many regions, it is best to conduct local research before guiding planning and development.

Overall, the adjusted R^2 of the regression equations indicate all the research variables in this study have a relatively low explanatory power for the normalised household energy consumption in London. Factors of the green and blue spaces are not sufficient in this study, especially those concerning spatial layout. Variables like edge density, patch cohesion index, and shape index can also be included in future studies. Of course, other factors that have nothing to do with the green and blue spaces, and those have not been controlled in this study influence the normalised household energy consumption. For example, urban density is tested to play essential roles in urban temperature and energy consumption of buildings (Steemers, 2003). Therefore, the existence of these factors has affected the explanatory power of variables in this study.

6. Conclusion

As the increasing concern of climate change and energy efficiency, a large amount of literature has studied the influence factors of urban temperature and energy consumption in order to help in achieving energy use reduction and climate mitigation. Due to the significant role of the residential sector in energy consumption, a considerable number of studies have focused on it (Abrahamse et al., 2005; Bhattacharjee and Reichard, 2011). However, the exploration of the effects of urban green and blue spaces on residential energy consumption is insufficient. Compared with the research on the influence of housing characteristics and inhabitant attributes, little literature has explored the direct effect of the urban ecosystem on household energy consumption. The literature on green and blue space mostly links the variables to climate, including UHI effects, rather than household energy consumption. This dissertation has filled in such research gap to a certain extent, proving that after controlling the influence of other major influence factors, the green and blue spaces in London have a direct impact on the residential energy consumption.

The spatial distribution of normalised residential energy consumption has spatial heterogeneity, so as the green and blue spaces in London. It seems that normalised residential energy consumption is related to some big green spaces, which usually are the low-value areas. Although this has been verified in most cases of London, the regression results also show that the relationship between the urban ecosystem and the residential energy consumption is not always consistent in different situations. In most cases, green spaces, especially those with big size, are found to have effects on residential energy reduction. By contrast, blue spaces are generally not conducive to reducing residential energy consumption. However, for special cases, such as the NRGC of Group C, these general rules tend to be reversed. This may be concerned with other factors that have not included in this study, or it may be similar to the view of some other literature that the relationship between urban ecosystem and the urban temperature is also variable in different areas (Gunawardena et al., 2017; Hathway and Sharples, 2012; Li et al., 2013). The exact reason can be investigated in future studies.

This dissertation also provides some advice on reducing household energy consumption from the perspective of urban planning and design. Although under normal circumstances, it is crucial to increase green spaces in cities for energy reason or other benefits like health, and control blue spaces, urban land resources are scarce in cities, especially in urban centres. Therefore, the distribution pattern of the urban ecosystem is vital to make a certain amount of green space play the role of energy saving as much as possible. This dissertation designs a layout pattern for green and blue spaces based on the study results which suit most cases in London. Generally, when other variables remain unchanged, the energy consumption of residences arranged around a large green space is often lower than that of residential areas with scattered small green space close to each unit centres.

Although urban green and blue space have been proved that have a significant correlation with residential energy consumption, many other elements should be considered comprehensively in order to realise energy reduction of a city, instead of focusing on only one aspect. It is because the city is a complex system that elements are interrelated in different degrees (Lombardi et al., 2012). Some features will be changed with the ecosystem. Generally, the urban ecosystem does not be considered alone in the planning progress as well, often related to elements such as buildings and transports. Therefore, the effects of green and blue spaces for reducing residential energy consumption will not be as ideal as the model, which may be affected by other factors. Besides, green and blue planning of a city is not only about energy reduction, since many other ecosystem services that benefit the environment and residents are being concerned (Gómez-Baggethun and Barton, 2013). Thus, various urban ecosystem services need to be balanced with each other during the planning process, so that it is hard to set the layout of green and blue spaces in a way that is most conducive to the residential energy saving. Even so, this dissertation provides a possible way for residential energy reduction and sustainable development.

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Appendix A: Risk Assessment Form

RISK ASSESSMENT FORM
FIELD / LOCATION WORK

UCL

The Approved Code of Practice - Management of Fieldwork should be referred to when completing this form
http://www.ucl.ac.uk/estates/safetynet/guidance/fieldwork/acop.pdf

DEPARTMENT/SECTION – BARTLETT SCHOOL OF PLANNING / MSC SUSTAINABLE URBANISM
LOCATION(S) - LONDON, UNITED KINDOM
PERSONS COVERED BY THE RISK ASSESSMENT – Li Huang

BRIEF DESCRIPTION OF FIELDWORK – No fieldwork will be conducted. The reaerch data is public, only collected from the Internet.

Consider, in turn, each hazard (white on black). If **NO** hazard exists select **NO** and move to next hazard section.
If a hazard does exist select **YES** and assess the risks that could arise from that hazard in the risk assessment box.
Where risks are identified that are not adequately controlled they must be brought to the attention of your Departmental Management who should put temporary control measures in place or stop the work. Detail such risks in the final section.

ENVIRONMENT	**The environment always represents a safety hazard. Use space below to identify and assess any risks associated with this hazard**
e.g. location, climate, terrain, neighbourhood, in outside organisations, pollution, animals.	Examples of risk: adverse weather, illness, hypothermia, assault, getting lost. Is the risk high / medium / low ? No specific risk related to the environment.

CONTROL MEASURES	**Indicate which procedures are in place to control the identified risk**
☐	work abroad incorporates Foreign Office advice
☐	participants have been trained and given all necessary information
☐	only accredited centres are used for rural field work
☐	participants will wear appropriate clothing and footwear for the specified environment
☐	trained leaders accompany the trip
☐	refuge is available
☐	work in outside organisations is subject to their having satisfactory H&S procedures in place
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

None.

EMERGENCIES	**Where emergencies may arise use space below to identify and assess any risks**
e.g. fire, accidents	Examples of risk: loss of property, loss of life

No emergencies.

CONTROL MEASURES	**Indicate which procedures are in place to control the identified risk**
☐	participants have registered with LOCATE at http://www.fco.gov.uk/en/travel-and-living-abroad/
☐	fire fighting equipment is carried on the trip and participants know how to use it
☐	contact numbers for emergency services are known to all participants
☐	participants have means of contacting emergency services
☐	participants have been trained and given all necessary information
☐	a plan for rescue has been formulated, all parties understand the procedure
☐	the plan for rescue /emergency has a reciprocal element
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

None.

EQUIPMENT	Is equipment used?	NO	**If 'No' move to next hazard** **If 'Yes' use space below to identify and assess any risks**
e.g. clothing, outboard motors.	Examples of risk: inappropriate, failure, insufficient training to use or repair, injury. Is the risk high / medium / low ?		

CONTROL MEASURES	**Indicate which procedures are in place to control the identified risk**
☐	the departmental written Arrangement for equipment is followed
☐	participants have been provided with any necessary equipment appropriate for the work
☐	all equipment has been inspected, before issue, by a competent person
☐	all users have been advised of correct use
☐	special equipment is only issued to persons trained in its use by a competent person
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

LONE WORKING	Is lone working a possibility?	NO	**If 'No' move to next hazard** **If 'Yes' use space below to identify and assess any risks**
e.g. alone or in isolation lone interviews.	Examples of risk: difficult to summon help. Is the risk high / medium / low?		

CONTROL MEASURES	**Indicate which procedures are in place to control the identified risk**
☐	the departmental written Arrangement for lone/out of hours working for field work is followed
☐	lone or isolated working is not allowed
☐	location, route and expected time of return of lone workers is logged daily before work commences
☐	all workers have the means of raising an alarm in the event of an emergency, e.g. phone, flare, whistle
☐	all workers are fully familiar with emergency procedures
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

ILL HEALTH	The possibility of ill health always represents a safety hazard. Use space below to identify and assess any risks associated with this Hazard.
e.g. accident, illness, personal attack, special personal considerations or vulnerabilities.	Examples of risk: injury, asthma, allergies. Is the risk high / medium / low? Low risk.

CONTROL MEASURES	Indicate which procedures are in place to control the identified risk
☐	an appropriate number of trained first-aiders and first aid kits are present on the field trip
☐	all participants have had the necessary inoculations/ carry appropriate prophylactics
☐	participants have been advised of the physical demands of the trip and are deemed to be physically suited
☐	participants have been adequate advice on harmful plants, animals and substances they may encounter
☐	participants who require medication have advised the leader of this and carry sufficient medication for their needs
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

TRANSPORT	Will transport be required	NO	X	Move to next hazard
		YES		Use space below to identify and assess any risks
e.g. hired vehicles	Examples of risk: accidents arising from lack of maintenance, suitability or training Is the risk high / medium / low?			

CONTROL MEASURES	Indicate which procedures are in place to control the identified risk
☐	only public transport will be used
☐	the vehicle will be hired from a reputable supplier
☐	transport must be properly maintained in compliance with relevant national regulations
☐	drivers comply with UCL Policy on Drivers http://www.ucl.ac.uk/hr/docs/college_drivers.php
☐	drivers have been trained and hold the appropriate licence
☐	there will be more than one driver to prevent driver/operator fatigue, and there will be adequate rest periods
☐	sufficient spare parts carried to meet foreseeable emergencies
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

DEALING WITH THE PUBLIC	Will people be dealing with public	NO	If 'No' move to next hazard If 'Yes' use space below to identify and assess any risks
e.g. interviews, observing	Examples of risk: personal attack, causing offence, being misinterpreted. Is the risk high / medium / low?		

CONTROL MEASURES	Indicate which procedures are in place to control the identified risk
☐	all participants are trained in interviewing techniques
☐	interviews are contracted out to a third party
☐	advice and support from local groups has been sought
☐	participants do not wear clothes that might cause offence or attract unwanted attention
☐	interviews are conducted at neutral locations or where neither party could be at risk
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

SUBSTANCES	Will participants work with substances	NO	If 'No' move to next hazard If 'Yes' use space below to identify and assess any risks
e.g. plants, chemical, biohazard, waste	Examples of risk: ill health - poisoning, infection, illness, burns, cuts. Is the risk high / medium / low?		

CONTROL MEASURES	Indicate which procedures are in place to control the identified risk
☐	the departmental written Arrangements for dealing with hazardous substances and waste are followed
☐	all participants are given information, training and protective equipment for hazardous substances they may encounter
☐	participants who have allergies have advised the leader of this and carry sufficient medication for their needs
☐	waste is disposed of in a responsible manner
☐	suitable containers are provided for hazardous waste
☐	OTHER CONTROL MEASURES: please specify any other control measures you have implemented:

OTHER HAZARDS	Have you identified any other hazards?	NO	If 'No' move to next section If 'Yes' use space below to identify and assess any risks
i.e. any other hazards must be noted and assessed here.	Hazard: Risk: is the risk		

CONTROL MEASURES	Give details of control measures in place to control the identified risks

Have you identified any risks that are not adequately controlled?			
	NO	☒	Move to Declaration
	YES	☐	Use space below to identify the risk and what action was taken

Is this project subject to the UCL requirements on the ethics of Non-NHS Human Research? NO

If yes, please state your Project ID Number

For more information, please refer to: http://ethics.grad.ucl.ac.uk/

DECLARATION	The work will be reassessed whenever there is a significant change and at least annually. Those participating in the work have read the assessment.

Select the appropriate statement:

☒ I the undersigned have assessed the activity and associated risks and declare that there is no significant residual risk

☒ I the undersigned have assessed the activity and associated risks and declare that the risk will be controlled by the method(s) listed above

NAME OF SUPERVISOR – Jonas De Vos

**** SUPERVISOR APPROVAL TO BE CONFIRMED VIA E-MAIL ****