Using Urban Green Systems as an Approach for Future Climate Change Adaptation in London

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Abstract

The main investigation of this thesis is to determine the thermal effect of different urban green systems (UGS) (as trees, living facades) and high albedo pavement at Pedestrian street level in mitigating urban heat island (UHI) and Carbon Dioxide (CO_2) reductions in London, the UK. This thesis quantifies the critical contribution by changing different urban greenery-covering densities (25% and 50%) or applying high albedo pavement in 2018 and future climate scenarios for the 2050 and the 2080 based on London climate change plans. Therefore, this strategy is designed to motivate pedestrians to walk for more extended periods and further distances during the summer season following the Health Streets Initiative introduced by Transport for London and turning London to the world's biggest national park by the 2050s based on the Mayor of London Plan.

However, the influence of different UGS is based on their thermal improvement and CO_2 reduction performance is mostly lacking, particularly for future climatic scenarios. The main aim of this research is to quantify the benefits and how they will influence pedestrians with streets. Different methodologies' phases were tackled in order to investigate the performance and the benefits of different urban green systems' interventions. This was achieved by ENVI-met software simulations, field measurements to validate the results, and a questionnaire survey. All these together have helped to achieve the objectives and to reach the required outcome of the research. First, a simulation for the current case of a typical central London neighbourhood with no vegetation (0%) is carried out, followed by simulating the same neighbourhood by applying urban green systems with 25% and 50% living facade and tree alternatives in addition to applying high albedo material on all pavements which represents 66% of the canyon area.

This simulation of different interventions was applied for 2018, 2050 and 2080 during the summer months in order to measure their influence on pedestrian thermal comfort and CO_2 reduction. Subsequently, first, a real field analysis was carried out to validate ENVI-met simulation calculations that have shown a great index of agreement. Second, a questionnaire survey analysis was formatted to determine the intangible benefits of urban green systems and how these would influence pedestrians' activities within the streets after applying them, in addition to determining the preferred UGS

alternative (Living façade or Trees) with the preferred covering percentage (25% or 50%) for pedestrians.

The ENVI-met simulations results determine that the outdoor thermal comfort was measured based on physiological equivalent temperature (PET) as a reference to evaluate modification benefits towards outdoor comfort level. These results confirmed that, across the three different climatic scenarios – 2018, the 2050s and the 2080s, for best thermal comfort increase, the recommendation was 50% trees followed by 25% trees. While LF with both 25%and 50% coverage did not have a noticeable influence on pedestrians, high albedo pavement has increased thermal stress as it reflects the solar radiation to pedestrians, acting as a second source of radiation. There was not a significant reduction in CO_2 levels from trees, while LF did not change the level at all. This reflects that oceans are the primary source of CO_2 sequestration and oxygen production. However, to eliminate CO_2, the CO_2 sources should be limited and UGS cannot act solely to sequestrate it.

Different canyon orientation in London requires different UGS percentage. For instance, North-South canyons do not require high UGS percentage because buildings self-shade on the canyon and hence receive lower solar radiation, leading to decreased thermal stress. On the other hand, East-West canyons need higher UGS coverage to reach higher thermal comfort levels. Therefore, it is advised to apply UGS coverage of 50% trees for East-West street canyon and 25% trees for North-South street canyon across all years to reach the ideal thermal comfort performance.

However, the ENVI-met software determined the physiological effect; the survey was required to determine pedestrian's perception of different UGS so as to evaluate the psychological effect. The survey reflected that pedestrians are willing to spend 30% more time walking outdoors after applying UGS. Pedestrians also preferred 50% trees as their top favourite preference. While 25% trees and 50% LF had similar preference, the UGS percentage is not the main factor determining the preferred UGS alternative.

One of the most important and crucial findings from the survey is that pedestrians' top reasons for choosing UGS was its aesthetic value and its air pollution reduction. This was followed by relaxation, connecting to nature and biodiversity increase. Thermal comfort increase ranked fifth which reflects that it is not a priority for pedestrians. This reflects the pedestrians' priority when they are looking at UGS. The outcomes based on the ENVI-met simulation and survey analysis including correlations and cross-tabulation propose the adequate UGS percentage and type for each canyon orientation in London. That will be able to provide the maximum thermal comfort level in order to achieve psychological satisfaction and physical heat stress relief, which motivates the city walkability through improving the overall comfort.

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Abbreviations

Abbreviation	Full Description
AOI	Areas of Interest
ARCC	Adaptation and Resilience In A Changing Climate
ASHRAE	American Society of Heating, Refrigeration And Air-Conditioning Engineers
BRE	Building Research Establishment
BUHI	Boundary Urban Heat Island
°C	Degrees Celsius
CAD	Computer Aided Design
CAT	Canyon Air Temperature
CCRA	Climate Change Risk Assessment
CEA	City Energy Analyst
CEO	Chief Executive Officer
CFC	Chlorofluorocarbons
CFD	Computational Fluid Dynamics
CH4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cross-Tab	Cross-Tabulation
CUHI	Canopy Urban Heat Island
FEMG	Facial Electromyography
FACS	Facial Action Coding System
FB	Facebook
GAC	Global Agenda Council
GDP	Gross Domestic Productivity
GF	Green Façade
GHE	Green House Emissions
GHG	Green House Gas

GI	**Green Infrastructure**
GLA	**Greater London Authority**
GR	**Green Roof**
GS	**Green Systems**
GSR	**Global Solar Radiation**
GSV	**Google Street View**
GVI	**Green View Index**
GW	**Green Wall**
HNO	**Nitric Acid**
HPA	**High Pavement Albedo**
IA	**Index of Agreement**
ICT	**Infrastructure Communications Technology**
IEA	**International Energy**
IPCC	**Intergovernmental Panel on Climate Change**
IT	**Information Technology**
JASP	**Jeffreys' Amazing Statistics Program**
K	**Kelvin Degree**
KJ	**Kilo Joule**
KM	**Kilo Meters**
LAI	**Leaf Area Index**
LAQN	**London Air Quality Network**
LEED-NE	**Leadership in Energy and Environmental Design For Neighbourhood**
LF	**Living Façade**
LST	**Land Surface Temperature**
LTCCM	**London Tree Canopy Cover Maps**
LUCID	**Local Urban Climate Model Intelligent Design**
LWS	**Living Wall System**
MAE	**Mean Absolute Error**
MET	**Meteorological Office**
NCDC	**National Climatic Data Centre's**

NS	**North South**
PET	**Physiologically Equivalent Temperature**
PMV	**Predicted Mean Vote**
PPD	**Physiological Percentage of Discomfort**
PPM	**Particle Per Million**
PTC	**Pedestrian Thermal Comfort**
RH	**Relative Humidity**
RMSE	**Root Mean Squared Error**
SET	**Standard Effective Temperature**
SRES	**Special Report on Emissions Scenarios**
SUHI	**Surface Urban Heat Island**
SVF	**Sky View Factor**
TfL	**Transport for London**
Tair	**Air Temperature**
Tmrt	**Mean Radiant Temperature**
Tr	**Receptors Temperature**
Ts	**Surface Temperature**
UBEM	**Urban Building Energy Modelling**
UEL	**University of East London**
UGA	**Urban Green Approaches**
UGC	**Urban Green Corridors**
UGI	**Urban Green Infrastructure**
UGS	**Urban Green Systems**
UHI	**Urban Heat Island**
UHIC	**Urban Heat Island Circulation**
UK	**United Kingdom**
UKCIP	**UK Climate Impacts Programme**
UKCP	**UK Climate Projections**
UMI	**Urban Modelling Interface**
UN	**United Nations**
UTCI	**Universal Thermal Comfort Index**

UWG	**Urban Weather Generator**
VGS	**Vertical Green Systems**
VIP	**Very Important Pedestrians**
VOC	**Volatile Organic Compounds**
VR	**Virtual Reality**
Ws	**Windspeed**
WEF	**World Economic Forum**
WWR	**Window to Wall Ration**
XR	**Extinction Rebellion**

1 Chapter One: Introduction

1.1 Introduction

This chapter introduces urban heat island and urban green systems and their influence on climate change mitigation in the UK and London specifically. The research context shows the need for urban green systems; and therefore, the benefits of investigating them in depth within urban city canyons within London and how they influence urban heat island and carbon sequestration.

This chapter clarifies the aim and the goals of the study through outlining the research plan. Subsequently, it shows the gaps in current knowledge and the research methodology utilised to fill these gaps. Furthermore, it illustrates the expected outcomes through ENVI-met computer simulations and questionnaire survey.

1.2 Research Context

Urban areas are typically warmer than rural areas, as urban areas tend to have denser configuration dominated by impermeable surfaces such as buildings, parking spaces and roads, compared to rural areas which are less densely built and mainly dominated by open spaces (Winguth and Kelp, 2013). Urban Green Systems (UGS) such as green roofs, green walls, living facades (LF), trees and high albedo surfaces may help improve the microclimate of the built environment, particularly in urban areas, through adapting to climate change and mitigating the Urban Heat Island (UHI) effect. It could also improve urban areas, support the growth of green cover, air quality improvement, and Attenuate rainwater, as well as an active role in reducing the inside and outside building temperature (Greenscreen, 2012, Taher, Elsharkawy and Newport, 2019).

A number of Vertical Greenery Systems (VGS) as a part of UGS have been implemented in Europe over the recent years, such as in The Palace Hotel in London (UK), Caixa Forum Museum and Cultural Centre, Madrid (Spain) and Musée du Quai Branly in Paris (France) with many more developing (Good Goal, 2017). However, these are being implemented on a project-by-project approach, as an outcome of investor interest or, occasionally, for the need to improve biodiversity (Mayrand and Clergeau, 2018). Application of VGS is also related to GDP (Gross Domestic Productivity), where the countries with higher GDP, have more VGS unlike countries with GDP which has low number of VGS. on the other hand, green roofs have also been applied but within a larger scale through countries with higher GDP. These green roof applications are probably because it is more practical and physically easier to install UGS on flat horizontal surfaces such as roofs, compared to applying it vertically as a Living Façade (LF). Furthermore, it is lower in cost due to less specialised skills required in the process (Pérez et al., 2014). Green roof emplacement, process validation and research is widely available, giving greater confidence in these systems. Nevertheless, VGS could have a more significant impact on our built environment and microclimate due to the increased availability of building surface area.s greater

Social benefits of VGS are more valuable in countries with higher GDP or countries/cities with policies more than other VGS benefits'. UGS existence and abundance is related to GDP and a countries' motivations, as it increases within countries with higher GDP and more populated cities since UGS has greater positive influence and substantial impact on climate mitigation; thus, its impact is higher within a location that suffers higher risks of pollution, UHI, noise and biodiversity loss. It may be asserted that some countries of similar climate classification may not consider the UGS benefits; this is due to each country's policies and targets (Semaan and Pearce, 2016).

Green roofs have been classified, discussed and investigated in many research studies (Darkwa and Yuan, 2014; Georgios Kokogiannakis, Darkwa and Yuan, 2014; Grigoletti and Pereira, 2014; La Roche and Berardi, 2014; Li and Yeung, 2014; Poptani, 2014; Vanuytrecht et al., 2014; Young et al., 2014; Dimitrijević, Živković and Tomić, 2015; Ahmadi, Arabi and Fatahi, 2015; Luo et al., 2015; Mazzeo et al., 2015; Najafi et al., 2015; Ravesloot, 2015; Yaghoobian and Srebric, 2015; Yang et al., 2015; Hui and Yan, 2016; Barozzi, Bellazzi and Pollastro, 2016; Thuring and Grant, 2016; Vinod Kumar and Mahalle, 2016; Collins et al., 2017; Koura et al., 2017; Mahmoud et al., 2017; Barozzi et al., 2017; Vera et al., 2017). These green roof studies have mainly explored the differences between different classifications of green roofs (intensive, semi-intensive and extensive). They have investigated, in depth, their influence on roof insulation, building energy performance, energy consumption, rain retention and slowing stormwater runoff, improved air quality, increased biodiversity, decreasing roof maintenance and increasing roof life, thermal influence on street level, and structure load.

However, Urban Green Systems inclusive of vertical green systems, green roofs, in addition to trees have not been sufficiently studied regarding benefits and environmental impact for future climate scenarios, particularly in temperate climates. Thus, this research focuses on determining Urban Heat Island effect and mitigation through UGS in a current (2018) and future (2050s and 2080s) climate change scenario.

1.3 Research Gaps in Current Knowledge

Currently, insufficient studies demonstrate the impact of implementing different types and scales of UGS in the future climate change scenarios through changing their percentages for three different climate change scenarios – 'low, medium and high' carbon emissions – through different decades, '2020 early, 2050 mid and 2080 future decade'.. This requires more investigation with regards to the potential mitigation of UHI. This will help decision-makers and urban planners to decide on the most effective measures while considering administrative and spatial limitations.

There is a lack of in-depth quantitative studies that use UGS, such as, living facades, trees and high albedo surface as a sustainable technique for different climatic conditions and urban settings for climate change mitigation by 2050 and 2080 and evaluate the potentials of UGS in mitigating the UHI by the 2050s and the 2080s climate change scenarios. This was linked to policymakers' futuristic targets as the Mayor of London Plan to make London the biggest national park in the world by the 2050s through achieving 50% covered green areas (GLA, 2015).

Further mathematical investigation was carried out to illustrate and explain the variances and gaps in changing the UGS types individually and their influence on mitigating future climate change within different emission levels – 'low, medium and high' and decades scenarios – the '2050s and the 2080s'. Researchers linked UGS alternatives to a questionnaire survey in order to specify pedestrians' preference for the suggested UGS in order to indicate the most appropriate UGS alternative with the best percentage. In this research, UGS is used within street canyons to determine their influence on UHI. This thesis aims to cover most of these above points and offer recommendations for future work to inspect other gaps.

These research gaps were identified by Susorova (2013) who questioned the benefits of vegetation and green walls and how they affect microclimate and UHI. A number of researchers (Yang et al., 2009; Bao et al., 2016; Park et al., 2017; Teshnehdel et al., 2020) have recommended finding the optimal configuration of plants and UGS positioning to mitigate UHI and climate change as gaps to be explored within future research in a temperate climate. Märit Jansson (2014) illustrated that more research is required to further understand which potentials and properties of UGS can provide urban benefits in sustainable dense cities. This was confirmed by Haaland and van den Bosch (2015) who stated that more research is urgently required on how to develop highly functional UGS under compact city conditions with optimal configuration.

1.4 Research Aim

This research focuses on significant environmental benefits of UGS as trees, living façade (LF) and high pavement albedo (HPA) for mitigating the Urban Heat Island effect (UHI) and improving Carbon sequestration. This study investigates the impact of UGS on climate change adaptation and mitigation in the current climatic situation (2018) quantitatively and future climate scenarios, the 2050s and the 2080s. This research provides the optimal UGS configuration through determining its influence on UHI and CO_2 levels in the air.

1.5 Research Objectives

The research objectives are to:

- Review the underlying reasons for mitigating UHI and improve Carbon sequestration, particularly in current and future climate scenarios.
- Investigate when and how the built environment may benefit from UGS in a temperate climate such as the UK.
- Investigate how UGS could be integrated within the urban environment.
- Develop and analyse a simulated urban environment for a prototype urban model to study UHI effect mitigation in an urban canyon through UGS.
- Evaluate the developed model to measure the potential for lowering urban heat island effect and CO_2 through different types of UGS.
- Demonstrate potential UHI and CO_2 mitigation effect within the urban canyon scale, by utilising UGS for climate change adaption, through collected data from simulated models.
- Determine the human perception of UGS alternatives and how these would influence their street activity.

1.6 Research Methodology

The research aim is to quantitatively and qualitatively investigate the use of UGS for climate change adaptation and mitigation in the current (2018) and future (2050 and 2080) climate scenarios, determining its influence on UHI and CO_2 levels. The climate change adaptation planning needed by the UK Climate Change risk assessment illustrates that climate change should be mainstreamed in all environment areas affected in the UK. The predicted uncertain climate change variables will reflect on future decisions with lower doubts; thus, a more comprehensive range of prospective climate change scenarios is needed (Defra, 2009; DEFRA, 2012).

The climate fluctuates naturally from one year to another and from one decade to another and, therefore, these variation details could be beyond current scientific abilities.

In the future, the GHG concentrations will rise, causing a global warming trend, although it is difficult to forecast how UK regional climates will respond. Based on this, the UKCP09 (Defra, 2009) classified the twenty-first century into three possible scenarios taking into consideration the uncertain response of regional climates and the natural variability due to global warming. These scenarios are short 'next one decade' 2020s, medium (mid-century) 2050s and long-term scenarios 'by the end of the century 2080s'.

The standard approach to emissions scenarios is followed by the Climate Change Risk Assessment (CCRA) based on the Intergovernmental Panel on Climate Change (IPCC) with Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000; IPCC, 2014; CCRA, 2017). These are classified in the report as 'High' 'Medium' and 'Low.' Thus, based on these findings, a quantitative method will be used (Groat;and Wang, 2002; Dunleavy, 2003) within this research to collect technical, functional and behavioural details of UGS 'living façade, high albedo pavement and trees.' A literature review of earlier studies with similar analysis and relation is carried out, as well as the conclusions of these findings.

On the other hand, a quantitative analysis is carried out since, according to Deming and Swaffield (2011), simulations are illustrations of characteristics and features of a real-time state. Simulation is distinguished from static representation and numerical predictive modelling through focusing on dynamic relationships of the UGS and UHI effects (Deming and Swaffield, 2011). While analysing the methods to use for this thesis on the impact of UGS on urban canyons to decide the influence on UHI and CO_2, different simulations were carried out to determine and imagine the urban impact and influence through applying UGS on a prototype urban neighbourhood within Central London (Oxford Street), within the urban street canyon. The strategies used in the research include exploration, forecasting, testing, and learning (Deming and Swaffield, 2011).

The simulations are conducted with computerized models using "ENVI-met software to run simulation for buildings in a canyon where different urban vegetation scenarios are applied on buildings in a canyon by applying UGS. These scenarios are addressed to assess the impact of UHI on future climate scenarios by 2020, 2050 and 2080 with different carbon emission probability scenarios of '10% low, 50% medium and 90% high'. This resulted in three possibilities for each scenario year, which quantitively illustrates the mitigation level and improvements to our future climate. To minimise the number of simulations runs, the emission scenario with 90% high emission scenario was used as it has the highest probability to occur. Running a simulation for the 2020s was eliminated as the current year (2018) simulation would be similar to it in terms of climatic characteristics.

Real-time field analysis was also carried out (LN Groat; and D Wang, 2002; Dunleavy, 2003) through field measurements and test simulation of an actual location at the Building Research Establishment (BRE) within the researcher's internship in order to validate and calibrate the ENVI-met measurements and simulations. Then the UGS influence and impact over the UHI effect were measured. Carrying out those two different computer simulations and real field analysis led to reliable and accurate results and increased certainty about the UGS impact and influence on future climate scenarios.

The average climatic characteristics (temperature, wind speed, relative humidity, solar radiation, etc.) of the summer season (21 June21 September) of each year (2018, 2050 and 2080) were examined as well as the projected annual impact for the 2020s, the 2050s and the 2080s. For all cases studied, a base case, where no vegetation exists (0%) in the urban canyon was first measured in terms of the current street vegetation coverage. Applying different urban greening systems, through HPA, LF and trees, whether it is applied to walls, pavements or streets, was compared with this base case "without vegetation" in order to validate how vegetation influences urban geometry and climate. The explanation of temperature and humidity distributions in the air and the fabric is quite detailed; the effect was studied near the vegetated surface and within pedestrian heights and across different times of the day across the canyon.

Correspondingly, a qualitative survey analysis included to explore the human perception of different UGS which suggest its influencing factor on the pedestrians' activity within the streets of central London. Photo elicitations for current street view with 0% green (Base case) was used in addition to photoshopped pictures for different UGS alternatives with particular percentages in order to quantify the pedestrians' preference and choice for their preferred UGS to be applied in reality based on ENVI-met simulation results. From this, an applicable recommendation can be applied in the future.

The main drive of this research is to respond to the question: to what extent UGS can be a key solution to the mitigation of the heat island effect and carbon dioxide levels for future climates and urban geometries by the 2050s and the 2080s and what the best percentage of vegetation is. With the growing urban population around the world, this hypothesis aims to contribute to solutions for sustainable living conditions in cities and greatly impact health risks. Through the restoration of nature in the city, particularly in the human habitats themselves, buildings can achieve thermal benefits and economic, social and environmental benefits as well. Consequently, this work focuses on the first aspect, which is the *thermal benefits of UGS in urban spaces*.

1.7 Research novelty

This research addresses an essential topic of assessing the influence of urban green systems (UGS) on mitigating Urban Heat Island (UHI) and CO_2 levels, since UGSs may lead to an increase in pedestrians' thermal comfort, in addition to minimising cooling and heating loads and overall operational energy consumption within buildings. It is also considered as one of the top prospects for climate change mitigation. Green roofs, trees and vertical urban green systems can potentially address the shortcomings of climate change; significantly, they will lower the UHI and improve building thermal insulation, leading to improved energy performance.

However, these points have not been studied in depth using future climate scenarios, and there is not enough numerical data and simulations regarding this. This research's original and novel elements mainly include deriving numerical values for the impact of vegetation, whether through green walls, high albedo pavement, or trees, which are three types of UGS on UHI and CO_2 reduction as a future climate change mitigation strategy by 2050 and 2080.

A relationship between UGS, CO_2 and UHI mitigation in future climate scenarios by 2050 and 2080 is established via experimental and numerical methods. Despite the environmental, social and economic benefits of trees, and LF, due to its multi-functionality, to the best knowledge of the author, no existing specific guidelines or recommendations currently exist for evaluating LF as a strategy for climate change mitigation by 2050 and 2080. Moreover, only a few studies have investigated the potential of integrating UGS into the building envelope. Thus, the present research addresses this knowledge gap in this field.

The expected outcomes of the research are mainly to determine how to create those UGS focusing on plant types, integration between natural vegetation and the built environment—exploring the UGS influence on UHI effect within urban street canyons by investigating the effect on three different time periods – "2018, the 2050s and the 2080s".

The quantitative approach shows that there is lowering temperature within a street canyon when building envelope is covered by vegetation; that is, the hotter the weather is, the higher climate mitigation and improvement can be shown,

, particularly in the case of higher solar radiation. More saved energy and canyon temperature can be decreased when it is covered by vegetation.

The vegetation usage on poorly oriented high dense canyons can compensate their poor design and orientation particularly in higher emission scenarios than in lower emission scenarios, and this becomes more evident for the 2080s followed by the 2050s and 2018 due to its higher UHI effect. However, if it had been applied to the whole city scale, many improvements for urban heat island effect could be achieved and it could be lowered on a large scale.

This thesis has progressed by many means as it started with a different focus and went through different phases and stages until it finalized in the current form adopted herein. First, it focused on the green walls and energy performance in a temperate climate, then switched focus to green walls and their influence on pedestrian thermal comfort. Next, it changed to include different urban interventions (trees, green walls, green roofs) to increase pedestrian thermal comfort. At this point UGS was narrowed down to be trees, green walls and replaced green roofs by high pavement albedo/cool pavement as these have a direct connection to the pedestrian level. Next, due to multi-functionality of UGS, the researcher linked thermal comfort to air pollution, which was later narrowed down to CO_2 reduction only.

All these processes were constructive as the researcher gained more knowledge, although he would have benefitted from more time to further analyse the final approach through focusing on this viewpoint in the early phases. It would have been interesting to take into consideration more parameters influenced by UHI during different climatic scenarios during the evaluation as building energy use and energy consumption for applying different UGS alternatives (living facade, trees, high pavement albedo) which influence building energy consumption.

The results from this study will enable the decision-makers, urban designers and architects to improve the pedestrian thermal comfort within the summer season, particularly during the sunny hours of the day through evaluating different UGS alternatives and these data gathered will inform them to improve both current and future decisions in the 2050s and the 2080s. Furthermore, it will give the essential and required information and data to London policy-makers on how they could apply UGS in their current and future plans as (Healthy Streets Plan by Transport for London) and (Mayor of London Plan to make London the Greenest City in the World 2050).

1.7.1 The significant contributions of this thesis to knowledge

The production of a reliable methodology in this research is a significant contribution to knowledge that can be widely applied in many similar urban canyon contexts in the UK with similar urban geometry. This is not only for the current climatic scenario of 2018 but also for future climatic scenarios in the 2050s and the 2080s. The research has established a clearer argument than ever before for the importance of UGS in central London. It not only revealed many issues regarding pedestrians' preferences of and attitudes towards different UGS, but it also correlated these preferences with their demographics and activity, making it much easier for policymakers and urban planners to arrange the urban environment more precisely and specify their priorities of development based on UGS environmental benefits and on the human need.

This thesis reports the contemporary status of the UGS in London through analysing, representing and exploring the influence of different UGS interventions with different densities on the urban microclimate of central London street canyons. The core goal of the research has been to create a clear, holistic understanding for different variables, factors, and influences which play a significant role increasing PTC and CO_2 sequestration in London for the current 2018 and future climates in the 2050s and the 2080s.

This thesis is perhaps the most detailed research yet undertaken of the most appropriate type, quantity and distribution of UGS in London across different street canyon orientation and across different years. Identifying pedestrians' top priorities within central London to choose UGS as visual comfort and air pollution reduction were the top followed by connecting to nature, increased biodiversity, and relaxation. Improved thermal comfort is followed by increased productivity. This research also illustrates pedestrians' motivation to walk around 30% more after applying different UGS, while the type of UGS alternative is more important than its percentage; for instance, 25% of trees had a similar satisfaction percentage compared to 50% LF.

As a final fact, the author strongly believes that the research and the investigation carried out can become a part of PTC improvement in addition to CO_2 sequestration and UHI mitigation. Climate change mitigation and adaptation using the suggested UGS alternatives has led to a better solution for central London thermal comfort improvements, particularly in future climate scenarios in the 2050s and the 2080s. Improving the quality of urban life in the present 2018 and future developments in the 2050s and the 2080s will extend the scope of researchers in the related fields.

1.8 Assumptions and limitations

Sample selection for the questionnaire survey was one of the research limitations as the sample was ideally targeted for frequent visitors to the study area (Oxford Street, London, UK), but due to restricted access to stores within Oxford Street, it was not easy to reach workers there. Subsequently, the researcher tried to expand the sample selection to include frequent, regular street visitors and infrequent visitors such as tourists, shoppers, and passers-by. Nevertheless, due to the recent risks due to COVID-19, there were difficulties in ideally selecting or visiting the street to find the most accurate street sample, and it was dependent on random passers-by within Oxford Street.

A lack of available or reliable data from weather stations within central London as Kew Gardens for future climate scenarios for the 2050s and the 2080s and the only available one was from Heathrow Airport which was accurate but not representative of the actual city centre scenarios. There was a lack of available or reliable hourly weather data in UKCP18 while UKCP09 had hourly weather data available, even though the predicted weather files' difference for temperature, humidity and wind speed patterns are similar or almost the same as each other.

Due to the shortage of prior research studies on the future climate change and UHI in London, the UK specifically might have given a slight background indication of what the future climate would look like and how that would reflect on pedestrians and locals within the city.

The researcher made efforts to avoid natural bias towards different UGS alternatives and vegetation in general (trees, lawns, living façade, etc.). However, he tried to eliminate and limit any sort of bias related to UGS choice or implementation. However, no one can deny that it is one of our core instincts to be connected to nature and that most of the questionnaire survey participants will prefer UGS alternatives. Therefore, the researcher has tried to link questions to each other so as to validate and correlate if there was a link between the human preference of specific UGS and their activity within the street, or whether it is just a choice based on their nature which will not make any improvements to their street activity.

An online survey has limited contact with participants although it usually reflects many of their comments, suggestions and preferences based on their survey experience, which is the core of the survey investigation. On the other hand, in the additional comments part within the survey, many participants indicated their ultimate wishes to see a proposal for a combination of trees and living façade instead of showing one alternative.

1.9 Outline of Research Thesis

Chapter 1: Introduction

This chapter mainly focuses on presenting a brief outline of the research and provides an introduction to aims, scope, objective and other subject area motivations.

Chapter 2: Literature Review and Research Background on Climate Change

All essential and necessary information related to the topic is included in this part to get an in-depth insight into the area under discussion. Questions are formulated regarding the background research on climate change, climate shifts and future climate scenarios in the 2050s and the 2080s.

Chapter 3: Literature Review of Urban Green Systems

This chapter presents all fundamental data and information for urban green systems such as trees, green walls, green roofs and cool pavements (high albedo pavement) In order to get a more in-depth view of how to mitigate urban heat island and climate change through increasing pedestrian thermal comfort and sequestrate carbon emissions. Then, the questions that were formed throughout investigating the most appropriate UGS alternative for this research are addressed.

Chapter 4: Methodology

An elaborated structure is included describing and illustrating all methods and processes for UHI measurements to formulate this research study. Having calculated final thermal stress levels within London, the UK, a comparison is made at this stage to show the differences in the outcomes between each urban green system alternative (trees, green wall, high albedo pavement) with different percentages (25% and 50%) within different years (2018, 2050 and 2080) within different street canyon orientations (North-South and East-West).

Moreover, a questionnaire survey is carried out to investigate the human perceptions to indicate the favourite alternative for pedestrians within Oxford Street, London, UK, in addition to formatting an overview of how UGS would influence pedestrians' activities within the streets.

Chapter 5: ENVI-met Software Findings

This chapter contains a stage-wise discussion and analysis for different chapters on data collection, interpretation and its proceeding. Based on the methodology, its outcomes and results from a discussion are formulated in detail regarding each outcome and its impact on different simulation output Subsequently, a more profound analysis is carried out regarding each green system alternative (trees, green wall, high albedo pavement) with different percentages (25% and 50%) in the different years (2018, 2050 and 2080) within different street canyon orientations (North-South and East-West).

Chapter 6: Questionnaire Survey Findings

Following the ENVI-met simulations, a questionnaire survey is formulated to determine the human preference for different UGS alternatives and how these alternatives would influence pedestrians' street activity and time. First, the survey responses were collected within frequency tables; then, a cross-tabulation analysis was carried out to draw a deeper investigation on survey responses and their relation to demographics. Later on descriptive statistical analysis and Pearson correlation analysis were explored in order to investigate the means and variance of questions in addition to the correlations between questions. Finally, this chapter analyses participants' perceptions and their activity in the street before and after applying UGS.

Chapter 7: Discussion

Through applying different UGS alternatives in different street canyon orientations in London using ENVI-met software across different climatic scenarios, all alternatives are discussed to specify the best alternative in reducing UHI and carbon dioxide reduction with related research. Subsequently, a questionnaire survey is employed to identify the human perceptions and the responses from the survey are investigated in comparison with similar research. Based on the ENVI-met and questionnaire survey discussion and the research argument formulated, a suggested UGS alternative for London canyons is proposed with photo illustrations.

Chapter 8: Conclusion/Further research/Recommendations and Limitations

Finally, all the recommendations are stated coherently and concisely in order to develop a set of guidelines to understand and mitigate UHI and CO_2 levels within climate change across different years, orientations and different UGS alternatives. This was combined with questionnaire survey responses, findings, frequency tables, cross-tabulation and correlations. After formatting an argument between the literature review, the survey and ENVI-met simulation, conclusions are also presented, along with research limitations and suggestions for future research.

2 Chapter Two: Climate Change, Global Warming and Urban Climates

2.1 Introduction

This chapter provides definitions and broad-scale concepts for climate change, global warming and urban climates, going deeper into investigating London's temperate climate and how climate shifting influences it. The chapter then assesses possible climate futures for the UK and the range of estimated changes within the UK future climate in the 2050s and the 2080s with associated risks and vulnerability such as overheating and buildings and urban heat risks.

The second section of this chapter starts with clarifying the broader ideas, classifications and meanings for urban heat island and its levels and intensity. Next, the subsection discusses how to mitigate urban heat island and its mitigation levels through urban green systems as (trees, green walls, green roofs, cool pavements, etc.) and their benefits on climate change.

2.2 Climate Change: Definition and broad-scale concepts

Weather and climate are different: weather is a short period atmospheric condition, which takes place for hours, days or a few weeks. It is forecast by clouds, humidity, rain, solar winds, floods, snow and thunderstorms, among other events. Climate on the other hand predicts longer-term conditions on a regional or global basis. It is shown by average temperature, clouds, rainfall and snow patterns over seasons, years, and decades (NASA, 2018). Earth's climate throughout history has faced many changes in the last 650,000 years, around seven cycles of glacial advance and retreat. The last phase of ice-age ended about 7000 years ago, marking a new climatic and human civilization era. Most of the previous climatic changes were credited to slight variations (NASA, 2018).

Climate change refers to significant fluctuations and changes in global temperature, wind patterns, precipitation, and further climate measures that take place over many and different decades or longer. Various exciting climate changes are linked to rising carbon dioxide levels and different greenhouse gases in the Earth's atmosphere due to human activities, which lead to global warming (GISS, 2010; John Cook, 2010). Global warming is an increasingly rising temperature movement across the whole Earth, notably since 1970, due to the rise in fossil fuel emissions from the time of the industrial revolution. The average surface temperature has increased by 0.8°C (1.4°F), compared to the mid-20th-century reference line (1951-1980) (Shah, 2015; NASA, 2018).

The current warming is driven by significant changes taking place due to human factors which are rising in extraordinarily high rates over the most recent decades (IPCC, 2014), and most of the warming is going into the oceans with 93.4%, followed by the atmosphere by 2.3% and continents by 2.1% (John Cook, 2010) as shown in Figure 2-1. Climate change brings up to a wide variety of world-wide phenomena formed mainly by fossil fuels burning, leading to trapping gases within Earth's atmosphere and increasing temperature. These changes also include sea-level rise, ice mass loss, and shifts in flower and plants blooming, in addition to shifts in climatic zones and more extreme weather events (NASA, 2018).

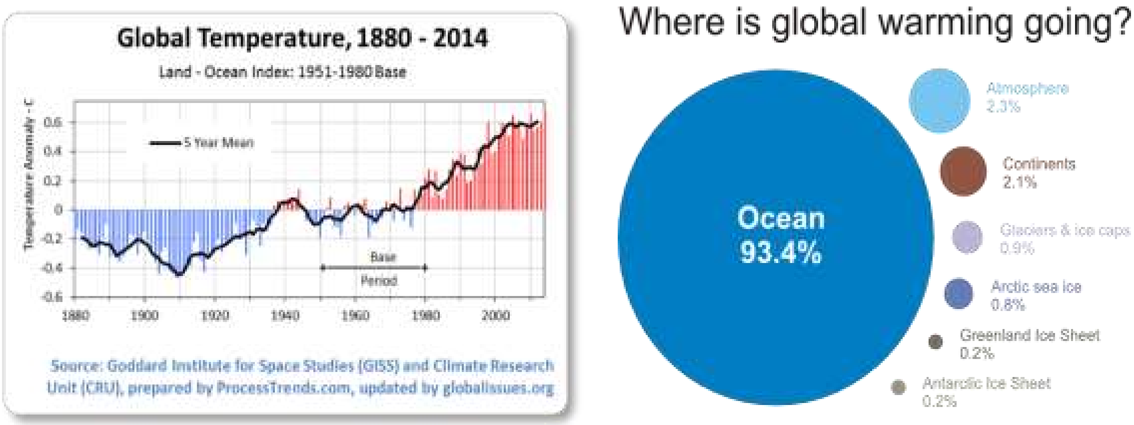


Figure 2-1 On the left is Global Temperature, one the right is main global warming affected areas (John Cook, 2010)

Global warming isthe increase in global temperatures as a result of increased concentrations of greenhouse gases in the atmosphere, while *climate change* indicates the increasing changes in the climate through long periods, including precipitation, temperature and wind patterns (USGS, 2018). The *Greenhouse Effect* (GHE) happens when the sun drives Earth's climate and weather through heating up the Earth's surface with solar energy, then it gets reflected back into space. With the existence of atmospheric gases such as water vapour, methane, carbon dioxide, and others, a big portion of this heat becomes trapped within Earth's atmosphere. This retained heat acts as the glass panels of the greenhouse; thus, these gases are widely known as greenhouse gasses (GHG) which influence the rising Earth's temperature (Shah, 2015).

Most climate scientists agree that the main cause of the current global warming trend is a human expansion of the 'greenhouse' effect. Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to temperature changes are described as 'forcing' climate change. The evidence for rapid climate change is global temperature rise, warming oceans, shrinking ice sheets, glacial retreat, decreased snow cover, sea-level rise, declining Arctic sea ice, extreme weather events, and ocean acidification (WMO, 2018).

The future effect will also impact on the earth through higher temperatures, more droughts and heatwaves, sea level rise of one to four feet by 2100, stronger and more intensive hurricanes and precipitation pattern changes, and frost-free seasons and growing seasons will lengthen (IPCC, 2014; NASA, 2018). Climate scientists agree that human expansion of the greenhouse effect is the main reason and source of current global warming as certain gases which remain semi-permanently in the atmosphere block heat from escaping, leading to forcing climate change through water vapour, carbon dioxide (CO_2), Methane, Nitrous oxide and Chlorofluorocarbons (CFCs) (NOAA, 2010; NASA, 2018).

2.3 Temperate climate

Sometimes researchers do not specify the climate of the study; on other occasions they mention it without using a recognised climate classification, and thus comparing them is problematic. The Koppen climate classification system is widely used due to its worldwide recognition. It could be classified as the most wide-ranging climate system across the world, and it is classified into two types (ISC-AUDUBON, 2013; GA, 2018). The UK is classified as temperate climate, which has two sections – continental and maritime temperate climate. Maritime temperate regions which are located near coastlines where oceanic and sea wind deliver more rain and temperatures are relatively steady across the year; such regions include Western Europe and the UK mainly.

In contrast, Continental temperate regions are usually warmer in summer and colder in winter. In temperate climates, buildings are designed to remain cool in the warm summers and be warm in cold winters through seeking solar radiation gain in winter and providing summer shading (HH, 2013). Within the temperate climate, building materials are also designed with moderate thermal mass, with moderately-sized openings and adequate thermal insulation properties in order to provide satisfactory conditions for most of the time, through overcoming over-heating in summer and cooling in winter (SKAT, 1993).

2.4 The UK's possible climate futures

The climate fluctuates naturally from one year to another and from one decade to another, and therefore, these variation details could be beyond current scientific abilities. In the future, the GHG concentrations will rise, leading to a global warming trend although, it is hard to forecast how UK regional climates will be responding. Based on that, the UKCP09 (Defra, 2009) classified the twenty-first century into three possible scenarios taking into consideration the uncertain response of regional climates and the natural variability due to global warming. These scenarios are short "next one decade"

2020s, medium “(mid-century)” 2050s and long-term scenarios “by the end of the century” 2080s.

Within the near-term (next one to two decades), uncertainty ranges are usually associated with natural changes, while warmer average temperatures are expected by the longer term than the current situation; on the other hand, colder temperature periods are expected to be more challenging. Precipitation might be drier or wetter, depending on climate variables. During the mid-term (mid-century), GHG will influence the UK climate, shifting the temperature to be warmer, although cold winters will remain. This will lead to wetter winters and drier summers. By the end of the twenty-first century throughout the last decades, the perception of GHG and emissions will be influencing the climate strongly leading to more significant warming and more frequent stronger heatwaves.

The standard approach to emissions scenarios is followed by the Climate Change Risk Assessment (CCRA) based on the Intergovernmental Panel on Climate Change (IPCC) with Special Report on Emissions Scenarios (SRES) *(Nakicenovic et al.,* 2000; IPCC, 2014; CCRA, 2017). Figure 2-2 shows that these are classified in the report as “High”, “Medium” and “Low”. The *high* emission scenario would have a significant global population with a rapid economic growth cooperated with the intensive use of fossil fuels. In the *medium* emissions scenario, the global energy production is balanced between fossil fuels and other sources. Last, *low* emissions would have the same pattern

Table 1.1 CCRA emissions scenarios and respective IPCC Fourth Assessment Report AR4 code names

Scenario name		Description
IPCC	CCRA	
A1FI	High	A future world of very rapid economic growth with a global population that peaks in mid-century and declines thereafter, with convergence among regions and decreasing global differences in per capita income. New technologies are introduced rapidly, but with a continued intensive use of fossil fuels.
A1B	Medium	Similar to the A1F1 scenario in its underlying assumptions, except that global energy production is more balanced between fossil fuels and other sources.
B1	Low	The same pattern of population change as the A1F1 scenario but with much greater emphasis on clean and resource-efficient technologies, with global solutions to economic, social, and environmental sustainability and improved equity.

Figure 2-2 CCR emissions scenarios in relation to IPCC report code names (CCRA, 2017)

of population change as IPCC but with more dependency on clean and efficient resources and technology for environmental sustainability.

2.4.1 The UK's climate shifting

Fighting climate changes requires collaborating across all community and governmental sectors while diminishing the gap between public opinion, knowledge and the scientific information. (J.-F. Bastin *et al.*, 2019)analysed pairs of 520 cities across the world in order to visualise the change in their climate to the current situation and the similarity of their future climatic scenario to other cities within the current climatic scenario. Within the optimistic climatic scenario (RCP 4.5), 77% of future cities are expected to have a similar climate to a neighbour country in the current climatic period. At the same time, the remaining 22% of cities are going to expect climatic condition, which is not similar to any existing major cities today.

In general, for Europe, both summers and winters will get warmer, with average temperature increases of 3.5°C and 4.7°C, respectively. Southern hemisphere cities were shifting with approximate velocity 20 KM/year with average 1000 KM towards the South while Northern hemisphere cities are shifting towards sub-tropical cities with warmer climatic conditions. For the 2050s' climatic scenarios of cities, London's climate will resemble Barcelona's climate today, Edinburgh to London, Madrid's to Marrakech's climate, Stockholm to Budapest, and Moscow to Sofia (J.-F. Bastin *et al.*, 2019).

(J.-F. Bastin *et al.*, 2019) study was critical in visualising the actual climate shifting and change significantly for the public which will help them to understand the massive expected changes and finally facilitate and force quick responses to climatic actions for mitigation and adaption. Their study shows that London's climate by 2050 will be similar to the current climate in Barcelona.

2.4.2 The UK climate projections (UKCP09)

The UK Climate Impacts Programme (UKCIP) is the authority for predicting climate changes in the UK through developing a comprehensive climate model, which will help local authorities and policymaker with their business plans. Through seven overlapping time lapses, the UKCP09 provided three futuristic climate emission scenarios, Low, Medium and High emissions. UKCP09 and have close ranges of emission

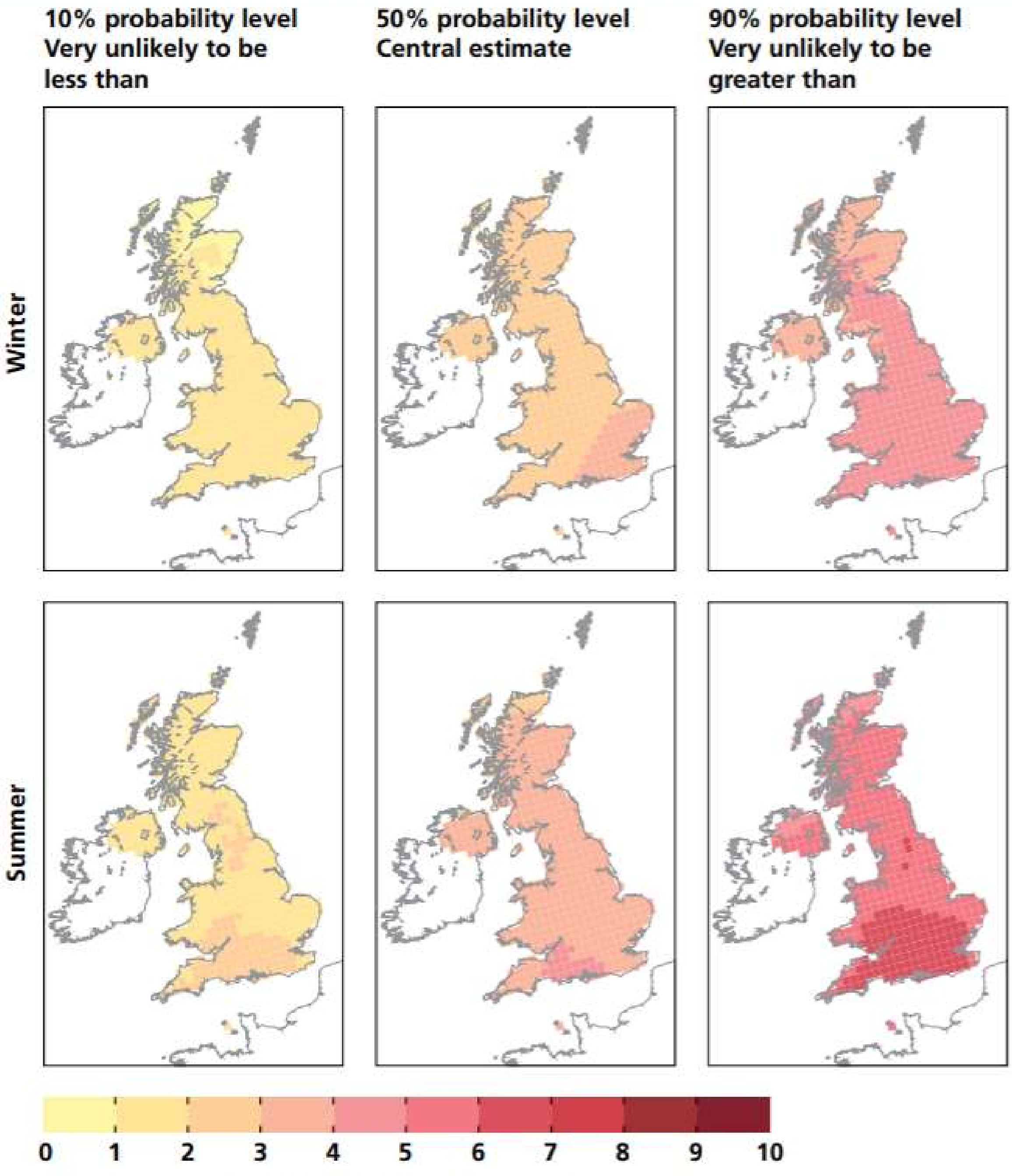


Figure 2-3 UK under different emission scenarios (10%, 50% and 90%) during Summer and Winter with a change in mean temperature (Jenkins et al., 2009)

scenarios, although the CCRA probabilities are not assigned to any future risks or projections (Jenkins *et al.*, 2009).

Figure 2-3 illustrates that under the medium emissions scenario, there are 10%, 50% and 90% probability levels of changes to the average daily mean temperature (ºC) of the winter (upper) and summer (lower) by the 2080s Within the winter season, central change estimates ranged between 2-3ºC across the UK, with an increase in the South East and decrease in temperature in the North West of Britain. In summer, there is a more noticeable gradient from South to North started with 4ºC in the South, and reaching 2.5ºC in northern Scotland.

The UK temperature difference during winter in the 10% probability scenario will be around 1-2 ºC higher, while it will increase to e 3-5ºC higher until reaching 5-7 ºC more with a dominant area with 7ºC higher temperature. The UK temperature difference during summer, there is a 10% probability of achieving a temperature between 2-3ºC, increasing to 4-5ºC during the 50% probability scenario, reaching 8-9ºC by 90% probability. Overall, the South East part of the UK is going to face severe heatwaves, especially during summer (Jenkins et al., 2009).

Figure 2-4 shows that, under the medium emissions scenario changes (%) in yearly (top), winter (middle) and summer (bottom) mean precipitation at the 10%, 50% and 90% probability levels, for the 2080s. In some parts of Scotland precipitation ranged from zero to +29% in parts of England. Corresponding precipitation changes in summer ranged between –9% in parts of southern England up to +25% in some parts of Scotland. Annual mean precipitation varied between +10 to +30% over the majority of the UK in winter, while in summer, there is a gradient from South to North, and precipitation decreased by almost 40% in South West England. The UKCP09 projections describe extreme events in the future as more expected floods in the winter and heatwaves and droughts in the summer.

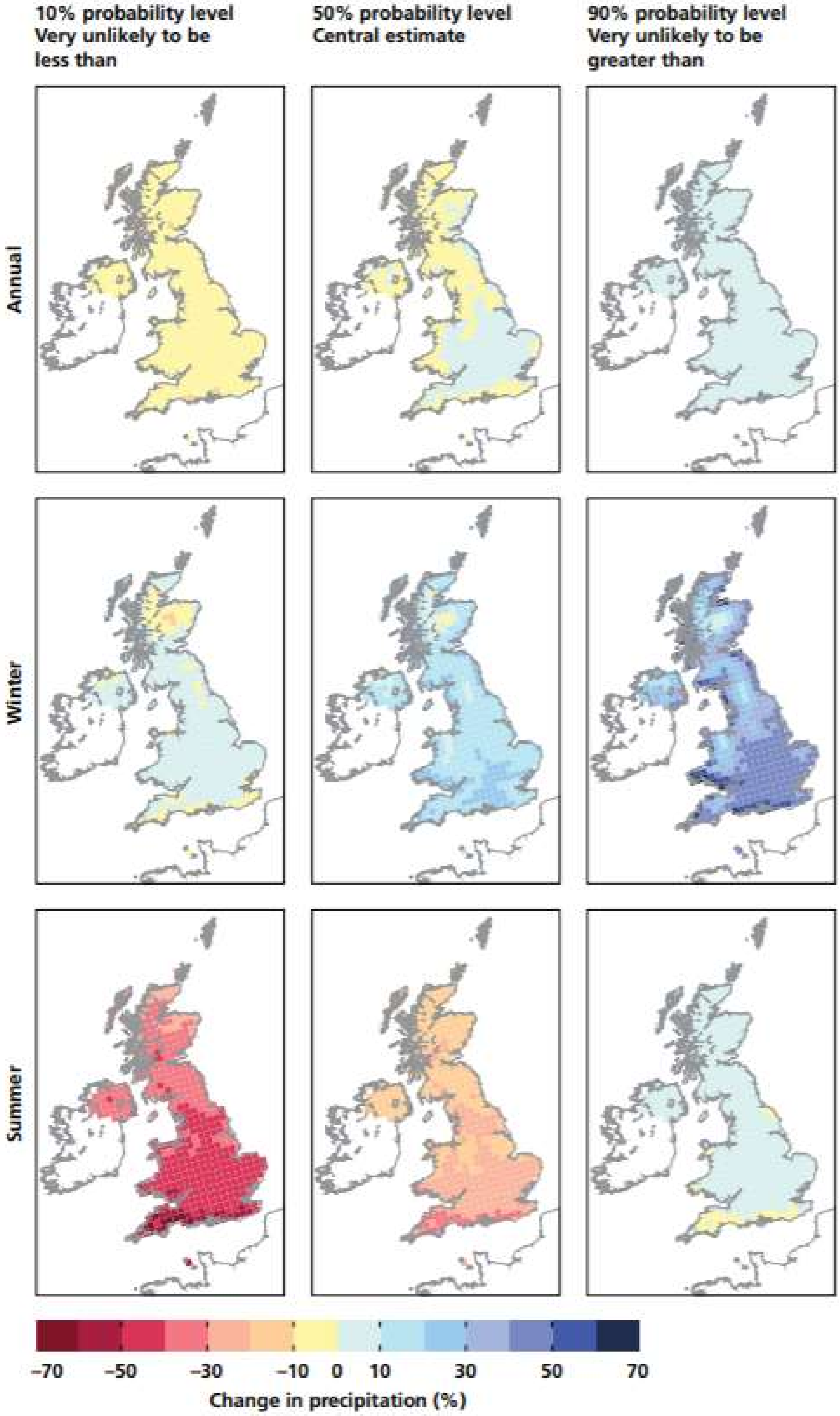


Figure 2-4 Perception change (%) across Summer, Winter, Annual mean for 10%, 50% and 90%

Neither UKCP09 and CCRA linked the probability of future and current emission scenarios as it is too early to judge it. Based on science development and progress, new modelling results might be indicating changes which could be lower or higher than the one presented in UKCP09. Thus, these projections are providing a broad possible outcome for each scenario's emission.

UKCP09 30-year period	Defined period for CCRA
2010-2039	2020s
2040-2069	2050s
2070-2099	2080s

Figure 2-5 30-Year time period assessed by CCRA (IPCC, 2014; CCRA, 2017)

Potential risks for the UK under the medium emissions scenario (IPCC, 2014; CCRA, 2017) show the climate change science agreed on considering that 30 years is the average change period; thus, it could be enough to provide estimated annual and seasonal climate variables. Thus, it is commonly used predominantly by the UKCP09 with 1961-1990 as the time base case. Based on these inputs, UKCP09 provided seven overlapping periods of climate change between 2010-2039 to 2070-2099 while on the other hand, the CCRA has been focusing on only a non-overlapped 30-year period, covering the years between 2010 and 2099. Both systems have been using the central decade of the 30-year period, which are the 2020s, the 2050s and the 2080s.

2.5 Current and future day risks and vulnerability in the UK

The UK's most significant climate risks, based on financial loss and disruption, under current climate conditions are potential risks, including threats and opportunities that are predicted to happen based on medium emission scenarios during the 2020s, the 2050s, and the 2080s. There are only nine opportunities which include benefiting from warm weather during winter, heating energy reduction, arctic shipment possibility, increased tourism and probability of growing new crops and all of that during winter of these years.

However, there are around 38 threats, and mainly five of them are addressed: these are flooding within urban scales, followed by more energy demand for cooling within buildings, wasted working hours (working deficiency), forest and species extinct, and human mortality rate increase. All these threats' vulnerability is increased within condensed cities and within unprepared locations, which will result in more severe and higher threats. The main threats which the research is looking at are overheating and infrastructure, which are discussed separately.

Based on building and infrastructure impacts with the indication for direction and magnitude and confidence (IPCC, 2014; CCRA, 2017), the heating load was the main drive for thermally comfortable spaces during winter across UK building design and thermal comfort. Thus, overheating during summer has not been considered as it was not a real problem. Overheating is dependent on several climate factors such as building orientation, location, solar radiation, external temperature and UHI, among others. It could also vary from a building type and material to others such as lightweight, highly insulated buildings and buildings with fully glazed facades and so on, which could face higher overheating risks.

Hospital buildings have been facing a rise in night-time temperature, even within newly built ones. This could be different from commercial buildings since they are occupied for 24 hours which is " inappropriate for night time cooling "which lead to performance disaffect and dissatisfaction, at which 90% of UK hospitals will be facing (Emily Gosden, 2014). Hospitals also have to regularly ventilate with fresh air to avoid infection, which will also finally lead to more energy consumption with high-temperature rates (Kevin Lomas; *et al.*, 2010).

Educational buildings such as schools also face overheating, but its effect varies depending on the type, age, and teaching environment such as classroom, sports room, or library among others. Most of the spaces should achieve a balance between natural light, indoor fresh air and thermal comfort which is quite hard due to having such constraints through large windows in order to allow acceptable daylight levels may lead to excessive solar gain.

The infrastructure and the built environment are classified as long-term assets, which are given as priority aspects of climate change adaptation (ASC, 2010). For instance, building overheating and water scarcity will be the principal risks of the 2050s, in addition to flooding, which is already a major one. Due to the correlation and the connectivity of infrastructure and buildings as "energy, water, transport and communications technology (ICT)", these sectors could be influencing each other whether directly or indirectly.

Climate change vulnerability is probably due to changing threats and opportunities for infrastructure and buildings since the UK is moving towards a low carbon economy. Decisions made on buildings and infrastructure will influence future climate vulnerability, as their lifetime could be 50 years or more, which will be challenging to withstand future changes. Cities with a higher population, especially in deprived areas, could be more vulnerable to climate change impacts, as heatwaves, flooding and any disruption or any increase in services prices.

Threats to infrastructure have been varying, whether it is due to increased flooding, which may affect significant buildings and infrastructure proportion, in addition to increased summer temperatures which will present a more common UHI effect with more frequent and stressful impacts. This would reflect on urban environments, leading to heat stress-related issues and risks for energy (to cool buildings, for instance) or for transport networks (ventilation purposes). In contract, opportunities may be presented whereby a milder winter could lead to a reduction in heating demand and hence reduction in winter CO_2 emissions.

The UK's urban environment

Climate change poses many possible risks to the urban environment. The connection between UHI, buildings and green spaces reduction in particular lead to rising summer temperatures. This has led to a 9°C rise in London temperature due to UHI, compared to surrounding areas. Average summer temperature is expected to increase by 2-3°C in the 2050s (medium emissions scenario) throughout the UK. At the same time, that would increase up to 3-4°C in the 2080s (medium emissions scenario). In addition to more frequent heatwaves are expected by 2050s.

Urbanisation characteristics and its climatic response

Urbanisation is the process of covering a vast land area with impermeable surfaces as buildings or pavements, and that leads to creating urban climate, which is usually warmer, drier and shadier with more reflected lights than the surrounding rural areas. Coherently, it is also defined as the local climate, which is affected by the existence of the city or town leading to lower wind speed and relative humidity and higher rainfall (Shahidan, 2011). The continuous developing of urbanisation components (residential, industrial, commercial projects) has led to a dramatic human change to the natural ecosystem and landscape through replacing them by building blocks in addition to limiting vegetation and green areas which, in turn, has changed the surface properties and atmosphere within urban areas due to the change of(radiation, emissions, thermal capacities and roughness. (Shahidan, 2011).

1. **Radiation** (short and long wave) which will change due to surface material, and characteristics change (albedo, emissivity) from the vegetated surface to impermeable surfaces which lead to the higher ground surface and wall temperatures through attracting more sun rays (short wave radiation) and reflecting them as longwave radiation during night time due to the urban thermal mass properties (Masumoto, 2018).
2. **Surface albedo** plays an essential role in defining the thermal comfort levels as it represents the reflected portion of received radiation over the whole received radiation by the surface and it usually represented from 0 (dark absorbing surface) to 1 (highly reflective surface) (GPWayne, 2016)
3. **Surface emissivity** represents energy emitted from a surface over the energy emitted from a black surface at the same temperature since the black body has the extreme possible thermal radiation at any given temperature. It is also worth mentioning that emissivity has a minor influence during the night-time, and it also depends on canyon geometry (Li *et al.*, 2013).
4. **Shading** is also a key factor for canyons and its radiation exchange processes either from solar radiation or between ground and wall surfaces which leads to urban surface temperature reduction. Shading benefits are maximised during the daytime, from limiting or decreasing the massive solar gain by urban surfaces (Evyatar Erell, David Pearlmutter and Terence, 2011)
5. **Urban thermal mass,** whether its building fabric or street materials is usually larger than natural surfaces which holds heat during daytime, and they release these thermal energies during the night which increases nocturnal (night-time) temperature, and it plays a more dominant role during the night-time hours.
6. **Thermal mass** usually depends on the materials' heat capacity, which means the ability of these materials to hold or store heat compared to green systems such as plant-based solutions as trees, green walls, etc., whose thermal mass is negligible.
7. **Evapotranspiration** (the interference combination of evaporation and transpiration) is one of the critical moderators to the urban environment. It leads

to increased air moisture leading to more humid local climate, which is very beneficial during drier summers or in dry weather in general.

8. **Emissions** from greenhouse gases and human or animal metabolism will generate excessive heat leading to the increase of urban atmospheric warming and air temperature.

Responding to climate change

Despite the increasing awareness of global climate change and its impact on our lives, our human emissions of GHG are at its peak. The CO_2 emissions in 2013 reached 400 parts per million (PPM) for the first time since three to five million years ago, during the Pliocene era. Based on these alerts, working on diminishing and lowering GHG has taken two paths and approaches, which are reducing emissions through "mitigation" and adapting to climate change "adaptation"(NOAA, 2010; NASA, 2018).

Mitigation and adaptation

Civilizations rise and fall partly because of major climate change events such as drought, and flooding, among others. However, climate over the past 12,000 years remained stable, which helped develop modern human civilization. Based on climate change, humans have been building dams as flood defences and water storage, and drawing up plan for heatwaves and higher temperatures through building better-insulated buildings, etc. These human interactions were considered as either mitigation or adaption.

Climate mitigation includes GHG and heat-trapping reduction, through either enhancing the "sinks" which help in storing these gases as Forests, green areas, oceans and soil" or through reducing the gases sources as "burning fuels, transportation, electricity, heat, etc. The target of climate mitigation is to stabilize greenhouse gas ranges within sufficient time to help ecosystems to tolerate and adapt naturally to these changes (IPCC, 2014).

Climate adaption includes adjusting climate targets to actual or expected future climates. The aim is to lessen climate change's side effects as more heatwaves, higher temperature, droughts and flooding, etc." It also involves in making the best out of any opportunity to associate with climate change as " increased crops in some regions, longer growing seasons, etc. (IPCC, 2014).

The faster the climate changes, the harder adaptation and mitigation become. Based on climate changes in Europe, northern Europe will face the most significant warming, while Mediterranean countries will face the highest during summers based on data from the (IPCC, 2014). Throughout the last 500 years, Central and Southern Europe have been facing summer droughts, while Northern Europe has been facing a drastic increase in daily precipitation (IPCC, 2014).

Figure 2-6 shows summer temperature fluctuations in Europe between the years 1500 and 2010. The upper graph indicates the distribution rate of summer land-temperature variances compared to the 1970-1999 period. The five highest warm and cold summers are highlighted. The following lower graph indicates a consecutive frequency of extreme summers each decade with temperature exceeding the 95th percentage of the 1500-2010 distribution (David Barriopedro, 2011). Thus, governments on several levels are working on climate adaption through managing climate change risks such as dealing with higher sea levels, managing forests and green areas; managing prospective droughts and floods, and others.

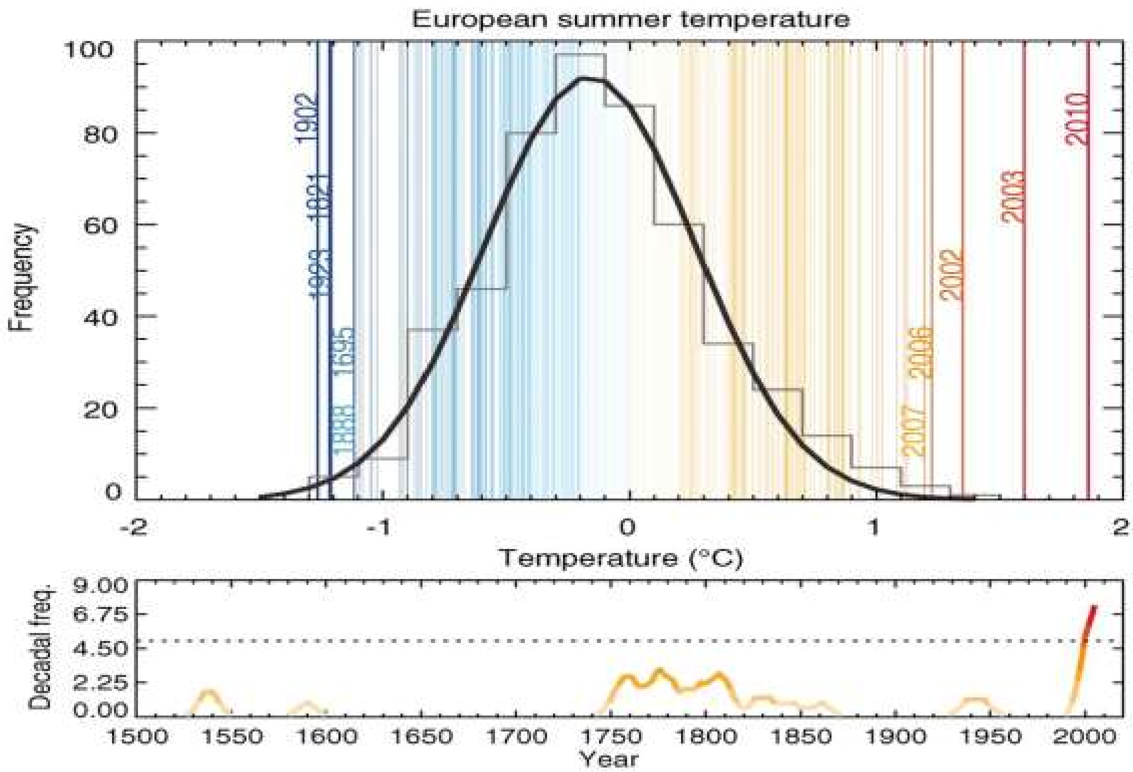


Figure 2-6 Summer temperatures change in Europe between 1500 and 2010 (IPCC, 2014)

Urban Street Canyon

Many urban climatologists define urban street canyon as the space on top of the street and among the buildings from both directions, as the basic urban unit. By analyzing climate in these canyons, they can extrapolate to the city entirely and to find general properties of urban climate applicable to be applied across the whole similar canyons in the city. Oke has described it as the way the wind turns down, the way the sun shines, where the pollution is released in the bottom from mechanical movements as vehicles. Based on it researchers can describe how the built environment behave, the difference between north-south and east-west canyons, and the general intersections. Therefore, models of these canyons are growing progressively more complex, since many researchers focus principally on canyon geomtry, which they find has a larger impact on microclimate than the materials the buildings and streets are made from (MIT, 2009).

2.5.1 Urban Heat Island (UHI)

It is the phenomenon at which cities are warmer with higher temperatures than the surrounding rural areas during hot weather particularly at night. The urban heat island (UHI) occurs due to solar energy storage within the urban fabric during the daytime, which is then released during the night-time. When green spaces are being replaced by buildings and roads replaces, the thermal, radiative, moisture and aerodynamic properties of the surface and the atmosphere are changed. (GLA, 2006). Due to urbanisation and development, the balance between raised solar energy from the sun (heating) and evaporation due to vegetated surfaces (cooling) was changed due to replacing these vegetated surfaces by impermeable concrete surfaces. Urban areas are rich in materials with a high thermal capacity such as asphalt and concrete (Taha, 2004). The temperatures can vary across a city depending on the land cover nature, as urban parks and ponds are colder than similarly built spaces. This temperature varies from 29°C to 34°C with an increase of 5°C between the rural farmland and downtown centre, which have the highest temperature.

Urban heat island effect intensity is a way which is used to measure the strength of UHI, showing the difference between rural and urban sites within a certain period. UHI intensities are higher during summer than winter due to the differences between the received solar energy by urban surface during the daytime and releasing it during night-time. Forecast for 15 European member states illustrated an increase of up to four times the air conditioning energy consumption. The air conditioning use led to higher temperature increases and hence more energy consumption and more UHI (Perini and Magliocco, 2014).

Only a few research types indicated the benefits of UGS on UHI in future climates which would have been beneficial if such research was shared in the early stages with policymakers so they can build their future plans. For instance, (Emmanuel and Loconsole, 2015) explained the benefits of UGS profoundly to mitigate UHI in Glasgow, the UK by 2050, while (Virk *et al.*, 2014, 2015) explored the benefits of cool roofs and trees and their influence on reducing building energy performance for the 2050s in London, the UK.

Infrastructure systems are sensitive and vulnerable to two threats for both short- and long-term extreme weather events (heavy rainfall, droughts, winds, cyclones, etc) while longer frequent duration climatic variations reflect on changing the typical weather settings. These weather settings can lead to circumstances that decrease infrastructure service quality, performance or reliance, leading to infrastructure retrofit (Proag, 2021).

(Gill, 2006) illustrated that by adding more 10% of UGS to Manchester city centre (UK), the temperature by the 2050s will be equivalent to the reference case in the 1961-1990s base case temperature. (Vaz Monteiro *et al.*, 2019) declared that however unlimited the benefits for UGS are including climate mitigation, this information and data were not entirely active or embedded into action within planning policies and green infrastructure development due to lack of dialogue between policymakers, researchers and practitioners, in addition to information overload in so many points which caused policymakers to misunderstand these data. On other occasions they were not able to access it and, finally, there is a lack of financial funding in UGS. Both nocturnal and diurnal UHI have weighty consequences on the primary and secondary pollutants in the environment as they can lead to amplifying the pollutant concentrations 10 times higher than the clean atmosphere (Arabi, Shahidan and Kamal, 2015).

Urban heat island circulation/urban heat dome (UHIC)

A dome-shaped profile results in the higher boundary of UHIC when the urban ventilation (wind flow) and pollutants transported between adjacent cities are absent or weak. It is usually a weak flow close to the ground level and directed to the centre of the city; this flow is also called country breeze. The vertical temperature difference specifies the maximum height of UHIC, and the horizontal temperature specifies the extent of this flow. UHIC might happen both during the day and at night, yet it is clearer during the winter nights when explicit ground inversion happens (Eliasson and Holmer, 1990; Abbassi, Ahmadikia and Baniasadi, 2020). UHI also increases pollutant concentration over cities (Arabi, Shahidan and Kamal, 2015).

Urban Heat Island levels and scales

Urban heat island is the land surface temperature (LST) differences between urban and suburban areas at which the urban canyon geometry (surface geometry) influence it. Atmospheric absorption and surface emissivity are the main factors for its intensity in addition to other parameters such as climatic effect (solar radiation) and physiographic effects such as topography. These factors reflect on the microscale climate within the

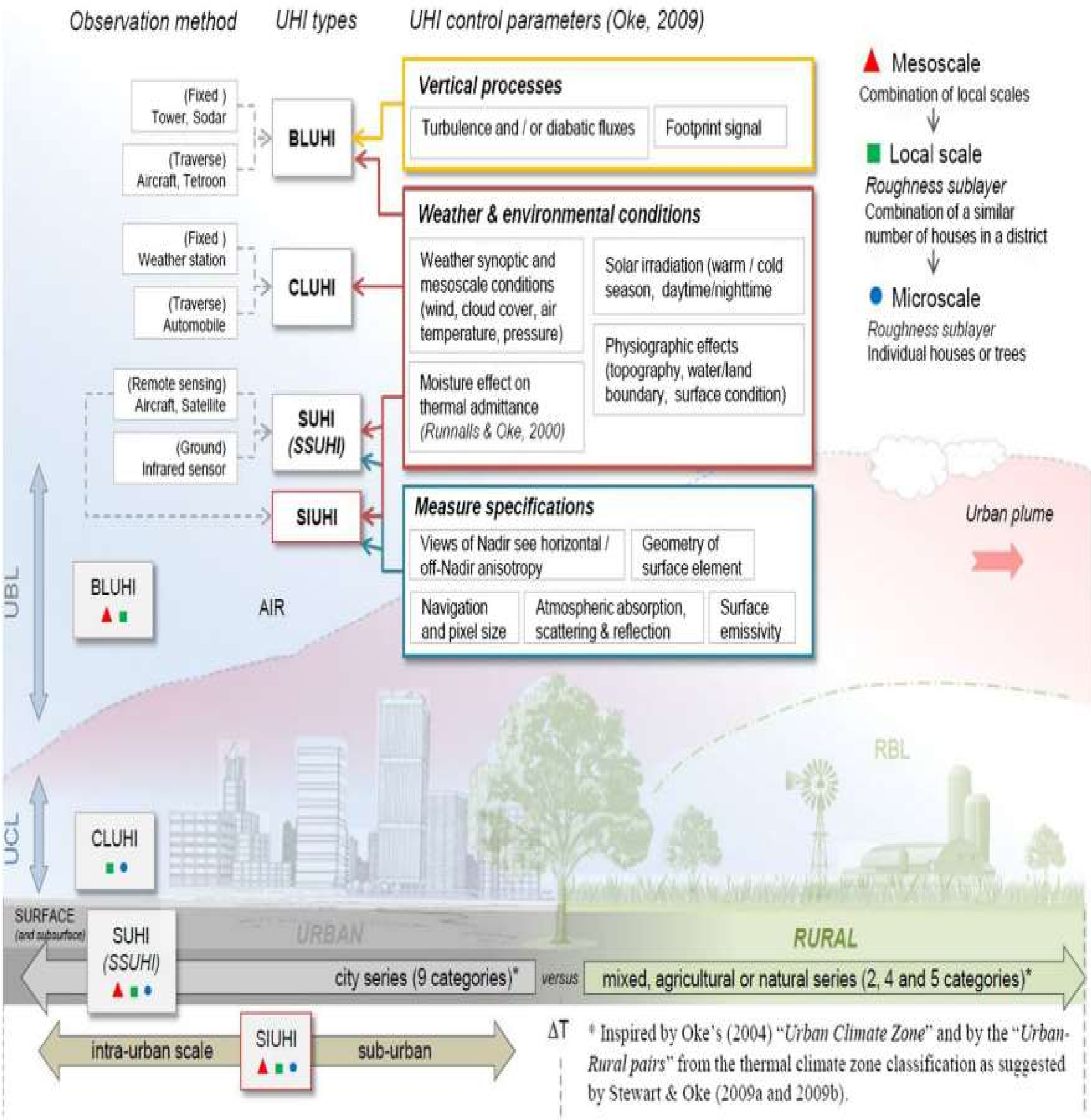


Figure 2-7 Urban Heat Island Levels and scales (Martin, Baudouin and Gachon, 2015)

neighbourhood. It is usually measured through either remote sensing or ground sensors (weather stations, handheld equipment) (Martin, Baudouin and Gachon, 2015).

UHI levels or types can be identified depending on location and height within an urban environment. The urban canopy heat island occurs within the area beneath the roof level while the boundary urban heat island occurs within the area above the roof level, including canopy and surface urban heat island as illustrated (Shahidan, 2011).

SUHI contributes in determining the intensity and the scale of the Canopy Urban Heat island (CUHI) which is more extensive and on a larger scale than SUHI as it is within the canopy level which reflects the measurements within a local scale (building levels). Meanwhile, the Boundry Urban Heat Island (BUHI) includes both CUHI and SUHI, and it occurs within mesoscale (combination of local and micro-scale) climates (Martin, Baudouin and Gachon, 2015).

For CUHI and BUHI, several research studies have demonstrated that roof surfaces are a main factor in the thermal balance of a city because the urban area consists of a noticeable percentage of roofs (20% to 25% of the urban surface) which participate mainly in UHI intensification, where conventional roof materials tend to heat up in the sun to temperatures of 50–90°C (Arabi, Shahidan and Kamal, 2015).

UHI provides London with warmer winter, leading to the earlier spring season and less snow settle. The UHI effect provides approximately 2°C warmer temperatures during the night and -0.2°C cooler temperatures during the day leading to UHI intensity reaching 9°C in 2003 compared to 4-6°C by 1960 in London compared to surrounding rural areas (GLA, 2006). UHI decreases with increasing wind speed and cloud cover while UHI Increases during anticyclonic conditions, summer, warm sunny days, increased city size and population (Wilby, 2008). For London, case studies illustrate rapid research for weather investigation alone, without considering the relation and connection between UHI and atmospheric chemistry (Wilby, 2008).

2.5.2 UHI Probability and intensity (how to classify UHI canyons)

Based on a number of researchers (Alexandri, Jones and Doussis, 2005; Alexandri and Jones, 2006, 2008; Vartholomaios, 2015; Zupancic, Westmacott and Bulthuis, 2015; Ahmed Shafeay and Shalaby, 2016; Wootton-Beard *et al.*, 2016; Alexandri, 2017; Sharmin and Steemers, 2017; Taher, Elsharkawy and Newport, 2019) the following Table 2-1 is formulated and generated based on previous literature on factors controlling UHI

Table 2-1 UHI Probability and intensity (how to classify UHI canyons)

		Street Width to Building Height (W:H) Ratio				Note
Factor	**Detail**	**1:1**	**1:2**	**1:3**	**1:4**	**UHI intensity depends on**
Canyon Geometry (Aspect Ratio)	**The roof has a higher temperature than south walls due to sun exposure. Roof air temperature depends on canyon temperature. Deeper canyons have higher thermal comfort during summers.**					
		H	**H**	**H**	**L**	**1:1 canyon depends more on received solar radiation and street surface materials due to wide SVF while narrow canyon 1:4 is more dominated by walls, however, their diffuse is small**
Canyon Orientation	**Canyon Orientation is more critical, especially when the GSR is high on vertical walls (temperate and cold climate). Latitude is more critical than orientation. Mean Radiant Temperature (Tmrt) is a more decisive factor to determine canyon orientation than air temperature. (Ta)since it is not as sensitive to the change of canyon orientation as Tmrt.**					
	North-South	**A**	**A**	**L**	**L**	**Due to self-shading and limited SVF**
	East-West	**H**	**H**	**H**	**H**	**More vital during the night for 1:3 and 1:4 (trapping radiations)**
Wind direction		**L**	**L**	**L**	**L**	**It is crucial in wind distribution only, but since Ws is low, so the distribution is small as well**
Wind Speed (Ws)	**Low**	**H**	**H**	**H**	**H**	**Increased wind speeds lead to an increase in climate variation**
	Average	**L**	**A**	**A**	**H**	
	High	**L**	**L**	**A**	**H**	
Global Solar Radiation (GSR)	**Direct**	**H**	**H**	**H - A**	**L**	**Depending on GSR**
	Indirect	**L**	**L**	**H**	**H**	**Due to trapping long waves radiations**

Sky View Factor (SVF)		**A**	**H**	**A**	**L**	**Strong during daytime for 1:1 due to receiving a large amount of GSR while it is weak at night, and vice versa for 1:4. Sky should be clear with less cloud cover.**
Building and Urban Fabric		**L**	**A**	**H**	**H**	**It has more of an influence during nocturnal time due to trapping released heat (longwave radiations) within deep canyons.**
Densification (population, cars, etc.)		**L**	**A**	**H**	**H**	
Urban Green Systems (UGS)	**In general**	**Vegetation (amount and location) and canyon geometry are more critical than Canyon orientation (within temperate and cold climates). Dry climates have more benefits from UGS on the roof and canyon levels. Parks create a 'cooling aura' at their leeward side with range tens of metres in length especially during a nocturnal period.**				
	Roof	**Influencing UHI on boundary scale and building energy consumption**				
	Façade	**The efficiency of UGS depends on GSR falling on walls. It has a more significant influence on building insulation**				
	Street	**More expansive canyon has weak influence from UGS. Trees have the most significant influence on pedestrians' thermal comfort (PTC).**				
Overall, factors which have low or weak influence on UHI does not mean that they do not affect UHI; although their influence is maximised during certain conditions more than others. UHI is also controlled by two contradicting effects which are trapping long-wave radiations and shading canyons from buildings from short-wave radiations which both also reflects on night-time UHI. Pollution as well can be contradicting, through blocking extra GSR and at the same time trapping heat underneath.						

Abbreviation	**Explanation**
L	**Low Urban heat island effect probability**
A	**Average Urban heat island effect probability**

H	High Urban heat island effect probability

Table 2-1 is generated based on previous literature on factors controlling UHI intensity and existence, which are canyon geometry, canyon orientation, wind spend and direction, global solar radiation (GSR), sky view factor, building and urban fabric materials, and densification. Canyon geometry which is the aspect ratio between street width to building height shows that within canyons of 1:1, 1:2 and 1:3, there is more intense UHI, since the amount of received GSR is high and it would be reflected and trapped within that canyon which is also called a narrow canyon, compared to wide canyons such as 1:4 which is able to quickly release the GSR during the night time hours, causing the canyon to cool down.

Canyon orientation, whether North-South or East-West, plays a crucial role as well, where North-South canyons have either average or low UHI due to self-shading from GSR while on the other hand, East-West canyons receive more GSR and the buildings are not blocking the rays. Wind direction does not have a noticeable impact on UHI. Nevertheless, wind speed has a major role in controlling UHI intensity, due to the wind's characteristics to carry and blow heat within canyons, at which low wind speed has weak properties to change the temperature within the canyon boundary. In contrast, average wind speed depends on canyon geometry and its sky view factor, and finally, high wind speed has a highly significant influence on decreasing UHI.

Wind speed impact on wide canyons such as 1:4 or 1:3 is more controlling as the canyon would have a higher sky view factor and a wider area of air exchange than narrow canyons such as 1:1 or 1:2 would have.

Global solar radiation (GSR) from the sun has two branches, direct from the sun (short wave radiation) and indirect (longwave radiation). For direct GSR, it has significant influence within narrow canyons as canyons are able to receive extensive radiation from the sun compared to very narrow canyons as (1:4) which are also called deep canyons causing shading to the canyon itself. For indirect solar radiation within deep canyons such as 1:3 and 1:4 allow GSR to be reflected many times (short wave), hence increasing short wave radiation causing an indirect increase in UHI which will release this excessive heat later depending on the thermal mass and the fabric of canyon and building materials.

Sky view factor (SVF) plays a key role; however, it depends on the canyon's dimensions and geometrical aspects, where wide canyons have high sky view factor, and a narrow canyon which has a narrow street compared to building height will have small sky view factor. SVF has an average influence on UHI within the 1:1 canyon as the amounts of open and closed sky view are almost equal. In contrast, within a 1:2 canyon, it has high UHI intensity as it could trap GSR; within the 1:3 canyon the UHI intensity is average as its GSR is trapped, yet the GSR amount received is lower than 1:2 and 1:1 canyons, and finally, UHI intensity is low within the 1:4 canyon as the SVF is very low due to the steep, narrow dimensions.

Buildings and the urban fabric have a major influence within deep narrow canyons, 1:3 and 1:4, while it is average within 1:2 and very low within 1:1 canyons as it is more dominated by canyon geometry and direct GSR than indirect one which is more critical within other aspect ratios. Densification such as people and transport, and other heat and pollution sources within the canyon are more evident within deep canyons, 1:3 and 1:4, while it is average within the 1:2 canyon and very low within the 1:1 canyon.

Both densification and building factor are usually more critical for night-time UHI as they play an essential role in the released heat from buildings or the trapped reflected heat (longwave radiation) within the canyon. The content and different major factors of Table 2-1 are usually carried together, and in case these factors are causing high UHI intensity, then the probability of having high UHI intensity is high, and vice versa. Overall, Table 2-1 has helped the researcher focus on areas with higher UHI effect through determining the main factors of its intensity.

2.5.3 Classifying UHI mitigation types

UHI mitigation measures are lacking a commonly accepted classification system which would help in mapping current research trends. A classification system by (Aleksandrowicz *et al.*, 2017) was established grounded on grouping the measures according to the intervention of their physical domination and selection criteria of action-oriented adaptation which reflects the shared and mutual view of policymakers.

These studies have led to classifying interventions into four main parts – building envelope, urban landscape, street geometry and pavements. The existence of real scientific evidence for its positive influence on UHI effect intensity reduction is the way of distinction between these measures, apart from other measures which could be additionally applied. This scientific evidence led to identifying 11 mitigation measures; these are cool building envelope, green roofs, green facades, ground vegetation, shading trees, cool pavements, water bodies, water-retentive pavements, built environment orientation, built environment prevailing winds, built environment orientation built typical environment section and built environment of the sun (Aleksandrowicz *et al.*, 2017). This research will be focusing on the urban green systems (green walls and green roofs) and their influence on the UHI effect.

Current research trends on UHI

Based on (Aleksandrowicz *et al.*, 2017), a large source of literature was found regarding UHI mitigation of 411 items between 2009 and 2013, which will be used in the assessment for research trends.

Figure 2-8 illustrate that 70% (288 of the papers reviewed) were mainly about shade trees, cool building envelopes, ground vegetation and green roofs) measures. These also depended on monitoring, and three out of the four measures (50%) used intensive vegetation for UHI effect mitigation. These measures were standard also as most of these countries which apply vegetations are developed and not suffering from water scarcity. In contrast, the least researched measures were water bodies, built environment orientation to the prevailing wind, green facades, and built environment to the sun which accounted for 20% (80 reviewed papers).

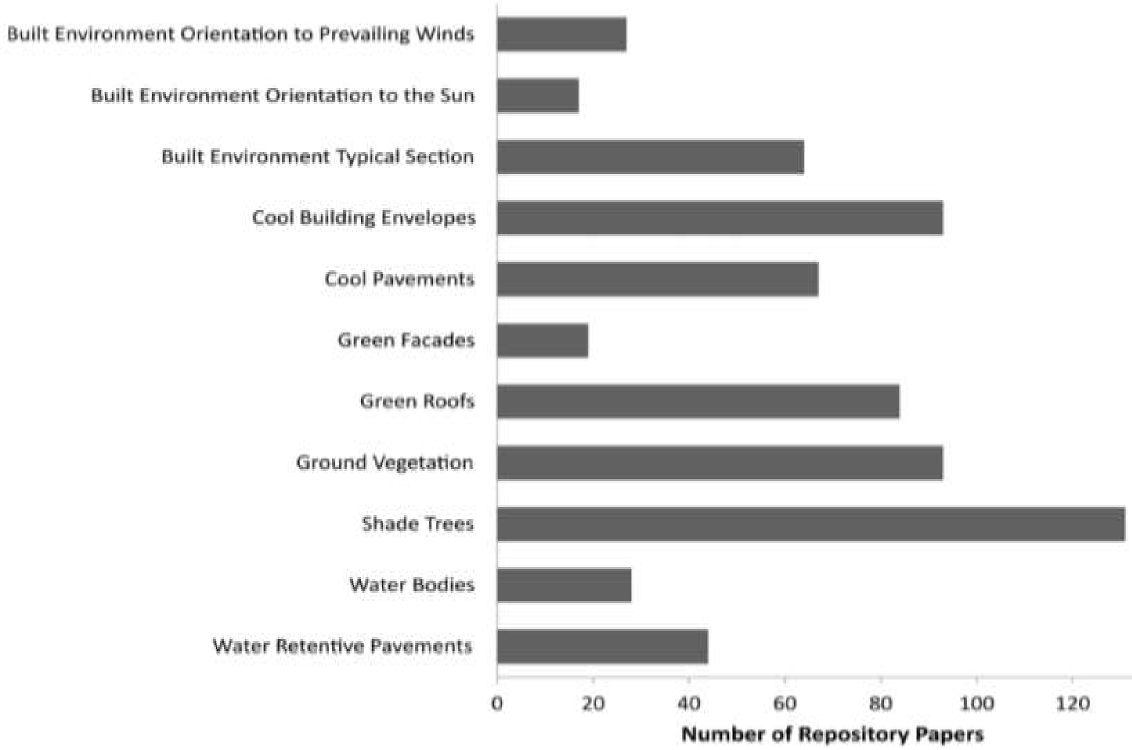


Figure 2-8 Number of research papers on different mitigation measures published in 2009-2013 (Aleksandrowicz *et al.*, 2017)

Shaded trees are the most researched UHI mitigation measure (131 papers). It helps in shading direct solar radiation, and it is relatively more straightforward for authorities to implement it within streets without changing or disturbing the urban form, in addition to not interfering with private properties ownership. Cool building envelopes rank in second place as UHI mitigation measure; local authorities adopt it as it is implemented within large-scale cooperation through private property owners by regulating and recommending the use of cool materials instead of spending public money.

On the other hand, Figure 2-9 represent the papers that the researcher reviewed which are exclusively focusing on single mitigation measures. He found that green roofs and cool building envelopes are the top researched measures. In terms of UHI mitigation measure shares in papers, whether it is a single measure or grouped, green facades and

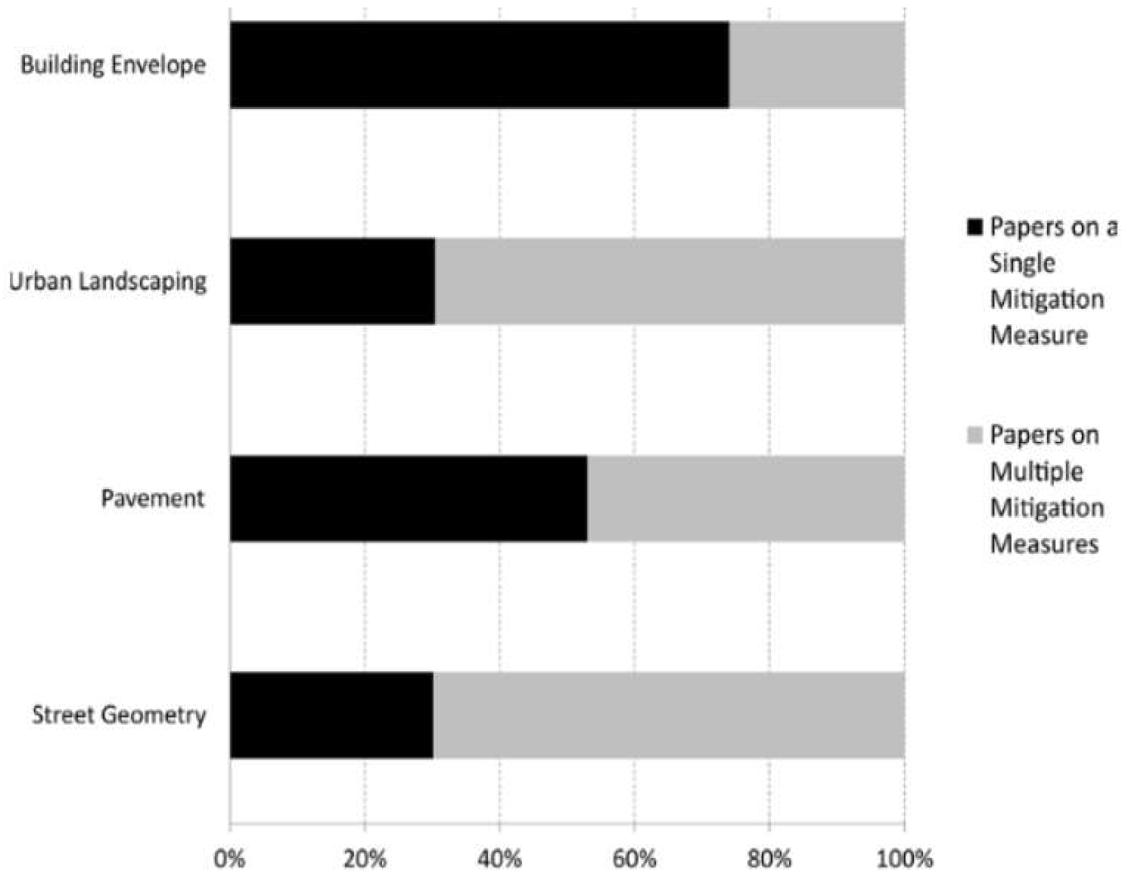


Figure 2-9 The relationship between papers studying single and multiple mitigation strategies (Aleksandrowicz *et al.*, 2017)

water retained pavements are the most researched measures. It is more preferred for policymakers to choose within several measures as each one has its values, benefits, costs, and effects. A total of 60% of researched papers deal with a single mitigation measure, while they lack beneficial costs and the corresponding cost values, which is reflected on the urban decision-making process for the UHI mitigations measures. One of the issues faced is that while analysing different research trends is marginal (18% of papers), due to the main components of urban design such as urban canyon geometry, prevailing wind and sun, these marginal aspects will influence the UHI mitigation differently, and it might also reflect on applying it on large-scale urban plans.

An interesting study by (Zupancic, Westmacott and Bulthuis, 2015) showed a statistical relationship between 102 relevant peer-reviewed studies published between 2009 and October 2014 between greenspaces, heat and air quality. The distribution of the 102 studies illustrates that 45% focused on air pollution and 52% on heat mitigation and only 3% focused on both air pollution and heat mitigation. Further, 92% of these studies represented air pollution mitigation effects compared to 98% that represented urban cooling effects from green spaces. On the other hand, 90% of these studies were observational studies, followed by 50% modelling studies, then 26% remote sensing, 21% ground-level data collection, 3% cross-sectional studies and 1% longitudinal study. Finally, there were six review studies and five experimental studies.

These studies were distributed across different green interventions classified as trees, grass, shrubs, a mix of greens, and comparison of green types. The distribution of papers focusing on heat mitigation mainly focused on comparing different green types with 17 studies, followed by trees with 13 studies then mixed green systems with eight studies and grass with one study. Studies on air pollution mitigation were different in the distribution as tree influence comes as the top research area with 24 studies, followed by comparing different green systems with nine studies, mixing different green systems with three studies and grass with one study.

Within those 102 studies, it was found that these studies were undertaken in 27 countries. Most of the research was located in the USA with 26.3%, then China 12.6%, then Japan 7.8% and England 7.4%, Italy 6.3%, Greece 4.2% and Germany 4.2%, and only two studies were conducted in Canada. Half (50%) of the research was located in a warm temperate fully humid climate such as London and Beijing; 25.8% investigated warm temperate dry summer climate such as Athens; 17.2% for snow climate fully humid such as Toronto; 5.2% for a warm temperate climate with dry winter such as Hong Kong, followed by 2.2% for snow climate with dry winter such as Seoul. All these climate settings were based on the Koppen climate classification. The majority of UGS research emerged from the United Kingdom, the United States, and Australia (roughly 60%). Most of the research =also comes from cities within the temperate and snow climate classification band (Parker and de Baro, 2019).

What are the main environmental and socio-economic consequences of Urban Heat Island?

Living in London as a high-density urban area may lead to high-risk factors for morbidity and mortality. These risks extend to increased chances of physiological disorders, organ damage, heat strokes or even death. The major factors that control the increase or decline in these risks are: (i) Age is one of the greatest factors that greatly influences older people due to heatwaves. Mortality rates in London increased by 45% higher than the 17% for Wales and England. (ii) Gender is a factor as women suffer more than men because of physiological and socio-economic factors. (iii) Lack of ventilation and cooling in buildings causes higher risk of heat-related mortality in hospital patients and nursing/care home residents—pre-existing health problems as respiratory disease, electrolyte disorder, diabetes and neurological disorder also have an influence. (iv) Deprivation increases risk within groups with lower socio-economic status, especially within the elder age group. This might be because of differences in neighbourhoods or housing, which might be the underlying prevalence of lasting disease or reason. However, ethnicity difference does not show clear evidence being at higher risk than other groups.

How might climate change affect Urban Heat Island?

Over the next decades and beyond, climate change will have a major influence on London's climate and would also reflect on the occurrence and frequency of extreme UHI events. The UKCIP02 provide projections on socio-economic scenarios for the 2020s, the 2050s and the 2080s for 50 km^2 regions across the UK. These scenarios do not represent London morphology in detail, nor the climatic impact due to unknown future land use in London. Further, the models used to produce the scenarios undertake the whole surface area of land of rural land use as vegetated. Consequently, the variations defined by the UKCIP02 scenarios should be considered as symbolic changes to the rural climate around London.

Outside of the UHI area, the impact of uncertainty sources for climate models, predictions and assumptions about future GHG emissions, economic and population growth rates, among others,. are being determined based on uncertainties, leading to giving different predictions based on variables as solar radiation, wind speed and cloud cover. Climate change scenarios are averaged over 50 km^2 within London, showing three scenarios – low "best scenario", high "worst scenario" and middle "middle scenario".

Climate change will reflect UHI as their average daily temperatures increase for both minimum and maximum temperatures. There will be a reduction in windspeed (<10%) and in relative humidity across the different season, especially in summer by up to 15%. There will be a modest fluctuations in solar radiation (of up to 20%), due to cloud cover drop. A slight rise in winter precipitation (rainfall) (up to 26% upsurge) and a further decrease in summer precipitation (up to 54% reduction).

2.5.4 What are the options for managing the Urban Heat Island?

The purpose of climate policies is to reduce UHI within different city scales, neighbourhoods and buildings, while considering the type of the scale – whether it is new, or retrofitted, or something else. This would reflect on current and next developments within the local and city scales. Vegetated surfaces are one of the dominant principles of UHI as, based on UHI, the land is the primary source of solar energy storage during the daytime, then releasing it during night-time to the atmosphere. Thus, due to rapid urbanisation, the balance between solar energy which is used for raising the air temperature (heating process) and that used for evaporation (cooling process) has been altered as a result of replacing vegetated green natural land by built grey engineered land (Ipcc, 2000). Thus, this thesis is going to focus on the critical strategies for tackling the root sources of UHI, through controlling both absorption and releasing heat from the urban fabric.

Anthropogenic heat plays an essential role in the UHI effect, depending on air conditioning trends; for example, =managing waste heat emissions and their locations are one of the most critical strategies, like considering London underground and its emissions. London UHI mitigating strategies must be developed coherently within several levels. In developing mitigation strategies for London's UHI, it must be considered that the UHI is a city-scale phenomenon and the outcome of the combination of the vast range of microclimates that exist across London. For instance, the urban system-built components occur at different levels – from the individual building to the industrial park to the major industrial zone. Thus, physical change or shifting of these will influence the climate at different ranges. Therefore, the relationship between management policies, urban heat island, and urban climate scale should be acknowledged as in **Error! Reference source not found.**.

The UHI form and intensity are based on the cumulative effect of time within local scale climate modification which could be significant. The practical strategies which could influence UHI could be Green systems – that is, green walls and green roofs, cool roofs, planting trees and vegetation and cool pavements. To improve UHI and pedestrian thermal comfort within city canyons a combination of physical (building materials, orientation, use), policy (building and urban regulations and strategies) and urban climatic scales (urban geometry) should be used and integrated to maximise the mitigation level. (Sharples, Fahmy and Hathway, 2011) also showed that outdoor thermal comfort is varied not only based on urban forms layout and geometry but also on the time of the day and how the urban layout is greened. On the other hand, (Fahmy and Sharples, 2009a) deeply investigated that tree arrangements, green coverage area and their geometries that play a crucial role on outdoor thermal comfort.

Green Walls and Green Roofs

Like green walls, green roofs, which includes of a growing medium planted over a waterproof membrane, might have an influence on the climate of, planted walls in the green wall case or the upper floors of buildings on the green roof case and their natural environments. Through hot sunny days, the vegetated roofs could be 20-40°C cooler than a straight flat dark coloured roof, while green walls had similar savings in addition to evapotranspiration, water retention, noise reduction, increased biodiversity, higher aesthetical value, among others. They might need regular maintenance based on the green wall and green roofs type.

Planting Trees and Vegetation

Urban greening is an effective way of enhancing and improving harsh urban climates throughout individual buildings within the neighbourhood scale. They are also cost-effective from the financial aspect, in addition to evapotranspiration and reducing surface temperatures due to shading between 5-20°C. Human thermal comfort within the neighbourhood scale could be impressive if trees are integrated with green roofs.

Choosing tree type should be defined in order not to pick trees that are primary sources of volatile organic compounds (VOCs) since, during warm weather, these will enhance the formation of ozone.

Cool Roofs

Based on dark coloured roofs in London, excessive heat was stored within them, reaching 50-60°C on hot sunny days. Subsequently, they stored and released a higher amount of energy back to the atmosphere, leading to decreased roof materials' lifespan and decreased indoor thermal comfort on the upper floors. On the other hand, cool roofs are built from high solar reflecting materials or albedo, reaching lower temperatures as they store and absorb lower solar energy during the day, and therefore reflect lower heat at night which finally leads to maximising the lifetime of the roof.

Cool Pavements

London pavements are characterised by dark planes. Thus, installing cool pavements with high reflective solar material and water preamble will help high urban temperature mitigation through rain storage and reflect high solar energy rates. For London, noticeable climate impacts of cool pavements might be reached by applying for large parking areas, airports, terminal facilities and urban roadways with large paved areas. Although researchers are still in the early stages of enquiry in this field, high albedo roads and pavements could have benefits for night-time street lighting. Reducing pavement surface temperature through implementing the most innovative pavement designs is the main aim to adapt to UHI (Nwakaire *et al.*, 2020).

Sky view factor

Sky view is one of the key factors due to released heat from urban environments during night-time; the rate of urban cooling is based on sky view since a narrow sky view, such as small narrow streets with tall buildings, will block heat from escaping the street canyons, ending by having more heat within the urban block. It also illustrates the relative space openness between buildings, which will contribute to heat escape. Besides, the orientation of the streets - with "prevailing, non-prevailing wind" - will influence the UHI effect intensity, in addition to will reduce the ventilation chances within the street canyon and will also increase perceptions and impacts of the pollutants.

Wind influence of urban city scale

The high concentration of both roads and buildings within the urban area leads to different heat exchanges (conduction, convection, radiation) in addition to internal energy storage within the urban region compared to the rural area. In parallel, there are dense transportation and energy demands which contribute to massive pollution volumes and heat releases (Abbassi, Ahmadikia and Baniasadi, 2020). One of the critical solutions to these problems within the urban area scale is the wind whereby, with relatively very low or no wind, the heat and pollutants would harm the city ventilation and human comfort while strong or acceptable wind speeds will transfer excessive heat and pollutants outside urban areas (Abbassi, Ahmadikia and Baniasadi, 2020).

2.5.4.1 UK and climate change risk assessment over the 2020s, 2050s and 2080

UHI managing plans are helping in reducing the health risks due to hot weather by setting out the plans and immediate actions that the public, health and social care professionals should consider within the heatwave occasion. The adaptation planning needed by the UK Climate Change Risk Assessment illustrates that climate change should be mainstreamed in all areas affected. The predicted uncertain climate change variables will reflect on future decisions with lower regrets; thus, a more comprehensive range of prospected climate change scenarios will be needed (Defra, 2009; DEFRA, 2012). Damage and disruption costs for extreme events due to climate change is varied based on type of climate change event. For instance, the threshold of for low, medium and high costs associated with climate change are £I billion, £10 billion and £100 billion. Flooding from the sea and estuaries costs over £200 million is the predicted annual damage (ABI, 2016) while flooding from rivers costs over £400 million in England and Wales is the predicted annual damages and consequences for flood victims (ABI, 2016). Cold mortality influenced by extreme cold conditions ranges between 26 to 57 thousand premature deaths each year is estimated in the current climate ((Health, 2016)). These risks are still clear if combined with high rates of influenza, although early deaths appear to be declining over the last decade (Hajat *et al.,* 2014) (Rosie Amery, 2015).

Snow and ice conditions costs £1 billion per annum is the average transport and welfare disruption costs due to snow and ice conditions, although it is expected to decline due to warmer conditions on the long-term, while the extreme cold weather will be more (DfT, 2010). Heat morbidity through extreme warm environments costs 100 thousand patient days per year is expected, under the current climate, with the expected rise in death numbers due to heatwaves (Hajat *et al.*, 2014). Wind storms and gales costs £620 million is the average annual insured losses from UK storms, causing significant property damage, energy supplies disruption and loss of life (ABI, 2009).

2.5.5 Benefits of climate change adaptation

This thesis focuses on *climate adaptation*, specifically *urban* adaptation, as cities nowadays are currently full of half of the world's population, which will increase by 70% by the 2050s (UN, 2014). The UK has more than 60% of its population living in the cities, while most European countries have almost 50% living in the cities (UN, 2016). Thus, the higher population densities, the more significant influence and impact from climate change in cities, which would be enhanced by more risks posed by the nature of the built environment within the cities (Ibarrarán, 2011). For instance, the broad impermeable surfaces areas in cities will lead to an increase in flooding. These implications will lead to pressure on drainage systems and channelised urban watercourses since the flow-rate and the volume of rainwater runoff will put increasing pressure on them, which compromises their capability of water excess dealing and resulting infrastructure flood damage (Whitford, Ennos and Handley, 2001).

Climate change associated with rising temperatures is attributed to the UHI effect, especially during hot summer times. When the temperature gets closer to 37°C human body temperature, physiological stress occurs. Climate change also negatively impacts health by increasing infectious diseases, stress, population migration, and lack of food and water (Lundgren Kownacki *et al.*, 2013). Depending on relative vulnerabilities of the population, infrastructure, ecosystem, and other factors., cities' impacts could have different influences (HuntP *et al.*, 2011). Thus, the planners and future planning are focusing on climate change programmes through focusing on building knowledge, which motivates architects, planners and urban designers to integrate climate proofing in refurbishment, retrofitting and developments (Shaw, Colley and Connell, 2007).

Based on that, in the UK recently, the Adaptation and Resilience in a Changing Climate (ARCC) research network for different scales and level projects, has targeted the development of adaption analysis tools for urban areas, focusing on the built environment, infrastructure and transportation system as the main focus and objective for a healthy environment and climate change (Scott, 2011; ARCC, 2018). They are increasing urban vegetative cover as an adaptation strategy for future climate change in urban areas, in order to reduce the impact and to mitigate the UHI, which is called passive soft engineering adaption strategies (Hardin and Jensen, 2007). *Passive* adaptation strategies are better and more desirable than *active* ones, such as mechanical air conditioning, among others, because passive adaption strategies will reduce the energy demand, leading to lower greenhouse gas and air pollution levels (Papadopoulos, Oxizidis and Kyriakis, 2003).

Climate change adaptation's main target is to minimise the rising temperature, which influences energy usage and human wellbeing, although targeting flooding and air pollution impact receive so much attention for climate adaptation as well. Thus, an adaptation which can tackle many targets is much more beneficial and desirable than those who can adapt to a few or one climate impact such as high albedo roofs. Urban vegetation is very multifunctional in the way in which it can target different climate changes, in addition to other indirect benefits such as physiological. Adaptation appears to be a low priority issue for governors and city planners in Europe at present; however, progress is still ongoing to overcome barriers through policies, governance frameworks and uncertainty in climate science (Carter, 2011).

Climate change may increase the number of heat-related deaths in the European countries which are predicted to rise from 152,000 a year to 239,758 a year by 2080, leading to 50 times the current death rate, while in the UK a predicted 540% increase by 2080 could led to nearly 11,000 d deaths per year as a result of heatwaves. On the other hand, a 118% spread of urban areas in the UK and a 148% increase in people living in flooding areas is predicted (Martin Bagot, 2017). Dr Giovanni Forzieri declared that continuous urbanisation would amplify the urban heat island effect in that built-up area in which heat is trapped and absorbed inside canyons (Giovanni Forzieri, 2017).

South-East of UK temperatures in summer are expected to go up to 3.5°C, five degrees warmer by the 2050s and the 2080s, respectively. In addition Urban Heat Island (UHI) adds 5-6°C to summer night-time temperatures (Hulme *et al.,* 2002). London centre will face up to 9°C in temperature higher than the surrounding greenbelt with expectations to more UHI frequency increase of these effects (GLA, 2006). A study by Exeter University, the UK, used 18 years of survey data from more than 10,000 participants and showed that there was a strong correlation between access to green space, self-reported well-being, and even physical health, in the way that sensations linked with living close to green space produce similar feelings and satisfaction levels to getting married or getting a new job (Luísa Zottis, 2014).

Adaptation with green space

Green spaces as open green spaces, green roofs, green walls, etc. have a multi-functional role. The main focus here is combating UHI effect and providing climate refugees. Thus, local residents would be able to go for walks during heat periods in addition to providing a cooling effect, providing shading capacity and reducing heat vulnerability of the surrounding areas. Urban vegetation would have an impressive influence on the microclimate (Wilmers, 1988; Dimoudi and Nikolopoulou, 2003; Gómez, Gil and Jabaloyes, 2004; Gómez *et al.*, 2008). It could be formed within different forms such as city parks, trees over roadsides and city walks, vertical urban greenery systems, residential gardens, and green roofs (Grant and Lane, 2006; Köhler, 2008; James *et al.*, 2009). Indirect benefits of UGS could improve ecosystem services and communities' built environments; for instance, UGS features can provide at least two benefits, given the operational range of several benefits (Kim and Song, 2019)

These green covers are found in different spatial scales with different levels of integration (Heidt and Neef, 2008), which could influence the urban environment through impacting on thermal performance (Eumorfopoulou and Kontoleon, 2009), wind speed (Perini *et al.,* 2011), Urban Heat Island Effect for climates and canyon geometries (Alexandri, Jones and Doussis, 2005), life cycle energy and carbon savings (Altan *et al.*, 2017), air quality (Taha, 1997), humidity (Wang *et al.,* 2016), and noise levels (Gidlöf-Gunnarsson and Öhrström, 2007) on a localised scale (A Darlington, 2001; Paevere and Brown, 2009; Bozonnet, Doya and Allard, 2011) and finally on the city-wide scale (Alexandri and Jones, 2008) through biodiversity (Mayrand and Clergeau, 2018).

Lowering UHI effect through urban vegetation is achieved through solar heat gain reductions from leaf shading (Hardin and Jensen, 2007), increasing solar reflectance due to the higher albedo of leaf shading (Gary Grant, 2012) and increasing latent cooling through evapotranspiration (Taha, 1997).

While investigating the UHI climate adaptation, it must be noted that a reduction will follow it in UHI temperature, greenhouse gases, and carbon sequestration (Solecki *et al.,* 2005). There are urban strategies for climate "adaptive mitigation" as urban afforestation programmes which is vital and precious for committed nations to climate goals (Stone, 2012). Urban green spaces have multiple benefits, besides the climate adaptation, pollution and water attenuation, generating social cohesions and biodiversity (Alexandri, Jones and Doussis, 2005; Rob MacKenzie, 2012; Perini and Rosasco, 2014; Schmidt, Reichmann and Steffan, 2018). Thus, urban greening is much more than just a luxury and aesthetical material for cities; it is considered as a vital part of urban planning and people's health (James *et al.*, 2009).

2.6 Conclusion

UHI is caused by extensive urbanisation which impacts on different world cities within different locations. The greatest influence is within the mostly covered up spaces with buildings. This reflects on the main microclimate components which are solar radiation, relative humidity, air temperature, wind speed and precipitation. In relation to other reasons, the lower albedo and low vegetation surfaces have led to stronger UHI. These two components were modified to mitigate and adapt the UHI.

On the other hand, this chapter describes how climate change and global warming would influence UK temperate climate nowadays and in the future by the 2050s and the 2080s. Subsequently, the chapter illustrates the negative influence on urban life, whether on buildings, cities, and residents as it will cause overheating, heat stress and increased flooding events.

Changes over the next 30-40 years are mainly determined through historical emissions of greenhouse gases; however, current daily emissions will also reflect on the severity of future climate changes where the UK will face warmer drier summers and wetter colder winters. Climate mitigation and adaption become the critical solutions for the current and future climatic scenarios through using different urban green systems such as trees, green walls, green roofs and cool pavements, among other initiatives, which are investigated in greater depth in Chapter three.

3 Chapter Three: Urban green systems in Temperate Climate

3.1 Introduction

This chapter provides a historical background for urban green systems in the past, followed by definitions and broad-scale concepts for urban green systems (trees, green walls, green roofs, cool pavements, etc.). It explains their benefits in general and at environmental and physiological levels, specifically, in this research in the context of increasing carbon sequestration and increasing thermal comfort levels for pedestrians within urban canyons and the limitations of different urban green systems. It also addresses the limitations of implementing urban green systems within urban neighbourhoods.

The second section of this chapter identifies the thermal comfort levels and measurements, starting with physiological equivalent temperature, predicted mean vote, and universal temperature climate index, and discusses how they are affected by meteorological data such as air temperature, wind speed, global solar radiation and relative humidity.

3.2 Greenery as a primary urban utopian concern in the 20th century

In the 20th century, vegetation in the neighbourhood was valuable and vital within the urban scale, not only for individual buildings. Since the industrial revolution, planners, architects, scientists and utopians have been planning the ideal scenario for the ideal future cities. They provide critical solutions to challenges as unhealthy living conditions by picturing vegetation as one of the main drivers (Svetlana Perović ;Svetislav Popović, 2013). The inventor of the word *Utopia*,, Thomas More, fancied and pictured an ideal capital of gardens attached to houses where these gardens are full of fruits, plants and vegetables, to be cultivated by the inhabitants (Eylers and Eva Eylers, 2015), while Robert Owen mentioned the importance of vegetation for the urban environment at the beginning of the industrial revolution, when it was done through well ventilated, heated and cooled housing units.

These units are surrounded by greenery and fresh air (Angelfire, 2018). New Utopian ideas called for *Hygeia* or " The City of Health", led by Dr Benjamin Ward Richardson, who sought to bring the fresh environment to the city through providing green open spaces, fresh air, pure water and sunlight (Angelfire, 2018). Raised urban temperatures or ("UHI was not known at that time and the ideas of social improvements were meant to occur as a result of good architecture and urban planning, although the concept of greening roofs and walls was not the primary concern in the 20th century.

Both (Ebenezer Howard, 1902; David Rudlin, 1998) expressed the importance of vegetation within the urban scale level as a garden city, illustrating that it will be able to solve the problem of industrialised cities and would affect the urban planning around the world in the 20th century. These ideas would be realised through having gardens next to houses, and the existence of large parks within the city and farmlands surrounding the urban area, which will be a communal ownership land so as to avoid affecting the surrounding environment from individual interests and profits.

The world's first garden city, *Letchworth* in England" was built in 1903 to be an industrial city with a population of 32,000 inhabitants. It was designed by Unwin and Parker to be free from pollution, overcrowding and slums in order to bring the countryside within the city through providing parks and opens spaces and extensive landscaping

(Mervyn Miller, 2002). Although there were no plans for green roofs and walls, neither in Howard’s visions nor by Unwin and Parker, there were a few buildings in Letchworth with green walls.

The garden cities became popular within the modernists in Russia before the revolution as shown in Figure 3-1. After the revolution, Markovnikov understood that there should be a rationalisation of the traditional low-rise housing, due to the poor conditions of mass housing. Thus, Howard’s visions started to also appear within the Soviet Union rather than anywhere else in the world for above-stated reasons; for example, Vesnin and Markovnikov designed the *Sokol Garden Suburb*, outside Moscow, which becomes the first Garden Suburb and subsequently, became known as a critical solution for a food source (P. Papadopoulou-Symeonidou, 1995).

Figure 3-1 The Soviet Union typical urban block, surrounded by vegetation (courtesy of P. Doussis)

Le Corbusier and Frank Lloyd Wright considered vegetation as a vital element for urban transformations. Le Corbusier suggested the vertical garden cities instead of the horizontal, which would be a repeat of the previous era as the society is becoming nomadic, leading to drag societies into garden cities, since copying these buildings on the land will override the proposed green areas, besides, residents would be overlooking green areas through their homes, instead of roads and vehicles (Le Corbusier, 1948).

Le Corbusier's skyscraper was meant to represent hanging gardens through having a green veranda, green roofs covering office skyscrapers, surrounded by gardens, although green roofs and vegetation would not be exhibited in the residence of working people but only in the dwellings, workplaces and entertaining buildings of the ruling people. The dwellings of working people could benefit from the greenery views, and although urban green systems are not attached to them, they can see these in the park next to them. Frank Lloyd Wright suggested the ideal city of *Broadacre* as in Figure 3-2, with a more individualist view, where the city had gone to the countryside in a decentralised form, where the city than Howard's garden city. It is a more decentralised concept than Howard's garden city. In Broadacre, the city integrated and melted down with nature, with vast separated distanced buildings, covered by highways (Fishman, 1982).

Figure 3-2 On the left, Frank Lloyd Wright's Broadacre city while on the right Building with green terraces for the same city

Throughout nature buildings, some of them covered with greens, the city thermal challenges on which this study is focused, will not have an impact on the urban and rural layout (Ip, Lam and Miller, 2010). Hence, vegetation is considered as an essential aspect and core element of design, whether through applying it on the buildings as green walls, green roofs, or placing them next to the buildings as trees, although UHI was not proved or validated to the same extent as nowadays.

Cities have changed and developed in a different way than the Utopians predicted, leading to increase thermal challenges due to higher building concentration, in addition to the lack of vegetation in urban spaces, which has caused environmental issues which are mentioned in the previous chapter. Therefore, the old solution of replacing urban spaces with buildings is not an option anymore from the environmental and social aspects, where vegetation is meant to be for everybody. This replacement would happen by placing vegetation is already available urban surfaces like walls, roofs and terraces instead of creating new spaces for vegetation.

3.3 Greenery broad-scale concepts

Green infrastructure (GI)

Infrastructure refers to the primary facilities and structures which are necessary for society functioning efficiently with an area. In comparison, green spaces are defined as any form of vegetated areas in any shape or type (Forest-Research, 2020b). When green is included with infrastructure, it refers to a network of different green spaces types which deliver several benefits whether to space or the users or the whole system. These types could be parks and gardens, green corridors, natural and semi-natural urban green spaces, outdoor sports facilities, allotments, community gardens and city farms, accessible countryside in urban fringe areas, cemeteries and churchyards, amenity green space, and civic spaces. (Forest-Research, 2020b).

The benefits of UGIs based on EU objectives are similar to the benefits to urban green systems and green areas which shows how intersected and identical they are; these benefits are: climate change mitigation and adaptation and increasing resilience; enhancing, restoring and conserving biodiversity and ecosystems; enhancing cultural and social connections with nature; minimising urban sprawl; make the best use of land resources, and improving the surrounded environment (Sturiale and Scuderi, 2019). It is environmental features which stand alone and are strategically designed for environmental, social and economic benefits, such as trees, green walls, green roofs, and cool pavements, among others. It does not require significant changes in order to be implemented or integrated within spaces as it is quickly delivered within the existing planning process. When planning systems make supportive design standards to be implanted in plans, GI delivery improves (Barker *et al.*, 2019)

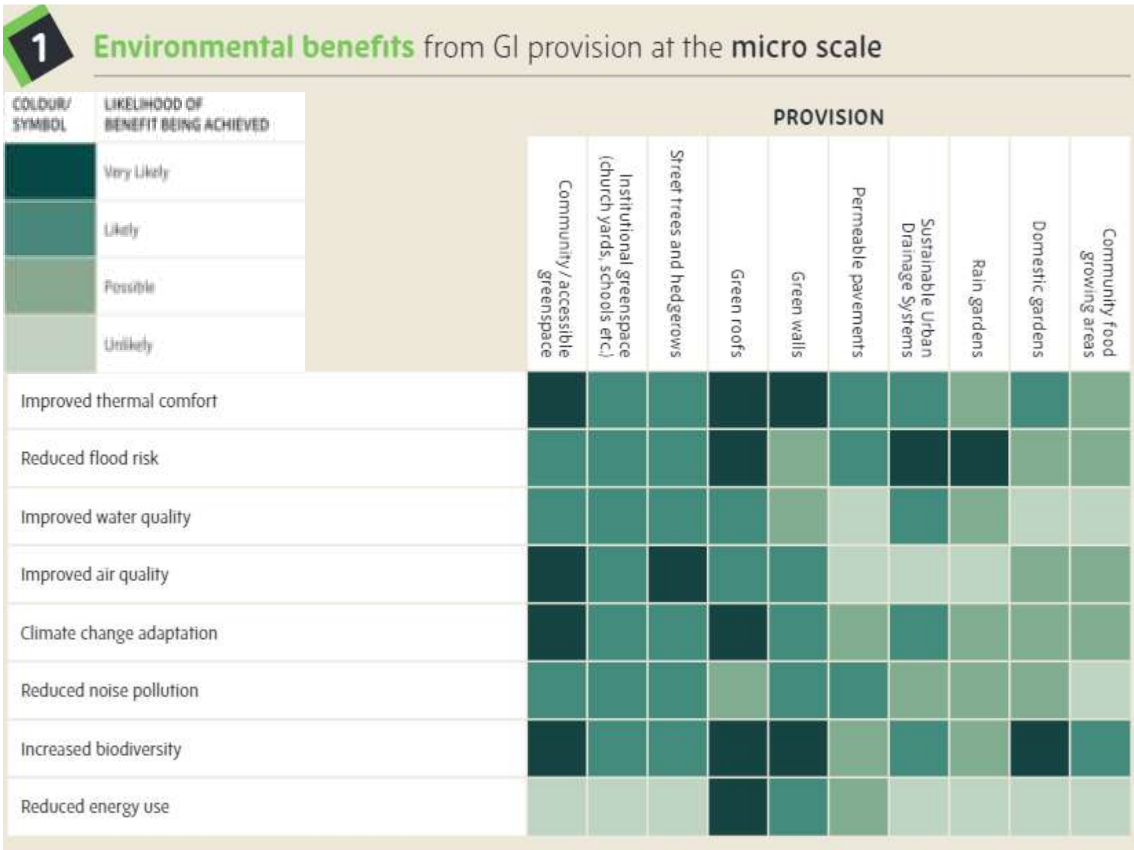


Figure 3-3 Green Infrastructure provision at the microscale (Barker *et al.*, 2019)

For green infrastructure provision at the *microscale* level as shown in Figure 3-3, it has several environmental benefits such as improved thermal comfort, reduced flood risks, improved water quality, improved air quality, climate change adaptation benefits, reduced noise pollution, increased biodiversity and reduced energy use. GI at the microscale has several provisions varying between community accessible green spaces, community food growing areas, domestic gardens, rain garden, sustainable urban drainage, permeable pavements, green walls, green roofs and street trees and hedgerows. GI has a very strong influence on improved thermal comfort, improved air quality, reduced air pollution, and increased biodiversity.

For green infrastructure provision at the *meso-scale* level as in Figure 3-4, it has several environmental benefits such as reduced UHI, reduced flood risks, improved water and air quality, increased habitat area, facilitation of species movement and increased population of protected species. GI at the meso-scale has several provisions varying from large parks, woodland, ponds and lakes, sports and recreational grounds, green corridors, community agricultural areas, local nature reserves and sustainable urban drainage. Overall, GI on the meso-scale level has a strong influence on reduced UHI, reduced flood risk and improved water quality.

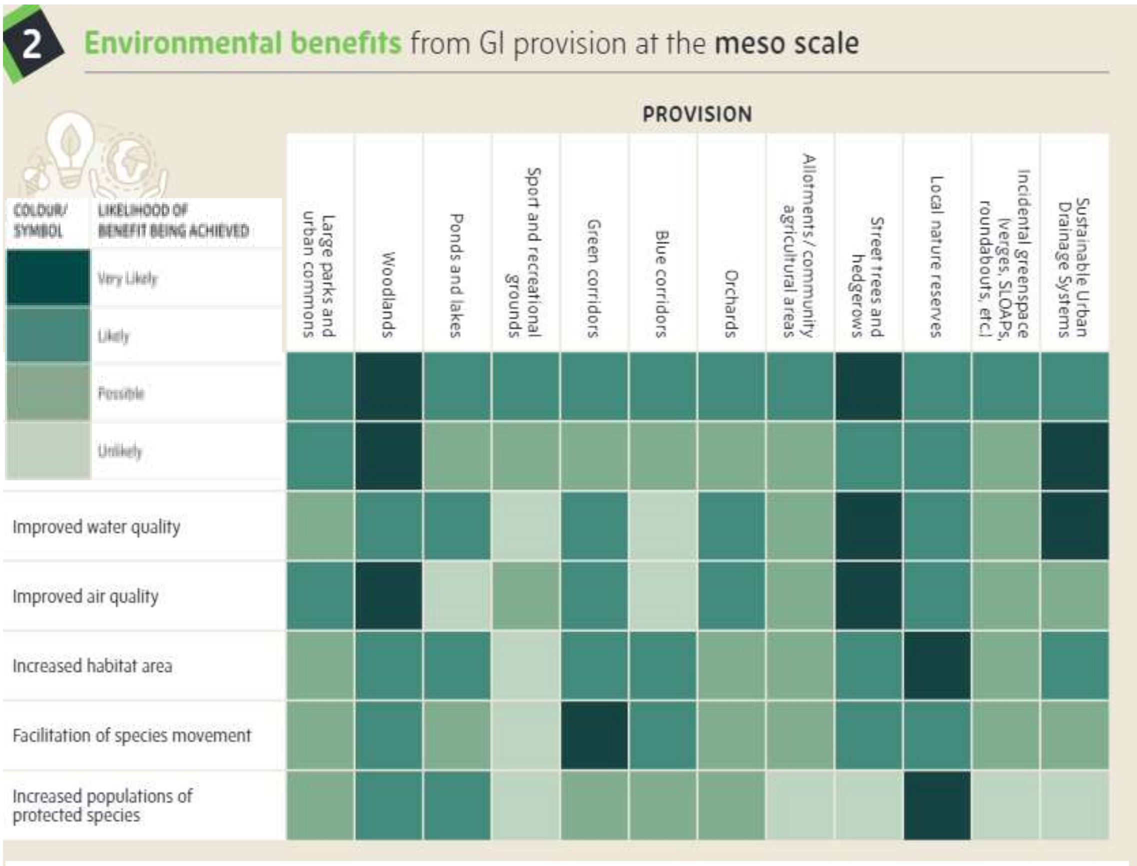


Figure 3-4 Green Infrastructure provision at the meso-scale (Barker *et al.*, 2019)

For green infrastructure provision at the *macro-scale level* as shown in Figure 3-5, it has several environmental benefits such as reduced UHI, reduced sub-catchment scale flood risk, improved sub-catchment water quality, improved macro-scale air quality, enhanced species movements and enhanced climate change adaptation and mitigation (Tauhid, 2018). GI at the macro-scale has several provisions including uninventive and intensive agricultural lands, designated greenbelt, green corridors, blue corridors, regional parks, urban forests, canopy cover and lakes and reservoirs. Overall, GI on the macro-scale level has a strong influence on reduced UHI, improved macroscale air quality, enhanced species movement, increased biodiversity, climate mitigation and adaption.

It was interesting that by adding 10 more trees in a city block in Canada (CA), it has the equivalent health perception on increasing annual income of CA$10,000 in addition to moving to a neighbourhood with CA$10,000 higher income average or feeling seven years younger. Adding extra 11 trees within the same city block would decrease cardio-metabolic conditions equivalent to the increase of annual income of CA$20,000 in addition to moving to a neighbourhood with CA$20,000 higher income or being 1.4 years younger (Kardan *et al.*, 2015).

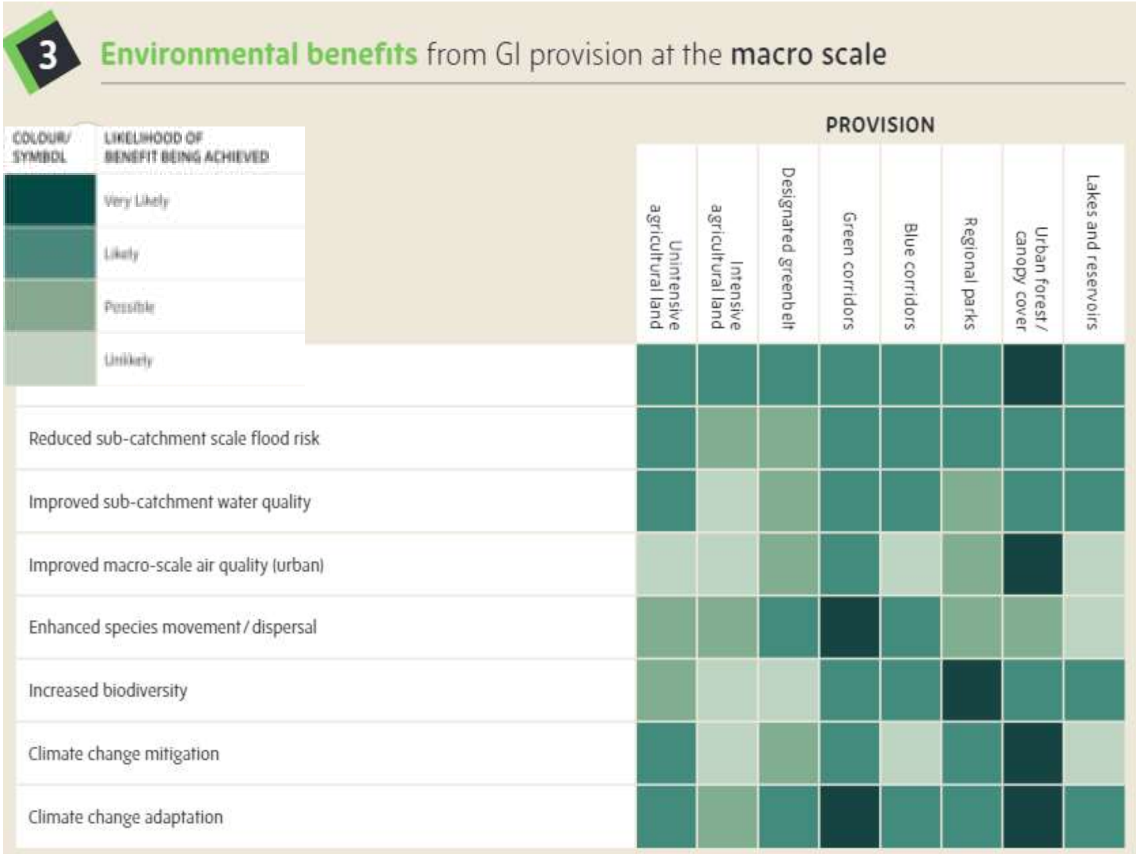


Figure 3-5Green Infrastructure provision at the macro-scale (Barker *et al.*, 2019)

An estimated £2.2billion is delivered from outdoor exercise due to the health benefits to adults in England from green spaces each year: that was from 30 minutes spent within green spaces by more than eight million people each week (Mark Kinver, 2016). It is also estimated that only 14% of the UK's population had asy access to woodlands within 500 meter from home, which means the benefits might increase with the increase of accessible spaces or with the increase of green spaces which confirms a report by Natural England that only 10% of children played in woodlands, compared with 40% of their parents' generation (Mark Kinver, 2016).

Urban green systems (UGS) and Urban green infrastructure (UGI)

Green spaces could be referred to as green systems (GS) or green infrastructure, and that includes all type of urban green spaces (public, private) within different forms (urban green corridors, networks and linkages). The promotion of urban greening (system, infrastructure) directed attention to the local natural environment by improving environmental, ecological opportunities, access, and recreation opportunities within urban communities (Forest-Research, 2020a).

It is also considered as a reversing mechanism for climate change due to its unlimited benefits such as adapting climate, increasing biodiversity and aesthetical value increase, among many other benefits (Forest-Research, 2020a). When a principal or large-scale urban infrastructure, its service, system or function is provided within a decentralised or distributed system, it is more beneficial and resilient to disturbance while when it is centralised (Lindholm, 2017).

On the other hand, UGS is considered as higher risk than conventional options for urban infrastructure and development in terms of regular maintenance due to their natural root behaviour through expanding within streets and destroying pavements. In comparison, most of the decision-makers are focusing on the economic costs and benefits rather than qualitative evidence of benefits which is usually ignored (Fairbrass *et al.*, 2018).

Urban green corridors (UGC)

The concept of UGC is to allow the contribution of urban environmental quality improvement. It was identified as *Greenway*s in English literature to protect the green space surrounding as the primary objective by improving/protecting air quality and recreation spaces. From these points, these corridors allowed for the structuring of urban and rural landscapes which promote the city image (Ben Plowden, 2011; Rocha and Ramos, 2012).

This *Greenways* typology includes two pathways along roads, cycleways, canals and riverbanks and railway lines in a linear route with the primary purpose of human (non-mechanical) transportation or leisure (walking, cycling, horse riding) in addition to facilitating wildlife migration (MCC, 2009). UGC can evolve spontaneously through enriching roadsides with trees and plants which would make it the infrastructural backbone of UGC (Sara, 2015) where the average Londoner walks for around 25 minutes per day (Peter Murray, 2016).

For instance, London greenways are a group of attractive coherent networked projects for pedestrians and cyclists, which improves access to green spaces as well. It is also proposed to extend the greenways to cover all city networks through linking them together (through planting/vegetating streets, connecting to parks, etc.) (Ben Plowden, 2011; Rocha and Ramos, 2012)

Urban green approaches (UGA)

Urban green approaches comprise UGS, UGI and UGC. Urban Green infrastructure (GI) is an evolving term (Austin, 2014). Both UGS and UGI are generally used for land development and land conversation discussions, and it usually depends on the challenge and location context. It might refer to natural solutions (trees, living walls, plants, etc.) or engineered solutions (cool pavements, stormwater management, water treatment, etc.) for existing or prospective future challenges (Benedict and McMahon, 2006; Tashiro, 2020). On the other hand, green systems (GS) refers to self-sustaining (naturally based) ones while UGS and UGI might require human participation or involvement at some stage or another to be sustained in order to be beneficial for both nature and people (Benedict and McMahon, 2006).

All UGA might not be a straightforward or direct exact way for natural land protection and conservation yet it also develops and improves human-made urban infrastructures and planning in order to serve the ultimate goal of enhancing the surrounded environment on different levels whether it is nature, ecological, social, or economic. Thus, that would also lead to a recommended framework for a city planner, urban designers and the current urban infrastructures to lead the development priorities to meet the needs of nature and people's needs (Benedict and McMahon, 2006; Derkzen, van Teeffelen and Verburg, 2017)

Urban Green Approaches (UGA) as climate resilience and control

Based on climate change, natural disasters and the need for environmental support within cities in order to face current and future challenges, multi-scale beneficial urban resilience systems are required to face expected challenges (Tashiro, 2020). These suggested solutions should be easily integrated within cities particularly with the massive population increase in cities and with their needs within a limited built-up urban area to promote and improve environmental, socio-economic and ecological benefits (Tashiro, 2020). Thus, within the last decades, people started accepting the UGA potentials in providing cost-effective urban sustainability solutions and roles (Shackleton *et al.*, 2017).

3.3.1.1 Trees

Street trees are practically well-doing based on original planting reasons when they have been initially planted; however, the aesthetical reason was the main aim which was similarly found in 1920 by Webster, who estimated that reasons for planted trees were made up of 60% of the trees used for shade and good view, and that decreased to 4% in inner London and even lower to 1.4% in Greater London (Ian Jack, 2017). There are multi-benefits from trees, especially street trees, as tree-lined streets have been confirmed to increase 15% of house prices, and are energy saving for building as a second insulation layer either for shading or warming through blocking cool wind, improving air quality, CO_2 sequestration, UHI reduction, stormwater attenuation, affording food, increasing biodiversity, reducing crime and increasing mental stability and health recovery (Kardan *et al.*, 2015), and improving humans' overall thermal comfort (Huttner, Bruse and Dostal, 2008).

Forest bathing is considered as a medical prescription in Japan (Rachel Nuwer *et al.*, 2019). A worldwide planting plan (1.7billion hectares of treeless land) might eliminate two-thirds of all the emissions from human activities that persist in the atmosphere today, on which 1.2trillion native tree seedlings would naturally grow. This area is about 11% of all land and equivalent to the size of the US and China combined (Damian Carrington, 2019).

There are around 8.4 million trees in London with 900,000 street trees of around 500 different plant species (Ian Jack, 2017), which are collectively storing approximately 2.3 million tonnes of carbon. The most common tree in London is the London plane, which is a hybrid of the American sycamore and the Oriental plane which make up 7.8% of the London's overall tree population. Combined, they sequestrate CO_2 by 7.58 metric tonnes per year, while they are assumed to store in total 216,000 tonnes of CO_2 with an average life span 200-400 years (EDWINA LANGLEY, 2019; Woodland-Trust, 2020).

There are around 1.58 million trees within inner London, and around 6.83 million trees within outer London, despite the fact that the benefits of trees within inner London £60 million, and £73 million in the outer London area (ITree-Project, 2015). The English

Oak comes in second place with 7.3% of the overall London tree population but its numbers are declining very fast due to drought and bacterial infections; however, it sequestrates around 482 tonnes of CO_2 (EDWINA LANGLEY, 2019). It was noticed that trees that positively influence people are those planted alongside the streets as they may have the most visual presence and contact with pedestrians (Kardan *et al.*, 2015) (ITree-Project, 2015). In addition, adding 10 or more trees to a city has health benefits equivalent to seven years reduction in residents' ages and CA$10,000 increase in median income for residents within the neighbourhood (Diana Fleming, 2020).

Trees reduce UHI through evapotranspiration, reflecting solar radiation, low heat storage capacities, offering a more open view to the sky and finally providing shade, as shown in Figure 3-6. It is calculated that an average tree evaporates 1460kg of water during a clear summer day and consumes almost 860MJ of energy; this outdoor cooling effect is equivalent to five typical air conditioners (Arabi, Shahidan and Kamal, 2015) although the strength of cooling depends on tree characteristics (tree species, leaf area index, leaf thickness and roughness, etc.), site condition (the type of surrounding materials within the pavement, surrounding water features, etc.) and weather conditions (relative humidity, air temperature, amount of solar radiation, clouds, etc.) (Vaz Monteiro *et al.*, 2019). On the other hand, placing trees in heavily built-up neighbourhoods leads to higher pollution concentrations (Jesionek and Bruse, 2003).

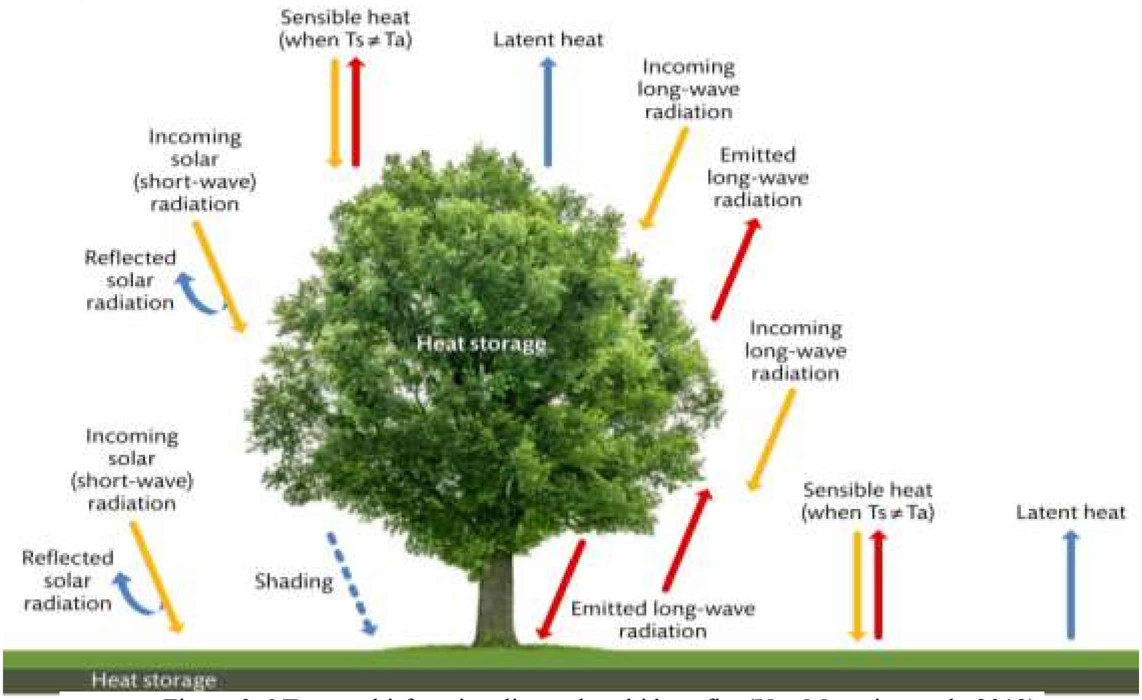


Figure 3-6 Tree multi-functionality and multi benefits (Vaz Monteiro et al., 2019)

There is relatively intensive study about trees' benefits due to their effectiveness in fighting climate change (Mark Tutton, 2019), CO_2 sequestration (DTE, 2019), aesthetical value (Wolf, 2005), improving pedestrian thermal comfort (Yasser, 2017), building energy performance (Aboelata and Sodoudi, 2020) and biodiversity (Woodland-Trust, 2020). Meanwhile, (Fahmy, Sharples and Eltrapolsi, 2009) showed the role of trees in decreasing wind speed and inducing high relative humidity to the environment in addition to their impact on indoor building environment. However, there is no research about the benefit of trees within future climatic scenarios within urban areas in the UK, except for that of (Virk *et al.*, 2014, 2015) who looked at the benefits of trees and cool roofs on future climate and their influence on building energy performance by 2050.

3.3.1.2 Green Roofs (GR)

Green roofs are formed when a planting scheme is formatted on a roof structure. Green roofs can be considered as recreational spaces to be enjoyed by people, as aesthetic, sustainable or environmental features to support wildlife or a mixture of both. GR can be classified into three main systems which are intensive, semi-intensive and extensive green roofs (Allnut *et al.*, 2014).

Extensive green roof systems generally provide a visual or biodiversity interest and are considered to afford a less suitable amenity and leisure space as they mainly consist of grasses, sedums and mosses. They are usually lower maintenance due to the shallow substrate depth compared to the other two types. *Semi-intensive* green roofs are an intermediate green roof type between intensive and extensive, which can include physical characteristics of both. Substrate depth ranges between 100mm and 200mm. Regular irrigation and maintenance requirements are reliant on the plant species installed. *Intensive* green roofs are designed to make recreational and amenity spaces open spaces for people to enjoy; thus, they are called green gardens. Most of the time, they are accessible and contain landscapes similar to traditional gardens, including soft landscape such as lawns, trees, shrubs and hardscaped areas. They have a deeper substrate of more than 200mm and need to bear the structural load in mind, with a higher level of maintenance, including regular irrigation.

3.3.1.3 Vertical Urban Greenery systems (VGS)

Vertical Urban Greenery systems are known as vertical gardens or bio-walls. They mainly consist of vertical structures which are fitted vertical expansion whether being attached to the wall or apart from it. The systems are also classified based on complexity level, as they could consist of a simple configuration or a high-tech design (Pérez-Urrestarazu *et al.*, 2015) based on plant type, supporting system and its materials, among other factors. Based on that, there are two different types of VGS – the *living wall* and the *green façade* (K€ohler, 2008; Manso, Castro-Gomes and M. Manso, 2015). They look similar, but their planting systems are different.

The Green Façade (GF)

It is a type of vertical greenery system at which plants climb the building facade either from the soil at the base of the building or from the top through planter boxes. It may take between three and five years for the plant to cover the whole façade and be fully grown over. Some plants, such as the English ivy, might harm the façade due to its strong roots (Othman and Sahidin, 2016). GF has several advantages such as having no materials involved (growing media, support and irrigation), low costs, and low maintenance. Simultaneously, its disadvantages lie in limited plant selection, slow surface coverage, and scattered growth along the surface (Manso, Castro-Gomes and M. Manso, 2015). Green façade is divided into direct and indirect " double skin " green façade (A.M. Hunter, N.S.G. Williams, J.P. Rayner, L. Aye, D. Hes, S.J. Livesley, 2014; T. Safikhani, A.M. Abdullah, D.R. Ossen, M. Baharvand, 2014; E. Cuce, 2016)(K. Perini, 2013).

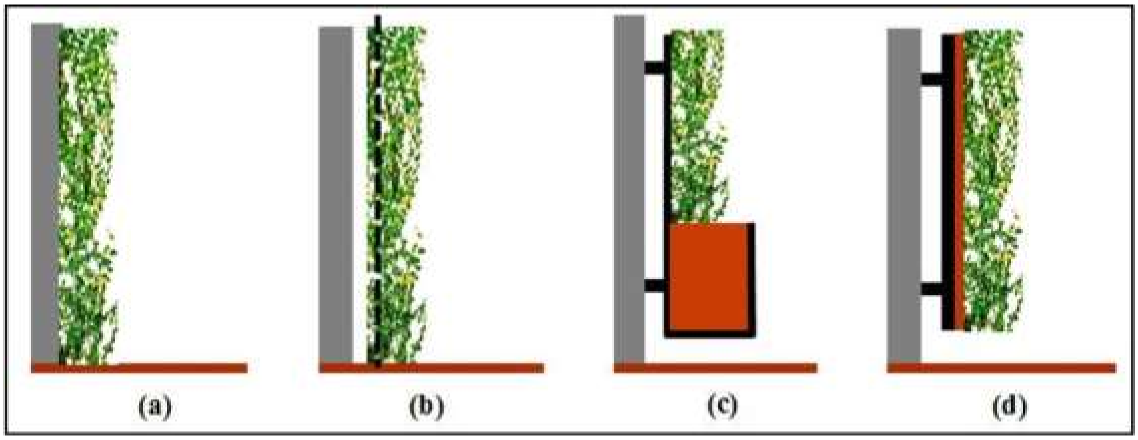


Figure 3-7 a) Direct green facade on the wall, b) Indirect green façade , c) planter box Indirect to the wall, d) Green living wall (Shamsuddeen Abdullahi and Alibaba, 2016).

In Figure 3-7, shows a direct green façade as a traditional green façade at which climbing plants stick to the building façade through their adhesive roots, without the need for structural support (S. Isnard, W.K. Silk, 2009; A.M. Hunter, N.S.G. Williams, J.P.

Rayner, L. Aye, D. Hes, S.J. Livesley, 2014). On the other hand, indirect green façade is a double skin green façade at which structural systems such as modular trellises, stainless steel mesh or stainless steel cable are used to support vertical climbing plants through the second layer of façade at the desired distance from façade (Pérez *et al.*, 2011, 2014; Manso, Castro-Gomes and M. Manso, 2015; E. Cuce, 2016)).

Living Wall System (LWS)

The second type of VGS is the LWS, which comprises a mix of different plants generally used for green walls. Unique vertical planting medium allows ground-cover plants to be planted vertically whether in a modular or a continuous system, which is made of one continuous piece of felt-layer or a single continuous concrete block (Dover, 2015; Charoenkit and Yiemwattana, 2016). The structure is metal, plastic, or other materials which are connected vertically by a structural frame. More maintenance and care is needed due to its structural load, as well as fertilising, trimming, and removing and replacing dead plants (Othman and Sahidin, 2016).

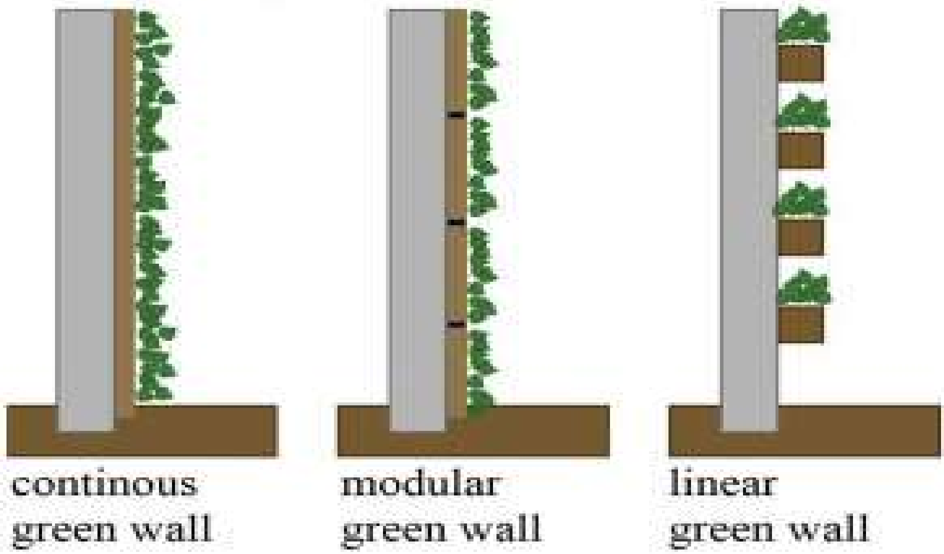


Figure 3-8 a) Panel continuous system (Left), b) Felt modular system (Middle), c) Container/ Trellis linear system (Right)(SAA, 2014)

LWSs have several advantages such as the benefit of consistent growth, and a wide plant variety can be used. The LWS is easily maintained due to its modular units which could be easily replaced, besides its higher aesthetic value. At the same time, its disadvantage lays in its frequent maintenance, complex system, high water and nutrients consumption, high environmental burden and its heavy weight (Manso, Castro-Gomes and M. Manso, 2015). There are three systems of living walls which differ according to its function, design and construction system and materials and whether it is being used within the interior or exterior spaces (Loh, 2008).

In Figure 3-8 show three different types of living façade. The first type is the Trellis/Container system, in which containers are used to grow plants and climb onto trellises irrigation is done by controlled driplines. The second type is the Felt system, made of felt pockets of growing medium attached to a waterproof packing where plants are grown, which is then connected to a structure behind. The felt is kept moist with water which contains plant nutrients. The third system is the *Panel* system which usually consists of pre-planted panels and is connected to a structural system with a mechanical irrigating system.

3.4 Benefits of UGS in temperate climates

VGS potentials have a positive impact on buildings through several aspects, socially, economically and environmentally, as described below:

3.4.1 Environmental Benefits

Two main factors are considered in this paper as the key parameters for determining the impact of UGS as a passive technique for increasing pedestrians' thermal comfort; carbon emissions reductions and urban heat island effect. There have been several approaches and studies on the advantages and disadvantages of UGS on energy performance in temperate climates. These aspects have been studied through synthesising and analysing outcomes of critical studies. The main aspects of focus are the orientation of the UGS, climate and sub-climate classification, the season of growth, duration of the study, and finally whether empirical data analysis or modelling and simulation was used.

UGS has gained increasing support politically, and recognition as an adaptation and mitigation option; however, its integration into urban planning policies and plans remains insufficient. There is also little comparative information available to support planners and decision-makers in deciding what type and quantity of UGS would be most effective in a particular urban location (Zölch *et al.*, 2016).

3.4.2 Urban Heat Island Mitigation

Climate change may increase the number of heat-related deaths in the European countries rising from 152,000 to 239,758 a year by 2080, leading to a 50 times rise in deaths, while in the UK it is predicted that there will be a 540% increase by 2080 as nearly 11,000 persons could die every year as a result of heatwaves. On the other hand, a 118% spread of urban areas in the UK is predicted and a 148% increase in people living in areas prone to flooding (Martin Bagot, 2017). Forzieri (2017) declared that continuous urbanisation would amplify the urban heat island effect in that built-up area in which heat is trapped and absorbed inside canyons. South-East of UK temperatures in summer are expected to go up to 3.5°C, five °C warmer by the 2050s and the 2080s, respectively. In addition, the Urban Heat Island (UHI) will add 5-6°C to summer nighttime temperatures (Hulme *et al.,* 2002) and London centre will face up to 9°C in temperature higher than the surrounding greenbelt with expectations that these effects will increase in frequency (GLA, 2006).

Jones (2017) examined all European countries' climates and found that green walls have a more profound influence than green roofs. Nevertheless, green roofs have a more significant impact on the roof level and, consequently, at the urban scale. They could mitigate raised urban temperatures through applying that to the whole city scale, which can lead to significant energy savings and additional "human-friendly" urban spaces, thus ensuring a sustainable future, from a thermal perspective, for urban inhabitants (Alexandri, 2017). (Fahmy *et al.*, 2018) illustrated that tree lines and green roofs are defined within Leadership in Energy and Environmental Design for Neighbourhood (LEED-ND) guidelines as UHI mitigation strategies improve the microclimatic performance of the site through reducing both air and radiation. This was confirmed earlier by (Fahmy and Sharples, 2009b) that urban forms can keep urban diversity as a sustainability measure at local urban planning scale, achieving thermal comfort not only by providing urban diversity but also helping thermal sustainability.

In general, green walls have a more substantial influence within the canyon than green roofs, but they do not affect the air masses' temperature above the canyon. Due to UGS plants' evapotranspiration, the Institute of Physics in Berlin illustrated that a mean cooling value of 157kWh/day could be achieved based on a 56 planter boxes study on four floors of their building (Schmidt, Reichmann and Steffan, 2018). A study by (Gill *et* *al.*, 2007) for green infrastructure potential in cities climate change adaption by 2080 found that maximum surface temperature is reduced by 2.5°C through increasing 10% of green cover, while removing the same percentage would lead to 7°C increase in surface temperature (Steven W. Peck, 2009). The frequency of heatwave events would also probably rise across Europe and the UK (Robertson, 2016).

(Alexandri, Jones and Doussis, 2005), showed that green walls have a higher impact than green roofs within the canyon, while green roofs have a more extensive influence at the roof level and urban scale. A combination of green roofs and green walls leads to the highest mitigations of urban temperatures, even for cold climates such as London and Moscow which realised the least benefits in temperature reduction 1.7-2.1°C and maximum from 2.6-3.2°C for the green-walls, while it ranged between 3.0 - 3.8°C and maximum from 3.6-4.5 °C for all green cases.

3.4.3 Current trends in urban heat island mitigation and the tendency of using Green Roofs and Green Walls on an urban scale

UHI effect mitigation scientific research has been rising and expanding, alerting scientists, governments and planning authorities to the influence of the UHI effect or UHI summer intensities. A study was carried out by (Aleksandrowicz *et al.*, 2017) between 2009 and 2013. They analysed 411 papers and identified 11 recognised separate mitigation measures, which are studied nowadays. It was found that there is an increase in research on a small set of mitigation measures (green roofs, ground vegetation, shade trees, and cool building envelopes).

Most of the research regions have been within the subtropical climate, wide well-developed urban regions in East Asia, North America, and the Mediterranean part of European countries. Most of these studies have compared and analysed single mitigation measures instead of several mitigation measures, which become less helpful and not beneficial to policymakers, who have to make decisions regarding the UHI effect challenges (Aleksandrowicz *et al.*, 2017).

3.4.4 Urban green systems and physiological benefits

Climate is the main factor that eases the use of public spaces. Cities shape the microclimate and microclimate shapes how individuals interact within the city, where walkability, comfort and health are the most important indicators of how residents will interact and use public spaces (ClimateFlux, 2020).

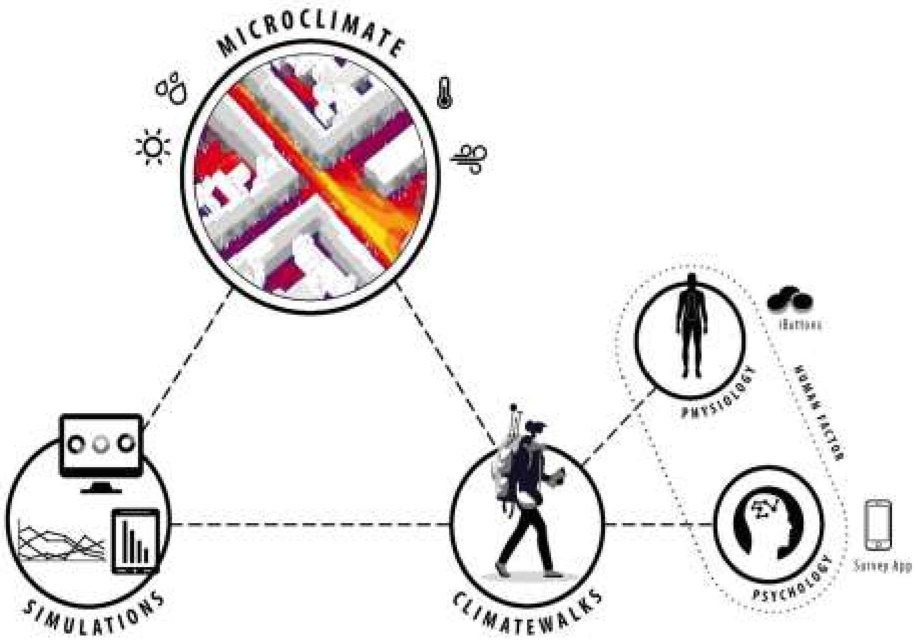


Figure 3-9 A representation of relation between human, environment, psychology, microclimate and simulations through city street software by (Santucci and Chokhachian, 2019)

A well-designed city street is supposed to have an exciting view and a new object about once every five seconds for the pedestrian who walks at an average speed of 5km per hour. Pedestrians seek inspiration, novelty and stimulation from their spaces in the same way as they do security and comfort. Thus, it was proposed that technological innovations solve this challenge, through using smartphones to warn people to avoid these stressful or boring areas of town that cause stress-related issues (Colin Ellard, 2015; Ellard, 2015). (Valtchanov, Barton and Ellard, 2010) suggested that utilising virtual nature settings has similar beneficial and valuable effects as being exposed to nature. These outcomes also propose that VR can be used as a tool to explore, investigate and understand the restorative effects of UGS.

City residents' attachment to the city is significantly correlated to the aesthetic attraction of their cities based on a Gallup survey (2018) at which their city aesthetic attraction came in third place after the city social offering (kind of activities to do there) and openness (perception of openness to different types of resident) as an indicator of city attachment. It also shows that it comes above basic services, safety and even education. The aesthetical perception was also linked to community satisfaction and ranked more important than individual demographic characteristics (Create-Streets, 2018), in addition to a study which links the street trees with a reduction in speed and crashes (Create-Streets, 2018).

Travelling and walking trips within England (NTS, 2017; Sustrans, 2018)

It was found that 62% of the public journeys were completed by personal vehicles like car, either as driver or passenger, followed by 25% of journeys covered by foot, then by bus with 5%, 3% by train, 2% by cycling and 2% by other. Furthermore, 68% of journeys were less than five miles, and 23% of journeys were less than one mile. This differs based on the travelling mode, where almost all walks are below five miles, compared to 56% of car driver trips and 9% of surface rail trips.

Walking and cycling, which are active modes of travel, represent 27% of all journeys, and 4% of all distance travelled, as active trips lean towards to be quicker distance trips. Between 2002 and 2016, the number of the walking trips declined by 17% and distance travelled by 19%, while for cycling, distance covered improved by 37%, although trip numbers by cycling declined by 19%.

Reasons to travel in England have been mainly for shopping, personal business and other escort and other leisure reasons with 19%,18% and 17%. In contrast, commuting and visiting friends had the same percentage of 15%, followed by education and escorting to education with 12% and business with 3%. On the other hand, this distance travelled in England were mainly dominated by being less than 5 miles at which 68% of journeys were below 5 miles, while 23% of journeys were underneath 1 mile. Each person walks 198 miles/year on average, representing 16 minutes walking/trip.

3.5 Pedestrian Thermal comfort (PTC)

Thermal comfort significantly affects the mode in which individuals respond to their surrounding environment based on a thermal basis. This environment's design shapes and influences the microclimate, which people’s behaviours are being controlled within. The relationship between people and the built environment can be explained through investigating outdoor thermal comfort levels and broad terms. Human thermal comfort is one of the most affected environmental qualities within urban scales outdoors, which is influenced by environmental factors (air temperature, mean radiant temperature, air humidity and wind speed) and personal variables (clothes, type of activity). In comparison, other personal factors for acclimatisation adjustment and adaptation are demonstrated to affect thermal sensation (Monam and Rückert, 2013).

PTC has several definitions: "it is the state of mind that expresses satisfaction within the thermal environment" based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), while it is considered as a psychological approach to investigate thermal comfort based on Hoppe (1993). Brager and de Dear (2001) identified PTC based on preference and the expectation of human psychological parameters regarding their surroundings. The wide diversity, broad definitions, and understandings of what satisfies humans make the PTC term subjective and based on people's behavioural, responsive actions based on the location they are in. This definition or thermal satisfaction could be different from people of the same area, location and climate (Al-Sabbgh, 2019).

The broad thermal comfort definitions have led to the use of models that mimic the physiological conditions and physical environment to predict comfort levels, quantitatively, creating a number of thermal indices. These models are known as balanced heat models which rationally analyse the heat flow between the built environment and the human body based on physics and physiology. Thermal stress and thermal comfort have several bio-meteorological indices as indicators as the physiologically equivalent temperature (PET) which is expressed in °C based on combining the heat balance model and two-node model which are used for effective standard temperature (SET) and effective temperature (ET) (Monam and Rückert, 2013). It is equivalent to air temperature within a typical indoor setting, which the balance of a human body is maintained with core and skin temperatures equal to those under the conditions being assessed (Monam and Rückert, 2013).

It is also vital to distinguish between pedestrians' comfort in a certain space and at a specific moment and their general comfort satisfaction in each journey. For example, pedestrians satisfied with their general journey could still describe themselves as 'very uncomfortable' if interviewed in a warm environment. It has also been noticed that although most investigated research studies focus on pedestrians' thermal comfort, they focus either on certain space or on the relationship between two sequential spaces (Al-Sabbgh, 2019). Therefore, a survey was conducted in the current study to identify the difference between UGS influential factors on people's decision to walk, their preference of UGS, and reasons for choosing one of them within central London.

3.5.1 Thermal comfort and its indices

Thermal comfort has over 100 indices established in hot and cold conditions (Crawford *et al.,* 2015). In order to achieve thermal comfort, the mind should express satisfaction with the thermal environment which is considered as a subjective criterion, while based on ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers), the thermal comfort is a zone at which 80% of humans find the environment thermally acceptable within stand-still or slightly active conditions (Epstein and Moran, 2006). Thermal comfort indices are divided into either empirical, rational or direct guides. The rational and empirical groups are sophisticated indices that require many physiological and environmental factors to measure them, while the direct indices are based on measuring the basic environmental variables.

There are interactions of six essential factors to define the feeling of thermal comfort for the human thermal environment based on Fanger. These parameters are divided into environmental factors and human behavioural factors. Environmental factors consist of ambient and radiant temperatures, humidity, and wind speed; while the behavioural variables consist of the metabolic rate and clothing (insulation and moisture permeability characteristics). These factors influence the human response to the thermal environment. Therefore, any thermal stress consideration should investigate these six factors (Epstein and Moran, 2006).

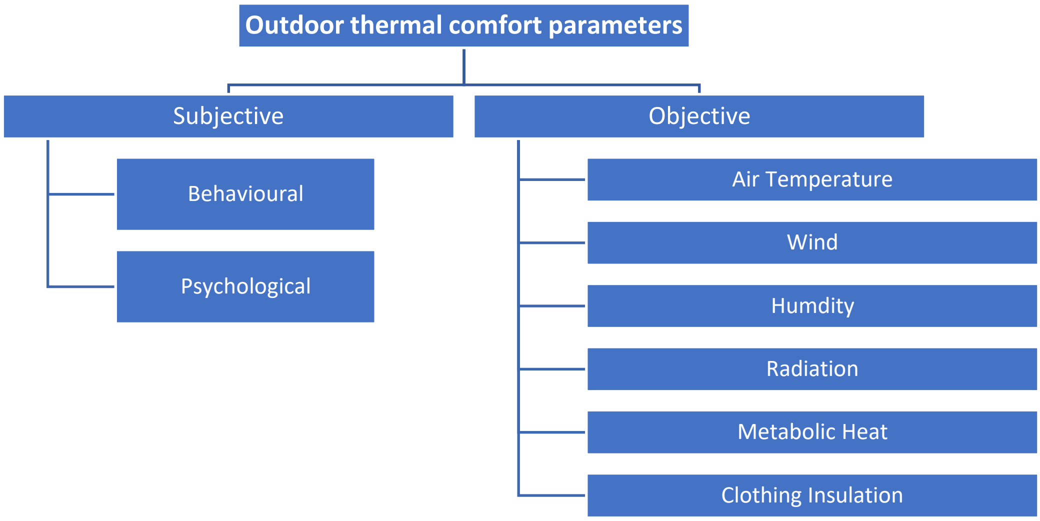


Figure 3-10 Outdoor thermal comfort parameters (Lee et al., 2017)

The rationales for thermal comfort indices are based on energy balance and heat transfer of a typical human body linked to spatial conditions. Many of these indices have been created for indoor environments where it is possible to keep constant conditions, while the empirical studies of personal experience of thermal comfort are linked to meteorological phenomena. Many cases of both of these types are grounded on steady-state models which expect that users are within a thermal equilibrium inside an ambient climatic environment (Crawford *et al.*, 2015). These factors might be independent of each other, but nevertheless they collectively contribute to a human's thermal comfort (HSE, 2020) (Zare *et al.*, 2018). Thermal comfort results from the energy balance equation, as the physiological equivalent temperature (PET), Universal Thermal Comfort Index (UTCI), the standard effective temperature (SET) and the predicted mean vote (PMV) are of specific importance and presented with their thermal perception in Figure 3-10 (Besir and Cuce, 2018).

Predicted Mean Vote (PMV)

It is one of the most used thermal indices which calculates the average thermal response of people. To calculate the PMV, a combination of air temperature and radiant temperature, relative humidity, airspeed, metabolic rate, and clothing insulation are taken into consideration. PMV was developed mainly for indoor environments with the aim to indicate thermal comfort or discomfort at various states of clothing or activity; then it was developed to include outdoor environments as well. It is ranked on a scale of 7, with -3 being cold to +3 being hot.

Thermal perception	Indices				
	UTCI	WBGT	SET	PMV	PET
Very cold[1] (Extreme cold stress[1,2])	< -40			-3	<4
(very strong cold stress[2])	-40 to -27				
Cold[1] (Strong cold stress[1,2])	-27 to -13			-2.5	4-8
Cool[1,3] (Moderate cold stress[1,2]/ Moderate Hazard[3])	-13 to 0		<17	-1.5	8-13
Slightly cool[1] (Slight cold stress[1,2])	0 to +9			-0.5	13-18
Comfortable[1,3] (No thermal stress[1,2]/ No Danger[3,4])	+9 to +26	<18	17-30	0	18-23
Slightly warm[1] (Slight heat stress[1])				0.5	23-29
Warm[1,3,4] (Moderate heat stress[1,2]/ Caution[3,4])	+26 to +32	18-23	30-34	1.5	29-35
Hot[1,3,4] (Strong heat stress[1,2]/ Extreme caution[3,4])	+32 to +38	23-28	34-37	2.5	35-41
(very strong heat stress[2])	+38 to +46				
Very hot[1,3,4] (Extreme heat stress[1,2]/ Danger[3,4])	> +46	28-30	>37	3	>41
Sweltering[4] (extreme danger[4])		≥30			

[1] PET and PMV [2] UTCI [3] SET [4] WBGT

Figure 3-11 Thermal comfort indices (UTCI, WBGT, SET, PMV, PET) and their thermal perception (Zare *et al.,* 2018).

It is more accurate within indoor environments than outdoor environments; however, it is an easier way for the public to indicate their thermal comfort along the indicated scale and it is easy for non-scientific people to understand the thermal state of the person and what they feel (Honjo, 2009; Walls, Parker and Walliss, 2015). The clothing temperature is the only parameter of the PMV model that responds to the environmental conditions, while the skin temperature depends on the activity of the person only (Michael Bruse, 2014; BioMet, 2020)

Predicted Percentage of Dissatisfied (PPD)

Fanger has also established an equation that related the PMV to predict the proportion of populations who could be dissatisfied with the thermal environment through a relationship based on several studies that surveyed subjects in a controlled room where the indoor conditions will be controlled precisely. However, although the PMV/PPD model is applied worldwide, it does not take adaptation mechanisms and outdoor thermal conditions into account. Both of the PMV/PPD models have a low prediction accuracy, at which PMV has an accuracy of 34% (almost one-third of the measured times is accurate), while for PPD it was overestimating the thermal unacceptability (Zare *et al.*, 2018; Al-Sabbgh, 2019; Cheung *et al.*, 2019). PMV and PPD have a linear relationship (BioMet, 2020).

Physiologically Equivalent Temperature (PET)

This is a thermal comfort index which is grounded on a predictive model of human energy balance that calculates skin temperature, the sweat rate, the body core temperature, and, as an auxiliary variable, the clothing temperature (BioMet, 2020). PET was developed specifically for outdoor environments as an index that considers all basic thermal processes based on the thermo-physiological heat balance model. PET is one of the suggested indices in new German guidelines and is used to predict changes in the thermal component of urban or regional climates for urban and regional planners (Honjo, 2009).

Universal thermal climate index (UTCI)

UTCI is classified based on different values and degree of heat stress with different classifications which are defined according to the physiological answers based on reactions from the environmental conditions to the human sensation, where these responses indicate the magnitude of the heat stress load (Ghalhari *et al.*, 2019). It is the air temperature in the reference condition (50% humidity, still air and full shade) which causes the same physiological reactions as the real detected conditions —the range and classification of UTCI as given in Figure 3-12.

Above 46°C	38°C to 46°C	32°C to 38°C	26°C to 32°C	9°C to 26°C	9°C to 0°C	0°C to -13°C	-31°C to -27°C	-27°C to -40°C	Below -40°C
Extreme Heat Stress	Very Strong Heat Stress	Strong Heat Stress	Moderate Heat Stress	No Thermal Stress	Slight Cold Stress	Moderate Cold Stress	Strong Cold Stress	Very Strong Cold Stress	Extreme Cold Stress

Figure 3-12 Range of UTCI thermal comfort classifications (Zare et al., 2018)

The main aim was to create an index that could be accurate for all climates, seasons and scales, which would be independent of personal features as (gender, age, activities and clothing (Walls, Parker and Walliss, 2015). The mean radiant temperature is used for the calculation to indicate solar radiation's thermal effect and temperature on individuals from a surrounding area and materials (Ghalhari *et al.,* 2019). UTCI calculation within ENVI-met has limited wind speed at 10-meter height, while the biometeorological parameters are usually investigated around 1.5 and 2 metres (BioMet, 2020).

Standard Effective Temperature (SET)

This is developed for indoor environments as it calculates the dry-bulb temperature which relates the (effective) temperature to the real conditions of an environment in order to assume the metabolic rate, standard clothing, and 50% relative humidity. SET uses skin wetness and skin temperature as the limiting factors (Walls, Parker and Walliss, 2015).

The Major Limitations for Implementing UGS in a temperate climate (GRHC, 2009; Amy Storey, 2015; Mayrand and Clergeau, 2018)

UGS is similar to gardens; thus maintenance is required regularly for different systems' parts such as weeding, irrigation and other gardening activities as fertilising, depending on plant type and season besides installation costs (RA Francis and Lorimer, 2011). Recent technologies showed that urban green systems achieved 28% cost reduction due to industry innovations in 2017 (Martin and Knoops, 2014), on top of an affordable cost study which was carried out by (Oluwafeyikemi and Julie, 2015), who afforded VGS for a low-income neighbourhood in Nigeria living on less than £1.00 a day from recycled materials.

The structure could be a barrier especially designed for retrofitted buildings due to its load impact; therefore, the vegetation weight should be considered while calculating structural load, although this could be addressed through using lightweight recycled plastics and media with decrease total weight considerably. Patric Blanc also designed much lightweight VGS at less than six lbs./ft2. Survivability of different vegetating species is a concern as not all plants can be guaranteed to grow and flourish, based on the climate. Therefore, it is advised to prioritise the survivability over the plants' beauty.

VGS and GR can protect buildings from fire if they followed the main general guidelines in addition to being well irrigated and maintained. While if not, only 10% of its material is flammable. UGS policies might be more problematic for smaller communities, due to the lack of applying UGS in the construction sector. However, larger cities started to implement programs and incentives to encourage green infrastructures.

UGS enhances wildlife habitat for birds and insects, which might not be wanted by building occupants, who might ask for more protection.

The main messages that evolved from the urban climate modelling component of LUCID are to be applied within Policy and Practice (ARCC, 2018) as the significance of urban temperatures in urban land-use scattering. London's scattered green spaces cool it down. The bigger the greenery areas are the more influence they have over UHI; thus, to influence the UHI on a city scale, a higher percentage is required. Urban temperature is moderately influenced by building shapes. Anthropogenic heating is likely to be important. The increase of albedo could increase daytime cooling energy. London could benefit with its energy from UHI savings. The UHI is not as important as the building's thermal quality since building geometry has greater importance than the building located in the UHI. The current typical buildings are exposed and have weak heat resistance. The distance from the centre is linked and related to overheating. UHI has a significant influence on death and mortality rate.

3.6 Conclusion

This chapter provides detailed definitions for urban green systems whether they are classified as green infrastructure, green systems or green corridors, among others, and how these systems has been implemented within urban cities across history by urban designers and city planners. These different urban green systems approaches could be implemented through using trees, green walls, green roofs and cool pavements depending on the site constraints and expected mitigation level and demanded benefits. Due to the multifunctionality of urban green systems, research to date has mainly investigated the environmental and physiological benefits and its limitations within the urban environment through focusing on thermal comfort levels and carbon sequestration within the urban environment through measuring thermal comfort levels which could be physiological equivalent temperature, predicted mean vote, predicated percentage of discomfort, universal thermal climate index or standard effective temperature.

Shaping the built environment to produce more favourable connected outdoor spaces requires a deep understanding of the microclimatic conditions, risks associated, and outdoor environment spatial characteristics in a real urban setting. The design of a thermal comfort street to motivate people to walk more through UGS is a key challenge in urban environments' bioclimatic design methodology. It is the interaction of architectural and urban and climatic factors since it is based on the environment formatted between buildings and the open urban space. Efficient urban designs should provide PTC to enhance their activities outdoors within thermally stressed seasons.

This chapter has summarised on how ground UGS can be adjusted and combined in enhancing the CO_2 sequestration and optimum cooling effects. These combination adjustments required to be evaluated and quantified further in order to confirm the influence on the urban street canyons within central London. Moreover, the actual bioclimatic impact and microclimate enhancement needs to be fully adjusted to recognise the importance of different UGS on mitigating the UHI effect and CO_2 sequestration. Therefore, to assess the overall effect, additional research methods have been constructed based on previous research and this literature review which will be investigated in Chapter four.

4 Chapter Four: Methodology

4.1 Introduction

This chapter focuses on the methodology used to conduct the study. The experiments, simulations and questionnaire survey, which are carried out in this research, investigate and examine the quantification and optimisation of applying urban green systems (cool pavements, trees, green walls) in an urban environment. The research and simulation are mainly planned to contribute towards understanding and quantification of vegetation influence and urban forestry on UHI effect reduction and improving thermal comfort level for pedestrians.

The research work addresses the most adequate and optimised application for applying vegetation (urban green system) in terms of their percentage to the whole urban area, configuration, location, type, way of application and their relationship between these variables to canyon geometry in terms of design guidelines. The findings are proposed as guidelines for different UHI mitigation strategies in parallel with enhanced micro-scale pedestrian comfort levels and anthropogenic sources in the temperate context of London, the UK.

Consequently, an online survey took place in order to determine the human factor on the proposed alternatives from the computer simulation. This chapter explored how the survey sample was selected and its size. A quantitative statistical analysis was established in order to identify more profound findings through a correlation between questions, cross-tabulation and frequency tables.

4.2 Research design

The hottest months' climatic situations during the warm summer season (21 June – 21 September) are examined as well as the warm season impact for each year 2018, the 2050s and the 2080s, taking into consideration that 2020 is relatively the same as 2018 which is practically measured on site. Thus, there would be no need to make a similar simulation run for 2020 as it would be more or less the same. [Based on climatic data files, it provides similar measured/predicted weather data.] For all cases studied, a base case, where no vegetation exists in the urban canyon is first measured. The greening systems, through the cold pavement, VGS, and trees, whether s applied to walls, roofs or streets, are compared with this base case "without UGS alternative", so as to validate how vegetation influences the urban geometry and climate. The explanation of temperature and humidity distributions in the air and the fabric are quite detailed; the effect is not only studied near the vegetated surface but also at different heights and times of the day across and above the canyon.

This study's main drive is to respond to the question: "To what extent can UGS be a key to the mitigation of the heat island effect for future climates and urban geometries by 2020, 2050 and 2080, and what is the best percentage of vegetation?". With the increasing urban population around the world, this hypothesis aims to contribute to solutions to sustainable living conditions in cities, with reduced illness and death risks in general, and to reduced UHI effect, pedestrian thermal stress and CO_2 specifically. This is because, through the restoration of nature in the city, especially on the human habitats themselves, buildings can have not only thermal benefits, but also economic, social, and environmental benefits. Thus, this work focuses on the first aspect, the thermal benefits of UGS in urban spaces and CO_2 sequestration.

From the extensive literature review carried out in Chapter 2, a matrix is generated based on the research papers and information about green walls and green roofs in each climate (equatorial, arid, temperate, continental, or snow and polar climates) which was classified based on Koppen's classification (Parker and de Baro, 2019). The main focus during this research phase was to investigate the past and ongoing research within the field of temperate climate whether it is mid or oceanic and the influence of green systems on its UHI, building energy performance, air quality, noise reduction, biodiversity, carbon sequestration, hydrological benefits, economic benefits and planning and infrastructure.

Research is ongoing on VGS in different climates based on Koppen's classification. Based on the work of (Taher, Elsharkawy and Newport, 2018), it was clear that UHI and biodiversity are thought-provoking topics of investigation for the researcher, while air quality, carbon sequestration and hydrological benefits are recommended by researchers for further investigation. There was very limited research on the economic and energy performance benefits for green walls and living façade. Based on these facts and the interest in vertical green systems, the researcher started to link VGS benefits to UHI and air quality (carbon sequestration). This was later analysed further for application to an urban scale, which is quite complicated, so the researcher excluded building energy performance and air pollution and included other urban green systems (cool pavements, trees) which will have an influence on surface urban heat island effect and carbon sequestration.

4.2.1 Research framework

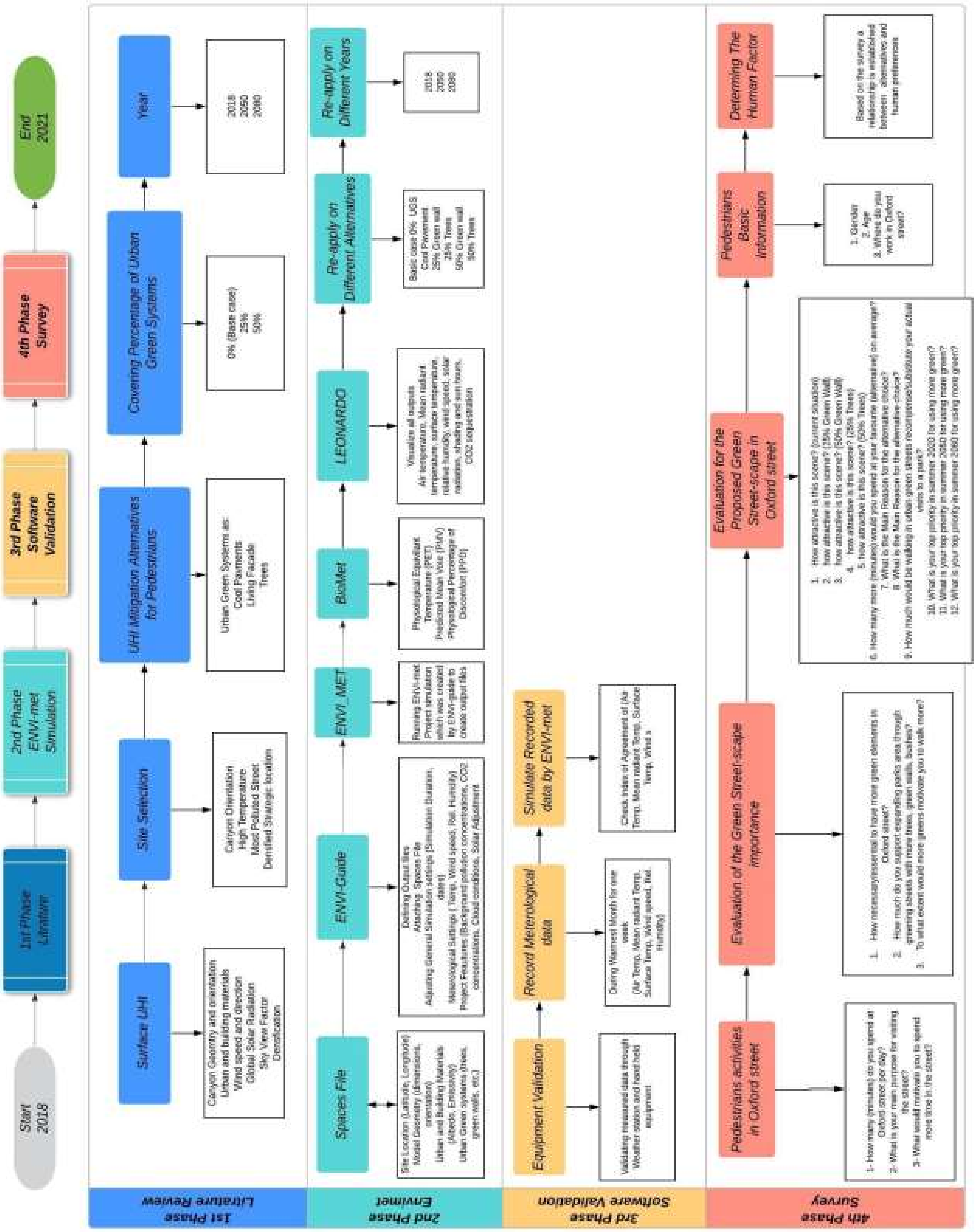


Figure 4-1 Research Framework

In Figure 4-1, the research methodology framework is designed to collect data systematically, using different methods from literature using field measurements and computer simulation software. A precise summary was illustrated in a complex framework, including all research methods and a procedure which is employed in order to achieve the research goals and objectives. The research methodology is defined in four phases in order to reach the ultimate research goal.

The first research phase included data collection gathering of information about UHI reasons and factors. Then the study area was specified based on literature, drawing from meteorological data, satellite images, observations, different data and information about the site and buildings and urban details. This information established a general idea of the site, which is considered as a base case. Next the site was into three major groups (urban properties as hard surfaces and soil, building geometry and fabrics and green systems as trees) which were similar to the software site requirements within Spaces File and meteorological data. These data were arranged and organised o be used later within software simulation and measurements on-site in phase two.

The second phase mainly focused on computer simulation using ENVI-met software. The urban neighbourhood of the study base case (central London) was divided into two streets, North-South and East-West orientations based on the previous phase of data. Meteorological data were collected on-site and from the Meteorological Office (MET) weather station near the site in order to validate measurements on-site. These meteorological inputs with site details and information from the first phase were used as inputs for the ENVI-met simulation. Software adjustment started by adjusting Spaces File, which includes urban and building geometry, urban green systems alternatives, site location and orientation. Then is used to include spaces file in addition to adjusting meteorological data followed by specifying the output locations for simulation results and Subsequently, running the simulation using ENVI-met button.

After finishing the running time and extracting the results BioMet Button was used to extract physiological equivalent temperature (PET), predicted mean vote (PMV), and physiological percentage of discomfort (PPD) in order to determine the pedestrian thermal comfort. Finally, the Leonardo button was used to visualise all results in graphical illustration maps later used to determine PET, PMV, PPD, wind speed, relative humidity, air, surface and mean radiant temperatures. Running ENVI-met simulation for the current climatic scenarios for the existing current vegetation case took place in order to predict the pedestrian thermal comfort within the street and validate the software. Subsequently, another two climatic scenarios (the 2050s and the 2080s) were used with different urban green systems' (UGS) percentages (25% and 50%) for different types (trees, green walls) in addition to pavement albedo and the base case which has no green at all to include all of these simulation results in phase three. Phase three involved validation of the field measurements using ENVI-met software in addition to simulation outputs for all proposed years with different climatic scenarios which are mainly based on changing vegetation type and percentage, and pavement albedo. The outputs and simulation results were compared based on their thermal comfort improvement for pedestrian with CO_2 sequestration analysis.

Phase four focused on collecting survey results that were obtained online from diverse users within the site location to indicate to which level they are comfortable with the proposed UGS alternatives. The survey results were collected in order to be used to determine pedestrians' and frequent visitors' preference for different UGS alternatives within central London. The Survey was analysed via frequency tables to illustrate the distribution of responses and their percentages across different choices. Following this step, a cross-tabulation was applied between different questions so as to relate responses and to identify further findings, and to see the relation between participants' responses to different UGS. Moreover, Pearson correlation heatmap was included to identify how strongly or weakly questions are correlated.

Based on the four phases, all outcomes and discussions were collated and summarised as guidelines for UHI adaptation effect within Oxford Street, London by drawing on findings obtained in each research phase and presented in the research framework.

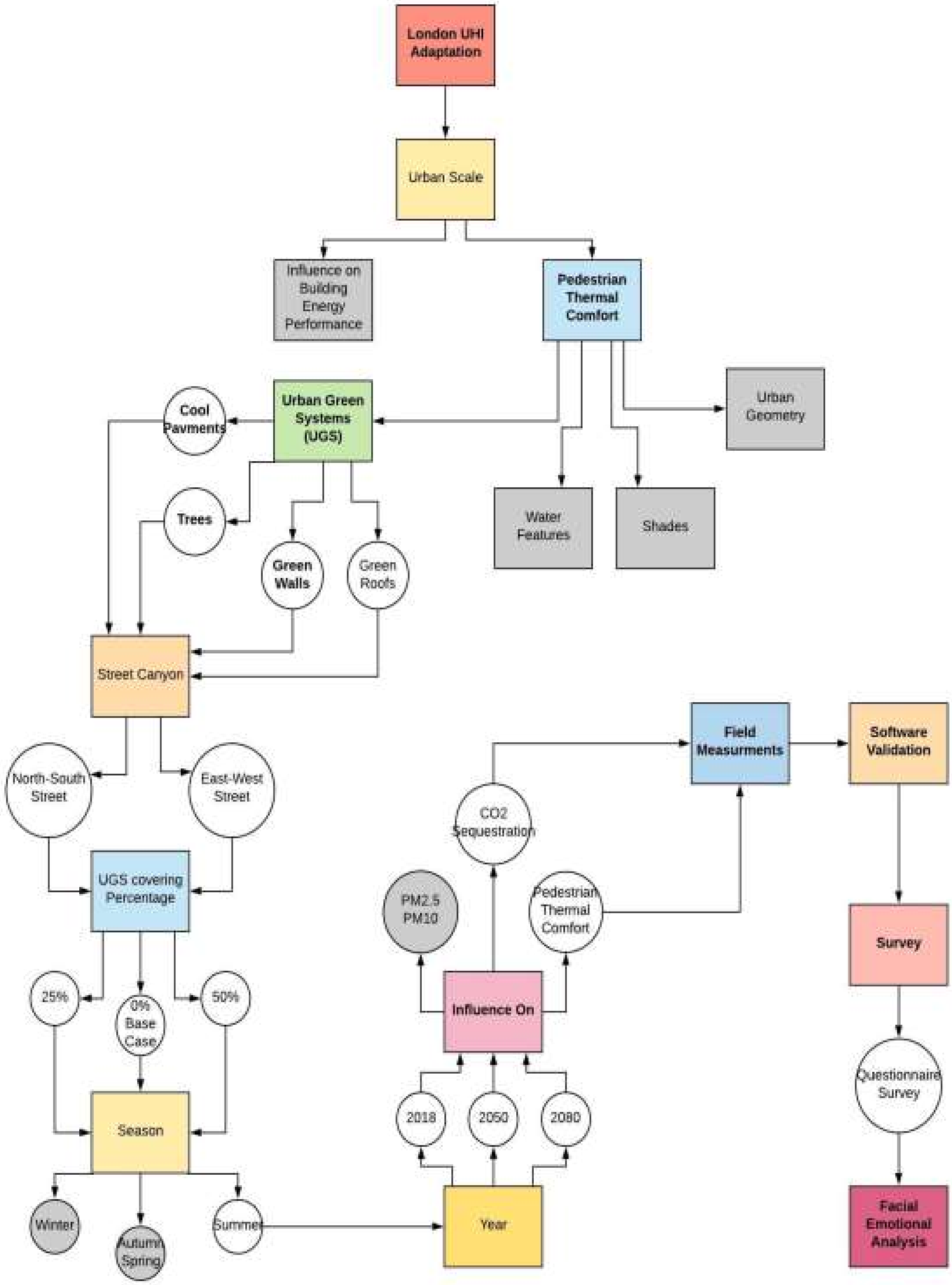


Figure 4-2 Research process and progress through starting research focus area until the final research area (Disregarded research aspects illustrated in grey and the rest of colours are for clarification)

Figure 4-2 illustrates the research development process from the start of the research by investigating the literature review in order to reach research novelty and to fill the identified gap in knowledge. This was approached through investigating previous research points and gaps within vertical green systems (VGS) and green roofs (GR) and their influence on building energy performance, which led to the finding that they are not beneficial within the current temperate climate. Subsequently, the research investigated the influence of future climate and its benefits by the 2050s, but similar research has already investigated it (Virk et al., 2014, 2015). Thus, after checking their benefits within the urban scale (Alexandri, 2004; Alexandri and Jones, 2008) investigated it; however, they did not cover all benefits within canyons particularly for pedestrian thermal comfort levels and in future climate in general. To the best of the author’s knowledge, none of the researchers investigated this. Moreover, the Mayor of London (Sadiq Khan) had a strategic plan to make London the greenest city in the world within the urban scale by the 2050s (Taher, Elsharkawy and Newport, 2019).

Thus, linking urban green systems, pedestrians’ thermal comfort and future climates was a research gap. However, after contacting the GLA and attending meetings, it was found that they did not have any prepared strategy on how to apply these UGS, and hence the research focus widened to include other UGS such as trees in addition to VGS and GR. Subsequently, the researcher replaced green roofs with cool pavements as it was proven that GR does not directly impact pedestrians’ thermal comfort and surface urban heat island, while cool pavement might.

Urban geometry and water features were excluded as factors in the research site study as London central buildings are mostly built-up areas, and without any water features or available spaces for water features within the city’s densely built-up areas, so it was not applicable to change the urban geometry or add extra space as water features. In comparison, shading were included within UGS as trees, which represent a green system for urban spaces and provide shade as well. Thus, it was not essential to explain it exclusively as a separate section instead of green trees which will help in achieving the Mayor's strategy plan. After specifying London as a site location to apply UGS, it was classified orientations into North-South and East-West canyons as a grid in order to see the influence on each canyon orientation. Subsequently, a proposed vegetation percentage was applied to the model at 25% and 50%, the Mayor's goal.

These measurements were carried out during the warm summer season as UHI is more vital and will influence more people lives mostly in dense areas within London city centre. This was carried out for 2018 (current year) and the 2050s and the 2080s in order to see the right UGS percentage and alternative within each street orientation within each year. The researcher subsequently has deeply investigated the UGS influence on carbon sequestration beside pedestrian thermal comfort as based on many research papers; usually, researchers focus on one benefit only while it was recommended to focus on two or more benefits and assess their outcomes. Thus, CO_2 sequestration was included as it is always linked to UGS as plants are used as a main alternative. Pollution dispersion was a captivating topic; however, the researcher excluded it as it is a profound science which needs extra investigation and research background before linking it to current investigated factors which will not be foreseeable within the research time.

Later on, field measurements were recorded in order to validate software measurements, followed by a questionnaire survey to specify the human factor and their perceptions of the most preferred UGS alternative to be applied within London canyons. Finally, the researcher had planned to carry out a facial emotional analysis of participants' facial reaction while completing the survey and while checking UGS alternative pictures in order to see how they react to them, but that was eliminated due to COVID-19 restrictions on physical contact during the research.

4.3 Quantitative analysis

The literature review in Chapter 2 and Chapter 3 has explored a range of factors shown to affect the distribution of different urban green systems within central London streets (Oxford Street). This chapter sets out how these factors are investigated in this study. A conceptual framework is developed which proposes relationships between urban green systems (trees, green walls), their densities within urban canyons (25% and 50%) and human factors and human perceptions. These points will be revisited in Chapter 5, considering the research findings. The research context is Oxford Street in central London, the UK. The used methods to meet each objective in the research are briefly outlined, with further detail in Chapters 5 and 6.

Numerous data collection methods have been employed to gather together the puzzle pieces of observations, literature review, and detailed analysis of the most appropriate UGS in Oxford Street, London. Different data collection levels at different periods were adopted in conducting this research. For instance, observation and secondary data analyses were beneficial in illustrating a general understanding of the field area, while primary data analysis of questionnaire responses led to a more in-depth analysis. Thus, the research has used quantitative research methods depending on both primary and secondary data in terms of software simulation and questionnaire survey.

Methodologically, in the research field there are two main sections investigating and assessing comfort conditions in cities: computer-based simulation and the data integrated method. They are supported by cloud computing resources and robust computational systems to run complicated and multi-large-scale models. However, these simulations are getting more common; these simulation tools are not entirely capable of modelling all physiological behaviours within a microclimate. By creating a virtual representation of different urban designs proposed by urban planners, architects can quickly (and relatively cheaply) examine responses, allowing them to choose the best alternative design, instead of settling for more personal opinions.

This research is interested in the individual's subjective experience based on their experience and their perception; thus, a phenomenology analysis is utilised, which is divided into descriptive and interpretative phenomenology. Therefore, in the human science field, it is not grounded on exact prediction in the same profound way as statistical probabilities which could be generalised on behaviour or an in-depth description in a detailed manner for a particular social-cultural context (Yasser Osman Moharam Mahgoub, 2013)

Descriptive phenomenology tries to avoid imposing the researcher's ideas and theories as its objective is to reflect the participants' subjective experiences in their own expressions and terminologies, while interpretative phenomenology wishes to go beyond the texts in order to interpret the experiences, thus rendering them meaningful. Thus, placing participants in a broader social, cultural, theoretical context will better reflect their experience (Harper and Thompson, 2011).

This research utilises photo illustrations as a method that has been used widely within environmental and landscape research in order to determine the human preferences towards landscapes as to what characteristics attract us, preferred planting style, and spatial distribution for greens. Within previous research in this context, a rating scale tends to be used in order for respondents to specify what they consider the most desirable and appealing style or green systems from pictures provided within the research. This photo illustration has proven its effectiveness in enhancing memory retrieval, bridging physical and psychological realities, and deliver concepts to receivers (participants) which were hard to verbalise (Lhomme-duchadeuil, 2018)

By relating simulations and individual and subjective responses to environmental conditions adaptation, these methods help the researcher to relate microclimatic conditions to human thermal behaviour in urban spaces and generate a deeper understanding of their choices and thermal social behaviour during summer and heat stress.

4.4 Methods selected for the current research

A state-of-the-art review on the relationship between carbon dioxide emissions, UHI, urban green systems has discovered that most of the studies are usually carried out during the present time of publishing the research. Consequently, policymakers and other people who are in power had not had much time to apply it in a wide range as it was limited to the current time. In order to apply significant changes, there is a need for more time to be applied and more precautions to be taken. On the other hand, most of the research was carried out regarding UHI was in the link to UGS. Potential approaches for linking and investigating the microclimate impacts on UHI changes include descriptive case studies, mathematical modelling, analytical modelling, empirical modelling, and remote sensing.

Urban designers use meteorological models within a limited way since the model parameters are not influenced by structures as much as they are influenced by the urban canopy (Karatasou, Santamouris and Geros, 2006). Simplification of morphological characteristics and scale issues did not allow the required investigation by planners and urban designers to go into the local scale, which leads finally to scale-down to neighbourhood and block scales. Furthermore, it is focused on the urban morphological characteristic details; for instance, canyon geometry, wind speed, surface energy balance parameters and surface cover.

A number of potential approaches were provided in the previous section, which revealed that modelling and empirical studies are frequently used for research investigation although, while carrying out empirical studies, several impracticalities were involved due to wide variables’ range between canyons and green system type (trees, VGS, pavement albedo). Within the experimental study, selected urban green systems are different in their installation location (pavement, building facades), the type of green itself (deciduous or evergreen), and canyon geometry (width, height, orientation, etc.). Also, the climatic condition which would be used for running simulation was determined (the hottest day in summer, or hottest week or month) for instance.

All these variables lead to more complications for analysis in order to determine which of the urban green systems are influencing the UHI and CO_2 and on which basis. Furthermore, it was hard to go through urban green systems and buildings at the same time as the city parts have different building types, and within the same neighbourhood, buildings are also different. Thus, there is a building diversity which leads to a wide range of their function, material used, size, orientation, and height, among other factors.

Therefore, usually within simulated model software, the proposed simulation environment is similar to the most common environment in reality from climatic conditions of the used UGS. On the other hand, it was harder to specify each urban green system's standard or the basic type (cool pavement, living facade and trees). Hence, the researcher tried to use the most basic common type and specifications. Due to these limitations within empirical data, modelling is considered as a key tool for evaluating and determining the UHI and UGS as a way of mitigating it.

Modelling Software

One of the most significant challenges of the century is urbanisation, with its inextricable links to climate change and the urgent necessity to develop sustainable energy use and natural resources. Thus, the use of urban energy models mainly aim to investigate the issues caused by urbanisation by combining cities' data with new simulation tools. These urban computational tools combine urban data management, urban sensing and data analytics to assess the city-scale environmental system and performance (Hong *et al.*, 2020)

Urban modelling is an interdisciplinary field at which city-related fields meet computer simulation science as climatic data, city planning, transportation, Structure/civil engineering, environmental science, building physics, ecology, supply and demand analysis and sociology in the context of urban spaces (Hong *et al.*, 2020). To design and operate interdisciplinary urban systems would need dynamic software simulation and optimisation for the whole urban/city scale inputs complexity as Building and city fabric/materials, city geometry, weather variability and UHI.

Based on (Deming and Swaffield, 2011), real-world situations could be represented or illustrated by certain or selected features through simulations as they are distinguished from basic static representation and predictive modelling through a series of dynamic relationships. A simulation is used as a method to visualise the urban change by applying urban green systems (cool pavements, green walls and trees) on urban canyons. Exploring, forecasting, testing and learning are used as approaches in this research. In this research, four critical variables, cool pavements, green walls, trees and time are used to study the influence of UGS on Pedestrian thermal comfort and Carbon sequestration in Oxford Street, London, the UK.

This section reviews proposed research software which could be used to run simulations for different study models with different UGS. Currently, ENVI-met is one of the few software packages which is available that can model the microclimate effect of urban green systems and their influence on Pedestrian thermal comfort and Carbon sequestration through measuring thermal stress indicators, such as PET, PMV and PPD, among others, and Carbon dioxide sequestration as Particulates per million (PPM) (Envimet, 2018).

Different software was taken into consideration; for instance, urban energy systems using the City Energy Analyst (CEA) (CEA, 2018b), Simple Urban Neighbourhood Boundary Energy Exchange Model (SUNBEEM) (Allegrini and Carmeliet, 2017), Canyon Air Temperature (CAT) (Erell and Williamson, 2004) and Town Energy Balance for exchange of energy and water between cities, the atmosphere (Pigeon et al., 2014) and the Soil Model for Sub-mesoscales Urbanized Version (SM2U) (Leroyer, 2006). Nevertheless, these models are either single-layer or slab, which does not allow for the canopy modelling, while they do not have adequate detail for distinguishing vegetation variances within the SUNBEEM multi-layer model.

Urban Building Energy Modelling (UBEM), is a rising field in building energy modelling, covering a three-dimensional scale from large city-wide scale to a small neighbourhood scale. UBEM has an impressing potential to support the optimisation of urban buildings on different scales for energy efficiency, sustainability, and resilience within different climatic scenarios in cities (Hong *et al.*, 2020). However, despite its importance, that is not the central core of the research objective, although it is essential to consider it for future research.

The main aim for CEA is to ensure that a wide range of dynamic demand prediction applications are covered through visualising, analysing and optimising energy systems. However, these features are being developed within research projects CEA can generate 3D heat maps and spatial visualisation through utilising ArcGIS 10.4 in order to generate maps automatically representing cold and hot energy consumption areas (CEA, 2018a). Thus, CEA would help with the analysis of the patterns, information of energy consumptions and demand within urban scale rather than determine urban heat island effect and heat exchange within urban scale which is the focus of this research. CEA also does not illustrate the influence of UGS on UHI and carbon dioxide. Urban Modelling Interface (UMI) software is quite similar to CEA since it models the environmental performance of cities and neighbourhoods in terms of embodied operations energy, daylighting potential and walkability, but the former is Rhinoceros-based (UMI, 2018).

Urban Weather Generator (UWG) software evaluates the influence of urban geometry, morphology, energy consumption and surface materials on temperature, which enables urbanists to parametrically test built densities and vegetation for master plans. Urban planners could advocate zoning regulations as "land use, building height, cool roof, policies for traffic intensities energy and thermal implications" from these interventions. The workflow is integrated into Rhinoceros and CAD modelling. It estimates the air temperature and humidity for urban canopy by using weather data from the rural weather station (UWG, 2018). UWG also requires more than 50 parameters based on performed sensitivity analyses in order to reduce the number of user inputs. The main aim was to eliminate meteorological variables from user input, in addition to analysing the planning strategies and critical design on energy use reduction and thermal discomfort (UWG, 2018).

Dragonfly plugin enables modelling the urban heat island as a large-scale climate phenomenon, local climatic factors "topographic variation" and future climate change through using Urban Weather Generator and CitySim as urban thermodynamic engines. It links different datasets like the National Climatic Data Centre's (NCDC) database of publicly available hourly weather data and thermal satellite image datasets – for instance, "LANDSAT" (Dragonfly, 2018). Although it takes vegetation like trees and shrubs into consideration, it makes many simplifications and assumptions, in addition to neglecting the evapotranspiration by plants (Ladybug, 2018).

ENVI-met is the only software which meets the research objective of microclimate modelling. It was developed in Ruhr-University Bochum in Germany by the Climatology Research Group for modelling surface-plant-air interactions in the urban environment (Envimet, 2018). It is specifically intended to investigate the changes to the landscape and the built environment in urban areas. One of the core benefits of ENVI-met software is that it handles multilayer vegetation in detail such as soil moisture, and develops site-specific vegetation profiles and their latent heat. It also uses thermodynamic processes and computational fluid dynamics (CFD). The model software version used in this research is v4.4.3 Beta V. Within this study, three-dimensional model ENVI-met was used as it is computer software which predicts microclimate within urban areas based on a three-dimensional and energy balance model. It takes into consideration the physical processes between vegetation, building, atmosphere and ground and stimulates them within an urban area with a high temporal and spatial resolution which enables a detailed study of microclimatic variations (Monam and Rückert, 2013). One of the ENVI-met limitations is that the wind speed and cloud cover have to be constant at the model boundary during the simulation period. Modelling scenarios for ENVI-met include a combination of urban green systems within the same fixed canyon geometry which is the typical one. Modelling scenarios are based on case-study canyon areas selected for their mix of building types and urban green systems characteristics. In order to determine the canyon characteristic to apply different types of urban green systems on, thus, ENVI-met software is used.

ENVI-met (Bruse, 2017; Bruse and Bruse, 2019; ENVI-met, 2020)

With around 3000 independent studies, ENVI-met is the most assessed microclimate model presented, demonstrating its abilities and broad options to precisely simulate the outdoor microclimate since it allows the analysis of design effects on the local environment, the condition of the ground plane, building materials, and the vegetation usage on walls, roofs or both in any formation to help in mitigating urban heat stress. ENVI-met allows different climatic factors and their influence and reflections on the built environment to be simulated, whether outdoors, indoors, shaded or open to the sky environment, including all liveable factors such as trees, vegetation, water features, and so on.

For *outdoor thermal comfort*, ENVI-met investigates and examines: (i) sir temperature, (ii) radiant temperature of surrounding surfaces, solar analysis (sun and shade hours, glazing analysis, shadow casting, solar energy gain), (iii) air movement in the vicinity of the body (relative humidity), and (iv) *Tree Pass* (analysis of plant growing conditions, simulation of wind stress and tree damage, simulation of water usage). For *building scale*, ENVI-met analyses (i) building physics (façade temperatures, exchange processes with vegetated walls, interaction of outdoor microclimate with indoor climate, water and energy balance of living wall systems), and (ii) green-blue technologies (benefits of façade and rooftop greening, impact of green spaces and bodies of water, simulation of the living wall, air cooling through water spray),

For *pollution and airflow and aerodynamics*, ENVI-met covers (i) air pollutant dispersion (emission and transport of particles and gases, chemical reactions between NOx, Ozone and (B)VOC; includes deposition on plants and surfaces, and integrated tools to calculate traffic emission profiles) and (ii) wind flow (wind patterns in complex environments, wind speed around buildings and trees, wind comfort). Not limited to these options, the software also allows researchers to create a user-defined traffic emissions profile based on standard emission factors for vehicles, generating "urbanised" weather data to be implemented in building energy simulation software, in addition to a separate water droplet dispersion and evaporation model which is able to simulate the cooling effect of fine water spray on air temperature.

One of the key features for the software is that researcher can estimate thermal factors and wind speed and all of their related features as meteorological factors within any point in the model or even at building facades; moreover, a high-resolution analysis for energy heat fluxes coming for the environment and their influences on the overall thermal sensation of a person standing in the virtual environment can be calculated for any given scenario which is represented by Physiological Equivalent Temperature (PET) or Universal Thermal Climate Index (UTCI). The ENVI-met significance is optimised when it comes to vegetation and the software option, *Tree Pass*, which can investigate trees individually at the level of the crown geometry with the resolution of a single branch using the idea of L-Systems.

The effect of the local growing environments as light access will be considered in the analysis in addition to different maintenance strategies. Even the risk of uprooting or mechanical damage will be visible down to separate branches for an unlimited number of trees inside a city area. These options supported the researcher to be able to find the best spots to place different types of vegetation (trees, green wall, green roof, etc.) in addition to identifying the appropriate species and maintenance strategy for each location and environment which finally led to a sustainable and resilient landscape.

4.4.1.1 ENVI-met modelling requirements and processes

For computer simulations using ENVI-met software, the researcher has to go through different steps as in Figure 4-1 at which each step is in a separate window to be adjusted as the Spaces file, ENVI-Guide, ENVI-met window, BioMet, and Leonardo. Each step is explained separately in detail as below.

ENVI-met is based on two input files which are Spaces file and ENVI-guide file. See Appendix A – ENVI-met windows, Figure 0-2 represents that the ENVI-Guide file is mainly used for location determination and initialisation parameters “input and output folder locations, saving data interval, start time, wind speeds and other initial values, while the second file (Spaces file) shown in Figure 0-4, is mainly for determining urban and building geometry and layout; for instance, building heights, trees and other vegetation parameters and their location and soil parameters.

Modelled rectangular areas can range between less than 20 x 20 cells up to 250 x 250 cells, with a resolution between 0.5m and 10m per cell. Loaded example models with an ENVI-met range between 30 X 30 up to 150 X 150 cell, with 3-5 m typical cell resolution. Larger models or higher resolution would lead to more running/simulating time. It can adjust material types, specifications and adjustments through the database manager as in Figure 0-1.

Thus, it is essential to select a model size and resolution with reasonable time within the research project timeframe. 2500 m is the top fixed height of the model with near-surface layer height which can be modified by the user. Model guidance mentions that the last layer should be twice the height of the highest structure with 30m as minimum height. Data input is based on a cell-by-cell basis, through determining “soil, vegetation types, and building height”. Areas and points interest of examination can be specified as receptor points (for instance, for corresponding field measurements).

Within the spaces file, different types of vegetation can be placed, whether it is trees or living façade and the vegetation properties and details are found and edited in a separate window (Albero), as shown in Figure 0-3, where all vegetation species (London/Hybrid Plane with actual name Platanus × Acerifolia), specifications (height 20 metres and width 15 metres), and details (deciduous tree, foliage shortwave albedo 0.18, and foliage shortwave transmittance 0.30 with leaf weight of 100 g/m2 and isoprene capacity 12 in addition to root depth of 1.5 metres and diameter of roots is 10 meters) are stored.

The user's running time is set by the user with a typical running time of one day (24 hours), saving data each hour. On the other hand, it takes between four and five hours or more depending on the model size, area and details which are a consequence due to numerous outputs and extensive calculations.

In order to adjust the personal human parameters as body parameters (age, gender, height, weight), clothing parameters (static clothing insulation) and finally the person's metabolism (total metabolic rate), the Biomet window in Figure 0-3 is used to adjust and set all of these factors and how they will reflect on thermal comfort indices as PMV/PPD, PET, UTCI and SET. This could proceed after finishing the simulation with ENVI-met window and adjusting further human activities in Biomet.

Finally, in order to visualise results, as shown in Figure 4-3, LEONARDO window is used to extract the required meteorological factor (air temperature, wind speed, PET, RH, sun hours, etc.) in a graphical map either in 2D or 3D. X graphical map

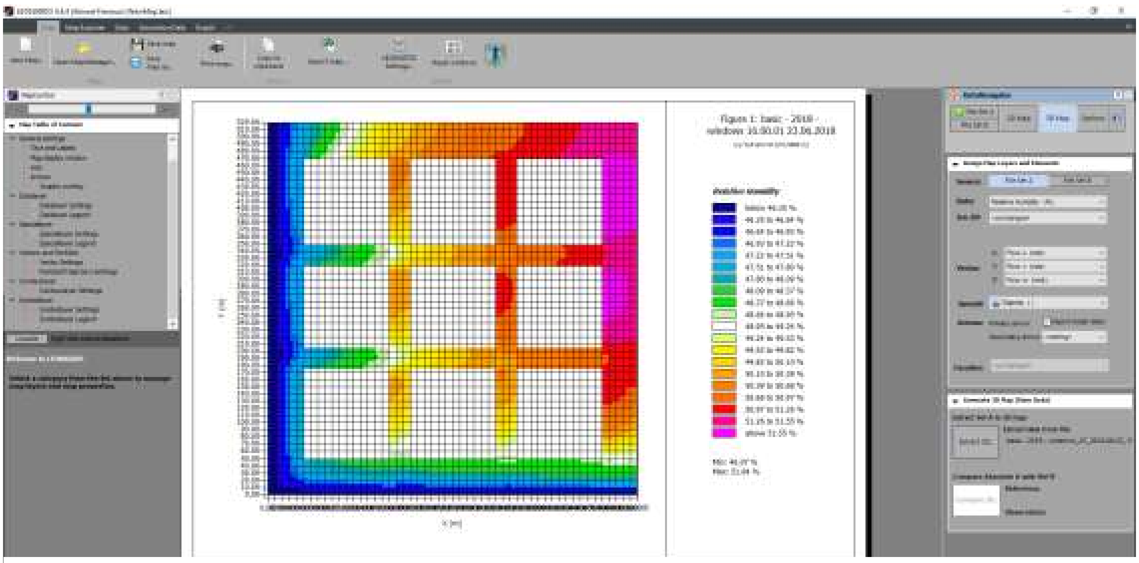


Figure 4-3 Leonardo window to illustrate simulation outputs in a presentable graphical method

illustration can be used, depending on the required data the user needs at whatever location point they need, whether its position is in X, Y or Z.

Model and Software adjustment

Through ENVI-met software, there have been three phases to go through before running any sort of simulations. First adjusting model geometry through Spaces File ENVI-met software window which includes the built environment for the buildings and urban canyon. Next,— the ENVI-Guide follows, where simulation folders are placed for the required simulation in addition to any further meteorological detail regarding the climate inputs "temperature, wind speed, relative humidity, etc." as in Figure 0-2. Third, ENVI-MET window is used to run the simulation. Finally, the results are run through the Leonardo window, which is a clear way to visualise results and simulation outputs in graphs and coloured 2D and 3D maps.

Model Geometrical Specifications/inputs

While these simulations would be carried out during the average temperature of the hot summer season (21 June – 21 September) for three years, 2018 being the current base case, and then the 2050s and the 2080s. Simulations for the 2050s and the 2080s will be carried out for the high emission scenario, which has a 90% probability of happening. Canyon vegetation is identified as that most of the studied canyons have almost 0% of green areas which is calculated as the following: the area of tree bushes (5-10 m2) is divided by the area of the canyon (120m X 30m = 3300m2) in the Oxford Street case while greenery is almost negligible in our cases. Thus, the base case vegetation percentage is 0% of greens.

A few challenges are taken into consideration such as the how to weight densification, pollution rates, vegetation percentage and, based on that, ENVI-met has proven its accuracy and its efficiency as it can take into consideration the background pollution in addition to pollution sources which emits pollution within specific hourly rates such as cars, buildings, people CO_2 exhaust from densification, dust, and others. Within simulation in Spaces window, background pollution is identified instead of active pollution sources emitting pollutant within specific hourly rates since background pollution is more accurately precise in any reference for yearly rates and occurring within central locations while active pollution sources are vaguer and not always measured hourly, and sometimes measurement are missed in certain locations.

Based on choosing the summer season as one in which UHI occurs at a high level in order to see the influence of UGS, the extreme measurement for pollutants is used as well for the same reason. On the other hand, vegetation is considered as a living organism which reacts with air and climate throughout different hours of the day, which will reflect on the outcomes of simulation results and will be different based on plant type and percentage and the way of application.

Last but not least one of the main challenges is the running time for simulation, particularly when it takes, on average, four to six days to run each simulation. =In the case that the inputs run smoothly without any errors, this estimation was extracted based on the researcher's trial simulation for 0% green areas and during one day of the year, 23 June 2018. The number of simulations would be three vegetation scenarios (0%, 25% and 50%) for three years (2018, 2050 and 2080) and for three different UGS types which are trees, green walls, and high albedo for pavements. Thus, on average, there will be nine simulations which will take on average 18 days of non-stop running simulation in addition to trial and error days.

Study Site Location

The primary intent is to simulate, analyse, and quantify the influence of various green system types and density scenarios. Besides, their configuration and placement in the form of temperature influence urban surfaces would reflect on pedestrian outdoor thermal comfort and carbon sequestration within the urban context.

The selected site in West London is assessed and used as a case study with high UHI effect and heavy pedestrian traffic expectations. First, one of the most polluted, condensed and highly populated area with people is used to maximise the benefits of this research and to see how the findings will influence people's life. Based on these specifications, more focus was paid to central London, the UK where most of the

Figure 4-4 London Air Quality Network (LAQN, 2020)

challenges are present. Following further assessment, that the researcher found that Oxford street, Bond Street and Regent Street are at the top of the list for polluted streets which are also highly populated with people as in Figure 4-4 (LAQN, 2020).

4.4.1.2 Study Area: Oxford Street, London, the UK

Oxford Street is one of the major streets in West London in the city of Westminster with a length of 1.2 miles. It runs from Marble Arch to Tottenham Court via Oxford Circus. It is visited by half a million visits daily to make it Europe's busiest shopping street (Westminister, 2019). Despite the existence of more massive traffic flows, pedestrians tend to walk more on London's main streets, leading to several walking congestions happening across different patterns of the day; for instance, the highest period for tourists is late afternoon while for the older people it is late morning. Usually, the peak flow in total is is during lunchtime and the evening rush hours. Women tend to walk more than men and non-tourists more than tourists within the central London area (Space-Syntax, 2020).

London also has the highest nitrogen dioxide pollution concentration in the world with at 135 micrograms per cubic metre of air (µg/m3) and one of the top polluted streets across the UK for all pollutants, based on the King's College Report (2015) (Steven Poole, 2015; Isobel Hamilton, 2017). Based on the Transport for London (TfL) analysis for Oxford Street, it was classified as city street type. However, the delimitation could change with the change of time, users and functions. The main priorities for city streets are classified as the public realm on a world-class level, free pedestrianised movement, reliable bus journeys to get commuters to their destinations, and high footfall with high visitor satisfaction (TfL, 2014).

Pedestrianisation

There have been several initiatives to pedestrianise Oxford Street which ran from 2005 to 2012 each Saturday before Christmas; the street was closed to motor traffic on a Very Important Pedestrians (VIP) initiative that boosted sales by over £17million in 2012. The street was then proposed to be pedestrianised by 2020 by the Liberal Democrat members of the London Assembly in 2014 (Knight, 2014). The aim of The Mayor's Transport Strategy for 2018 was that 80% of trips be covered using sustainable transportation modes (walking, cycling and public transport) by 2041, with an ultimate target for all Londoners to cover at least 20 minutes of active travel daily by 2041 (which is very challenging, because only a third of Londoners reported doing this in 2018) (Lakache and Smart, 2018).

In 2006, the (then) Mayor of London, Ken Livingstone and the New West End Company proposed pedestrianising the street with a tram end to end, while Boris Johnson the following Mayor in 2008 declared that it would be troublesome, not cost-effective and would not go ahead. However, based on Johnson's request, the Transport for London (TfL) reduced 10% of bus flow between 2009 and2010 although the New West End company called for 33% of bus reduction ('Mayor's Oxford Street tram vision', 2006; *Streets ahead: Relieving congestion on Oxford Street, Regent Street and Bond Street*, 2010; NWE, 2009).

Figure 4-5 Oxford street pedestrianising (New West End, 2006)

Subsequently, the TfL pedestrianisation was not suitable at the time – 2014 because after opening the Crossrail, that would lead to demand reduction on the several bus lanes across Oxford Street. At the same time, it could be considered as an opportunity to reduce traffic by limiting it only to buses and cycling while other services such as deliveries and taxis could be permitted during off-peak shopping hours in addition to optimising traffic and pedestrian countdown signals (TfL, 2014).

By 2015, the next and current London Mayor, Sadiq Khan promised pedestrianisation by 2020 after winning the Mayoral elections. Surprisingly the plan faced disapproval by Westminster City Council, local residents and the Fitzrovia Business Association (BBC, 2016; Fitzrovia, 2017).

4.4.1.3 Site Analysis

In order to make the research feasible, a study of the different areas in Oxford Street was undertaken, and based on the data generated by the study, the area was chosen, which is the downtown area. Hence, central London's Oxford Street was chosen as the research case study where many of the aforementioned challenges exist in the Study Site Location (on page 123).

Based on the Oxford Street pedestrianising plan, the Street was into three zones: East where traffic will be removed by December 2019, West where traffic is planned to be eliminated by December 2018 and Marble Arch after 2020. The canyon between Orchard Street and Park Street is characterised by Height: Width of 1:1 while the length of the building's semi-square block is 120m for each side and the street canyon length is 140 metres.

Figure 4-6 Oxford Street neighbourhood urban cluster and street orientations

Several studies (Ahmed Shafeay and Shalaby, 2016; Shalaby and Shafey, 2018) have asserted that similar canyons' dimensions need to be investigated for the purpose of improving pedestrians' thermal comfort (PTC), especially during the summer season (Shafeay and Shalaby 2016; Shalaby and Shafey 2018). Thus, measurements are taken within the North-South (NS) street (S1) canyon and the East-West (EW) street (S2) canyon , which represent Oxford Street case, as shown in Figure 4-6.

Secondary data were collected through supporting documents and drawings from Google Maps, Greater London Authority (GLA) and the Transport for London (TfL). Based on it the research is carried forward in order to determine the influence of UGS on UHI and carbon sequestration in order to make the best applicable decisions on the UGS placement, type, and covering percentage in each year of future climate scenarios. Finally, after collecting these data they were overlaid to generate the most probable and potential study zone based on canyon characteristics. As shown in Figure 4-7, a matrix of green spaces, building heights and types are generated in order to classify different canyons. Subsequently, all datasets were overlaid or combined to find the selection criteria areas which best fit the research aim.

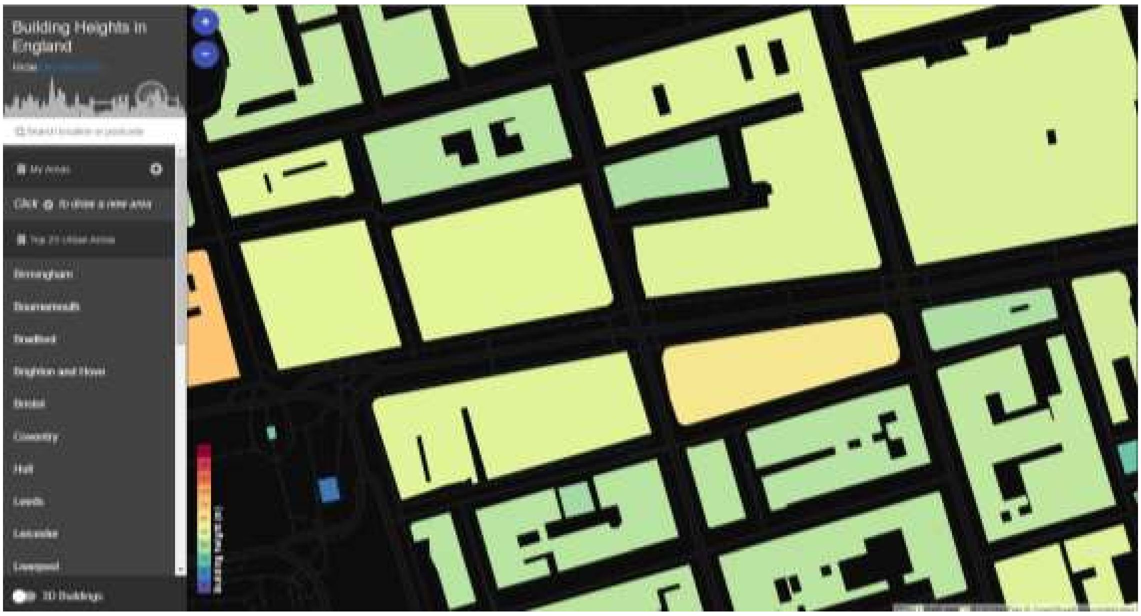


Figure 4-7 Top (building height in England) showing all buildings heights (EMU Analytics, 2020)

4.4.1.4 Canyon geometry and orientation

A closer look was taken at these streets' canyon geometry and specifications in order to determine canyons' width and building height which could be found through Google Maps or London Building Height Map as in Figure 4-7. Based on this map, a canyon geometry map Figure 4-7 was easily extracted following Google Map ruler. Based on Google 3D maps and Building Heights maps in England, the average building height was determined to be within 30 metres. Further, the street canyon dimension was around 30 metres on average as well, leading to building height to canyon width ratio: H:W = 1:1 as illustrated in Table 4-1.

Table 4-1 Canyon geometry (width, length and buildings height)

Street	Canyon Width	Canyon Length	Building Height
Bond	**15**	**110**	**15**
Oxford	**30**	**120**	**30**
Regent	**24**	**120**	**24**

Canyon orientation will be identified to be South West because that is the prevailing wind direction, while another canyon is perpendicular to it would be South-East "non-prevailing" wind direction. So, the difference and influence of this study's UGS within two different canyon orientations (North-South and East-West) is clear, and could be similarly applied on other streets within London in future research.

Building Use and height

Most of Oxford Street's buildings are retail shops and major department stores, accounting for more than 300 shops by 2012 attracting half a million visits each day in 2014, and leading to a turnover of over £1 billion as a significant part of West End of London shopping district. The canyon buildings were determined and classified based on their height (low, medium and high-rise) as in Figure 4-7. Since UHI is mainly clearer when the height of the street is between the 1-3 times the width of the canyon, so the selected building height is mainly determined based on the canyon geometry in order to

Figure 4-8 Oxford Street Buildings use and heights

sense the UHI effect as in Figure 4-8. Then, building heights which are more common within the street canyons are used.

Buildings Fabric

Based Taher (2016), it was found that the window-to-wall ratio (WWR) is around 50% on average, in addition to eliminating any extra WWR which is more than 50% because that would exceed the 50% possible green wall vegetation in this study. A simplified urban fabric cluster (buildings with precise geometrical dimensions and shapes) is used based on these inputs is used in order to extract the urban map where these canyons are located. This would finally lead to having clear simulation output and results through using fixed canyon geometry for a typical central London canyon geometry such as height-to-width dimension, wind speed, orientation, building fabric, solar radiation, sky view factor, and others.

4.4.2 Weather files for 2018, 2050s and 2080s

Weather files are one of the core basics to adjusting the model based on its location and time of the day or season. Since this study is based on current and future climatic scenarios, the researcher had to get trusted climatic weather files recorded for 2018 and weather files which are predicted and expected to happen in 2050s and 2080s within London. However, some weather predictions were investigated and analysed deeply by the researcher as MET Office weather data were recorded for different years (2018, 2050s and 2080s). The predictability and accuracy of these weather file data might change from one year to another, which requires further analysis to understand any changes.

To avoid weather change across the summer, the researcher decided to use the average hourly data across the whole summer season. In comparison, some other studies used the average data for the hottest week (Nakata-osaki *et al.*, 2018), or the hottest three days (Park *et al.*, 2017; Herath, Halwatura and Jayasinghe, 2018), or the hottest one day (Ridha, 2017; Yasser, 2017) which shows a biased methodology in order to show an extreme difference before and after placing alternative solutions.

Thus, to run simulation during the summer season for 2018, the MET Office did not have data for 2019 daily temperature during the summer season (21 June – 21 September). Thus, the researcher requested weather files from weather stations near Oxford Street from the MET Office for 2018. Since Oxford Street was investigated, weather files for Met Office were requested from the MET Office in order to run the simulation, which supported the research with four weather stations within London which are Kew Gardens, Heathrow Airport, Saint James Park, and Teddington Pushy Park. Analysing these files was a must to pick the proper weather file for the current case study.

Table 4-2 Weather station in London and their locations and reading difference (Tsapakis, Cheng and Bolbol, 2013)

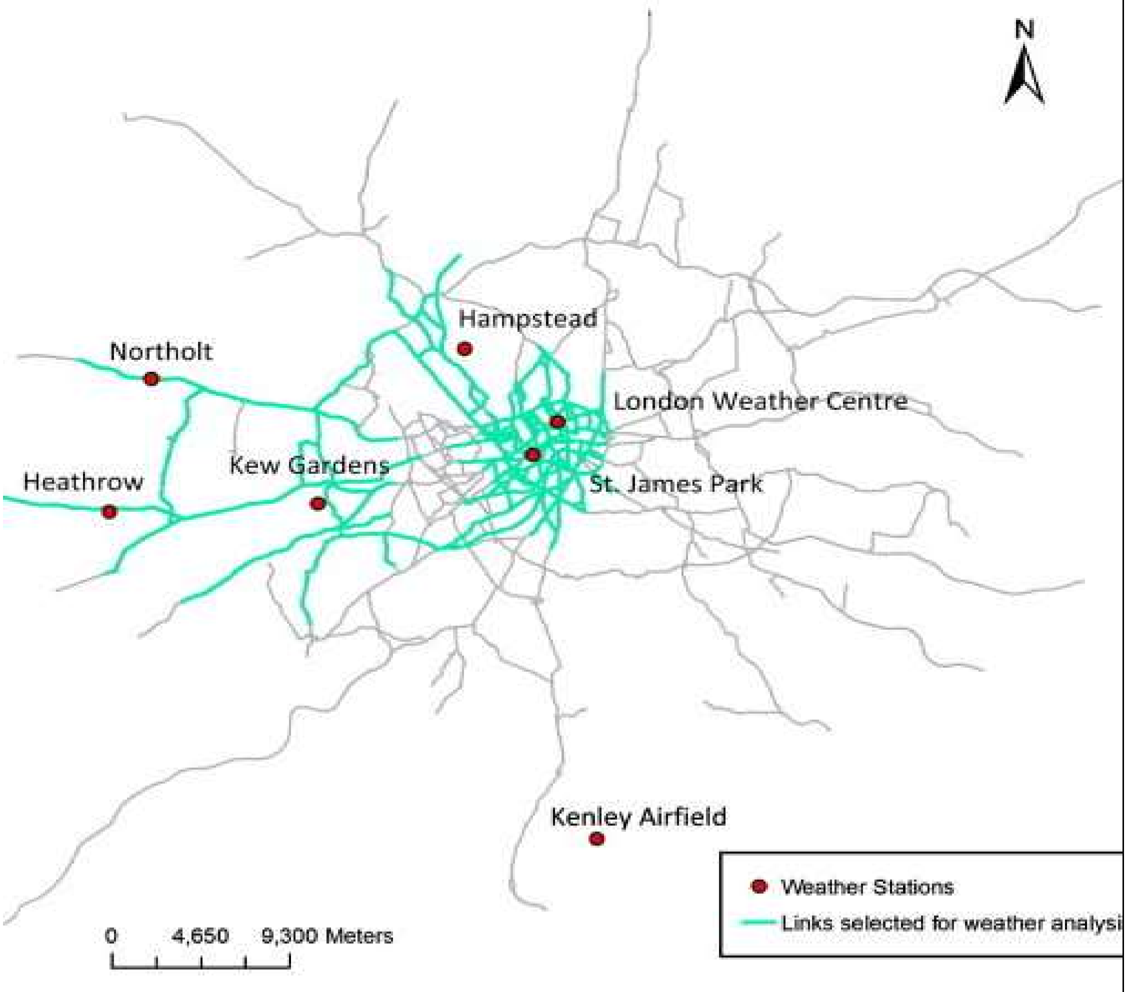


Figure 4-9 Location of different weather stations

Weather Station Name	Weather Station Altitude (m)	Distance from Case Study (Km)	Mean summer Temp. (°C)	Wind Speed (m/s)	Solar Radiation Average (KJ/m2)	RH (%)	Hourly Data Availability
Kew Gardens	6	12.8	19	2.01	20390	67.5	Yes

Heathrow Airport	**25**	**26.56**	**20**	**3.6**	**20184**	**N/A**	**N/A**
Saint James Park	**5**	**2.24**	**19.9**	**N/A**	**N/A**	**N/A**	**N/A**
Teddington Pushy Park	**9**	**20.16**	**18.9**	**1.54**	**N/A**	**N/A**	**N/A**

Based on Table 4-2, it is clear that Kew Gardens is the only station which is offering hourly weather data which is a must for carrying on simulations on ENVI-met. However, for further years – the 2050s and the 2080s – a relationship could be estimated based on the average weather data during summer. Despite having Hyde Park closer to Oxford street, there were no available data from the MET Office, and that is why more weather files were requested in order to check out the difference between each weather data and the other based on their location within the city.

Surprisingly, there was not that much difference between different weather files (maximum 1.1°C across mean summer temperature), while wind speed varied between 1.54 and 3.6 m/s and solar radiation had a negligible difference of 206 KJ/m3 out of 20390 KJ/m2. However, these weather stations are located in significantly different locations with different environment and urban forum and clusters. The only apparent difference was in wind speed where it was particularly high at Heathrow (3.6 m/s). That might be because that there were not any buildings close to Heathrow Airport while Kew Gardens is surrounded by an urban fabric.

While Heathrow wind speed was much higher than Kew Gardens and the same for Teddington Pushy Park, the latter missed a few days where the wind speed was not measured, which is why it is relatively lower than that recorded at the Kew Gardens weather station. Based on these findings, Kew Gardens weather data are used for this study's 2018 simulations.

Similar findings were released when comparing 2050 and 2080 weather files (M Eames, 2011) which were located in Heathrow Airport and the one which was located in London Islington which is closer to the site location (5.6KM) away. These weather files were generated based on UK climate projections 2009 (UKCP09). These files were available for the current climate and three future time periods for two emission scenarios – *medium* emissions (a1b) and *high* emissions (a1fi). These weather files were generated through Exeter University climatic experts in order to be used as an input for hourly futuristic thermal simulation (Eames, Kershaw and Coley, 2011).

High emission scenario files (A1F1) were used during simulations since they have a probability exceeding 90%, which means weather data are unlikely to be less than predicted one in the future by 90%. The medium emissions (A1B1) has a probability of 50%, which means that 50% of predicted weather data will not be less than the actual weather in the future. While comparing results of MET office for 2018 weather files (Kew Gardens, London) to Exter University weather files which is for (Islington, London) UKCP09. Different patterns were found regarding Wind Speed (Ws) and Global Solar Radiation (GSR)(Jenkins *et al.*, 2009; Eames, Kershaw and Coley, 2011; IPCC, 2014):

In the 2018 weather file, wind speed was (2.01 m/s) and (5663.8 w/m2) for GSR. In 2050 and 2080 they were around (4.1 m/s) for Ws and (5210 w/m2) for GSR. Based on an email conversation between the researcher and the author, Professor Matt Eames, there would be lower confidence in the wind speed measurement because wind speed and direction are usually generated based on the dominant wind direction and the average wind speed which means there is high variance within the measured/observed cases during field measurements for instance. Thus, it is not surprising to have more difference in the probabilistic future measures (Eames, 2019). Meanwhile, for global solar radiation, the difference was not that much – 20184 KJ/m2 instead of 20390 KJ/m2 – and that might lead to clouds. That is why 2050 and 2080 had similar GSR since they were calculated in the same way. Hence, we can use the 2018 GSR provided by the MET Office as the actual input for different years (Eames, 2019).

Based on Figure 4-10, the average of air temperatures (Ta), relative humidity (RH), wind speed (Ws) can be easily noticed across the different years. Figure 4-10 compares them on the average of hourly basis across the whole summer season, followed by the whole day average, percentage increase/decrease compared to the 2018 year as a base case to be easily understood. Across the three decades, average temperature has increased 4.4C (22.3%) in the 2050s and 7.8C (40.5%) in the 2080s, reflecting that the climate will be warmer. RH would slightly decrease by (-2.8%) in 2050 and by (-13.1%) in 2080 leading the climate to be dryer. While wind speed is expected to increase by 200% more in both the 2050s and the 2080s, which might be due to the meteorological site change from London city centre (Kew Gardens) in 2018 to Heathrow (Greater London) by the 2050s and the 2080s.

Tair	2018	2050	2080
01:00	15.8	21.2	25.1
02:00	15.2	19.7	23.6
03:00	14.6	18.6	22.6
04:00	14.2	18.4	22.4
05:00	13.9	18.3	22.3
06:00	13.9	18.3	22.4
07:00	14.9	18.7	22.7
08:00	16.4	19.9	23.9
09:00	18.1	22.0	25.8
10:00	19.6	24.2	27.4
11:00	20.9	25.8	28.9
12:00	21.8	26.9	29.9
13:00	22.6	27.9	30.6
14:00	23.3	28.2	31.0
15:00	23.6	28.4	31.2
16:00	23.9	28.3	31.3
17:00	23.7	28.3	31.1
18:00	23.3	27.9	30.8
19:00	22.4	26.8	29.9
20:00	21.3	25.1	28.5
21:00	19.7	23.5	26.9
22:00	18.5	22.0	25.6
23:00	17.5	21.0	24.8
00:00	16.6	21.1	24.9
Average Temp	19.0	23.4	26.8
Avergae Temperature difference	0.0	4.4	7.8

RH	2018	2050	2080
01:00	80.3	75.4	65.6
02:00	83.6	79.9	70.5
03:00	85.6	83.1	74.2
04:00	87.5	83.8	75.2
05:00	88.6	85.1	75.9
06:00	89.3	85.1	76.1
07:00	86.7	83.9	74.9
08:00	80.1	79.9	70.6
09:00	72.2	71.4	63.5
10:00	65.2	62.8	56.3
11:00	58.8	55.9	50.8
12:00	55.2	51.6	46.8
13:00	52.0	47.7	44.3
14:00	49.3	46.0	42.5
15:00	48.1	45.2	41.6
16:00	47.4	44.9	41.1
17:00	47.8	45.2	41.3
18:00	49.3	46.6	42.3
19:00	52.2	50.4	45.0
20:00	56.2	56.8	49.9
21:00	62.6	63.3	55.6
22:00	68.7	69.3	60.7
23:00	72.8	73.4	64.3
00:00	67.3	75.2	66.3
Average RH	66.9	65.1	58.1
Avergae RH difference	0.0	-1.9	-8.8

Ws	2018 - Kew Gardens	2018 - Heathrow	2050	2080
01:00	1.61	NA	3.31	3.39
02:00	1.45	NA	3.29	3.25
03:00	1.36	NA	3.19	3.12
04:00	1.36	NA	3.19	3.05
05:00	1.29	NA	3.18	3.03
06:00	1.33	NA	3.10	3.12
07:00	1.42	NA	3.19	3.18
08:00	1.62	NA	3.52	3.48
09:00	1.80	NA	3.95	3.96
10:00	1.99	NA	4.34	4.30
11:00	2.17	NA	4.71	4.69
12:00	2.35	NA	4.98	4.93
13:00	2.50	NA	5.16	5.22
14:00	2.65	NA	5.21	5.42
15:00	2.67	NA	5.36	5.49
16:00	2.68	NA	5.50	5.62
17:00	2.68	NA	5.30	5.50
18:00	2.60	NA	5.06	5.37
19:00	2.60	NA	4.75	5.18
20:00	2.44	NA	4.47	4.77
21:00	2.22	NA	4.15	4.24
22:00	1.93	NA	3.84	3.86
23:00	1.75	NA	3.55	3.55
00:00	1.68	NA	3.34	3.34
Average Ws	2.01	3.60	4.15	4.21
Difference	0.00	1.59	2.15	2.20

Figure 4-10 Different meteorological measurements for 2018, 2050s and 2080 (Eames, 2019)

4.4.2.1 The steps taken before data collection

1. Literature review for studying the concept and impact of cool pavements, green walls, trees and urban heat island effects, Mean radiant temperature influence on Oxford Street, London and their influence on the urban heat island.
2. Computerised simulation by using ENVI-met software.
3. Modelling physical models and then measuring them.
4. Comparing the data obtained from simulations and subsequently validating the results.

4.4.2.2 Tree Canopy Cover

Figure 4-11 London Street Trees Website map (Street Trees, 2019),

Since trees are a good ecological performance indicator for determining air quality influence, globe and surface temperature, reducing energy consumption and urban heat island effect mitigation (K. Coder, 1996; Whitford, Ennos and Handley, 2001; Solecki *et al.*, 2005; Jaafar, Said and Rasidi, 2011; Aleksandrowicz *et al.*, 2017), the tree cover volume was used to determine the study area and to be used as the initial greenspace percentage.

Table 4-3 London Street trees website output for trees existing within streets (Street Trees, 2019)

Street	**Number of trees/ Canyon**	**Dominant Tree Type**	**Diameter (m)**	**Vegetated Percentage**	**Start-End (station)**
Oxford	**64**	**Pear**	**4.5**	**0.067 %**	**Marble Arch-Tottenham Court**
Regent	**0**	**--**	**--**	**0 %**	**Oxford Circus – Piccadilly Circus**
James	**6**	**Unspecified - Liquidambar styraciflua**		**<1 %**	**Wigmore St. – Bond Street**
Baker	**26**	**London Plane**		**<1 %**	**Baker street - Portman Square**

Duke	**0**	**--**		**0 %**	**Portman & Manchester Square – Grosvenor Square**
Marylebone	**30**	**London Plane**		**<1 %**	**Edgware Road - Regents Park**

Based on (Street Trees, 2019), Table 4-3 and Figure 4-11 show clearly that the vegetation percentage within London central and specifically within highly polluted streets does not exceed 16%. Most of these trees were London Plane, a typical common tree, while in Oxford Street, there were very few trees apart from Pear trees, which were introduced to the USA's environment. A study by (Sanusi and Livesley, 2020) illustrated that the London Plane trees (Platanus x acerifolia) are vulnerable to heatwave conditions, since micrometeorological benefits within heatwave conditions were beneath those measured on a warm sunny day. Nevertheless those trees still provide significantly milder micrometeorological environments compared to open street locations on warm summer days. Large mature deciduous London Plane trees were used in a study by (Simon, 2016) who illustrated that larger trees with their more advantageous surface area-to-volume ratio can endure and survive more environmental extremes and conditions than smaller trees within ENVI-met software.

4.4.2.3 London Tree Canopy Cover Maps (LTCCM)

Cities across the world are implementing strategies to increase green canopy cover as increasing green canopy cover is on the top ten list for urban initiatives set by the World Economic Forum’s (WEF) Global Agenda Council (GAC) for the Future of Cities (Treepedia, 2020). The type of trees within London could be easily identified through London Street Trees websites (Street-Trees, 2020). Although London tree canopy cover which was developed by Breadboard labs in collaboration with the GLA, shows the canopy cover for trees, across the whole of London, whether they are in streets or parks with an accuracy of 94%, the model however sometimes mistakenly identifies football pitch markings, scrub and reed beds as tree canopy (Breadboard-Labs, 2018, 2020).

Around 21% of London is covered by trees; however, some other countries might have +25% trees which might be dominated by moorland or farmland rather than the forest. The LTCCM was spotted by machine learning from an aerial image, which might have a few errors such as determining railway lines as forests in the map instead of grass which is the actual coverage. The same error might happen in backyard gardens for residential terraced areas. So it is advised to use extra maps for verification (Ollie, 2018). Most of the people have a favourable impression of a street landscape if more than 30% of the view includes greenery (Yang *et al.*, 2009).

Figure 4-12 (left) London street trees, (Right) London Tree Canopy Cover (Treepedia, 2020)

Remotely sensed imagery might miss the lawns and shrubs under tree canopies in case of a multi-layer green space in addition to failing to acknowledge what people usually see; however, it is useful for quick urban greenery measurements (Li *et al.*, 2015). London National Park City Map was created using GiGL (Greenspace Information for Greater London) data and Ordnance Survey data for the aim of mapping all green and blue spaces within London, including private gardens. From the data it is estimated that 50% of London is green and blue spaces. It covers all the 3000 parks, woodlands, nature reserves, playing fields, rivers, canals, and farms which depict London as the world's first National Park City (Ollie, 2017).

In order to calculate the Green View Index (GVI), Google Street View (GSV) panoramas from Google Maps were used to identify the percentage of green coverage along a street. This could be explained through representing human observation of the environment from the street level which is logical because that is the actual observation for a green percentage within a scale of 0-100% (Seiferling *et al.*, 2017a, 2017b; Li and Ratti, 2018; Ian Seiferling, 2020). Hence, Treepedia software was designed in order to increase the urban vegetation improvement within streets using computer vision strategy to be applied on Google street view images; however, it does not indicate parks (Treepedia, 2020).

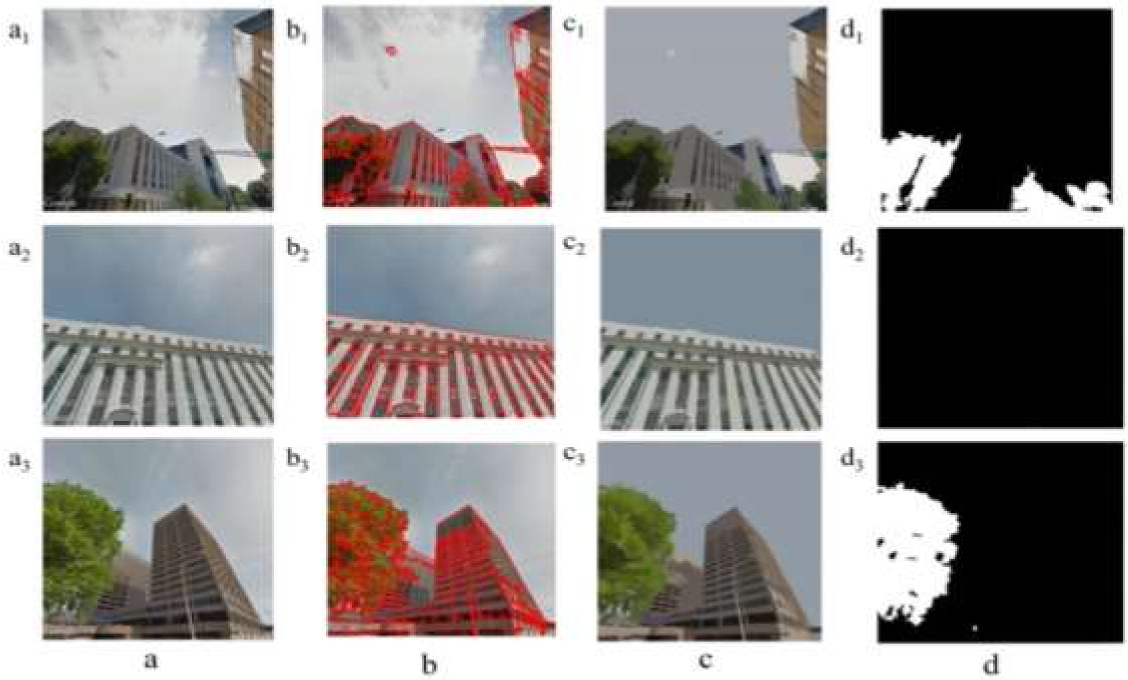


Figure 4-13 (Treepedia, 2020) Software method of analysing street view

However, it is mentioned that London is 47% green cover (Simon Usborne, 2014). Nevertheless, it is not the actual green percentage which exists within the street, which is what the researcher found within central London streets. That was also confirmed by Treepedia software, which reflects that London streets lack a massive amount of greenery as the Green View Index (GVI) in London is 12.7% with population density 5518 people/ km^2 compared to Frankfurt and Geneva with GVI of 21.5% and population density 3000 people/km^2 and 12000 people/km^2. Meanwhile, Cambridge has GVI 25.3% for the population of 6500 person/ km^2 and Amsterdam has 20.6% for the population of 4900person/ km^2 (Treepedia, 2020).

The most commonly used objective method for measuring urban greenery is remote sensing that is due to the large area it covers, and hence, it helps in understanding people's street visualization for street greenery based on being shown images for the green coverage. This helps increase greening pressure on political and decision-makers since these images represent the actual percentage of green existing in urban spaces. However, one of its limitations is that it shows pedestrians' levels only, not a hemispheric view while one of the main advantages that it is very precise in measuring the actual green percentage as it can identify the actual greenery scene for a pedestrian. In contrast, remote sensing cannot identify it with accuracy, such as identifying a green space under the large tree canopy, for instance (Li *et al.*, 2015).

Figure 4-14, illustrates different cities – (Durban, Frankfurt, Geneva, Johannesburg, Kobe, London, Los Angeles and Miami – with green view indices of 23.7%, 21.5%, 21.4%, 23.6%, 9.4%, 12.7%, 15.2% and 19.4%, respectively. Surprisingly, London is not the city with the highest green view index, although London is widely known by its urban green coverage of 37.3%. Therefore, London's urban green coverage does not represent actual green street-view percentage, which confirms with the London Street Trees map that London does not have street trees with an acceptable percentage and reflects that most of the urban green areas do not exist on streets (either in parks or green belts). On the other hand, London population density is one of the highest at 5.518 person/ km^2.

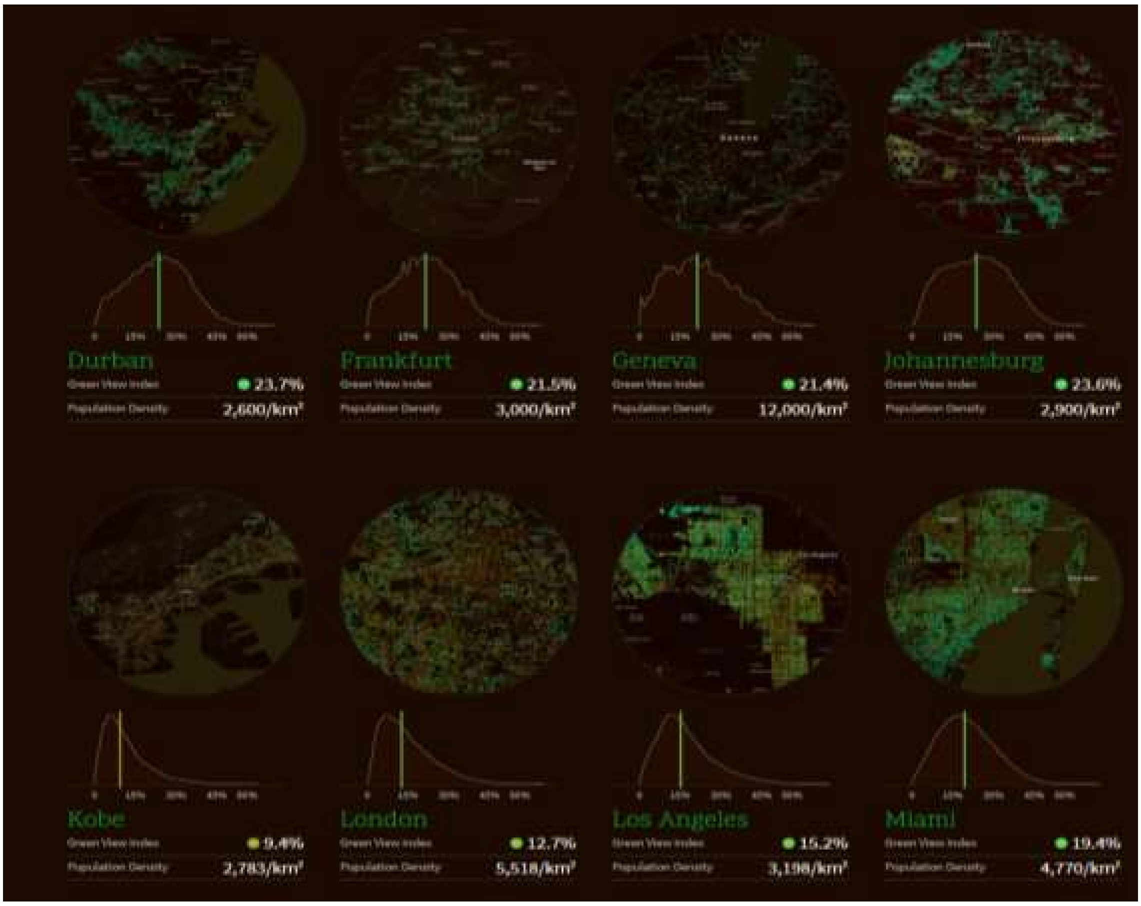


Figure 4-14 Different cities tree canopy cover percentage by treepedia (Li et al., 2015)

4.5 *Questionnaire survey*

The questionnaire survey is one of the core research methods employed to answer the research question since it has been extensively used by researchers to analyse statistical relationships between thermal comfort outdoors and urban green systems and their variables (percentage of UGS, type, etc.) in numerous relevant studies. This method has been widely used to investigate implications between outdoor thermal comfort and UGS (Lin *et al.,* 2014; Kangur, 2015; Sarkar *et al.,* 2015; Lhomme-duchadeuil, 2018).

This survey will be based on proposed UGS alternatives within ENVI-met simulation in order to check the pedestrians' perceptions of and preferences for which UGS percentage (25% and 50%) and which UGS type (trees, green wall). Graphics will illustrate this alternative in order to assist pedestrians to choose their favourite alternative. The survey follows ENVI-met simulation analysis as an approach to understanding human interaction and response to suggested possible UGS alternatives. The HPA alternative is excluded from the questionnaire due to its deficiency in improving thermal comfort

The questionnaire survey in an experimental study combines participants' experiences and preferences in the street. The survey is also designed to allow participants to choose their own preference, comments and attitudes relating to each UGS and its influence on them. The survey as a research method has been widely used to analyse statistical relationships between pedestrian thermal comfort and social and aesthetical variables in several relevant studies. The structured questionnaire survey uses a qualitative phenomenology method where the focus is more directed to individual experience which includes questions with expected formats of answers such as numbers, rating scale, different pictures for comparison and choosing the best preference of UGS, and the pedestrians' expressed top priority for their walking experience.

The survey is divided into four sections: (i) Evaluating pedestrians' activities within the street, (ii) evaluating UGS importance, (iii) choosing the best alternative for them and (iv) basic information about pedestrians. It aims to collect quantitative data with standardized means. The survey is structured (pre-designed questionnaire) with closed format/ended questions of multiple choices including (other) option where pedestrians can include their own reason/choice/preference and a label scale format (from 1 to 5). It aims to collect quantitative data with standardised means.

The questionnaire survey was designed and distributed using the online platform SoGoSurvey (SoGoSurvey, 2020). SoGoSurvey is a cloud-based software as a service (SaaS) application which is used to build surveys to measure pedestrians' engagement and experience, to collect their feedback, and to conduct PhD research. The survey can be shared to the target audience using email invitations, public URLs, social media platforms, or SMS. Once sufficient responses have been collected, SoGoSurvey can run real-time reports using the platform's robust integrated reporting engine. There is a wide variety of reports available, including Bar Graphs, comparison, cross-tabulation, individual and statistical (SoGoSurvey, 2020).

4.5.1 The survey aim and objectives

The survey aimed to explore pedestrians' attitudes to UGS in central London's urban environment (Oxford Street). Questions were asked about UGS within streets in general, followed by questions about their outdoor activities within the streets and questions about UGS in their street (if any). These questions were designed in order to study if there are any differences between UGS alternatives in general. The objective of the survey is to deliver a better understanding of the pedestrians' reactions and experiences while walking in an outdoor environment in addition to a survey which will find the thermal responses of pedestrians. To achieve this it will:

(i) Evaluate how pedestrians interact within open urban canyons as street pavements, their activities, time patterns spent outdoors, visits patterns, their priorities for walking more.

(ii) Evaluate the value of a visual online questionnaire to discover human perception on favourite UGS, through showing different photoshopped pictures for all proposed UGS alternatives in order to indicate their level of satisfaction with each alternative.

(iii) Evaluate the relationship between preferred UGS, and thermal comfort and other benefits on city walkability.

4.5.2 COVID-19 implications for the Questionnaire

The questionnaire has passed through different phases starting with its design and structure, focusing on its target sample then getting ethical approval, piloting it, and improving it through comments and enhancement to maximise the benefits for the research and GLA and plans of Transport for London (TfL) and its Healthy Street plan. These phases were time-consuming for the survey refinement and tailoring it to fit the research, and London plans purposes until reaching the final questionnaire survey output to be distributed on the targeted sector. After finalising the survey sample and targeted sector and other related questions and their activities within central London, a global challenge occurred as COVID-19 which was classified as an epidemic (a disease that affects a large number of people within a community, population, or region which initially was China and neighbouring countries) which has reflected on the research and the questionnaire survey specifically.

In the beginning, the survey was designed to be completed face to face and to be distributed by email as well in order to cover a wide range of people such as workers at Mark and Spencer (M&S) in Oxford Street and the TfL workers there as well because people who work within this street will be frequent visitors and the change will directly reflect on them. They will be the most precise sample to get their feedback and comments on any changes within the street since they are the most frequent visitors for the street and hence they will be able to give deep comments and notes about the most appropriate UGS alternatives based on their frequent visits. However, at the beginning of the COVID-19 pandemic, M&S was trying to downsize and limit any physical contact, and the email distribution choice was not applicable at that time due to acquiring consent and admission approvals during this critical time.

Therefore, the researcher tried to adjust his survey to fit a more comprehensive sample of workers and visitors within Oxford Street in order to distribute it on several stores and companies who have branches in Oxford Street, but it was not feasible due to the challenging time, and acquiring admissions and further legal work was problematic too. Subsequently, the researcher tried to widen the sample size and target in order to cover Oxford Street pedestrians instead of only workers so he could recruit pedestrians taking part in different outdoor activities within Oxford Street instead of only workers. However, again, due to COVID-19 evolution and transformation of COVID-19 classification from epidemic to pandemic status, face-to-face and physical contact with people was prohibited by the University in order to avoid any risks related to the disease, and the only available option was to distribute the survey online.

This implication had directed the survey away from focusing on Oxford Street as a location to cover central London, which is similar to Oxford Street as it is full of commercial and touristic activities. While sharing and distributing the survey online, the researcher noticed that most people who tend to show interest in the survey are more academics within university connections or people interested in green-related research. Meanwhile, due to governmental restrictions, a new law has been put in place to limit social interactions, call for more social distancing, and promote working from home. Therefore, frequent Oxford Street and central London visitors now made less frequent visits which might affect their decisions and their interactions regarding the choices, and might create bias while completing the survey.

4.5.3 Questionnaire design and structure

Many urban and landscaping studies tend to use the photo-elicitation approach at which survey participants are supplied with real or edited (photoshopped) images and asked questions related to these images (Adrien, 2018; Hall, 2010). Since this study works on heavily pedestrian traffic walks which are bounded on both sides by new urban green systems as trees or green walls, the researcher planned to approach pedestrians on-site to get a more in-depth insight on their impressions and reflections on the research while completing it in addition to having their opinion within the context beside distributed emails. At the early stage of survey design and structuring, a consistent consultation, and discussion were developed with the TfL authorities (Appendix D – Professional Meetings, collaboration and Discussion for Presenting the PhD to Investors and Decision Makers) in order to formulate and design the core parts of the survey to achieve the final goal in motivating pedestrians and central London visitors to walk more.

The developed survey was carried out to explore and analyse the pedestrian preference of different urban green system (UGS) alternatives (trees, green wall) with different percentages in Oxford Street. The survey is divided into four sections and organised as follows: generic questions (Pedestrians activities' in Oxford Street), followed by more specific questions about UGS (Evaluate the Green Street-scape importance), then to more specific evaluation for the preferred UGS alternative (Evaluating the Proposed Green Street-scape in Oxford street), then checking if there was an impact of choosing UGS and pedestrian activity and reasoning comes in the pre-final survey phase (Evaluate activities and UGS choice reasoning) and (finally demographic questions) which coverage, gender, preference by the sample to be contacted for research results and whether if they have comments on the survey or not. The questions were closed-ended multiple choice, but with an opportunity for respondents to add other comments and answers where appropriate.

Pedestrians activities' in Oxford Street

- How often do you visit central London?
- What is your MAIN Reason for the time you spend outdoors in central London?
- How many minutes do you spend outdoors on the streets of central London per day (on average)?
- What would motivate you to spend more time outdoors on the streets of central London during the summer time?

Evaluate the Green Street-scape importance

- What do you think about increasing street vegetation and plants which may reduce pedestrian space and accessibility, however it would provide shade during summer and decreasing air pollution?
- To what extent would more vegetation and plants in the streets motivate you to walk longer (distances / more time)?

Evaluating the Proposed Green Street-scape in Oxford street (Questions illustrated with pictures)

- What do you think of this view? (current situation in Oxford Street) 0% Green
- What do you think of this view? (25% Green Wall)
- What do you think of this view? (25% Trees)
- What do you think of this view? (50% Green Wall)
- What do you think of this view? (50% Trees)

Evaluate activities and UGS choice reasoning

- How many (minutes) would you spend in central London per day (on average), after applying your preferred vegetation alternative (trees, green walls)? (e.g. compared to question 3)
- What do you think the reasons for choosing your preferred vegetation alternative above (trees, green walls)?

Demographic Questions

- Age
- Gender
- Do you have other comments?
- Would you like to be contacted for the results?

Figure 4-15 Survey sections and questions

This survey was designed to be completed online as shown in (Appendix B – Questionnaire Survey Design And Questions) whether through distributing it by emails or completing the survey on the researcher's laptop within the street for pedestrians within a busy environment in central London in order to cover a wide range of participants within the study with different street activities. Therefore, the survey was designed to be tailored for participants who would potentially have little time to spare (two to three minutes to fill out the survey). This questionnaire survey followed the University of East London (UEL) ethical approval process in order to be carried out as in Appendix C – Ethical Application and Approval.

Figure 4-15, Question sequencing was flowing logically from one to the next so as to achieve the best response rates and, hence, the questions were flowing from the least sensitive to the most sensitive, from the behavioural and factual to the attitudinal, and from broad wide generic question to the more specific question based on questionnaire survey design (Anol Bhattacherjee, 2012).

The first and second sections of the survey are based on single choice answers on pedestrian activities within central London streets for the first section which consists of four questions, then moving to the second part on evaluating UGS importance and relevance to their activities within the street with two questions. The third section is based on five different photos of current and proposed UGS for the street using a five-point Likert scale from Very unpleasant to "Very pleasant". The answers were coded from 1 for the extremely unpleasant view to 5 for extreme pleasant view with the suggested alternative. The third section is built on two questions investigating whether the proposed UGS alternative influences pedestrians' activities within the street through a single choice answer and the reasoning for their favourite UGS alternative through a multiple-choice question. At the end of the survey, a single answer question was meant to address participants' demographics and whether they have further comments or not through four questions.

The first section questions were designed to identify pedestrians' frequent visits to central London (how many days per week?) in order to identify and classify frequent visitors and in order to gain a more in-depth insight on the preference of frequent visitors compared to rare visitors and whether their visiting frequency will reflect on their UGS alternative choice or not. This was followed by the second question asking about the reason for being outdoors in central London streets (walking, tourism, transportation, sports, shopping, hanging around with friends). Subsequently, the third question checks the time span spent outdoors within central London streets during these activities in minutes from 15 minutes to 120 minutes so as to check whether the more extended time would have a different preference from the shorter time spent outdoors or not. Last, a fourth question focused on what would motivate pedestrians to walk more during summer (more vegetation, more sitting spaces, wider pavements, other)? This question helps to understand pedestrians' priorities for on spending time outdoors and whether UGS is a priority or not.

The second section questions focused on gauging the acceptability of UGS through questioning the participants about what they think about increasing street vegetation and plants which may reduce pedestrian space and accessibility; however, it would provide shade during summer and decrease air pollution. This was intended to quantify and measure pedestrian priorities and acceptance for vegetation disadvantages as taking up space within a bustling street, while the other question was to recheck whether more vegetation would motivate them to walk longer (distance or time), in order to validate if more vegetation would increase city walkability or not even with other disadvantages.

Third section questions gauge and quantify to what extent pedestrians would rate the current Oxford Street view with 0% green (current case situation) and 25% trees, 25% living facade, 50% trees and 50% living facade on a five-point Likert from 1 - Very unpleasant to 5 - Very pleasant. These questions give deeper quantifiable insights on human preference.

Fourth section questions were designed to recheck and to be compared with some questions which were asked before. The first questions ask similarly about the period the pedestrians would spend outdoors within central London after applying their favourite alternative in reality in order to check whether more vegetation motivates them to walk longer (time/distance) in addition to comparing this question's results to the same question about pedestrians' time span spent on their regular days with suggested UGS alternatives.

In comparison, the second multi-choice question tries to explore the reasons for pedestrians' choice for their favourite alternative which could be more one of the following: relaxation, connection to nature, increasing biodiversity, aesthetic improvement, improving thermal comfort, pollution reduction, and connection. This question is crucial for this research and future research as it could clearly identify what the priorities and prime concerns for pedestrians are. Based on this question, further research ideas, topics, and relations could be investigated.

Last, the fifth section of questions was about age, gender, other comments and whether survey participants would like to be contacted for future research results or not. These pieces of information were formed to categorise the participants for further analysis and correlations.

4.5.3.1 Confidence level and percentage

The error margin or confidence interval are the same and represents the plus-or-minus numerical values (participants' number) which are usually reported in studies or other related research, or print media or television, or opinion poll results. For instance, when a confidence interval of 5% and 45% percent is used of sample picks, a response "sure" means the entire relevant population between 40% (45-5) and 50% (45+5) would pick that answer to the question. The confidence level expresses how certain and definite it can be; it is illustrated as a percentage and symbolises how regular the actual percentage of the population who could be picking an answer lies within that confidence interval. The 95% confidence level represents that it can be 95% sure and confident; while the 99% confidence level confirms that it can be 99% confident (CRS, 1982; SSC, 2008; Qualitrics, 2020).

When the confidence level and the confidence interval are measured at the same time, it can be said that the sample is 95% sure that the actual percentage of the population is between 40% and 50%. The broader the confidence interval, the more confidence there is in the sample, and the more concise and accurate the whole population answers would be falling within that range. There are three factors which affect confidence intervals: the sample size, the population size and the percentage at which the more extensive the sample size is, the more confident we can be that their responses truly reflect the target population. This process reflects that for a given confidence level, the larger the sample size is, the smaller the confidence interval is. Nevertheless, the relationship is not linear (for example, doubling the sample size will not halve the confidence interval) (CRS, 1982; SSC, 2008; Qualitrics, 2020).

Most researchers use the 95% confidence level (Martínez-Mesa *et al.*, 2016) which is used in this study. The 95% confidence level means that if a whole population or sample frame completed the survey, the study will get the same results and answers as the survey sample which is in a range of (95% +5% = 100%) which means the same identical responses or (95% - 5% =90%) which means a 90% similarity between the sample response compared to the whole sample frame.

Based on that, the accuracy of the survey sample depends on the percentage of the selected sample, which picks a particular answer. If 95% of the sample have chosen "50% trees" and 5% have chosen "base case with 0% green" the likelihoods of error are very low, regardless of the sample size, which means that even if this was applied on a larger sample, the responses will be similar. Nevertheless, if the percentages are 52% and 48%, the chances and the probability of error are much larger, and it is easier to be confident of extreme answers than of average percentages. When specifying the sample size required for a given level of accuracy, it is advised to use the worst-case percentage (50%) in addition to determining a general level of accuracy for the sample. Moreover, it can determine the confidence interval for a specific answer which the sample has given.

4.5.4 Sampling strategy and procedures

Sampling can be identified as the method by which people or sampling units (houses, patients, trees, etc.) are selected from the sample frame. The sampling strategy and procedures need to be detailed in advance, knowing that the sampling method could affect the sample size estimation. Therefore, without a rigorous sampling process, the estimated sample derived from the sample frame may be biased (selection bias) (Martínez-Mesa *et al.*, 2016).

Sample size can be determined individually for each sample frame and each population, based on three factors which are the variability of the essential numerical variable, the confidence level required, and the acceptable level of error. The size of the sample final decision depends on the agreed balance between desired accuracy, time resources for conducting field survey and availability of financial resources (Wulf Killmann, 2002).

Frequent visitors to Central London are familiar with their own areas and are likely to have firmly held opinions about it, which will be helpful for this survey. The existing urban canyons where pedestrians walk is likely to have a considerable influence on how they perceive UGS; in a street of many attractive, well-maintained trees residents would probably have a complimentary view about trees. When there are no trees in the street, residents may be less well informed of the benefits of trees while taking a disproportionate view of the potential problems trees may cause. This means that pedestrians who are not frequently seeing streets might not be aware of the tree drawbacks within streets (taking up space, falling leaves, long bushes which need to be cut, etc.); therefore, that might lead to an inaccurate decision or bias towards trees or UGS in general. Pedestrians' attitudes may also be influenced by information advertising linked to street UGS and vegetation planting initiatives or pedestrians' involvement in recently completed UGS initiatives.

This identifies the sampling frame explicitly. To achieve the precise sample selection the researcher had to go through six stages (Guy M. Robinson, 1998). The *first* stage is defining the geographical area by specifying generic information regarding the study and its sample as its sample units, elements, sample area and the time period for this study. The *second* stage is defining the sampling frame by identifying how the geographical area elements can be described (shops, homes, etc.). This is followed by the *third* stage which specifies the sampling unit (participants) and whether they would be household, pedestrians, workers, or others.

Subsequently, the sampling method could be identified, whether through probability or non-probability schemes for the selected participants to approach the right sample for the study, which explained in depth in Appendix F – Survey Analysis. The fourth stage is identifying the sample size, which causes the study's satisfaction at which the responses does not change through a representative number of participants, representing the general number of the public.. Finally, the *fifth* stage specifies the sampling plan and method of collecting data through operational procedures necessary for selecting data on how to approach those specific targets. The sampling procedures have been developed through a stepwise process following (Guy M. Robinson, 1998) to construct a sampling frame, as in Table 4-4.

Table 4-4 Sampling Stages and process

Stages	**Process**
1. Define the geographical area	Defined in terms of: (a) units, (b) elements, (c) area, (d) time period

2. Define sampling frame	How the elements of the geographical area can be described
3. Specify the sampling unit	Identify units for sampling, e.g., city street, pedestrians
4. Determine sampling method	Methods by which units are to be sampled, e.g., probability vs non--probability schemes
5. Determine the size of the sample	The number of units to be selected
6. Specify the sampling plan and method of collecting data	The operational procedures necessary for selecting data

Stage1 (*Defining geographical area*)

The geographical area of the survey is limited to the local authority area of Westminster, London. This is because the Mayor of London Plan has been most concentrated in this area and because proximity to the research base meant that approaching survey participants should not become impractical. Pedestrians who work there are familiar with their own street and are likely to have firmly held opinions about it; so, questions connected to the street environment were considered most appropriate.

In order to choose an area for the case study, area criteria must be produced to assure that the final selected case study area will fulfil research objectives. In order to achieve the aims and objectives of this research, the case study area should be:

1) A heavy density urban area, with a wide range of pedestrians' activities and.
2) An area with an extensive combination of socioeconomic and cultural background groups, so as to investigate different attitudes, backgrounds and behaviours of pedestrians within the street.
3) Wide-ranging urban areas of the high-density urban environment which has a broad range of urban canyons with mixed built environments (commercial, residential, etc.)
4) This urban area should have a broad range of different activities and users so as to minimise pre-classification.
5) An area with low UGS cover, so as to check how the suggested study would influence users.

6) This area should be representing similar spaces in order to have the flexibility to be widely applied.

Stage 2 (*Sampling frame*)

The sampling frame is within a dense urban space and the specific urban street canyon types within these areas, the sampling unit—the types of high-density streets within these areas formerly needed to be classified. There are different methods of urban area classification in the literature, including Space Syntax (Hillier and Hanson, 1984) Alexander's Pattern Language (Alexander, 1977), and Route Structure Analysis (Marshall, 2005). These focus on the future design of urban areas, highlighting urban network analysis (streets) and the connection between various types of urban land use, instead of focusing on the analysis of existing structures. Therefore, the study focused on high density and high pedestrian traffic streets, which particularly focused on central London as a potential area to apply different UGS.

Stage 3 (*Sampling unit*)

Within the different pedestrians' sampling unit, activities, actual street visits, and time spent outdoors needed to be sampled via a suitable method. Classification of pedestrians based on their activities was not considered appropriate due to the high level of data collection required to classify pedestrians' reasons for visits and time spent in the area. The sampling unit changed from focusing on workers at M&S, Oxford Street to cover all pedestrians visiting central London, whether for work reasons or not.

The existing streetscape where pedestrians walk frequently is likely to have a considerable influence on how they perceive UGS; in the street with many eye-catching views, well maintained UGS might need comments and suggestions from pedestrians who are the frequent street visitors. Since pedestrians could have mistaken thoughts about the benefits or associated problems and challenges of the UGS.

Stage 4 (*Sampling method*)

Data collected in this research could be used to conclude findings for a wider area across whole London; so a probability sampling method is essential for data collection. The two most simple forms of probability sampling are random sampling and systematic sampling (Guy M. Robinson, 1998; Martínez-Mesa *et al.*, 2016). Complex multi-stage sampling was used to identify the precise sample from the sample frame. First cluster sampling was used to pick central London visitors, which identifies the sample graphically. Then two rounds of statistical sampling were followed in order to narrow down the sample. Convenient stratified sample is utilized through approaching the researcher's connections and colleagues to take part in the study. On the other hand, exponential non-descriptive snowball sampling was used to approach more people by distributing the survey online through Facebook.

Stratification can be used to reduce these problems in both sampling strategies. Random sampling within a spatial (stratification) sampling frame can produce an additional spread of sample points within a pre-defined area (Robinson, 1998). Random sampling was selected as the best sampling strategy for investigation of pedestrian street activities and time spent outdoors in the street. Risks of oversampling in one pedestrian group (age, gender, visiting and time patterns) and under-sampling in another are not a great worry due to the wide variety of pedestrians and their activities, interests and backgrounds.

This research has adopted a complex sampling approach consisting of *cluster* sampling, *convenience stratified* sampling and *exponential non-descriptive snowball* sampling.

Stage 5 (*Sample size*)

The minimum sample size was specified based on the sample frame, which is the number of workers at M&S, which were around 200 workers. This target sample was pre-planned as staff working there would be familiar with Oxford Street across the whole year. Hence, they will have a stronger view and comments on UGS benefits within this busy street. Nevertheless, while applying that on a wide scale to cover central London instead of Oxford Street alone with time limitation as well (sample saturation time) due to the study time constraints the researcher extended the sample frame to reach anyone who visits central London. The sample frame was around 1.1 million visitors (TfL, 2019) and based on that the response rate and sample bias can be specified.

Stage 6 (*Sample plan*)

Finally, after collecting all sample responses and survey data, it was first analysed on the SOGOSURVEY website in presentable charts to illustrate initial outputs and results from participants. Subsequently, it was applied to JASP software in order to create further and more in-depth statistical analysis and correlations between questions.

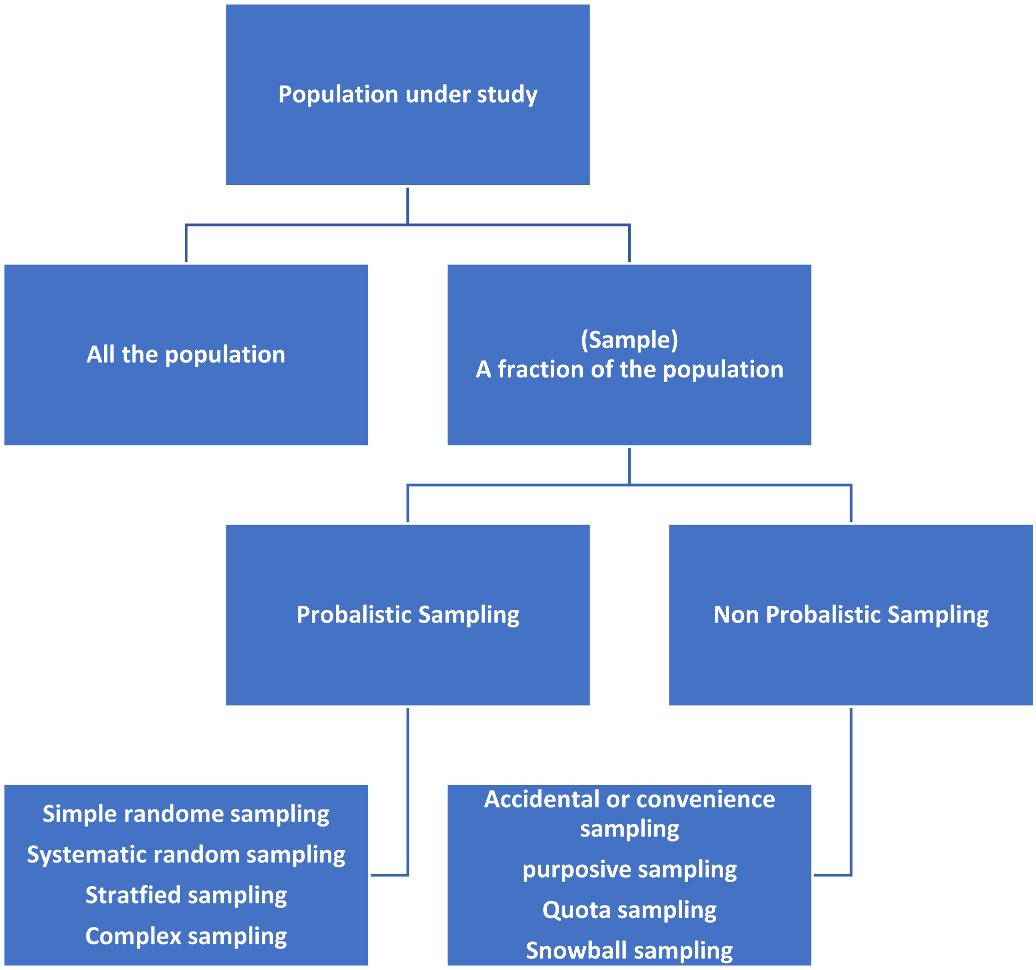


Figure 4-16 Sampling statistics cover two non-probabilistic and probabilistic sampling (Anol Bhattacherjee, 2012; Martínez-Mesa *et al.*, 2016).

4.5.4.1 Sampling statistics

Figure 4-16 shows sampling statistics that cover non-probabilistic and probabilistic sampling. Non-probabilistic sampling covers convenience, purposive, quota, and snowball sampling while probabilistic sampling covers simple, systematic, stratified, cluster and complex/multi-stage sampling (Anol Bhattacherjee, 2012; Martínez-Mesa *et al.*, 2016).

Non-Probabilistic Sampling is the likelihood of picking some individuals from the target population is zero. This type of sampling does not represent a typical sample; so, the outcome results are commonly not generalisable to the target population. However, unrepresentative samples could be helpful for particular research objectives and may help answer specific research questions, in addition to contributing to the generation of new hypotheses. There are different types of non-probabilistic sampling:

Convenience (consecutive) sampling occurs when the participants are successively selected in terms of appearance according to their accessibility convenience. The sampling process saturates (ends) when all the survey participants (sample saturation) or the time limit(time saturation) are reached. After sampling, participants are randomly distributed to the control group or the intervention group (randomisation). Although randomsation is a probabilistic process, the samples used in these studies are generally not descriptive of the target population. *Snowball sampling*: At this stage, the researcher picks an initial group of participants, who in turn suggest additional potential participants for the study with similar characteristic. This is commonly used in studies investigating unique characteristics of the populations. *Quota sampling*: The population is first classified by features such as age or gender. Then, sampling units are selected to complete each quota to reach sample saturation with sufficient numbers based on each study's requirements. *Purposive/Experts sampling* is commonly used when a diverse sample is required or the opinion of experts in a specific field is the subject of interest, and it is a precise sampling.

Probabilistic Sampling occurs when all target population elements have a probability of non-zero to be involved in the study. If all participants are equally expected to be picked in the study, equi-probability sampling is being used, and the odds of being selected by the research could be presented by the formula: P=1/N, where P equals the probability of taking part in the study and N represents the size of the target population. The different types of probabilistic sampling follow:

Simple random sampling is a full list of sample participants or units (sample basis), and the researcher randomly selects participants using a table of random numbers. All likely subsets of a population or the sampling frame have an equal selection probability. *Cluster sampling* is when sets, clusters and groups which are classified based on a geographical basis such as health facilities, schools, etc., are sampled. In the study, as mentioned above, the selection of central London visitors is an example of cluster sampling. *Systematic random sampling* is when participants are drawn with equal intervals previously identified from a participant's ranked list. Systematic sampling includes a random sample start and subsequently proceeds with the choice of every k the division from this point forward, where k = N / n, where k is the sampling ratio of frame size N and the (n) desired sample size and is defined as the sampling ratio.

Stratified sampling is first classified into separate strata. Subsequently, samples are selected within each stratum, either through simple or systematic sampling. The total number of selected participants in each stratum can be fixed or proportional to the size of each stratum. Each participant is equally likely to be selected to participate in the survey, although the fixed method typically includes the use of sampling weights in the statistical analysis (inverse of the probability of selection or 1/P).

Complex or multi-stage sampling combines different strategies in the sample unit selection, depending on the study's sampling necessities, and these single-stage techniques can be combined towards conducting multi-stage sampling. All of the expected sampling strategies within different stages are considered in the statistical analysis to provide correct estimates.

In general, survey sampling starts with a survey population, which is then narrowed down to a fraction of the population (sample frame). Subsequently, more in-depth statistical analysis is carried out through two major sampling types which are probabilistic (simple, systematic, stratified, complex) and non-probabilistic (accidental/convenience, purposive, quota, snowball). Based on these vast differences in each one's use and objectives, a complex multi-stage sample was used to identify this study's sample (probabilistic sample).

First, the sample was classified geographically as a cluster sample to identify people who are visiting central London. Then through survey distribution, the survey was distributed through two methods (email and WhatsApp group) to approach colleagues and connections of the researcher; this is classified as convenience stratified sampling because it is convenient and fits the sample saturation time frame of the research On the other hand, the survey was shared within Facebook pages and groups for people who live or work in London through exponential non-descriptive snowball sampling).

4.5.4.2 Target and study population

The target population has changed slightly before and after COVID-19. At the beginning, the survey was targeting workers within Oxford Street, as they usually visit it on a daily basis and spend most of the time there. At the same time, visitors might come to the Street due to its location or to fulfil their needs Nevertheless, due to the research time limit, this survey was limited to workers within Mark & Spencer (M&S) and TfL workers within Oxford Street. Oxford Street consists of approximately 300 shops which are serving around half a million visitors on a daily basis while the number of workers within the Street is around 50,000 s in different sectors (Westminster Council, 2018; Westminister, 2019). Oppenheim (1992) asserted that sample accuracy is more important than the sample size, while the sample size is more critical for statistical group differences.

Thus, the process of selecting participants (sampling selection) was focused on Oxford Street frequent visitors as they would be most likely to have a direct relationship to the proposed UGS changes. The targeted participants were those working in Oxford Street either at M&S (around 200 employees) or TFL. However, due to COVID-19, the participants have been widely open to anyone who visit central London and hence the sampling strategy has changed from simple random sampling of M&S workers in Oxford street to all visitors of central London. Therefore, the familiar travellers to central London (about 80% of 1.1 million) come by surface railway (860,000 daily) or by Underground (400,000 daily) (TfL, 2019). The target population was expanded to cover more people due to the access limitation to M&S store during COVID-19 in addition to limiting physical interaction with people, hence, the research should be distributed online and the population has changed from M&S store workers to cover all central London visitors.

4.5.4.3 Sampling selection and participants' recruitment approaches and response rates

The data collection was intended to be carried out in collaboration with Marks and Spencer (M&S) Oxford Street and Transport for London (TfL) and the Greater London Authority (GLA). The researcher participated in the preliminary consulting stage with the TfL and the GLA. The GLA has been working on the Mayor of London Plan to make London the greenest city in the world by the 2050s in parallel with the TFL Healthy Streets plan.

Both projects, as well as this research, seek to motivate pedestrians and Londoners to walk more by improving comfort levels within streets by improving thermal and aesthetical levels for pedestrians through using different UGSs. The research objectives, methodology, future benefits and incentives were introduced to the GLA and TfL in order to establish the research collaboration.

The questionnaire was created online via So Go Survey (online survey website) and emailed to the TFL and M&S employees to distribute the survey across their workers within Oxford Street. The proposed sample is supposed to be unbiased (neither chosen nor within the researcher's close circle). It was chosen based on clustered (area) sampling, which is classified based on geography and location, whereby people who work in stores along Oxford Street would be invited to participate in the survey as they are the most involved and have direct connections to Oxford Street, and any future improvements. However, this was planned before COVID-19 as participants' recruitment was intended to cover central London visitors.

Subsequently, stratified random sampling was applied to make sure that there were equal samples for the different selected companies whose employees would participate in the survey Selection of workers at M&S and the TFL at Oxford Street was based on to the intention to gather the perceptions and feedback of most frequent visitors to the street who would be affected by any changes Since it is impossible to approach all Londoners and residents who travel to Central London (1.1 million visitors to central London by the TfL (TfL, 2019) the sample recruited in this study was calculated based on the average central London Visitors through a survey sample calculator which is found in several online survey websites (such as (CRS, 1982; SSC, 2008; Qualitrics, 2020).

In order to calculate the precise sample size, the researcher used the SSC (SSC, 2008) in which he included the confidence level of 95% because it is the most common in research although there are no restrictions about the confidence levels. The researcher specified a margin error of 5% and the sample was about 50% of the population proportion as there are equal chances of the sample percentages' to be higher or lower than the selected population percentage.

When the population size is 1.1 million visitors, then the suggested sample size is 385 which is needed to achieve a confidence level of 95%, so that the real value is within ±5% of value. However, when a larger sample population is placed later on after distributing the survey via online platforms, the target sample frame reached 3.2 million with no change in the sample size as the SSC showed the same sample size of 385 participants. In order to reach this target sample, a reasonable response rate should be calculated, and it should be around 10% to 15% (conservative percentage), through dividing sample size over expected response rate (Bsurvey, 2014). So, if there is a sample size of 385 participants and an estimated response rate of 10% (worst case scenario) then the suggested approached sample is 385/0.1= 3850 participants.

The researcher approached the target population. A sample was selected to participate through the questionnaire survey that was mainly online via the researcher's and his PhD supervisors' circles, WhatsApp groups for Arab students at UEL, Facebook (FB) groups (such as Extinction Rebellion Rewilding, Climate Action Litigation UK, Living in London, Stop Killing Cyclists, Europeans in London, UK Marathon & Ultra Running, XR Volunteers, Tree Planting UK, LONDON LONDON AE, London friends, Walk London, Extinction Rebellion London, Extinction Rebellion London Group, Plant Swap LONDON, Handpicked London, Forest Garden UK, Peoples Climate March London, LONDON, Climate grief & eco anxiety hub for academics and concerned citizens, Tree Planting UK, Climate Action - Events and News (UK group), Jobs in London – UK, East London (Stratford, Ilford, Canning Town, Forest Gate, Barking ++), Europeans in London, Shooting People – London, London friends, Sustainable London, London Festival of Architecture, Growing in Haringey, London Students, Greenpeace UK, Trees for Cities, The Woodland Trust, Campaign against Climate Change, Londonist, UK Student Climate Network, UK Youth Climate Coalition, and Egyptians in London).

The researcher distributed his survey online through online platforms particularly within FB groups for people who live in London because it will impact on their life in London and FB groups and pages which has people who might become interested in the research topic and goal as it is related to the group FB page interest and field such as climate change, hiking, nature, tree planting, etc.. Those 42 pages and groups have 3.2 million plus followers with approximately 76,480 followers on average for each group and fan page. Alternatively, some of those people could be joining several groups at the same time.

Surprisingly, across those 42 FB pages and groups, the questionnaire survey did not generate much reaction, even with climate change, tree planting, and other climate and environment-related FB pages and groups as only 12 FB page/groups only had responded to the survey from the 42 FB pages. The followers had a reaction of 61 likes and 50 comments (including replies confirming completing the survey). Overall 598 participants completed the survey, mainly from FB pages since the researcher collected around 120 completed survey through his connections before distributing the research online, so he targeted an extra 265 participants to reach the survey saturation in order to avoid any of his extended network bias which led him to share it on FB and LinkedIn, and he achieved 478 through FB and zero from LinkedIn.

After the researcher distributed the survey link via online platforms, he received more than the 265 participants which he needed to reach the optimal or Ideal Sample Size, and luckily the researcher has received a total of 478 participants. Hence, he started into calculating what would be the margin error in that case if the confidence level is still 95% and the sample size is 598 with population proportion of 50% and population size of 3.2 million expected London visitor sample frame in order to cover the larger population (instead of the 1.1 million confirmed London visitor by the TfL The researcher found the margin error decreased from 5% based on suggested sample size previously (385 participants) to reach 4% which means, in this case, there is a 95% chance that the real value is within ±4.01% of the measured/surveyed value.

4.5.4.4 Piloting the questionnaire form

The questionnaire survey was conducted in two phases. The first phase examined the questionnaire form to obtain feedback and comments for enhancement. This was achieved through sharing the questionnaire with the TfL members and specialists, research supervisors, and colleagues who have used questionnaires for their own research, as well as randomly sampled students in the UEL Docklands Campus. Constructive feedback was acknowledged regarding the questionnaire structure and content, which helped to solve issues of the length of the questionnaire, ambiguity and unclarity of to some questions, and wording. Subsequently, modifications and enhancements were undertaken to construct the final questionnaire. On the other hand, piloting questions on different people with different backgrounds and motivations to UGS showed the roughly estimated time needed to complete the survey. This increased the researcher’s confidence level regarding the wording and clarity of the survey questions and photo illustrations included; for instance, questions 3 and 12 which both ask the same question regarding pedestrian time spent outdoors within central London before and after applying UGS. The researcher was worried that the sample would not notice the difference and would give the same answer, which did not happen. Meanwhile photo illustrations for different UGS intervention pictures showed that the sample has clearly noticed each picture and which UGS applied within.

The second phase for piloting the questionnaire was through emailing the survey link to TfL and M&S so they could forward it to their workers via emails in addition to face to face completing a survey online in order to boost survey completion and reach a satisfying sampling size. Subsequently, a comparison was made to see the response rate between sent emails and surveys completed online, and surveys completed face to face on the other hand.

Emailing the survey online had both advantages such as cheap, fast, covering a large number of participants, and anonymity, and disadvantages mainly due to low response rate, non-verbal behaviour, no control over the environment in which the questionnaire is completed in, probability of not understanding questions, leads to either increasing the number of unanswered questions or biased answered questions (Kafafy, 2010).

Face to face survey has benefits such as higher response rate compared to email questionnaires, ability to observe nonverbal behaviour, ability to record spontaneous verbal answers, control of time, the ability to set a time schedule for accomplishing the data collection task, respondents could be observed during their answer, higher reliability of collected data). Disadvantages can be expensive due to transportation and spending time, time consuming, the time of the interview might be inconvenient for the interviewee, and less degree of anonymity (Kafafy, 2010). But that had to stop after identifying that COVID-19 as a pandemic.

The number of participants who completed the survey each day starting from 15 May 2020 until 24 June 2020 shows that most participants have completed the survey in the first week. The first day, 43 participants completed the survey, while 152 participants completed the survey on the second day, 121 on the third day and 78 on the fourth day. The remaining days, re did not exceed 24 participants, and only one and two participants responded on the last two days of the survey. In total, the survey link was accessed by 2112 prospective participants, including people who completed the survey and people who did not, while 598 participants completely finished and submitted the survey, representing 28.3% of those who accessed the link number.

4.5.4.5 Photo elicitation

The second research step involves human participation as they will be interacting with the applied UGS; thus, it makes senses that pedestrians choose the preferable UGS alternative within Oxford Street. To illustrate the proposed UGS, it involves visual illustrations for current and proposed UGS. Taking pictures in Oxford Street and interpreting those pictures was the best way to illustrate conceptual alternatives for pedestrians to help them decide their favourite alternative.

The researcher captured several photos in order to choose between them in different positions, locations and spots within Oxford Street within human-level vision, in order to be able to decide the most appropriate picture to be used later for photo-editing through photoshopping to add suggested UGS within the street. For landscape photographs in combination with questionnaires, based on a study by Dupont, Antrop and Van Eetvelde (2014) for participants within surveys with pictures, Responses will probably be more accurate and detailed if panoramic photographs are used.

Figure 4-17 Oxford Street picture current situation 0% green (researcher)

From Figure 4-17, the best image captured through the latest photo was Panoramic photo which shows two streets, Oxford Street (case study) which represents East-West orientation, and Park street which is North-South orientation, because the feelings of greenery were mainly related to the vision width of street view, while the amount of greenery perceived was influenced by the walking distance (Aoki, 1991). This was also confirmed by Jiang *et al.* (2014) who asserted that eye-level green cover density is closer to people’s visual experience as it has a similar visual viewpoint and perspective and it has a better influence on people than layout view.

This picture was chosen across other pictures because it mainly shows the whole streets with buildings and stores and any other street furniture (traffic lights, garbage baskets, etc.) in addition to UGS (trees, bushes, lawns, green walls, etc.) which is not existing.

Figure 4-19 Oxford street, 25% Living facade alternative

Figure 4-18Oxford street, 25% Trees alternative

Figure 4-19, Figure 4-18, Figure 4-20 and Figure 4-21 represent the proposed UGS alternatives (trees, living façade) and their cover percentages (25% and 50%) of the canyon were chosen based on its thermal benefits from ENVI-met simulations which were carried out by the researcher in the first phase of the research (software simulation). Cool pavement (high albedo pavement) was removed from the picture as it increased thermal stress which will not be beneficial for pedestrians; thus, it was ignored.

Subsequently, alternatives were illustrated by Adobe Photoshop CC (2019) software in four pictures (25% trees, 50% trees) and (25% living façade, 50% living façade). Each photo represents an alternative to be used within the questionnaire survey later.

Within this research UGS density (covering percentage) is used instead of green street-view factor as the researcher is looking at covering all London city streets to achieve the Mayor of London plan by 2050. The researcher is also looking into thermal benefits of UGS instead of only visual aesthetical benefit (green street-view factor). The findings will assist planners to strategically select the locations, sizes, and types of UGS to achieve maximal benefits thermally and visually for pedestrians.

Figure 4-20 Oxford street, 50% Living facade alternative

The researcher spent ample time trying to capture the best picture for Oxford Street without people and transport where possible. . This was mainly to avoid any effect which might cause bias while comparing between UGS alternatives and the main base case.

It is worth mentioning that the applied number and percentage of trees and living façade are exactly as applied within ENVI-met simulation, which was previously simulated to indicate the thermal benefits. Although it would have been easier and time-saving to compare the base case and UGS alternatives within ENVI-met 3D model geometry visualisation, the visualisation within ENVI-met software was not realistic enough to deliver the futuristic images and proposed alternatives.

Figure 4-21 Oxford street, 50% Trees alternative

4.5.4.6 Observation

One of the main benefits of observations within research is its truthfulness and directness in reflecting actual cases as it helps researchers to study behaviours in a clearly visible way where the researcher can just watch and observe This finally led to collecting first-hand data so preventing "contamination " or distortion (Frankfort-Nachmias, 2008). The research observation was totally natural and uncontrolled. A mix of direct and indirect observation was implemented where direct observations mean seeing people and their actions (as behaviour) while indirect observations include the consequences of people's actions (Rugg and Petre, 2007).

For instance, in this research, direct actions would be noticed on how people will react to different photoshopped pictures for Oxford Street (before applying UGS and after) with different green percentages. How long did it take different survey participants to realise the difference between 25% and 50% living façade and trees, for example? This was valuable for two reasons: first, it shows that participants realised the difference between the four suggested UGS alternatives with different vegetation percentage and hence that showed they were able to identify their preference. This was noticed when they looked at the 50% LF and then returned to the 25% LF to quantify their preference, which has repeated for the 25% and 50% trees. The second reason for the importance of observing participants while filling out the survey is that the researcher reassured participants that they were able to easily realise the difference and change in the UGS alternatives and the change in their percentage.

4.5.4.7 Questionnaire survey ethical approval

Ethics approval was received specifically for the online distribution of the survey and use of the statistics and data for the thesis. At this point, the researcher first phase highlighted that participation in the questionnaire is voluntary and that the interviewee's decision would be appreciated with thanks. Besides, participants stated that the interviewee is free to end the questionnaire whenever desired, and he/she is free not to complete the whole questions. All participants were fully informed about the questionnaire's procedures, and the aim and objectives of the study. The participant's verbal willingness to complete the questionnaire was considered a 'signed consent' for his/her approval to go ahead.

Two ethical considerations are applied to assure the privacy of research participants: confidentiality and anonymity. Within this research, the anonymity of participants was chosen to guarantee complete privacy. Participants were guaranteed that their identity is anonymous throughout the study. This was similarly clearly specified in the cover letter, and no place was provided in the questionnaire for any contact details of the participant so as to guarantee anonymity.

The questionnaire did not include any sensitive information or questions regarding participants in terms of personal, physiological or psychological status, either directly or indirectly. Where possible, participants' confidentiality will be maintained unless disclosure is made that indicates that the participant or someone else is at serious risk of harm. Such disclosures may be reported to the relevant authority. Participants will be anonymised at source through completing an online survey with no form of personal identification requests.

The samples and data are not de-identified. Participants will be anonymised in publications that arise from the research. Participants will not have the option of being identified in the research project and disseminating research findings and/or publication. The data generated in the course of the research will be retained in accordance with the University's Data Protection Policy. The data will be stored safely on a password-protected computer. The raw data will not be shared with individuals outside of the research team. Participants will not be audio and/or video recorded.

4.5.4.8 Research rigour

For the evaluation of the questionnaire survey, varied rigour principles were applied depending on whether the analysis is quantitative, qualitative or mixed methods. Since this research is quantitative, validity, reliability and replicability were used for the quantitative phase and credibility, dependability, transferability and confirmability for the quantitative rigour. The following sections explain how the rigour was achieved during the research (Woodford, 2015).

According to Bryman (2012) and Woodford (2015), validity is the most significant evaluation criterion that explains the truth of the research's conclusions and answers the main question and objective and whether the selected tool measures what the researcher intends to measure. The type of research question depends on the statistical analysis from a statistical point of view (correlational, descriptive or groups differences).

Reliability usually represents whether the questions are consistent or not, or repeatable and whether the measurements are stable or not. For this study, reliability is high as measurements (questions of the questionnaire survey) are built on the questions formerly established concerning pedestrians' walkability and preference within streets and their thermal comfort levels.

Confirmability has an equivalence to neutrality or objectivity at which it inquires whether the researcher allowed his skills and perceptions to affect or interfere with the research outcomes and conclusions, in addition to avoiding bias through reflective commentary and triangulation. Feedback from collaborative teams (TfL) and research supervisors and colleagues have helped reach confirmability while approaching, contacting and presenting the survey to the target sample.

4.5.4.9 Survey limitations

There are several practical and theoretical reasons which limit researchers from performing census-based surveys which covers the whole or extreme large number of participants, according to (Martínez-Mesa *et al.*, 2016):

Ethical issues: it is unethical to cover a larger number of participants than effectively required; however, that could be considered to increase the accuracy. The sample satisfaction level was set at 385 participants; however, 598 responses were received. Therefore, the researcher increased the survey accuracy to 96% instead of 95% and decreased the error margin in sampling to 4% instead of 5% which was explained in detail on page 148, in the section on Confidence level and percentage.

Time limitation: the amount of time needed to design, plan, improve and carry out a census-based survey may be excessive in addition to giving more time to allow more participants to take place. This was not totally helpful or practical due to the PhD research time limitations and deadlines; therefore, the researcher ran the survey for two months.

Financial limitations: the high expenses of a census survey usually limit its use as a strategy to select survey participants for a study. It would have been better if there was more funding available to target and include more diverse opinions, particularly if there were people who disagree on applying UGS because usually surveys are completed by people who are interested in the topic.

Logistical limitations: censuses often include several challenges in terms of required staff, tools, equipment, etc., to deliver the study. These challenges were due to the fact that the researcher had to carry out the survey distribution himself without the assistance of other parties as TfL and M&S, which was originally the plan.

Unusual circumstances: This happened due to COVID-19, which might have influenced participants' responses to how they react and perform within their daily lives within central London streets. For instance, most of the participants were in lockdown and had to work from home, which does not represent the actual case of travelling to central London.

Meteorological (seasonal) limitations: Seasonal difference between the time and season of what the participants are in at the time of the survey (May 2019) and during the extreme summer (21 June). Such warm conditions during the survey can influence responses.

4.5.4.10 Biases in survey research

Survey research is usually influenced by five systematic biases that could invalidate results; these are the non-response bias, social desirability bias, sampling bias, recall bias, and common method bias.

Online surveys tend to include an unequal number of scholars and younger people who are frequently using the Internet, and systematically eliminate people with restricted or no access to computers or the Internet, like the poor or the seniors. Correspondingly, questionnaire surveys are likely to exclude youngsters and the uneducated who are unable to read/write, comprehend, or respond to the survey. A dissimilar type of sampling bias relates to sampling the incorrect population, for example, asking parents or teachers about their children's academic learning or asking chief executive officers (CEO) about operational details in their company. Such biases make the participants sample unrepresentative of the targeted population and influence generalisability claims about drawing suggestions from this biased sample.

Recall bias: Responses to survey questions usually depend on subjects' motivation, memory, level of understanding, and their ability to respond. Specifically, when discussing events that occurred in the past, survey participants could not precisely remember their own behaviours, patterns, motivations, or memories of such events which have faded from memory over time and hard to retrieve. For example, if a participant was asked to describe his/her outdoor activity pattern a few months ago in central London or even memorable outdoor events before COVID-19, their response may not be accurate due to difficulties with recall. In order to overcome the recall bias this is done is by retrieving the respondent's memory in specific events as they happened, rather than expecting them to recall their perceptions and motivations from memory.

social desirability bias: Many respondents are likely to avoid bad opinions or embarrassing notes about themselves, their managers, friends, and family. With negative questions – for example, do you think that your teamwork is dysfunctional, are there many office politics in your organization, or have you ever criminally or illegally watched or listened to a movie or music from the Internet? –the researcher would be less likely to get truthful, unbiased responses. This tendency across participants to "spin the truth" to represent themselves in a socially appealing and desirable manner is called the "social desirability bias", which fakes and diverges the validity of response achieved from survey research. There is practically hard to overcome the social desirability bias in a questionnaire survey; nonetheless, in an interview setting, a wise interviewer could be able to spot inconsistent answers and ask investigative questions or use personal observations to supplement respondents' comments.

Non-response bias: Survey research is usually well known for its low response rates. A mail survey typical response rate is 15-20, even after follow-ups and reminders. If most of the targeted participants fail to respond to the survey, then a real concern is whether non-respondents are not participating because of a systematic reason, which could raise inquiries about the validity of the research's results. For example, dissatisfied customers are likely to share their experience more than satisfied customers and more likely to respond to questionnaire surveys or interview requirements than satisfied customers. Therefore, any respondent sample is likely to have a higher proportion of dissatisfied clients than the underlying population from which it is drawn. On this occasion, the results lack generalisability, and the recorded outcomes may also be an artefact of the biased sample. Several strategies may be taken into consideration and used to improve response rates:

Advance notification: A short message sent beforehand to the targeted participants petitioning their involvement in an upcoming survey can break the ice for them in advance and enhance their tendency to respond. The message or means of contact should state the purpose and prominence of the study, type of data collection (e.g., email, online, via a phone call, a survey form in the mail, etc.), and gratitude for their assistance.

The relevance of content: If a survey studies issues and challenges are relevant or significant to respondents, then they are more expected to respond to surveys than other people.

Respondent-friendly questionnaire: Shorter survey questionnaires tend to provoke higher response rates than lengthier questionnaires. Moreover, questions that are short, clear, non-offensive, and easy to respond to tend to attract higher response rates and interest from a more comprehensive range of participants.

Follow-up requests: Multiple follow-up requests could change the mind of some non-respondents to respond, although their responses are late.

Confidentiality and privacy: Assurances that participants' private data or responses will not be shared with third parties could help improve response rates.

4.5.4.11 Statistical analysis software

Statistical tests were carried out on the data using SoGoSurvey, SPSS (version 15, SPSS Ins., 2006), Microsoft Excel 2003, and JASP (Jeffreys' Amazing Statistics Program) Version 0.14. The response is a quantifiable value submitted by sampled participants. Each participant would give a different response to different questions in a survey. Responses from different participants to the same survey or question could be graphed into a frequency distribution based on their existence frequency. For a vast response number in a sample, this frequency distribution tends to be illustrated by a normal distribution (a bell-shaped curve), which could be used to represent general characteristics of the entire sample, such as sample mean (average of all observations in a sample) or standard deviation (variability or spread of observations in a sample) (Anol Bhattacherjee, 2012).

These sample evaluations and calculations are called sample statistics (a "statistic" is a value that is assessed from collected data). Populations likewise have means and standard deviations which can be obtained if we could sample the entire population. However, since the whole population will never be possibly sampled, population characteristics are usually unknown and are called population parameters (not "statistics" because they are not statistically estimated from data). Sample statistics could vary from population parameters if the sample is not representative of the targeted population and the difference between the two is sampling error. Hypothetically, whenever the sample size increases to become closer to the population, then sampling error will decrease, and a sample statistic will increasingly approximate the corresponding population parameter (Anol Bhattacherjee, 2012).

4.6 Conclusion

In this chapter, the research methodologies used have been discussed. Simulation software and questionnaire survey adjustments, procedures and specifications were further explained individually according to five main sections in terms of UHI, different UGS as a mitigation strategies, thermal comfort and questionnaire survey creation, design recruitment of sample, and analysis. This chapter has presented an urban characterisation for central London street vegetation percentage. The results illustrate that the UGS coverage is less than 1% in general, although London UGS coverage is 47% in total by the GLA.

The research aim is to investigate the impact of UGS on climate change adaptation and mitigation in current 2018 and future climate scenarios, the 2050s and the 2080s in determining its influence on UHI and carbon sequestration quantitatively. The adaptation planning needed by the UK Climate Change Risk Assessment illustrates that climate change should be mainstreamed in all areas affected. The predicted uncertain climate change variables will reflect on future decisions with lower regrets; thus, a more comprehensive range of prospective climate change scenarios will be needed (Defra, 2009; DEFRA, 2012).

Thus, based on these findings, a quantitative method is used (LN Groat; and D Wang, 2002; Dunleavy, 2003) within this research. The researcher collected technical, functional and behavioural details of UGS "cool pavements, green wall and trees" drawing from previous studies with similar analysis and relations, as well as the conclusions of these findings.

The quantitative analysis is used since according to Deming and Swaffield (2011), simulations are illustrations of the characteristics and features of a real-time state. Simulation is distinguished from static representation and numerical predictive modelling through focusing on dynamic relationships of UGS and UHI effect (Deming and Swaffield, 2011). While analysing the methods to use for this thesis the impact of UGS on urban canyons to determine the influence on UHI, a simulation was carried out to determine and imagine the urban impact and influence through applying UGS on prototype residential buildings, within the urban street canyon. The strategies used in the research include exploring, forecasting, testing, and learning (Deming and Swaffield, 2011).

The simulations are conducted for computerised models using “ENVI-met for urban design and creating an urban environment in a canyon where different urban vegetation scenarios are applied in a canyon by applying UGS with different percentages in different street orientations. These scenarios are addressed to assess the impact of UHI on present and future climate scenarios (2018, the 2050s and the 2080s with different carbon emission scenarios – low, medium and high. This resulted in three possibilities for each year of them, which finally illustrates the mitigation level and improvement quantitatively to our future climate.

On the other hand, real field analysis is also carried out (LN Groat; and D Wang, 2002; Dunleavy, 2003) within the street canyons (NS and EW), by measuring current UGS within that canyon and its influence and impact over the UHI effect and pedestrian thermal comfort. These two approaches – computer simulation and real field analysis – lead to more confidence and increased certainty about the UGS impact and influence on future climate scenarios.

Subsequently, a questionnaire survey was distributed online after the emergence of the COVID-19 pandemic. Initially this survey was designed for Oxford Street workers, but this changed to cover all central London visitors due to the lockdown and social distancing rules. The survey questions are based on ENVI-met simulation results to specify how participants would be influenced by different UGS alternatives and whether participants' activities would change before and after applying UGS.

5 Chapter 5: ENVI-met simulation results and discussion

5.1 Introduction

This chapter provides more in-depth investigation and studies on the influence of different urban green systems with different percentages on pedestrians' thermal comfort and carbon dioxide across different years. The chapter is classified into two phases; the first phase explores the influence of different UGS on UHI and CO_2. The second phase is based on generating the most appropriate UGS alternative with the most appropriate UGS density (percentage of green coverage) in each canyon orientation. Later on an argument is carried out in order to formulate a scientific discussion between the current research findings with similar research findings.

In this chapter, an investigation is carried out by looking at the thermal comfort levels from different urban green systems in 2018, followed by 2050 and 2080 scenarios. The thermal comfort indices applied are physiological equivalent temperature, predicted mean vote, predicted percentage of discomfort, and considering the influence on different UGS on Carbon Dioxide sequestration.

Subsequently, the second phase investigates the performance of applying the most appropriate urban green system and its percentage for each year based on previous simulations in order to indicate the most appropriate percentage and urban green system for both increasing pedestrian thermal comfort and for carbon dioxide sequestration.

5.2 *Proposed ENVI-met simulation scenarios*

In order to evaluate the optimisation for the proposed UHI mitigation scenarios through using UGS concerning carbon sequestration and pedestrian human comfort (PTC), the actual current case (base case) empirical model will be testing the following scenarios:

1. Base case: simulation of the real situation with asphalt streets and other surface pavement and concrete sidewalks; locating and modelling existing ground vegetation cover percentage within the canyon within its fixed geometry throughout all different scenarios.
2. Three different green system types (trees, green walls and cool pavement) are used; each one is used with the current vegetation percentage (0%) on a separate model.

   On the other hand, the simulation scenarios will be testing the following scenarios:

3. Base case: simulation of the real situation with asphalt streets, other surface pavement and concrete sidewalks locating and modelling existing ground vegetation cover percentage within the canyon within its fixed geometry throughout all different scenarios.
4. A 0% of vegetation would be simulated (replacing all current green areas by asphalt), so as to check what is the actual benefit from the current vegetation percentage.
5. Running the simulation for three different urban green system types (trees, green walls and cool pavement) in order to mitigate the UHI effect.
6. Subsequently, three different ratios for each vegetation type will be used by increasing the current case to reach 25% and 50%. These ratios were determined by the Greater London Authority (GLA) (GLA, 2015; Mayor of London, 2018) who planned to increase the green areas from 38.4% of the current case up to 50%, which is the future target. In order to achieve this, 30.2% of more vegetation is required (to achieve 50% green in London, 38.4% is the current green coverage, therefore 30.2% more green should be added to the 38.4% to achieve the 50% green). However, from the literature, it was noticed that the actually presented greenery within streets in 12.7% on average (which is the aim of this research) (Treepedia, 2020), but it is worth mentioning that this 12.7% green cover within

streets is an average percentage and, based on research, the actual percentage within central London streets is less than 1% (0.067% in the Oxford Street case study).

7. Then, these simulations are carried for future climate scenarios in the 2050s and the 2080s with high emission scenarios which has a 90% probability of occurrence.

5.2.1 Proposed outputs and results

ENVI-met simulation outputs are illustrated in the layout graphical coloured map which shows the whole simulated area, and which illustrates all meteorological results and expects research outputs as PET, PMV, PPD, Tair, Tmrt, Ws, RH, and so on. Subsequently, the results are then analysed from the map in Figure 5-1 within the required locations during the required time and then recorded on Excel sheets in order to create a comparison as a graphical bar so it could be easily understood and used for further research.

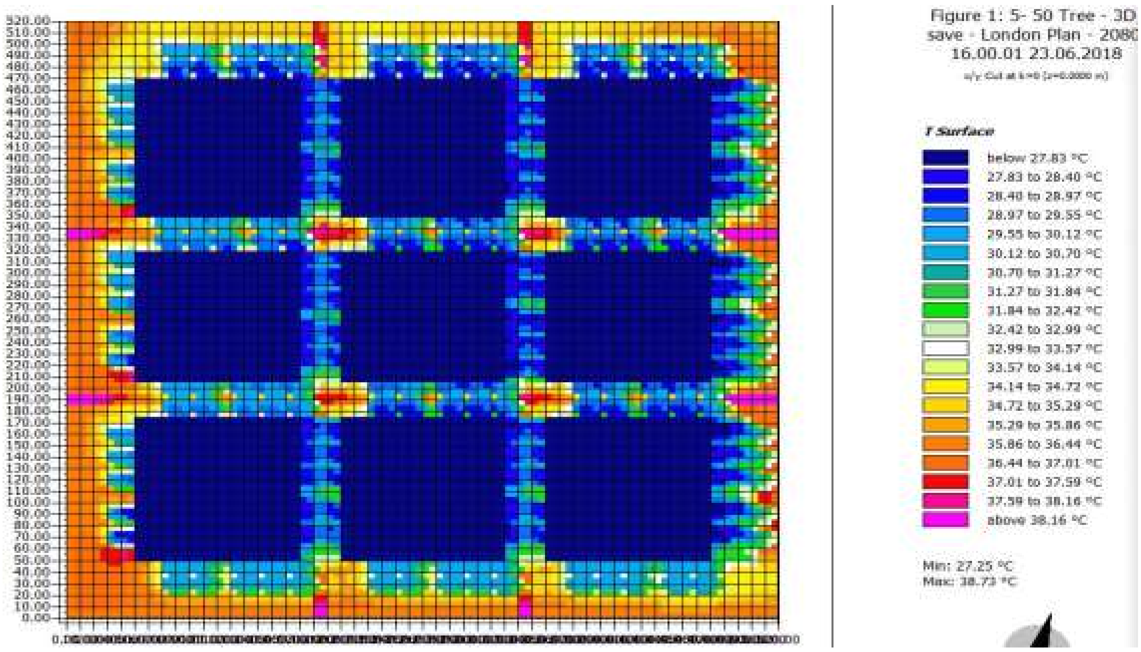


Figure 5-1 Leonardo by Envimet presenting outputs

5.2.2 Field Measurements and Input Data

In order to validate the ENVI-met software, the researcher had to take measurements within the intended location. This took place via recording air temperature (Ta), relative humidity (RH), wind speed (Ws) through both handheld equipment and weather station, in addition to measuring mean radiant temperature (Tmrt), ground surface temperature (Ts) and building wall temperature (Tw) through the handheld measurements and the solar radiation from MET office data for the study duration which took place between 17 and 26 July 2019. (Figure 5-2).

Figure 5-2 Used Equipment, on left Weather station, then Black globe thermometer, then Thermal imaging camera and last equipment is Anemometer (Willmott, 1981)

Onsite measurements were taken every day between 10 am and 6 pm representing the average working day hours. Each hour's handheld measurements were recorded for air, mean radiant temperature and relative humidity using (WBGT8758 Heat Index Monitor), Surface temperature using (TiS55-Thermal-Imager) and wind speed using (Testo-425) as in Figure 5-2. The measurements were taken for seven continuous days between 10:00 am and 18:00 pm. These data will serve as the simulation input values.

5.2.3 Statistical analysis of handheld equipment and weather station

Statistical comparisons were carried out between observed and simulated measurements, where index of Agreement (IA) and root mean squared error (RMSE) are considered as superior indices for making such comparisons and due to being easily comprehensible. Since IA ranges between 0 (no correlation) to 1 (strongly agree). RMSE indicates how divergent the predicted data are from measured or observed data, and that happens through a dimensional metric expression. RMSE is calculated by squaring the sum of variables' differences and then dividing them by the number of variables (Willmott, 1981; AMS, 2019; Ayyad and Sharples, 2019).

On the other hand, Pearson's correlation coefficient (r) is well-defined as the strength measure for two variables through a linear relationship. It consists of covariance of the data sets given and their standard deviation with a resulting value ranging between (-1 and +1) where 0 means no correlation within data sets. Finally, the mean absolute error (MAE) is calculated by measuring the error difference between two data sets through dimensional metric expression as well. Usually, climate researchers use MAE and RMSE to validate and test predicted values. It was argued that RMSE should replace MAE as it is not a precise method for the model-validating process, particularly during Gaussian error distribution. Thus, it was recommended to use a combination of model verification methods for more precise results (Willmott, 1981; AMS, 2019; Ayyad and Sharples, 2019).

Subsequently, both recorded measurements using the weather station and the handheld equipment across the study duration were analysed in order to calibrate and validate their accuracy as in Table 5-1. Interestingly, both recorded measurements – the weather station or handheld equipment – had significantly the same exact pattern where Tair and RH had an index of agreement 0.925 and 0.818, respectively.

Table 5-1 Error Statistical analysis between Weather station and Handheld equipment

	Tair	**RH**	**Ws**
Index of Agreement (IA)	**0.925**	**0.818**	**0.206**
Root mean square Error (RMSE)	**1.46**	**9.38**	**0.214**
Mean Absolute Error (MAE)	**1.248**	**9.132**	**0.172**
Pearson correlation coefficient (PCC)	**0.958**	**0.978**	**0.151**

On the other hand, Ws's IA had 0.206 due to high variability and turbulence, so the Ws continued to be too low (0.87-1.14 m/s) at which wind needs to be monitored for longer to estimate the average wind speed. These recordings were not possible with the anemometer used since other measurements were being recorded at the same time. Besides, all statistical equations showed a high agreement for Tair and RH, which gave the researcher great confidence about the equipment and the methodology used. Similar validation results were found by (Shahidan, 2011) confirming that ENVI-met were believed to correlate, predict accurately, and could be considered as a reliable tool for thermal analysis. This was also confirmed by (Huttner and Bruse, 2009) who found that it has high accuracy and realism in its calculations in addition to being able to predict the microclimate in terms of different variables with high accuracy (Yang *et al.*, 2013). Therefore, it could be used in this study. (Shahidan, 2011) also confirmed and recommended that the ENVI-met simulation model is a suitable model for any future research that needs to consider the effects of plants, surface and urban microclimate in future climatic scenarios.

5.2.4 Measurement procedures

Model Geometrical Specifications/inputs

The main criteria for deciding the case study is that it is one of the most polluted and highly populated streets in the UK (Isobel Hamilton, 2017) as the worst-case scenario. Hence, central London's Oxford Street was chosen as the research case study where many of the aforementioned challenges exist. The canyon between Orchard Street and Park Street is characterised by Height: Width of 1:1 while the length of the building block is 120m and the street canyon is 140m as in Figure 5-3 with total neighbourhood area of 520mX520m. This model which being drawn in ENVI-met software is an abstract model which represents the average of dimensions across Oxford street.

Several studies (Ahmed Shafeay and Shalaby, 2016; Shalaby and Shafey, 2018) have asserted that similar canyons' dimensions need to be investigated for the purpose of improving pedestrians' thermal comfort (PTC), especially during the summer season (Shafeay and Shalaby, 2016). Thus, measurements are taken within the North-South (NS) street (S1) and East-West (EW) street (S2) as shown in Figure 5-4 (middle picture) which represents the Oxford street case. This would also be for the middle canyon within our middle neighbourhood since it represents the real canyon within the central city urban fabric.

Measurements are taken at the location of six receptors (R) located in the middle of each canyon (total of 12 Rs in both canyons as in Figure 5-4: middle picture). The physiological equivalent temperature (PET) is used to determine PTC as it uses the skin of the human body to calculate all energy exchanges and core temperature, sweat rate while considering clothing as a secondary variable (Envimet, 2019).

In order to evaluate the effectiveness of the proposed UHI mitigation scenarios in relation to PET, the real empirical model will be testing the following scenarios as illustrated in the base case: simulation of the actual asphalt streets (albedo=2) and unclean concrete sidewalks (albedo=0.4) with 0% UGS within the canyon.

Two different green system types – trees and living facade – are then incorporated at 25% and 50%. High pavement albedo (HPA), such as white concrete (Albedo=0.8), is also tested at 66.6%, which represents all pavement areas. It must be noted that the vegetation in central London is almost zero in the main streets, whilst in the case study canyons it is zero, hence setting the base case at 0% vegetation.

The simulations are then undertaken for the four different scenarios (Figure 5-3) – base case, trees, living façade, and pavement albedo – using 2018 Met Office climatic data in order to evaluate their influence on UHI mitigation by using the 12 receptors. The two different ratios for each vegetation type are then applied, by increasing the current case by 25% and 50%. The Greater London Authority (GLA) (GLA, 2015; Mayor of London, 2018) plans to upsurge the green areas in London from 38.4% to 50%, hence applying 50% as the maximum level of vegetation.

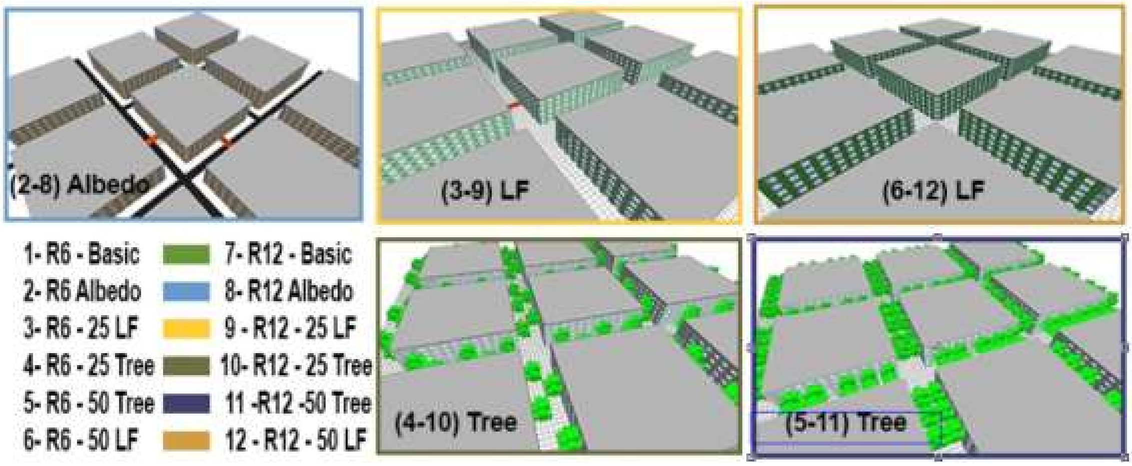


Figure 5-3 Different UGS alternatives

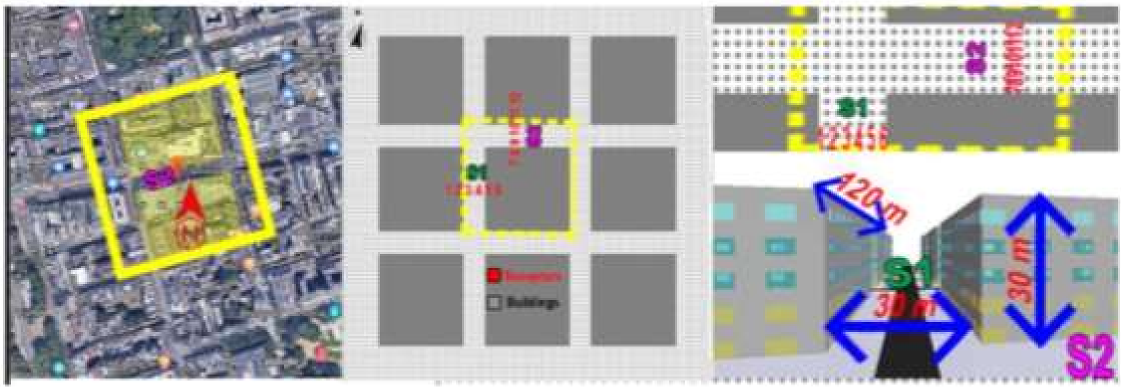
Through ENVI-met software, the canyon geometry is built with building specifications, dimensions and materials as base case scenario with twelve receptors (R), R6 in S1 which is the North-South street and R12 in East-West street orientations. This base case model had number 1 and 7, representing receptor numbers R6 and R12.The researcher then followed it up with five different alternatives representing 10 receptors; five receptors in each street orientation, R6 in S1 and R12 in S2 in each proposed UGS alternative. UGS alternatives were high albedo pavement, 25% Living Facade, 50% Living Façade, 25% trees, 50% Trees.

Different UGS alternatives were illustrated in Figure 5-3, such as cool pavement (high albedo pavement) (top left of the picture with number alternatives 2 and 8) is represented by R6 Albedo and R12 Albedo with blue colour; 25% LF with alternatives 3 and 9 representing R6 and R12 with yellow colour; 25% of trees with alternatives 4 and 10 representing R6 and R12 with dark green colour. Then 50% of trees of alternatives 5 and 11 representing R6 and R12 with dark blue colour and finally, 50% Living Façade of alternatives with numbers 6 and 12 representing R6 and R12 dark orange colour.

5.3 The ENVI-met Abstract environment specifications

ENVI-met software considers the Longwave and shortwave radiation fluxes (direct, reflected and diffused) take into account these short and long waves' reflections from shading and re-radiation from vertical and horizontal surfaces and the present vegetation. Vegetation's sensible heat flux, transpiration, evaporation and including all plant physical parameters, are also examined and explored within ENVI-met, for instance, the photosynthesis rate, surface and wall temperatures, mean radiant temperature, wind speed (Ws) simulation and three-dimensional turbulence, internal soil moisture-and heat exchange, Calculating Predicted Mean Vote (PMV) & physicological equivalent temperature (PET), dispersion of inert gases and particles including sedimentation of particles at leaves and surfaces, simulate the whole environment fluid mechanics, thermodynamics, and pollutant dispersion.

Table 5-2 ENVI-met Model specifications and adjustments

ENVI-met Abstract Model Area Specification	
 Figure 5-4 ENVI-met Model Area Specification	
Main Model Area	**520 metres X 520 metres X 63 metres**

Number of Grids in X, Y, Z	**104 X 104 X 21**
Grid Size in metre **Dx = size of X grid** **Dy = size of Y grid** **Dz = size of Z grid**	**104 X 104 X 21** **Dx=5,** **Dy=5** **Dz=3**
Each Canyon Dimensions **(Length X Width X Height)**	**120 metres X 30 metres X 30 metres**
Urban Construction Material	
Building material	**Wall: Default wall – Moderate insulation (Concrete and insulation and plaster) – 31 cm width** **Windows: Heat Protection glass – Thickness 3cm – Absorption 0.05 – Transmission 0.9 – Refection 0.05 – Emissivity 0.9 – Thermal conductivity 1** **Roof: Roofing Tiles – (Concrete and insulation and plaster) – 30cm**
Soil	**Road: asphalt - Albedo 0.4, Emissivity 0.9** **Pavement: Dirty paved concrete-grey – Albedo 0.4, Emissivity 0.9**
Receptors (R)	
S1 (North – South) Street Canyon	**1,2,3,4,5,6**
S2 (East – West) Street Canyon	**7,8,9,10,11,12**
Location	
Oxford Street, Westminster, London, UK	**Latitude (deg, +N, -S) = 51.51** **Longitude (deg, -W, +E) = -0.16**
Model Rotation from Grid North	**-15.4**
Start and duration of the model	
Date of simulation	**Average of whole summer season on an hourly basis**

Start time	**6:00 am**
Total simulation time (hours)	**24**
Urban Green Systems	
Tree	**London Plan tree – Height 20 metres – Width 15 metres – Albedo 0.18**
Living Façade	**IVY (Hedra Helix)- Deciduous – Albedo 0.2 – LAI 1.5**
Cool Pavement	**Light concrete pavement – Albedo 0.8**
Initial meteorological conditions (Simple Forcing)	
Roughness length at the measurement site **Wind Direction (degree)** **Specific humidity at the model top (2500 7** **m,**	**0.010** **225**
The initial temperature of the atmosphere (C)	
Simple forcing: Air temperature (C)	**Min 13.9 at 05:00 h;** **Max 23.9 at 16:00 h**
Simple forcing: Relative humidity (%)	**Min 47.4, at 16:00 h;** **Max 89.3, at 06:00 h**
Background Pollutants	
CO_2	**410**
Biometeorological Factors	
Clothing (clo)	**0.30**
Metabolic work (W)	**80**
Walking speed (m/s)	**1.21**

This simulation using ENVI-met aimed to investigate the UHI influence on Pedestrian thermal comfort (PTC) and carbon sequestration in Oxford Street, without urban green systems (cool pavement, green walls, roofs, trees) and after adding them. It also determines the influence of changing UGS ratios (0% current case, 25% and 50%

more) on UHI in different years (2018, the 2050s and the 2080s). The used temperature is based on the average summer temperature of each specified year for high emission scenarios.

5.4 Pedestrians' thermal comfort across different climatic scenarios (2018, 2050s and 2080s)

After running the simulations for 2018 and analysing them for different alternatives, within different street canyons orientation, a comparison was carried out between simulated software and taken measurements for 2019 within Oxford Street in order to calibrate and validate the ENVI-met tool. An ENVI-met simulation was carried out for the other two years, 2050 and 2080, in order to see the variance of the years' climate and its impact on pedestrians within different street orientations (North-South and East-West). The focus of this research was for thermal comfort and t CO_2 sequestration.

Figure 4-10 illustrates detailed information for Ta, RH and Ws across the different years in order to observe the climatic change across different decades. First, the three parameters (Ta, RH and Ws and global solar radiation) were compared between 2018 within weather stations at Kew Gardens and Heathrow Airport in order to visualise the difference in measured weather data. Then almost the same global solar radiation (GSR), Ta and RH were observed within the same weather stations; however, the Ws had massive differences changing from 2.01 m/s at Kew Gardens to 3.6 m/s at Heathrow. This can be ascribed to the wide-open space outside the city at Heathrow Airport while it is lower by 55% in Kew Gardens due to being within the heart of the city, where it is surrounded by tight urban clusters.

Similarly, by 2050 and 2080 at Heathrow Airport weather station, there were higher Ws outside the built-up area in central London which are not precise enough to be used and compared to 2018 within the centre of London based on the methodology followed for 2018 of entering weather file details from the MET Office of the average hourly temperatures, relative humidity, wind speed across the hot summer season (21 June until 21 September) of each year (2050 and 2080). The wind speed which was included within simulations was the average wind speed across the whole summer season applied on the whole city scale fabric. Based on that, further analysis was carried out to see the influence of urban geometry, temperature, relative humidity and wind direction on pedestrian thermal comfort. Heathrow's weather station is mainly located at Heathrow Airport within towers, which is not sheltered from the wind barriers as buildings and natural vegetation. Moreover, it does not represent the London city centre case. Thus, measurements may not represent the temperature within urban fabric at ground level (Gartland, 2008).

However, because the ENVI-met simulation was runn for the whole 24 hours, the measurements of UGS influence were considered for the warmest hour of the day, 16:00, in order to determine the influence of applying different UGSs with a different percentage on thermal comfort and carbon dioxide sequestration.

5.4.1 **Thermal Comfort for 2018 Climatic Scenario**

After running simulations within Oxford Street canyons, as previously shown, results were extracted from ENVI-met in the form of graphical illustrations and numerical Excel files from the receptors within both canyons. Street 2 (S2) represents Oxford Street, while Street 1 (S1) represents Regent's Street which intersects (S1). Six receptors were placed in each street, from left to right of the street. R1, R2, R3, R4, R5 and R6 were placed in S1 ,while R7, R8, R9, R10, R11 and R12 were placed in S2. All receptors have been placed in order to identify if there is difference in receptors' readings (temperature and thermal differences).

The different vegetation and albedo strategies were applied to determine which intervention(s) are more appropriate to be used within the case study canyons to improve pedestrians' thermal comfort. Thus, Physiological PET, PMV and Predicted Percentage of Dissatisfied (PPD) are the focus of the study. Further analysis is undertaken to explore how the air temperature (Ta), Mean Radiant Temperature (Tmrt), Surface Temperature (Ts) Wind Speed (Ws) and Relative Humidity (RH) influence pedestrians' thermal comfort.

Figure 5-5, the Mean Radiant Temperature (Tmrt) at all 12 receptors have been extracted for the average of the summer season in 2018. However, as there has been no significant differences between Tmrt and Tair at each receptor, the highest value of each street receptor based on PET and PMV has been chosen to represent the canyons (S1, and S2); these values are R6 and R12. Consequently, PMV and PET were measured to determine which time of the day has the maximum heat stress, which was found to occur at 16:00. Thus, further heat stress indicators (PET, PMV and PPD).

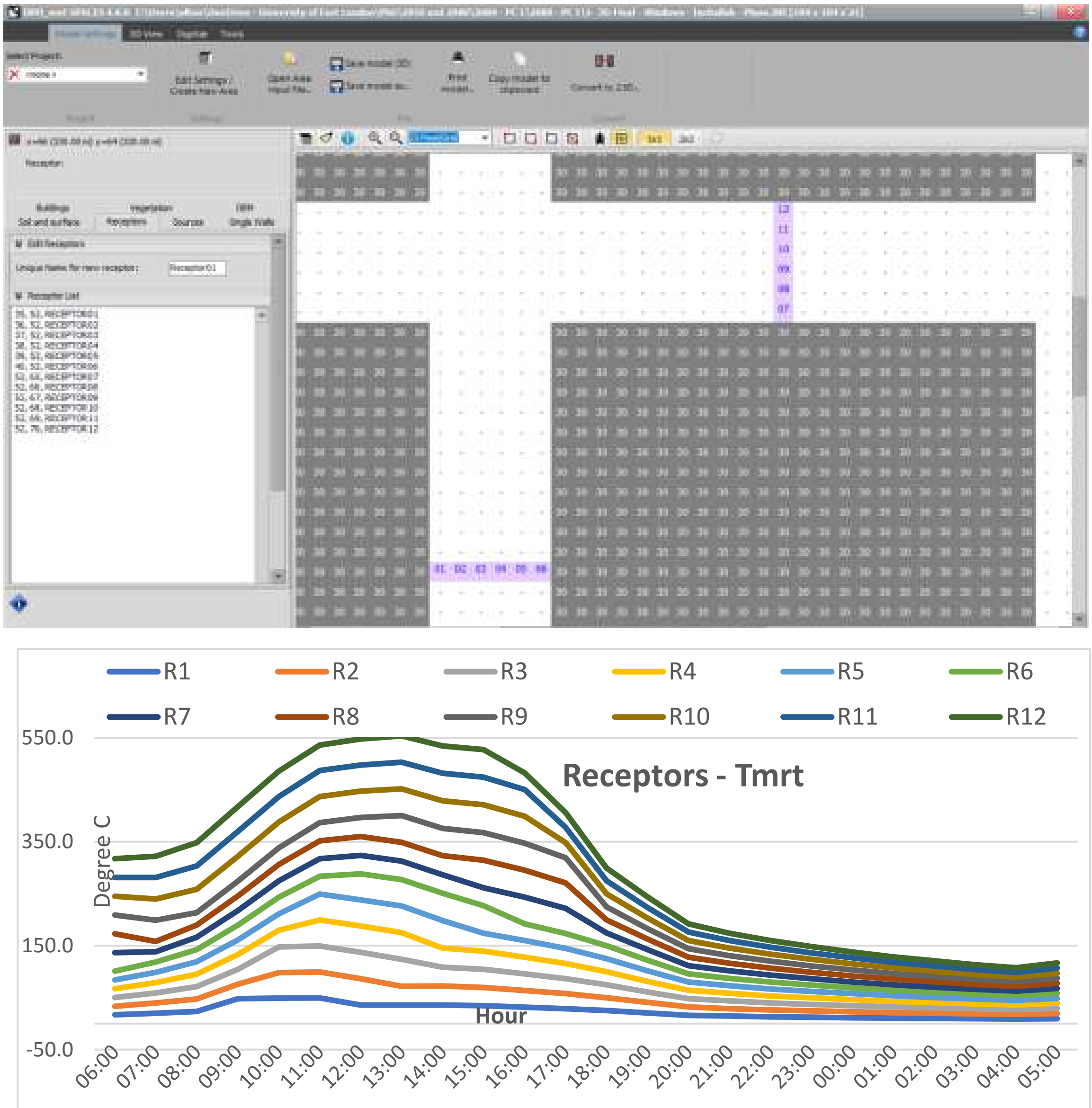


Figure 5-5 Top picture is for Receptor locations: (1-6) in NS orientation while Receptor (7-12) in EW orientation. Bottom picture is for Mean Radiant Temperature (Tmrt) Measurements of the 12 receptors (Source: ENVI-met)

and calculations regarding UGSs and albedo effect are then undertaken through those two receptors (R6 for S1 street orientation and R12 for S2 street orientation) in order to avoid unimportant calculations.

5.4.1.1 Thermal comfort values (PET, PMV and PPD) at street 1 and street 2

Figure 5-6 demonstrates the calculations at R6 and R12 concerning the Physiological Equivalent Temperature (PET), Air Temperature (Ta), Mean Radiant Temperature (Tmrt) and Surface temperature (Ts). It was clear that the Ta had no notable variance with the changing strategies. However, UGSs had a significant influence on both Ts and Tmrt, which have reflected on PET. Thus, PET was used as a clear indicator of pedestrians' thermal comfort within street canyons based on other outputs such as Ts, Tmrt, RH and Ws.

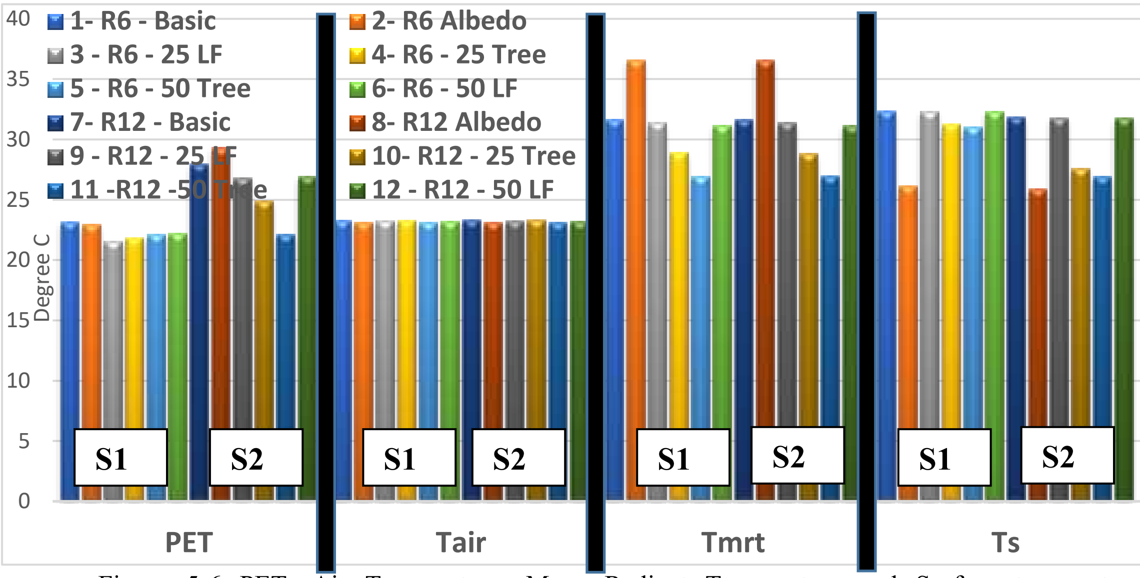


Figure 5-6 PET, Air Temperature, Mean Radiant Temperature and Surface temperature comparison (Source: ENVI-met)

For PET in S1, there has not been much difference between Rs, where the maximum temperature reduction (Tr) was -1.05°C and -0.98°C for alternatives 5 and 6, respectively. At the same time, it was observed that Tr has decreased with the decrease of vegetation percentage to be -0.6ºC and -0.35ºC for alternatives 3 and 4, respectively. However, it is actually unpredicted to see that this vegetation percentage (25%) is not following up with the same trend as the previous one (50%) where trees had more influence on reduction. Nevertheless, that happened because trees have not been shading Rs as in the 50% case. Albedo has also reduced PET by -0.21°C just through changing pavement colour, which is mainly from reducing the Ts of the pavements.

For S2, there has been an apparent fluctuation between the results of each strategy which was mainly due to street orientation which led to long sun hours of more than 11.52 hours compared to 5.01 hours in S2, which subsequently led to receiving more solar radiation during the daytime.

During high heat stress in S2, trees have been the best solution for Tr due to its shading capabilities, where Tr varied between -3.08°C and -5.84°C for 25% and 50%, respectively, while for living façade (LF) 25% and 50%, -1.17ºC and -0.09ºC were found as a Tr which is almost negligible for LF 50% for the cost of applying it onsite. This was mainly due to increasing RH accompanied by the high air temperature. In addition, solar radiation would normally fall on the street surface and not walls; thus, the LF strategy was not effective, particularly with 50% as this led to increasing RH higher than the maximum comfort levels. Surprisingly, R8 had higher PET with +1.3°C which caused extra thermal stress, although there has been a huge reduction for Ts due to its high albedo. However, as it was observed, Tmrt increased dramatically which can prove that high albedo may have caused solar radiation reflection, leading to increased heat stress and hence increasing PET which was similarly found in a recent study (Leal Filho *et al.*, 2018).

Overall, in S1 (North-South) UGS was not as effective as in S2 (East-West) due to higher solar radiation and higher sun hours associated with its orientation and canyon geometry. Hence, altering pavement albedo would be a feasible and cost-effective solution, particularly for the Ts. Shading pavements have been the main reason for lowering temperature due to blocking access of solar radiation to the pavement surface and hence improving pedestrians' thermal comfort level.

It was not as effective to change the UGSs percentage for either trees or LFs where the maximum reduction in PET was -0.3°C, which means that increasing trees up to 50% may not be an effective (or feasible) solution. However, it was -0.67°C for LF where walls have been receiving higher solar radiation and hence more temperature variations were found.

For S2, trees have been more practical in improving PET comfort levels where there has been a difference which was observed between 25% and 50% trees which reached -2.76°C. Surprisingly, PET increased +0.14°C when LF percentage increased from 25% to 50%, where RH might be the main driver for that; however, Ta lowered slightly in R12 and Ts, and Tmrt had a similar pattern to R9. High surface albedo was increased heat stress by +1.36C°C for PET than the base case; however, it has decreased Ta by -0.2°C and by – 4.91°C for Ts and increased Tmrt by +5.42°C.

Interestingly, the percentage of reduced PET due to UGSs in the North-South street had a similar pattern across different UGS alternatives. For instance, using 50% of either tree or LF had same influence of -1.04% while similar reductions found 1.06 and

1.07 from trees and high albedo pavement, while for the East-West Street, both LF of 25% and 50% had almost the same PET reduction of -1.04% and -1.03%, respectively. The higher reduction percentage was found for trees with 25%, and 50% reached -1.12% and -1.26% correspondingly. These percentages could be used to give us indications about how UGSs act to heat stress in the cloudy would or a cooler day or in winter, for instance, based on the North-South street.

5.4.1.2 Relative Humidity (RH) and Wind Speed (Ws)

In Figure 5-7, for S1, wind speed ranged from 1.1-1.3 m/s across the day with negligible changes for both LFs' percentage, but within the same range, which was 1.12- 1.28 m/s. For the two tree percentages, the wind speed reduced to 0.99-1.01 m/s for R4 and 0.92-0.95 m/s for R5, which clearly shows that trees have blocked even the low wind flow. For S2, wind speed ranged from 2-2.2 m/s for all cases except the R4,5 with trees at which trees have significantly reduced the Ws in R5 from 1.6-1.55 m/s and 1.43-1.38 m/s in R5. This clearly shows that a higher thermal comfort would have been expected during the hot season in the case of a higher wind speed.

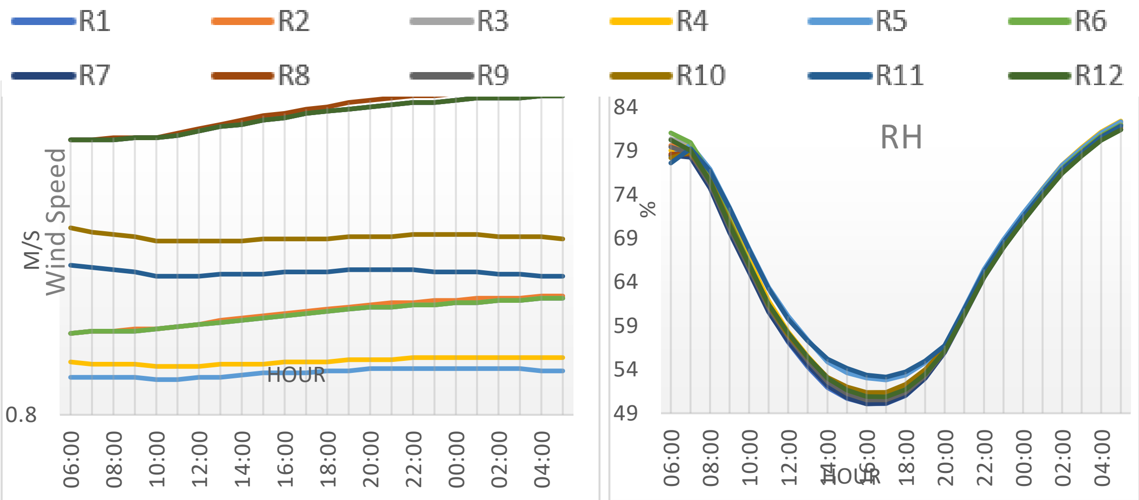


Figure 5-7 Wind Speed and Relative Humidity comparison (Source: ENVI-met)

Although trees have lowered Ws due to acting as a wind barrier, the highest thermal comfort was found in PET due to its shading effect. For RH in S1 and S2, it had the same pattern across different UGSs; however, Rs near trees or vegetated walls might have felt a slight difference (higher). Higher RH was noticed in S2 than in S1 particularly for R12 followed by R11, R10 and R9 and with the same vegetation sequence at S1. This is due to the increase in RH due to the evapotranspiration process by trees and LF.

5.4.1.3 Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD)

Figure 5-8 shows that measurements mainly investigated the warmest hour of the day which is at 16:00 in order to specify the thermal comfort levels and improvements if applicable. PMV and PPD have a linear relationship where PMV calculations are based on Ta, Tmrt, Ws and vapour pressure, where its assumptions were mainly for steady-state indoor situations by extending the energy fluxes with long- and short-wave radiations in order to use it outdoors (Envimet, 2019).

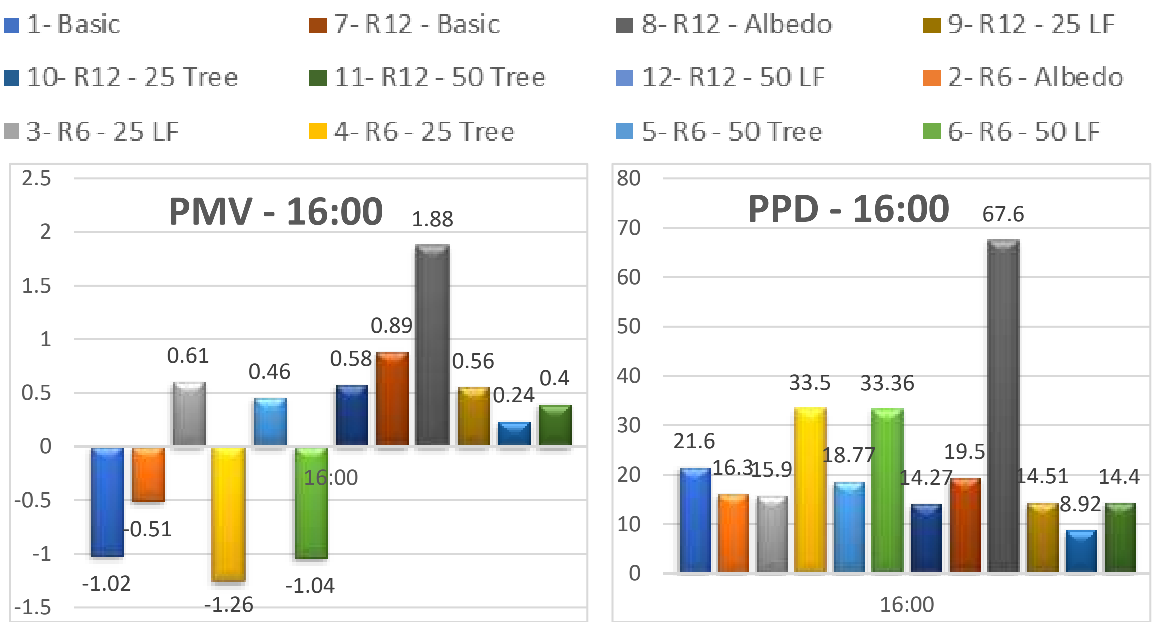


Figure 5-8 PMV and PPD comparison (Source: ENVI-met)

For S1, using higher albedo material, 25 LF and 50% tress have to led to change PMV positively from cold to slightly cool and slightly warm for R4 and R5 while it was cooler when we added 50% LF and cooler with 25% trees. For S2, its UGS improved PMV from warm to slightly warm, except for R2 and R3 where R3 has increased massively to become hot. PMV does not seem to be following PET results' pattern, Ta and Tmrt within the same trend, which might be because PMV takes clothes and human activity into consideration as a scale, not as a number, which might have several interpretations. For instance, adding lighter clothes within the warmer street canyon would lead to higher discomfort levels which is due to increasing the skin surface facing the sun; however, it is more logical that it should be more comfortable. PPD inS1 illustrated that around 33.5% of people felt discomfort at R10 and R12 however, it is still acceptable.

Meanwhile in S2, 67.6% of people were dissatisfied, which also shows a linear relationship between PMV and PPD (Envimet, 2019).

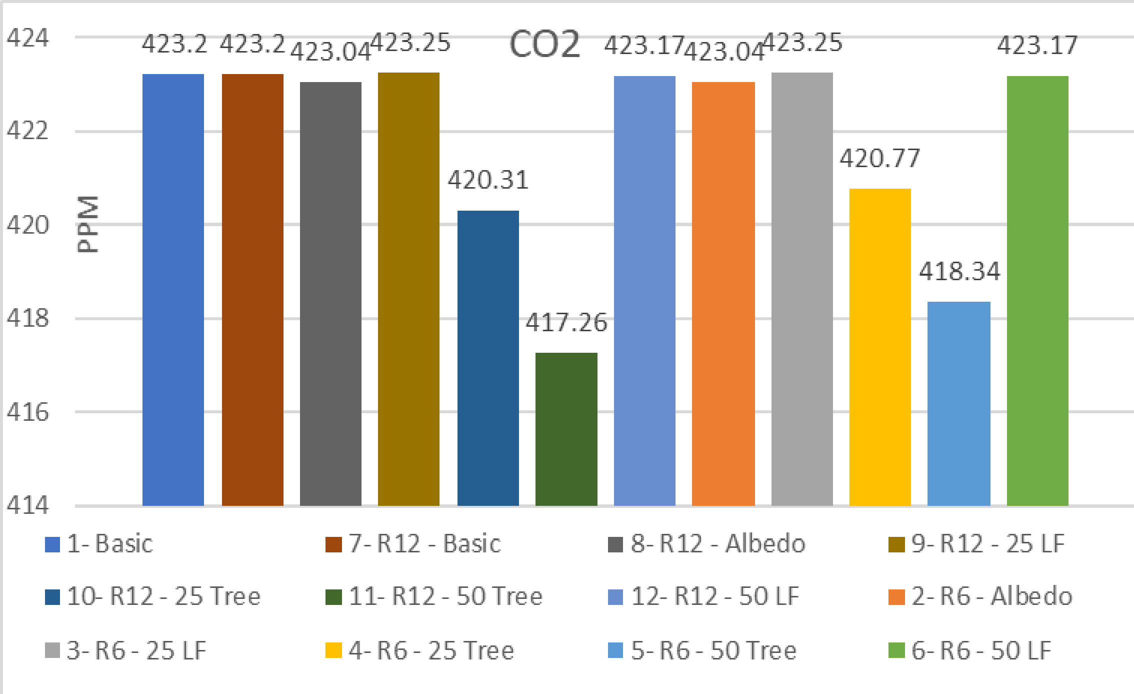


Figure 5-9 CO2 reduction (sequestration) for different UGS alternatives

On the other hand, using UGSs for Carbon dioxide (CO_2) sequestration, particulates per million (PPM) increased within canyon streets at pedestrian levels from PPM 410 to 423 PPM due to trapping air components in general and due to the physical properties of CO_2 particles such as its density and wind aerodynamics (force, direction and flow), and RH as shown in Figure 5-9. However, there was no remarkable decrease within CO_2 concentration within different alternatives: within 25% and 50% of trees' alternatives CO_2 decreased to 420.3 PPM and 417.2 PPM, respectively, within S1 while CO_2 sequestration for the same alternatives within S2 was not within the same efficiency as it decreased to 420.7 PPM and 418.34 PPM, respectively. These low reductions in CO_2 sequestration are due to selecting a particular time of the day, 16:00, which represented the highest thermal stress and hence it will also reflect on CO_2 sequestration levels to be more noticeable.

For both LF percentages across different canyon orientations S1 and S2, there was not a difference or improvement which, after contacting the software developers, was a result of a software limitation in that it counts LF as a system which interacts with the living environment but does not interact with CO_2 which is similar to the cool pavement, as changing the pavement albedo has no impact on CO_2 sequestration. The first main reason for not having significant influence for UGSs on CO_2 counts on the fundamental physics of CO_2 which is a global-scale problem and not a local scale and the main influence on reducing it is through limiting its primary sources first as climate mitigation then following it by climate adaptation through using techniques and strategies to diminish the consequences of climate change, which is being used in this research by UGSs (IPCC, 2014).

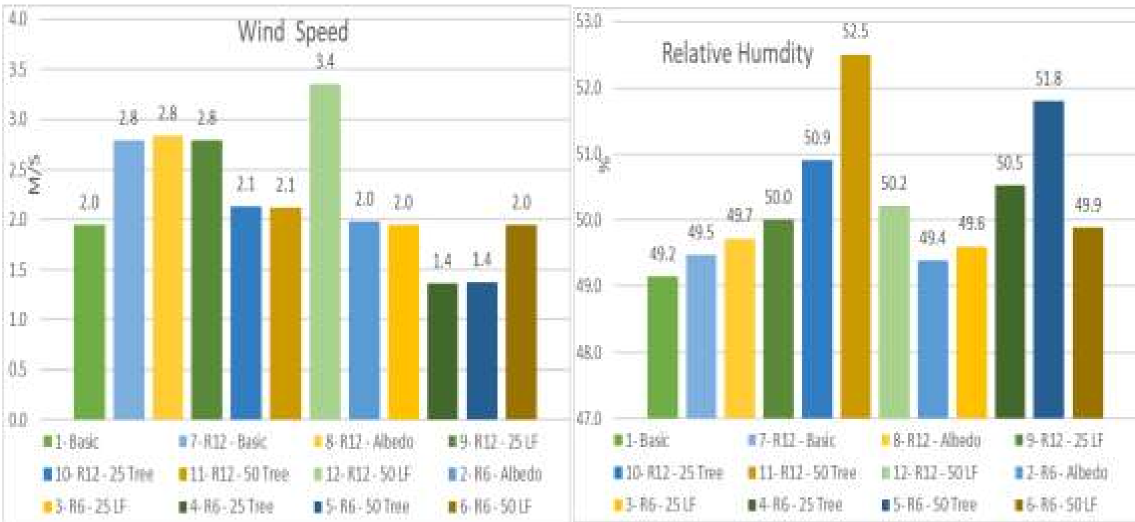


Figure 5-10 2050 windspeed and Relative humidity for all alternatives

The researcher calculated the CO_2 reduction across the whole day for each alternative, yet the findings of the reduction percentage were identical. This is due to the fact that the CO_2 levels were changing across the day as the sun moved. Further, there are other reasons for UGSs to have an influence on CO_2 sequestration such as the tree or LF age (young, mature, old), climate and weather (sunny, cloudy) which reflects on leaf stomata, irrigation and maintenance. All these factors have a massive influence on the efficiency of the UGS alternative and its efficiency (Rob Ludacer and Jessica Orwig, 2017; CO2-Meter, 2018; DTE, 2019).

5.4.2 Thermal Comfort for 2050s Climatic Scenario

However, predictions for 2050 show higher wind speed due to being predicted at Heathrow Airport, to get the accurate Ws within the city fabric for comparison with2018. The same percentage difference between Heathrow and Kew Gardens in 2018 was applied in 2050 to show a rough estimation for the predicted wind speed, which will be around 2.32 m/s.

From Figure 5-10 and Figure 5-11 a similar pattern was found. Almost the same findings were noticed at which wind speed increases with the East-West canyon (S2) reaching 146% and decreases at the North-South canyon (S1) due to aerodynamics around buildings reaching 60%. For both canyons, LF did not influence the wind while trees slowed down the Ws significantly by around 54% in S2 and 26% in S1. On the other hand,

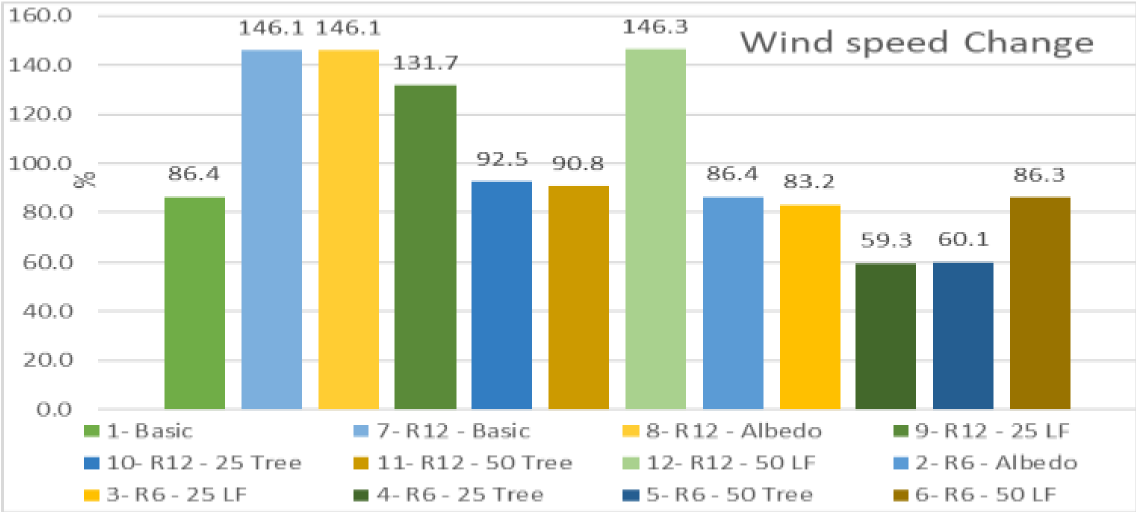


Figure 5-11 2050 wind speed change percentage

RH also had similar findings at which trees and LF within S1 and S2 increased RH around 2.3% maximum, which was for 50% of trees.

To be able to see the main influencers on pedestrian thermal comfort (PTC), a comparison was carried out between different alternatives in terms of PET while the rest of factors (Tmrt, Tair, Ts) were also involved in order to see the reason for the changes. From PET, within S1 it is clearly obvious that UGSs do not bring so much improvement to PTC. On the contrary, high albedo pavement increased thermal stress due to radiating temperature back to pedestrians even though it has decreased the surface temperature, while 25% of trees and 50% of trees had similar improvement which ranged around 2°C maximum, which is very low. The similarity in the thermal levels in S1 is mainly due to the shade from the buildings on the street and hence lower solar radiation is received in the street. Therefore, there is no improvement or change in the thermal indices with the change of UGS alternative or with its density (covering percentage).

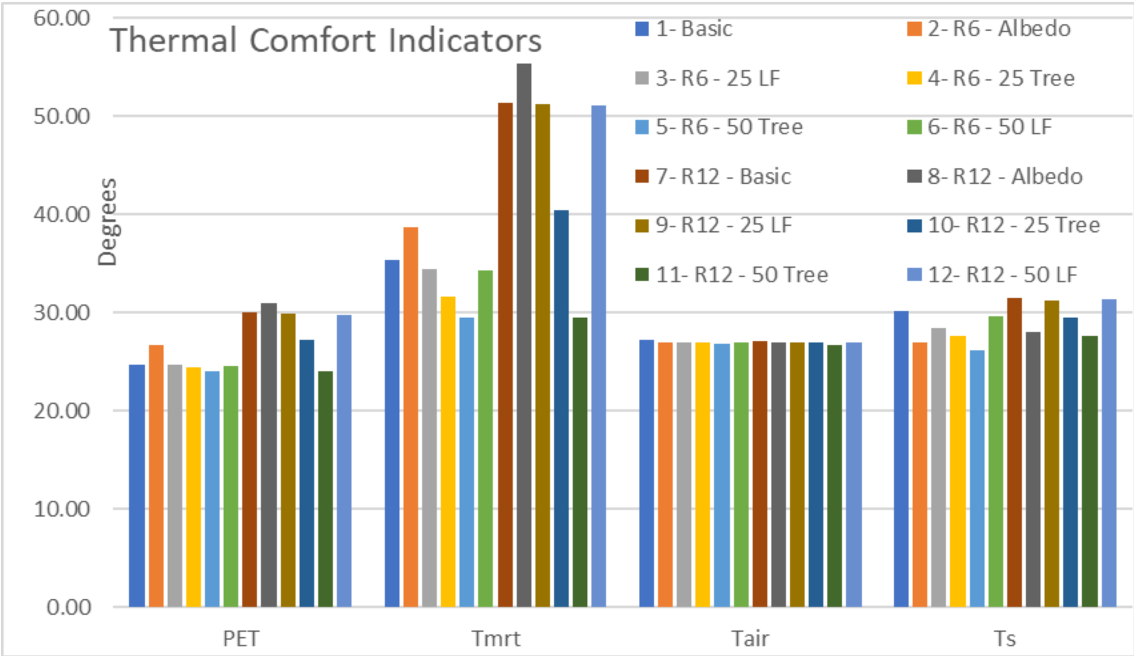


Figure 5-12 Thermal comfort indicators for 2050 (PET, Tmrt, Tair, Ts)

For S2, a massive improvement was indicated for both 25% and 50% trees, of 2.8°C and 6°C (10% and 20% improvement in PET), respectively. However, there was a slight unobserved improvements in which ranged about (0.04°C and 0.19°C) for 25% and 50% LF, respectively, as the main radiation is falling on the street and not the building walls. Overall, Tmrt had a major influence on PTC although Ts influenced it mainly within lower levels (lower than human height). PET has been improved by applying trees, particularly with higher percentage due to its shading effect on the street level. Meanwhile, LF did not influence PTC since the solar radiation is mainly falling on the street and not on the buildings; therefore, LF does not influence the PTC directly.

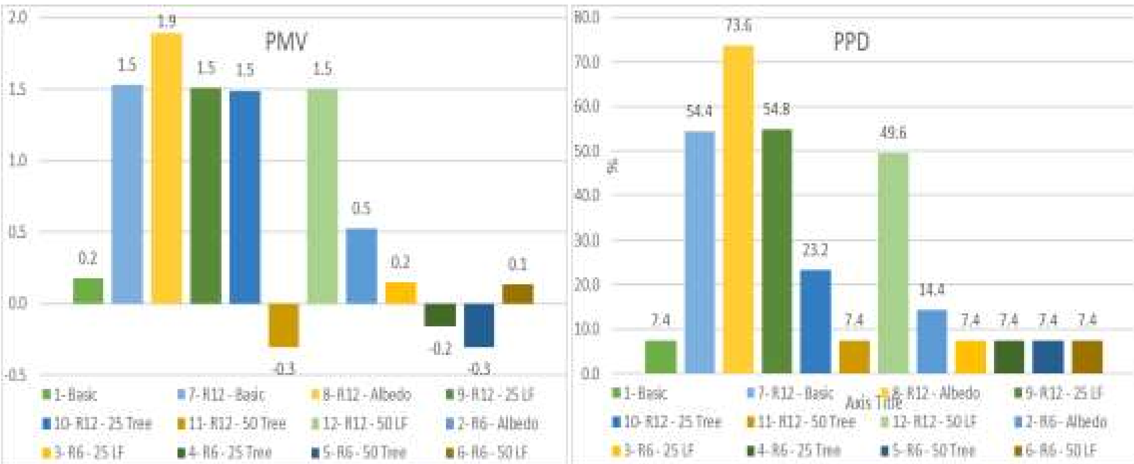


Figure 5-13 PMV and PPD for 2050

Figure 5-13 illustrates PMV which is used to be easily indicative for PTC which within S1 showed similar PMV, around -0.3 and 0.5, which refers to high thermal comfort rate. This also reflects on PPD with around 7.4% being the PPD level while, for S2, PMV increased between 1.5 and 1.9 which shows very warm weather, except for 50% trees which had similar PMV to S1 which reflects a very high PTC and confirms the high efficiency and effectiveness of trees.

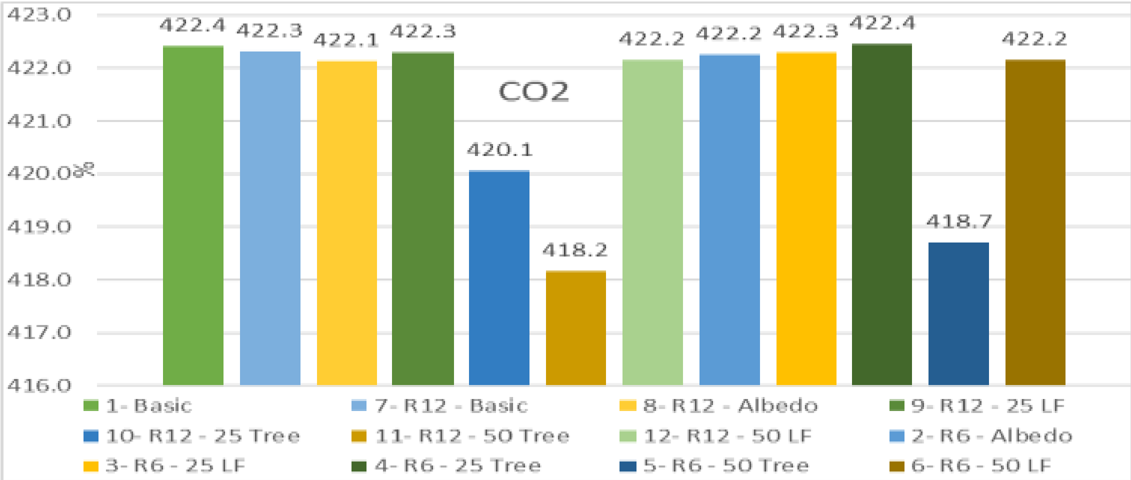


Figure 5-14 CO2 change in 2050

Similarly to 2018, CO_2 emissions in Figure 5-14 did not show so many improvements due to the same reasons as this is a global-scale challenge. CO_2 sequestration improvements did not show much change across different streets and alternatives; however, 50% trees had bigger improvement than other alternatives which reached 1% only within the pedestrian level to reach 418.2 PPM instead of 422.4 PPM. Interestingly, 25% trees had a different influence on both streets as within S2, which has higher Global solar radiation (GSR), 25% trees had a better influence on CO_2 decreasing from 422.3 PPM to 420.1 PPM. On the contrary, 25% trees in S1 did not have much influence which is due to stomata resistance decrease due to the lack of sunlight which decreases the photosynthesis process and hence decreases carbon sequestration which is already low.

5.4.2.1 Overall conclusion on 2050

Across different UGS alternatives for 2050, for the S2 canyon, it is strongly recommended to have trees with 50% coverage to attain a significant thermal comfort improvement due to its shading effect. For the S1 canyons, on the other hand, neither the UGS nor 25% trees is advised to be applied in order to reach a better thermal comfort level. The lower thermal improvement in S1 happened as buildings block solar radiation, which leads to creating shade during most of the daytime. However, for CO_2 sequestration, the more trees applied the better CO_2 sequestration; however, it is not that effective on the local scale, and it might actually be worse on a global scale.

5.4.3 Thermal Comfort for 2080s Climatic Scenario

Figure 5-15 and Figure 5-16, show that across S1, wind speed decreased by 13% for the base case and was constant across LFs and albedo alternatives, while it decreased by 28% for 25% trees coverage and 37% for 50% tree coverage. This happened as trees acted as a barrier. For S2, the base case alternative wind speed increased by 150% and was similar in range for high albedo and LFs alternatives which then massively decreased by 60% to reach 95% and 90% for 25% trees and 50% trees, respectively. To sum up, trees have lowered wind speed in the high-speed street canyon, S2 achieving a reduction between -60% and -65% while for S1 which already has a lower wind speed, applying trees did not massively change wind speed as was the case in S2. As the maximum Ws reduction achieved from trees in S was -24%, this reflects that trees' ability to block Ws increases with the increase in the Ws.

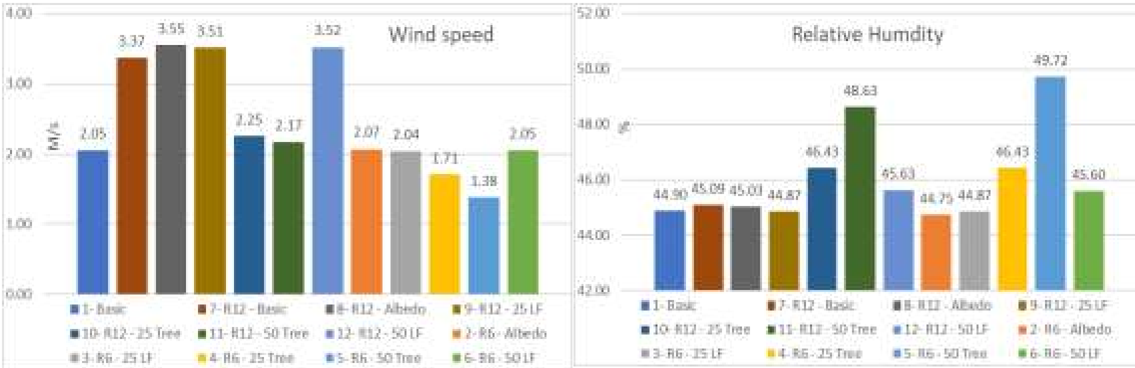


Figure 5-15 Wind speed and relative humidity for 2080

On the other hand, RH was similar and within the same range across different canyons as shown in Figure 5-16 except within 25% and 50% trees which have increased RH by 2% to 4 % for 25% and 50% trees in S1 and by 1.5% to3.5% for 25% and 50% trees, respectively in S2. There is a more significant increase in RH in S1 than in S2 due to lower wind speed and hence more air saturation with water vapour. This happened due to the evapotranspiration process which occurred during the photosynthesis process of evaporating water from leaves through plant transpiration during photosynthesis; therefore, the water vapour increased in the air leading to increased RH.

For 2080, Figure 5-18 Tair did not show massive changes, while Ts and Tmrt reflected a lot of alternative improvements or deterioration which is helpful to determine

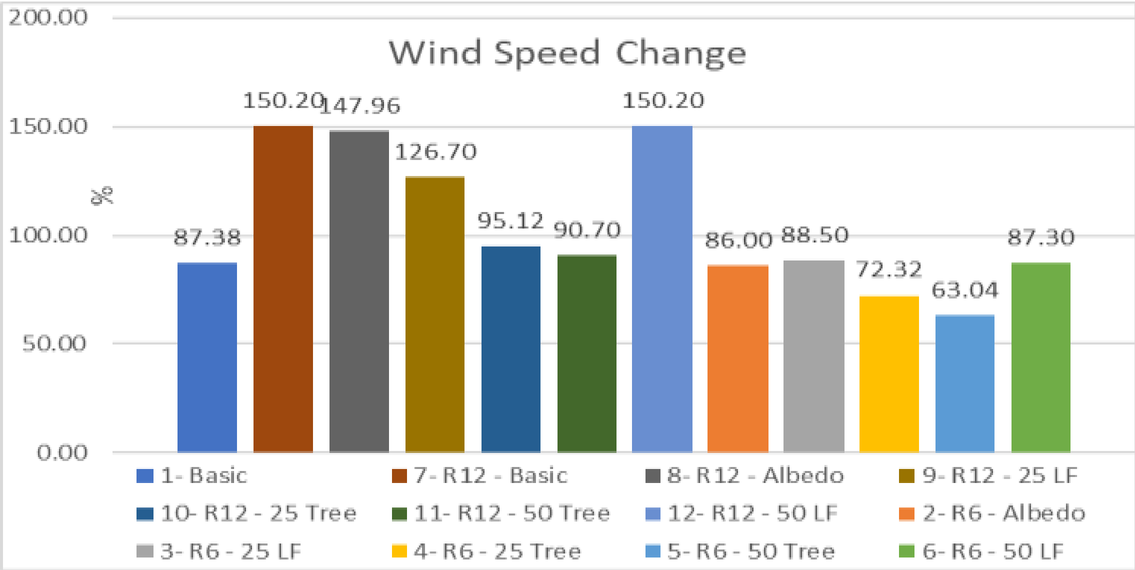


Figure 5-16 Wind speed change percentage for all alternatives

the best alternative for 2080 based on PET in each orientation what is the mean influence of this alternative. Within S1, the UGS alternatives did not have a noticeable change due to its orientation as it is shaded across the day; thus, changes are not significant. But high albedo pavement had actually decreased Ts, although it has also reflected it back to become a new source of heat radiation which led to increasing Tmrt by 10°C and PET by 5°C. The 25% and 50% LFs did not have so much change, while 25% of trees and 50% of trees had similar improvement of around 2°C maximum.

S2 canyons received more solar radiation which led to high temperatures, resulting in massive, noticeable improvements for UGS alternatives, at which trees had the best

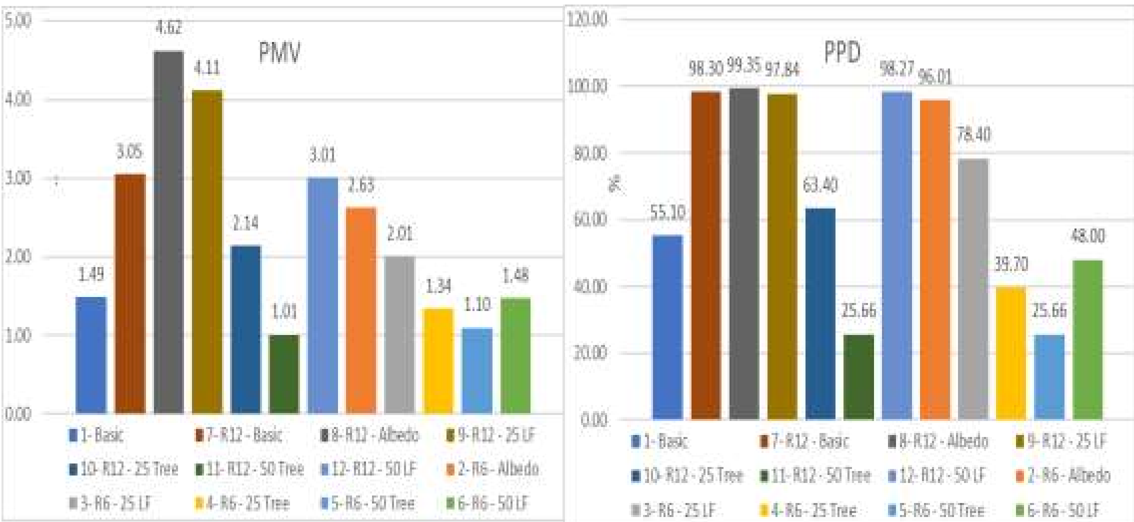


Figure 5-17 PMV and PPD for 2080

improvement due to their shading effects, which improved by 4°C for 25% tress and 9°C for 50% trees; these represent improvements of almost 20% and 25% correspondingly. For LFs alternatives, no changes have been noticed while for the high albedo pavement; a negative impact has taken place by increasing PET by 10C, representing 27% due to increasing Tmrt.

Across PMV in Figure 5-17, it was easier to notice PTC improvements through its thermal comfort scale which has greatly improved with increased percentages of trees from 25% to 50%, which achieved near equivalence across S1 and S2 for 50% trees. It was clear that high pavement albedo is one of the negative impacts from UGS alternatives which could be applied for urban canyons across London while LF with both 25% and 50% are not really improving the PTC due to increasing RH and being applied to building walls which do not receive so much sunlight.

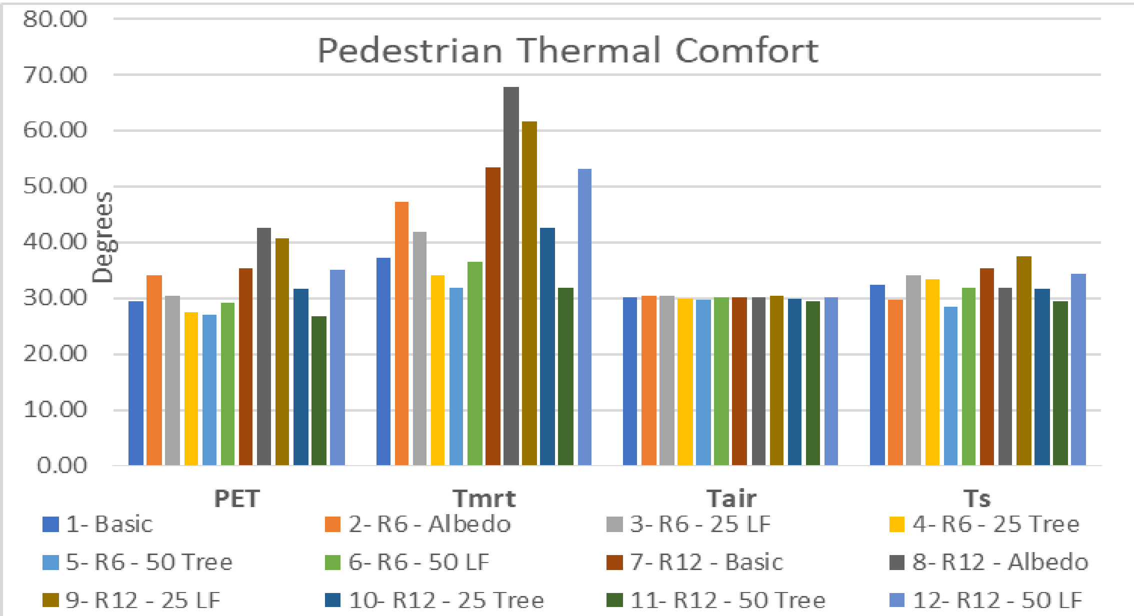


Figure 5-18 Thermal comfort indicators for 2080 (PET, Tmrt, Tair, Ts)

PPD was very high across S2 alternatives with an average of 98% PPD, except for trees with PPD of 63% and 25% for 25% trees and 50% trees, respectively. For S1, the basic receptor (R7) reached 55% PPD, while after applying high albedo pavement it has increased negatively to 96% followed by 75% and 48% for 25% LF and 50% LF, respectively. Both 25% and 50% of trees had an improvement of 40% and 25% for 25% and 50%, correspondingly. The decrease in PPD (increase in thermal comfort level) due to the shade the trees has afforded within warm hours, hence decreasing solar gain and thermal stress which was not applicable for LFs which are on the walls.

Across different UGS alternatives in Figure 5-19, CO_2 sequestration did not improve massively; however, CO_2 PPM decreased for 50% tree alternatives within S1 and S2 by 0.8%-1.2%, which represent an improvement of 3-5PPM out of 420PPM. For S1, 25% trees through the 2080s or the 2050s did not show any kind of improvement which might be due to limited improvement on a local scale in addition to lower GSR and hence lower leaf stomata, so that the photosynthesis process is almost not occurring.

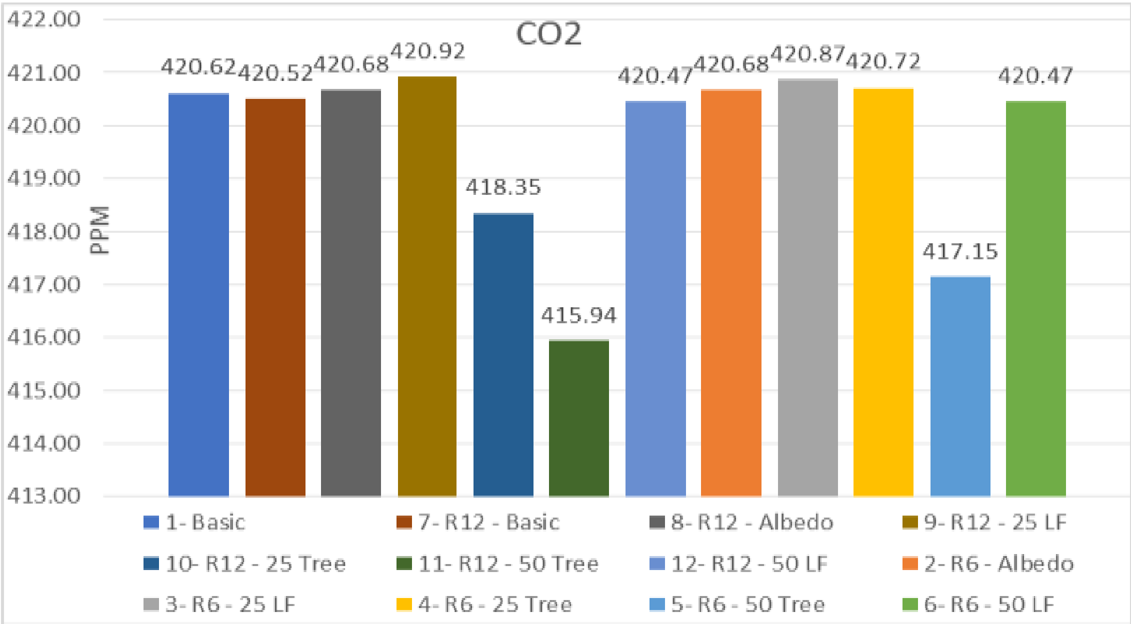


Figure 5-19 CO2 change in 2080

5.4.4 Comparison across different climatic scenarios 2018, 2050s and 2080s

A more in-depth comparison was carried out in order to see the influence of each individual UGS alternative of each year in order to be able to assess the most appropriate alternative for each canyon orientation within each year. These deeper comparisons and calculations were clarified according to each PTC and CO_2 sequestration factor (Ws, RH, Ts, Tair, Tmrt, PET, PMV, PPD and CO_2).

Figure 5-20, wind speed (Ws) for the 2050s and the 2080s, did not have so much change, 3.6 m/s across the two years on average, while it was 2.01m/s for 2018 and that was explained before due to the weather station location for the 2050s and the 2080s which shows similarity to the Heathrow weather station while the 2018 weather station was within the heart of the urban fabric within London City centre at Kew Gardens. Across the two canyons, S1 was lower than S2 in general; however, there was not so much difference across different alternatives within the same canyon orientation except for trees alternatives with 25% and 50%.

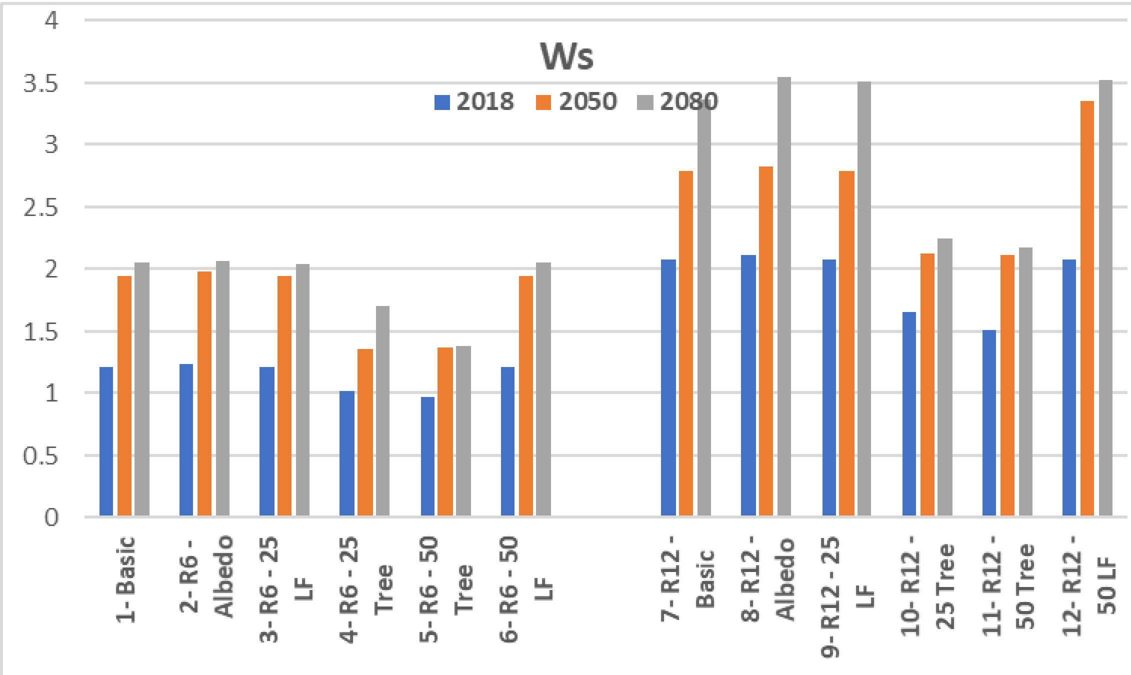


Figure 5-20 Wind speed across different years 2018, the 2050s and th e2080s

Wind speed change percentage shows similarity across different alternatives within different years, which confirms the stability of the simulation software (ENVI-met) during simulation running across different UGSs alternatives within different years as shown in Figure 5-21. Ws change in speed increases within S2 to range between 90% and 140% while for S1 the Ws change ranged between 60% and 80%. Across all years, placing more trees within higher Ws canyons leads to a reduction in their speed; however, the reduction decreases when the Ws decreases so the effect of trees acting as a barrier decreases as a result.

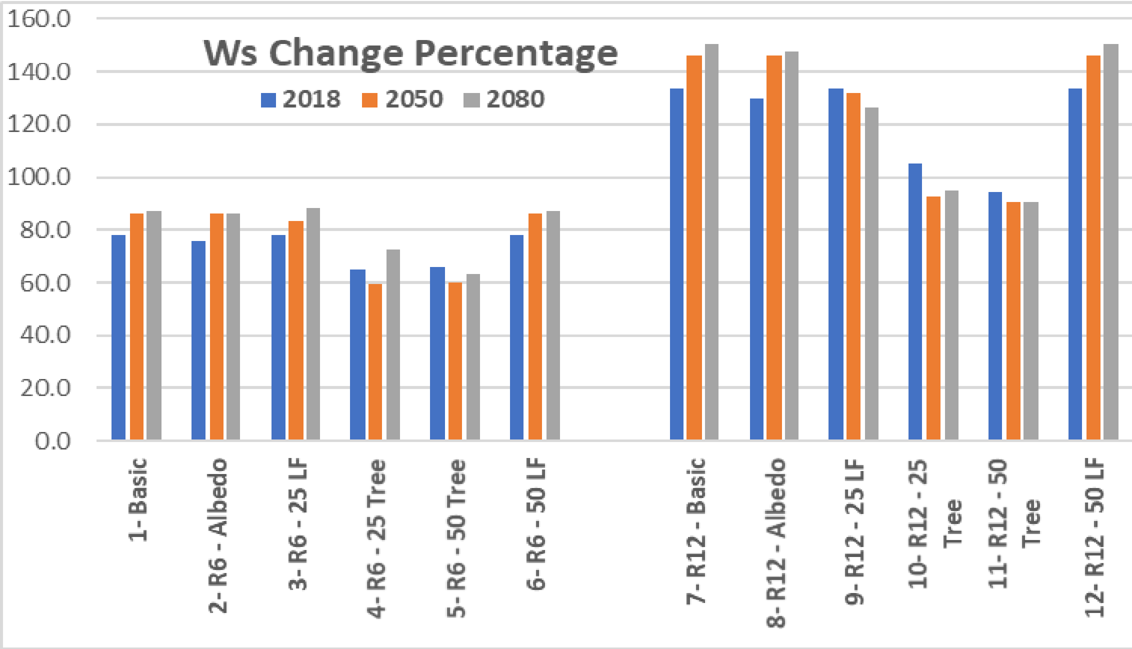


Figure 5-21 Wind speed change percentage across different years 2018, the 2050s and the 2080s

Relative humidity (RH) in Figure 5-23 is constant across different canyons; however, across 2018 had the highest RH with 50% then started declining by 2% for the 2050s and 8.8% by the 2080s which confirms that summer is going to be drier and sunny. Trees and LFs are the best alternatives for dry summers as they increase RH to compensate for the dry weather besides other benefits. Both LF percentages and trees with 25% had similar RH percentage of increase while trees with 50% coverage had the highest RH across whole years with the increase of between 6% and 10% in RH compared to its base case in each year and the drier it is, the higher the increase in RH provided by trees or LF would be. The increase in RH, especially with high percentage of UGS 50% trees of 50% LF, was due to evapotranspiration which helped in evaporating water from leaves through plant transpiration during photosynthesis leading to increased RH in the air particularly within future climates in the 2050s and the 2080s which helped to moderate the climate in summer as it will be drier. Therefore, placing more trees in the canyon in future climatic scenarios is not only helpful for reducing the temperature, but also to increase RH and hence increase the overall thermal comfort levels.

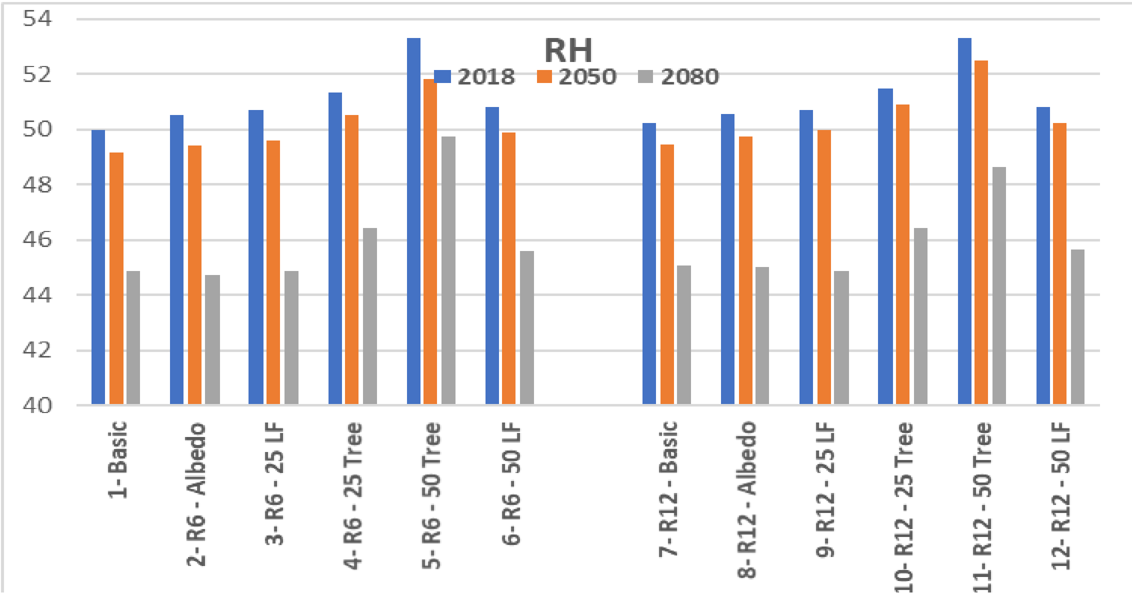


Figure 5-23 Relative Humidity different years 2018, the 2050s and the 2080s

Figure 5-22 reflects that climate change had increased PET differently across different street canyon orientations. For NS and EW canyons, PET has increased by 2.5°C and 7.5°C in 2050 and 2080 respectively. However, the temperature increase is the same; the temperature in the EW canyon was 5°C higher than for the NS canyon. This reflects that the amount of GSR received by the EW canyon is higher than the amount received in the NS canyon.

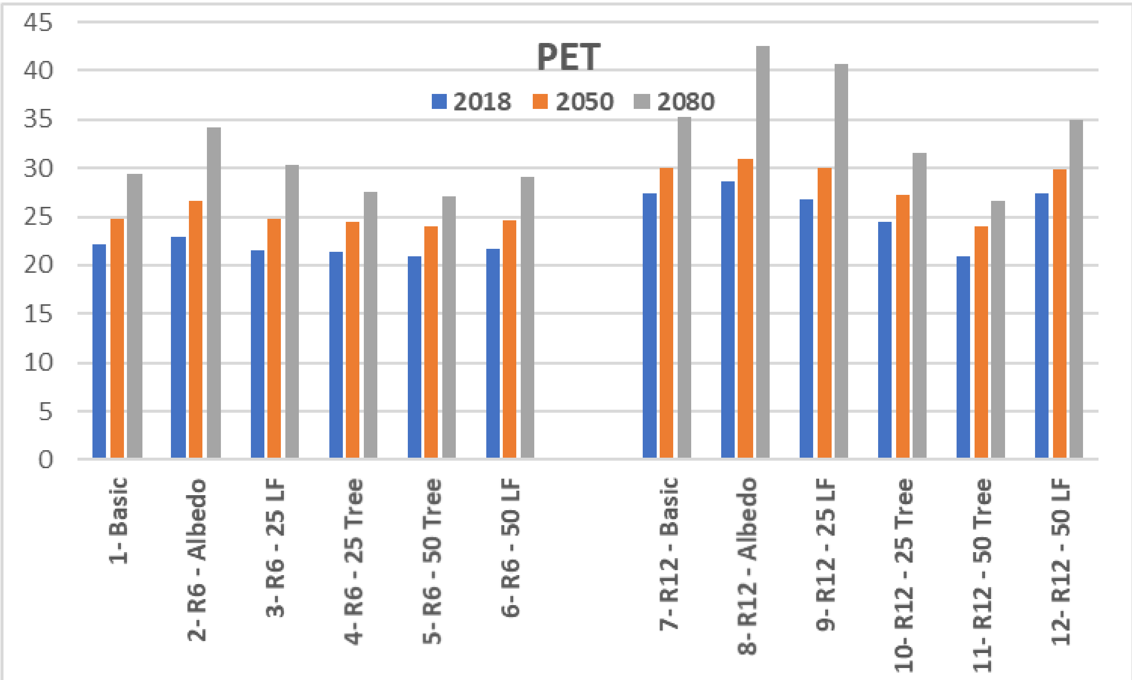


Figure 5-22 PET different years 2018, the 2050s and the 2080s

Since PET is the main factor to judge PTC within each year as it takes into consideration all thermal comfort factors (Tair, Tmrt, Ws, RH), it is very important to compare PET in order to determine PTC in each year as shown in Figure 5-22. The S2 was higher in temperature and PET across all years due to receiving longer hours of direct global solar radiation (GSR) as the canyon has an EW orientation. S2 was higher than S1 by 5.4°C on average, which represents 23.7%, 21.2% and 20% for 2018, the 2050 and the 2080s, respectively. Even though the temperature difference between S2 and S1 decreased with time, it is worth mentioning that the temperature averages are increasing noticeably with time which confirms that using UGSs become an essential solution to fight climate change and adapt to it.

It is also worth mentioning that, within S2, 50% of trees is the best alternative for UGS across all years, while S1 shows that across different years alternatives could be different depending on the level of climate change adaptation; for instance, by 2018 it could either used as an alternative or not, while for the 2050s and the 2080s different trees percentages shows similar PTC improvement. Thus using 25% trees would be more rational because it will not take up so much pavement space and on the other hand by applying the double of tree percentage (to reach 50%) the thermal improvement will not show a massive improvement in PET.

Through applying 50% of trees in S2 in the 2080s, the thermal comfort level reaches an equivalent value to the same canyon orientation in the 2018 base case with no greens. This shows an improvement in temperature and represents a shifting back in climate change by 62 years. Alternatively, the thermal improvement in PET in S2 by applying 50% trees could be similar to the thermal comfort level in S1 by the 2050s. Meanwhile, in the case of applying 50% trees in S2 by the 2050s, the thermal comfort levels in S2 would be equivalent to the thermal comfort level in S1 in 2018 which is 32 years apart and the street canyon in S1 is already shaded by buildings. This confirms the significant improvement from trees in shifting back climate change.

Across different UGS alternatives within different years in Figure 5-24, S1 had similar PMV due to the lack of GSR. It is also worth mentioning that within the ENVI-met software, PMV and GSR are not taken into consideration. Thus, it was not clearly visible to determine the influence of each UGS alternative from it; however, it is used to be easily understood by non-expertise within the field, and hence it can be easily explained. But if it a detailed explanation is required, then PET would be the right factor to analyse alternatives. Meanwhile, for S2, it was apparent that 25% and 50% trees had the best thermal improvement across all alternatives as, the drier and sunnier the weather is, the more trees percentage is advised which in general means 50% trees is better with the future climate.

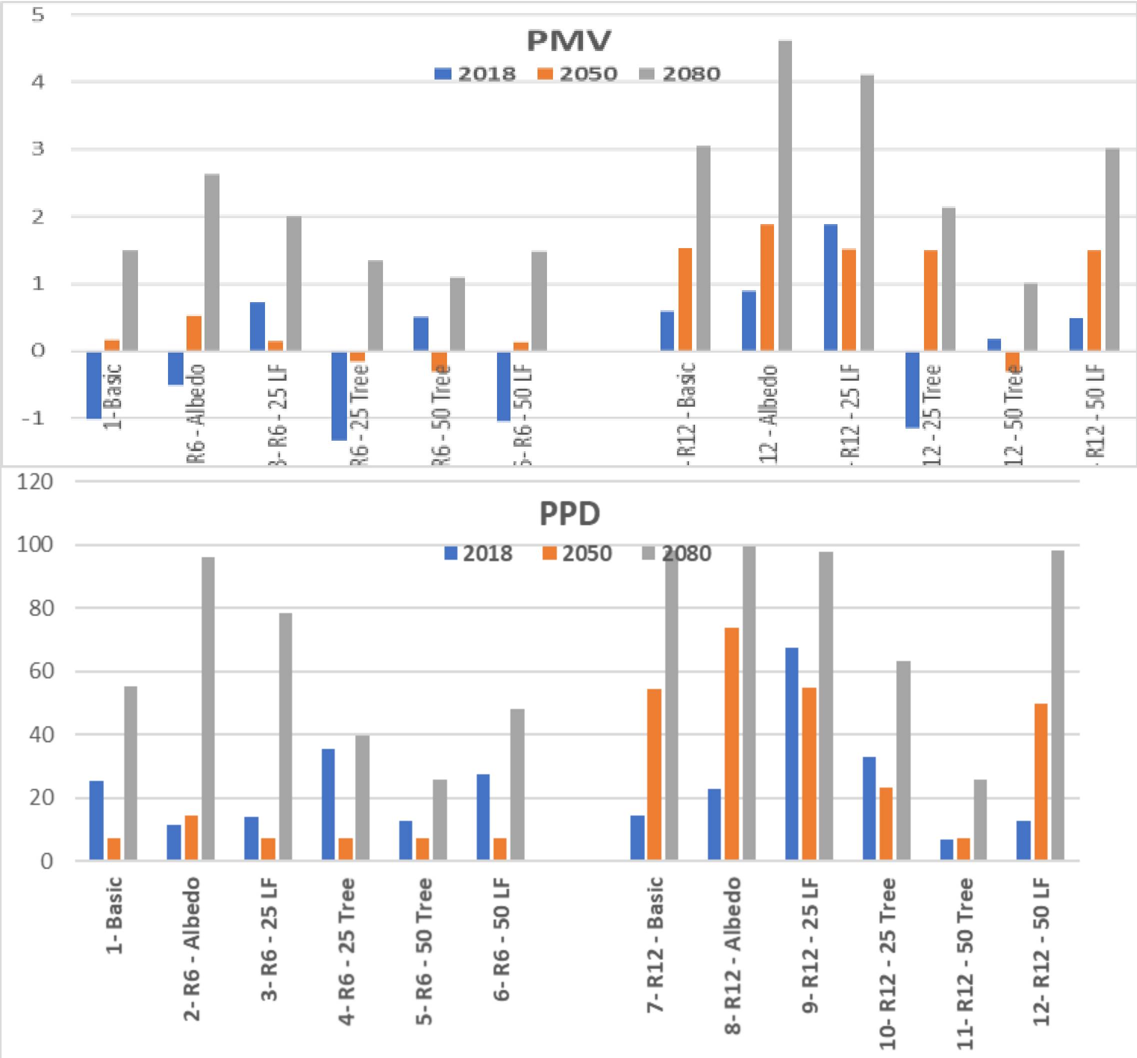


Figure 5-24 PMV and PPD for different years 2018, the 2050s and the 2080s

Carbon dioxide (CO_2) sequestration is one of the key factors determining the most appropriate UGS for each canyon across each year. As shown in Figure 5-25 CO_2 sequestration does not show much improvement across different alternatives, primarily through using 25% and 50% trees which have improved by 0.7%-1.2% and it is so small because it is mainly a global-scale challenge, a not a local-scale challenge.

It is worth mentioning that CO_2 PPM across different years was the same (410 PPM) since there was no available information and data for 2050 and 2080 CO_2 predications. However, using the same CO_2 PPM, the CO_2 concentrations within the pedestrian level were higher, reaching 423 PPM on average. On the other hand, this concentration decreased over the years, and that is due to the physical properties of CO_2, where its molecules volume/density decreases with the increase with temperature. One important fact is that this CO_2 reduction is being recorded within an hour (at 16:00) which, if it was applied across the daily hours and the whole season, then the results would be maximised. However, for this study, the researcher was actually looking at the daily average across the day which gives a view of CO_2 during the daytime.

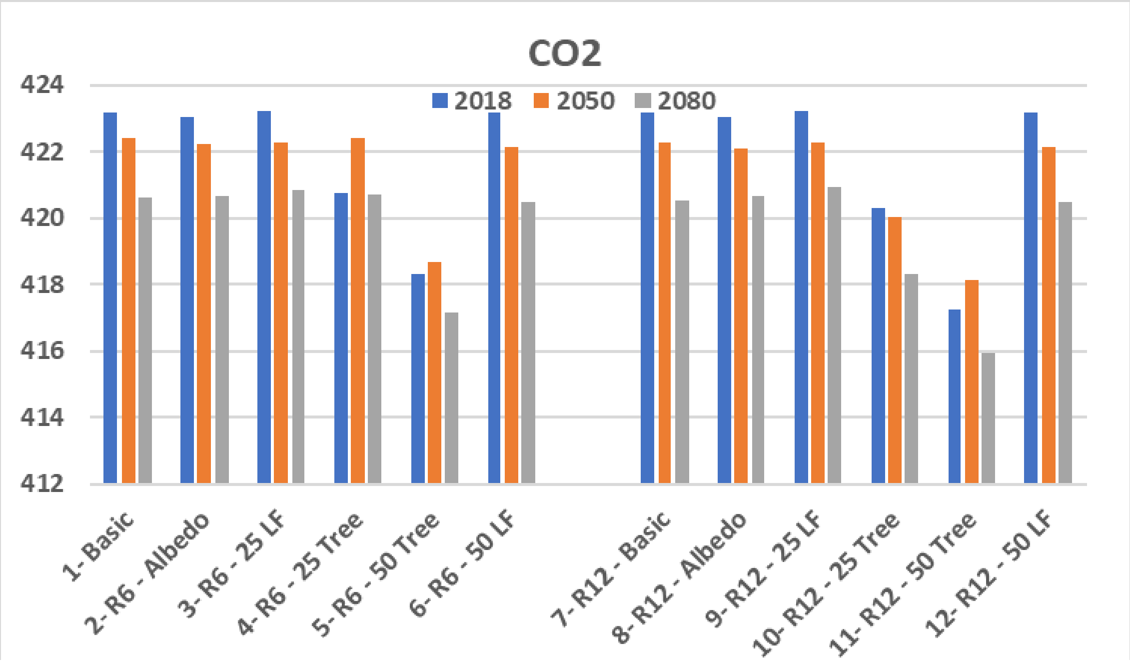


Figure 5-25 CO_2 different years 2018, the 2050s and the 2080s

5.5 2nd Phase – Recommended UGS alternatives for 2018, 2050s and 2080s climatic scenarios – same green percentages 25% Trees for S1 and 50% Trees for S2

Based on the first phase of running simulation for different UGSs within different climatic scenarios, a UGS alternative strategy was applied on each year in order to be able to recommend the most suitable and accurate alternative for each canyon orientation within each year depending on the level of thermal improvement and CO_2 sequestration which it affords to the pedestrians and then to the city in general. It for the S2 canyon, it was found that there was an urgent need for applying trees as a UGS alternative with 50% coverage within all alternatives while within S1 the 25% trees were very satisfactory in increasing PTC within it. Thus, 50% of trees were applied in all years (2018, the 2050s, and the 2080s) within S2 while, within S1, only 25% of trees were applied within those years.

All years were analysed to investigate the feedback outcome of the applied strategies. Taking into consideration that for the best thermal improvement and climatically control alter and to widen the thermal benefits of trees with 50% and 25%, they were shifted to avoid being parallel when placed within the street, and that would lead to more shade dispersed over the pavement and hence, more thermal comfort across the canyon to avoid any sort of shade overlaps.

Figure 5-26 illustrates that Ws benefited from the distribution of tree percentages across different canyons where S1 has lower Ws, so applying 25% would not really affect

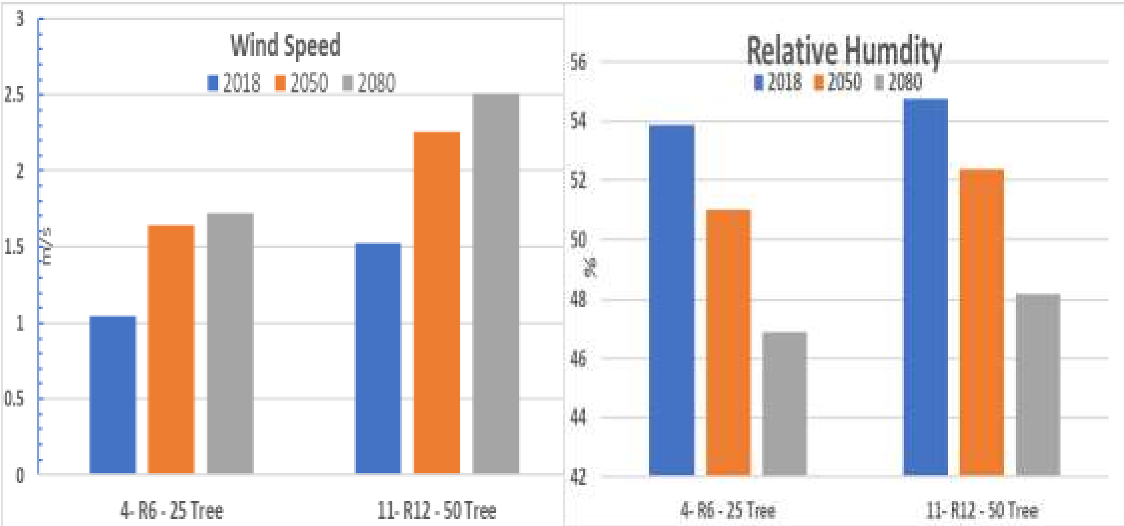


Figure 5-26 Wind speed and relative humidity for best alternative for each street orientation across 2018, the 2050s and the 2080s

the Ws that much; hence thermal comfort levels would be within acceptable ranges. On the other hand, within S2, with higher Ws showing higher thermal stress from more sunny hours, the 50% trees was the most appropriate alternative. Across different years, Ws within S1 were about 66%, 72% and 68% of S2 in 2018, the 2050s and the 2080s, respectively. Overall, trees have decreased Ws, yet it has improved thermal comfort due to its shading influence.

On the other hand, RH decreases within time, yet trees increased the RH of the air even by small margin during dry summers within those years which could be noticed through the increase of RH in S2 than S1 by +0.87%, +1.34% and +1.3% for 2018, the 2050s and the 2080s respectively. Wind speed change percentage in Figure 5-27 also reflects identical trend as wind speed graph in Figure 5-26

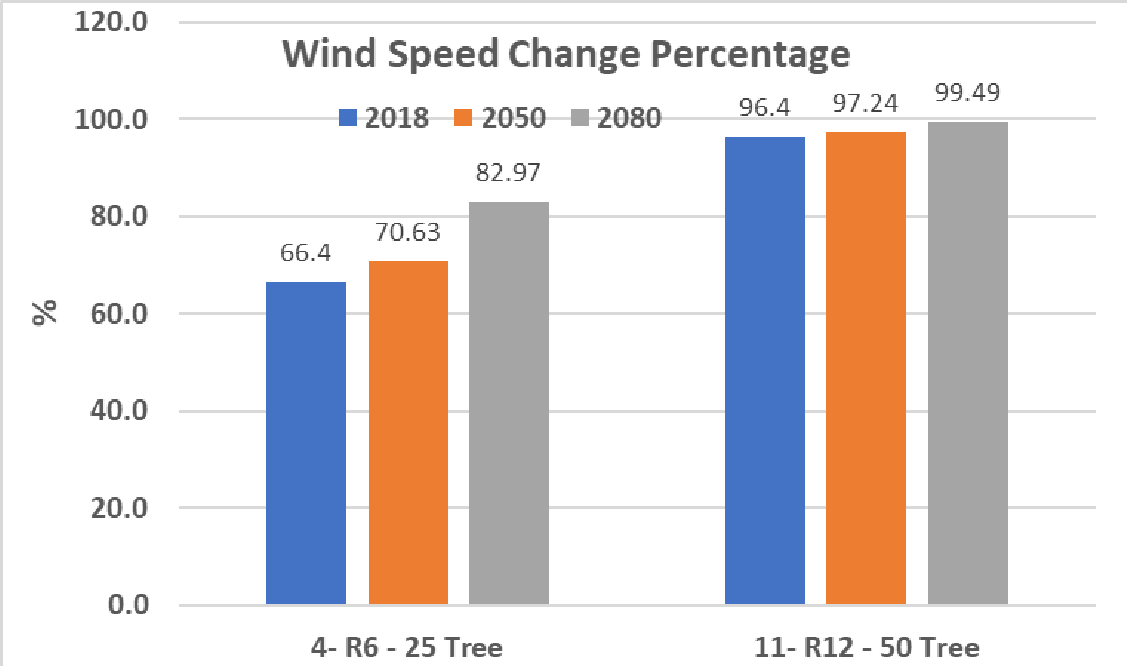


Figure 5-27 Wind Speed change percentage for best alternative for each street orientation across 2018, the 2050s and the 2080s

Interestingly, after applying the most appropriate tree percentage for each canyon orientation for each year, the researcher reached the thermal comfort level balance between S1 which is a well-oriented canyon and S2 which is a mis-oriented canyon due to intense solar radiation across summertime as shown in Figure 5-28.

In Figure 5-28, despite the fact that the PTC measurements are identical, on the map the PTC levels within PET, Tmrt, Tair and Ts are almost the same with negligible variation as with S1 the canyon lacks direct solar radiation, and hence, after applying 25% trees in a shifted layout instead of being parallel as shown in Figure 5-29. The PTC measurements were equivalent and stable across the whole canyon. For S2, after applying the 50% trees, it has improved the PTC levels significantly and stabilised the thermal temperature map (PET, Tmrt, Tair and Ts) across most of the whole canyon, yet there were a few spots where the sun penetrates the ground without being shaded by trees.

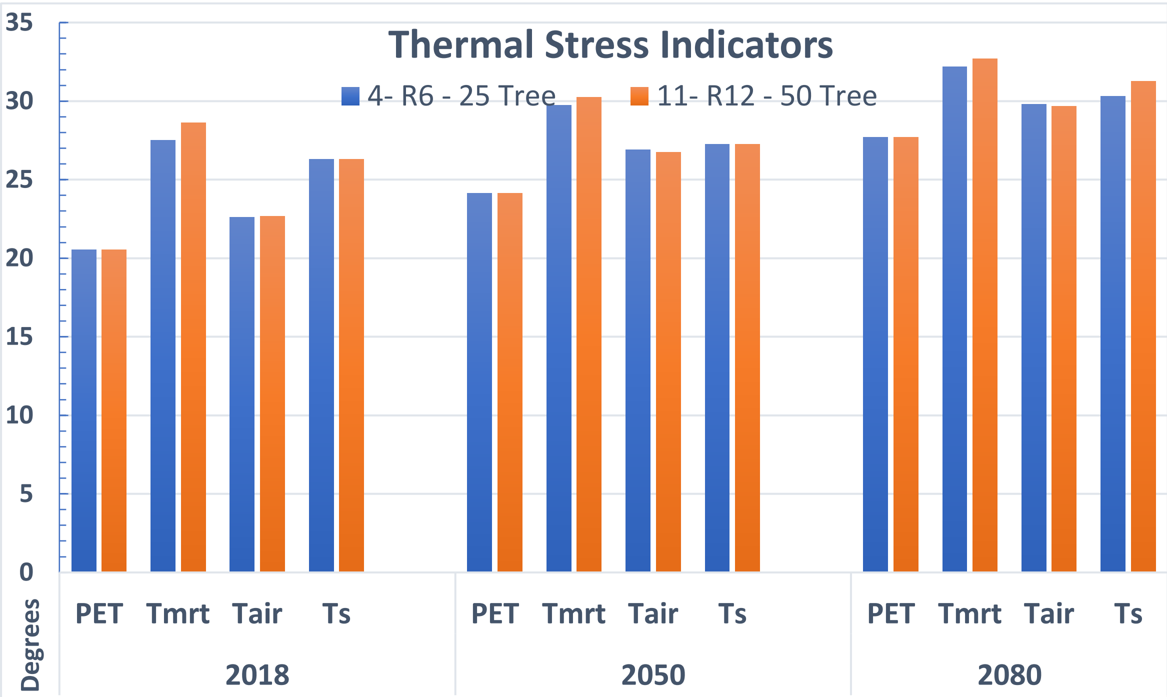


Figure 5-28 Thermal stress indicators for best alternative for each street orientation across 2018, the 2050s and the 2080s

Fascinatingly, however, the temperatures rapidly and significantly decrease through the efficient, effective way of using trees to lower temperatures within high thermally stressed canyons. Yet, the climate change is still taking place, and temperature levels are still rising, which means we can use adaptive, effective methods, but these will not reverse the change.

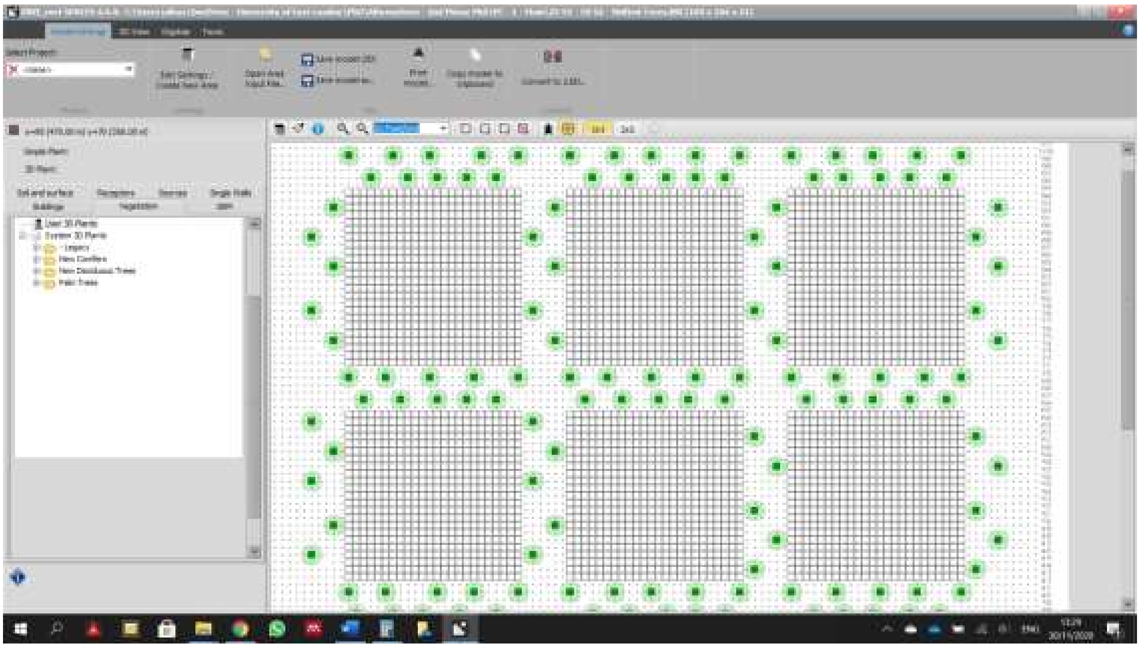


Figure 5-29 ENVI-met spaces file showing shifted street pattern 25% for NS orientation and 50% trees for EW orientation

In Figure 5-30, PMV reflects the same PET outputs and measurements, at which different canyons reach thermal balance within acceptable ranges; yet applying them within each year has a different comfort level for pedestrians while excluding direct solar radiation PMV is not considered during calculations. By 2018, applying trees cools the streets, to reach -1.5, which means it is thermally cool- cold, while in the 2050s with the same tree percentages and with the climatic change, the tree percentages just reach -0.08

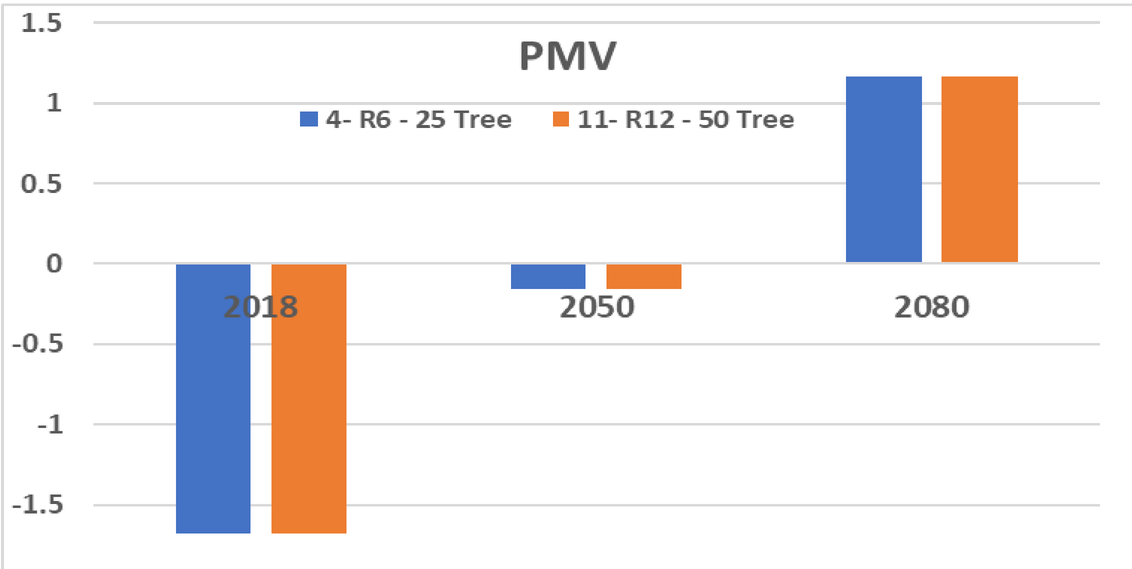


Figure 5-30 PMV for best alternative for each street orientation across 2018, the 2050s and the 2080s

which is almost 0, which means pedestrian are thermally neutral, while by the 2080s the same percentage affords warm temperature to the environment which shows the major shift in temperature and in climate from cool to neutral to warm.

In Figure 5-31, PPD reflects the PMV levels; however, the high percentages exist within 2018 and the 2080s that does not reflect the comfort temperatures as much as it reflects the dissatisfaction level where 2018 seems to be a cool level of comfort which is good and considered as a benefit for summer, particularly to motivate pedestrians and people to walk more. Meanwhile, for 2080, being warm within summer is still considered as acceptable during sunny days as it is common to be warm in summer. However, since it is not close to the neutral level, it is considered as discomfort which reflects the lack of accuracy for PPD and PMV to determine the PTC. Yet, it was essential to be included in order to be easily expressed for a non-expert.

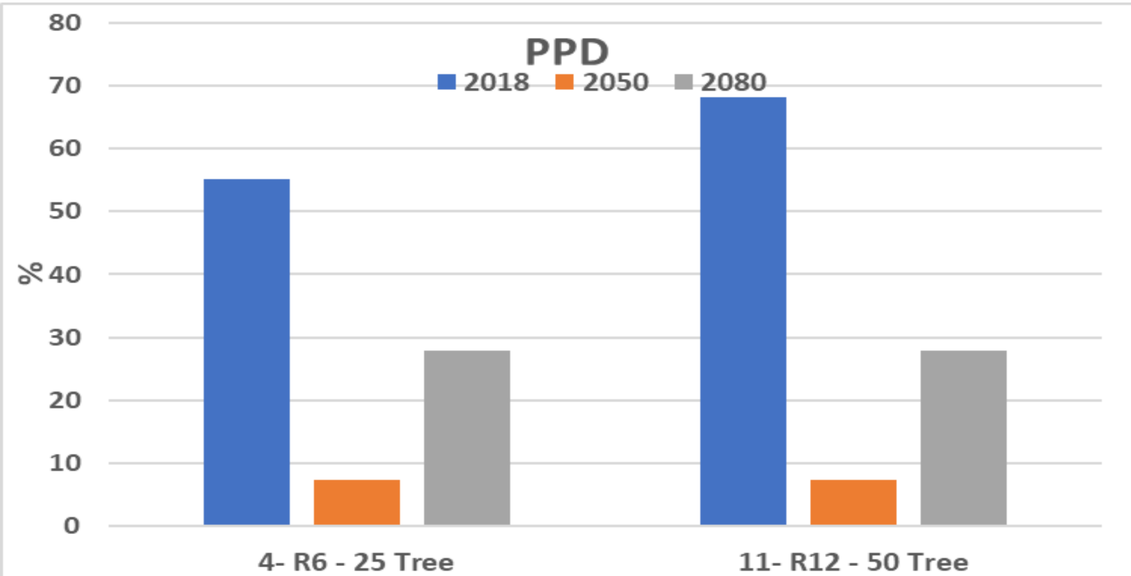


Figure 5-31 PPD for each street orientation across 2018, the 2050s and the 2080s

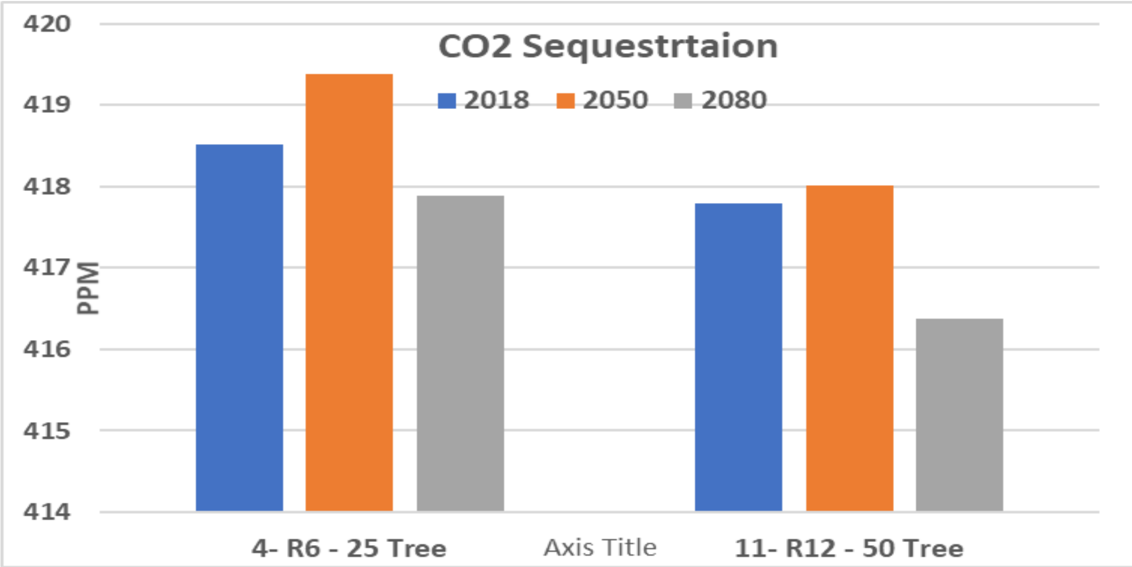


Figure 5-32 CO2 change for each street orientation across 2018, the 2050s and the 2080

CO_2 seems lower within S2 than in S1 in general due to the increase in trees' percentages, yet it was not that impressive in lowering CO_2 levels (CO_2 sequestration) due to its global scale. On the other hand, it is worth mentioning that within the 2050s, CO_2 levels increased more than in the 2080s and 2018, which might be because of some turbulence while the simulation was running.

5.6 Conclusion

This chapter mainly focuses on implementing the most adequate urban green system with urban street canyons with different percentages (0%, 25% and 50%) in current climatic scenario 2018, and future climatic scenarios of the 2050s and the 2080s. This was investigated in depth through computer simulation software (ENVI-met) which simulated a canyon with the same geometrical specifications as Oxford Street, London, the UK.

The microclimatic simulations results from ENVI-met had assisted to understand the behaviour of certain parameters questioned during the different years (2018,2050, 2080) in different canyon orientation (NS and EW) through applying different UGS with different densities. Within ENVI-met software it was crystal clear that North-South canyons and East-West canyons had to have a different configuration of urban green systems with different covering percentages; however, both of them had a massive positive influence on pedestrian thermal comfort through applying trees especially in the East-West orientation, while living façade did not show much difference and high albedo pavement increased thermal stress. East-West canyon orientation required more tree coverage than North-South due to receiving more solar radiation.

For carbon dioxide sequestration, none of the urban green systems showed massive positive impact in CO_2 sequestration which was confirmed through a literature review that limiting CO_2 emission sources is much more beneficial than planting more trees and greens. CO_2 sequestration did not show a difference across different street orientations. Overall, it was advised to apply 25% of trees in North-South streets while applying 50% trees across different years 2018, the 2050s, and the 2080s in the East-West orientation to increase pedestrian thermal comfort.

6 Chapter 6: Questionnaire Survey results and discussion

6.1 Introduction

This chapter provides more in-depth investigation and studies on the influence of different urban green systems on pedestrians' activity within central London. This investigation is carried out by collecting survey response of 598 participants in a four-section survey which is looking at pedestrians' activity within central London streets (walking, transportation, tourism, etc.) and how long these activities take outdoors. Then the following parts of the survey try to formulate different overviews of pedestrians' preferences towards applying UGS and whether they support their existence or not. Pedestrians have to determine their preference on a Likert scale for photoshopped pictures of different UGS alternatives in order to determine their favourite alternative. Finally, the last questions are demographical questions.

The responses of the survey are collected for further analysis based on participants' answers' frequency, followed by formatting a cross-tabulation between essential and related questions in order to form a more in-depth analysis and overview regarding participants' choices of the most appropriate UGS alternative and their street activity before and after applying UGS. Finally, a correlation heatmap is created to investigate which questions are correlated to each other and the significance and how strong or weak this correlation is.

From survey frequency, cross-tabulation and correlations, the researcher will be able to determine human's favourite UGS alternative and the priority of choosing their favourite alternative (biodiversity increase, thermal comfort, air pollution reduction, aesthetical improvement, etc.). Then, based on participants' responses, the researcher would determine the change in participants' time spent outdoors before and after the UGS alternative.

6.2 Questionnaire Survey analysis and discussion

After running computer simulations across different climatic scenarios (2018, the 2050s and the 2080s), for different UGS alternatives (HPA, LF, Trees) with different percentages, 0%, 25% and 50%, the researcher estimated the benefits and drawbacks of each alternative within each street orientation for each year for the CO_2 sequestration and the thermal comfort levels from a scientific perspective. The survey questions were classified into four sections, moving from generic questions about participants' street activity, then going to more specific questions about their preference for central London streets , going through classifying different UGS alternatives, until the final demographical questions.

As a part of the Healthy Streets Plan by the TfL, this research investigated whether different UGSs would have an influence on central London visitors. Because 28% of Londoners do not achieve 30 minutes activity per week while more than 40% of them do not achieve the recommended 150 minutes per week, these inactive lifestyles and decrease in physical activity are among the biggest challenges and health threats that lead to an increase in chronic diseases such as depression, diabetes, dementia, and cancer and heart diseases, which are the biggest killers in London. Therefore, the TfL had a consistent need to motivate Londoners into more active travel (cycling, walking, public transport use) in order to improve Londoners' health, reduce air pollution, ease congestion, bring economic benefits to businesses, and reduce noise (TfL, 2017).

The human body is involved in constant heat exchange with the built environment. Through this thermal heat exchange, humans go through physiological and psychological processes that they are unconscious of; however, they make conscious behavioural responses to reach or maintain thermal comfort at a certain level. All these unconscious reactions to maintain this thermal balance level or to reach thermal comfort fall into three main categories: environmental, psychological and physiological factors. It would be ideal to bring every relevant factor throughout thermal comfort investigation, making it as close to reality as possible, but these broad unlimited details and parameters involved make this unfeasible. At the same time, it is inadequate to explore one of these factors in isolation from the others because they are all connected and related in delivering the overall satisfaction (Al-Sabbgh, 2019).

The aforementioned factors have been determined through two stages. The first stage was through identifying the environmental factor of thermal comfort level through running ENVI-met simulations in order to determine the influence of different UGS in central London within different years in order to determine their influence quantitatively. Then, moving to the second stage determines the human aspect represented as physiological and psychological factors through a survey designed to identify the most appropriate UGS alternative from environmental, physiological, and psychological perspectives. These factors are discussed in this survey's outcomes, highlighting their prominence and the impact of each UGS on pedestrian thermal comfort and how it would influence their activity outdoors.

This survey focuses on some indicators of determining the Healthy Street as set out by the TfL (TfL, 2017). These indicators are things pedestrian are willing to see, people's choice to walk, cycle or use public transport, shade and shelter from extreme weather conditions, cleaner air, and welcoming place for all walks of life. On the other hand, some points were not the main focus of this study such as the ease in crossing streets, places to stop and rest, people feeling safe, and not too noisy.

The simulations did not include how pedestrians would be influenced by and react towards suggested alternatives, particularly how it will be for the next decades which was also suggested by the TfL in order to quantify the human UGS preference and how those alternatives would reflect on the pedestrians' activities within London's streets. Therefore, after distributing the questionnaire survey over the sample frame to specify participants in the survey study and how they would react to each alternative in addition to questioning how these UGS alternatives would reflect on their activities through 13 questions. Subsequently, the survey answers were collected and analysed through frequency tables to specify the general overview of participants and their answers.

Then cross-tabulations analysis was undertaken in order to specify the link between some the participants' answers and their choices for further breakdowns in order to investigate and explore the influences and relations between participants' responses. Finally, correlation analysis was carried out between different questions across the survey in order to investigate a deeper statistical analysis for survey responses and how to use it in the research.

6.2.1 Questionnaire Survey respondents

Next, the researcher undertook analysis of the number of participants, what questions they are going to answer or why they choose not to answer. based on several studies and a research paper by (William Smith, 2008) about survey respondents' and non-respondents' trends in who participate in surveys. Generally, it was found that more affluent and educated people tend to participate more. Women are also more likely to participate than men while younger people are more likely to take part in the survey than the older generations, and white people more than non-white people. The relevance of the survey topic to the audience participant and their interest strongly influence the response rates. On the other hand, some other points as survey fatigue, collection method and wording of the questionnaire title affect the response.

A similar pattern to this study was found in the respondents' demographics as women participated more than men by almost double with 65% while only 32% of men participated. Participants younger than 40 years old comprised 61% of the participants compared to ages 40+, 50+ and 60+ with participation of 19%, 15% and 5%, respectively. Further, 20% of the survey participants indicated that they want to receive the survey results which reflects their interest 15% of participants wrote additional comments which was either motivating the research and the researcher or asking for further enhancement requests from the policymakers or comments on their answers, which also confirms that they are either interested in the topic or or they believe they will be strongly influenced by the research findings or application. These demographical findings were explained in research by William Smith in 2008, explaining why participation in some ages and genders differs from others (William Smith, 2008).

6.2.2 Questionnaire Survey frequency

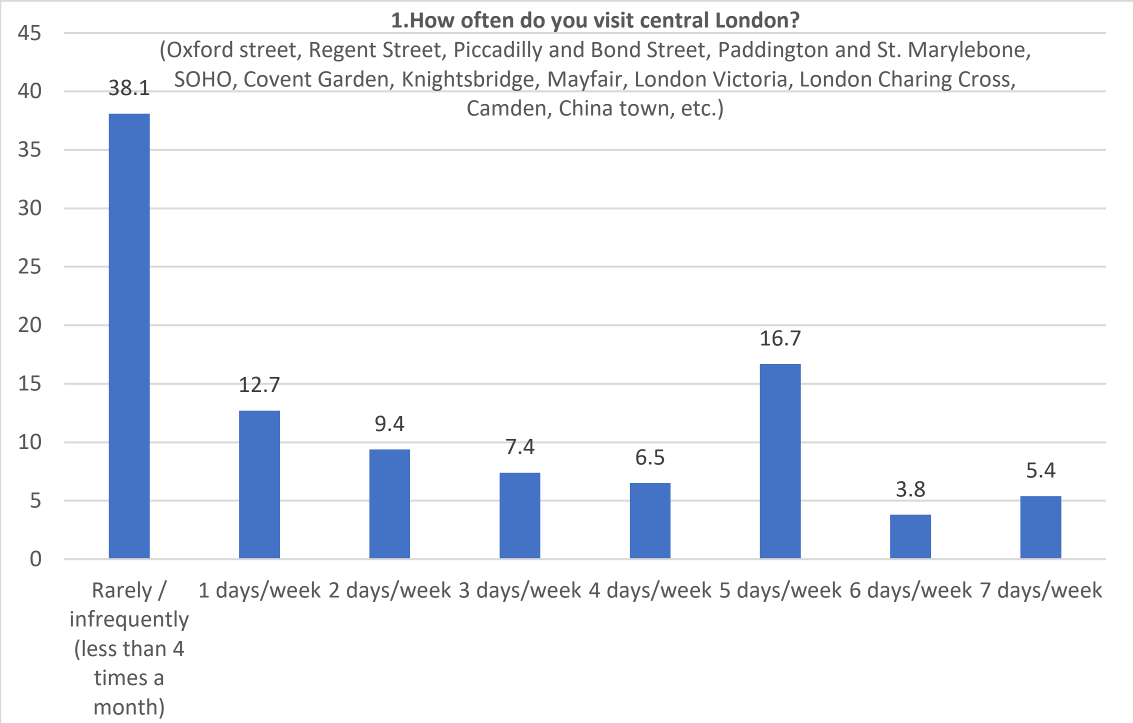
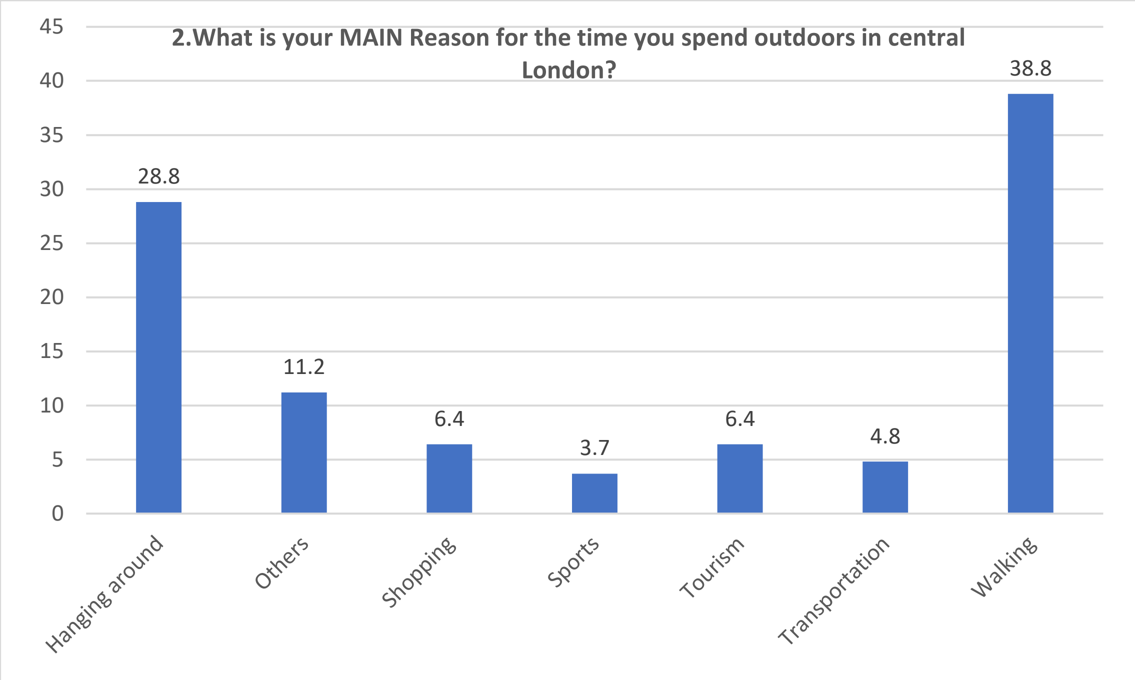


Figure 6-1 Q1 How Often do you visit central London frequency

This question is about how often the survey participant visits central London area (such as Oxford Street, Regent Street, Piccadilly and Bond Street, Paddington and St. Marylebone, SOHO, Covent Garden, Knightsbridge, Mayfair, London Victoria, London Charing Cross, Camden, China Town, etc.). This question aims to classify and identify regular, frequent and rare visitors to central London and, based on their answers, the researcher can identify the strength of their choices and how the proposed alternatives would influence them. At the beginning of the research, the objective was to identify frequent visitors who work part or full time within central London since they are the people familiar with the street. However, since the survey would be distributed widely and would include varied and different participants, it would be interesting to look at different street visitors and their different visiting patterns.

The question answers represent daily visits per week. From the surveys, 38.1% of the participant's visits were less than four times a month, followed by five visits per week, with 16.7%. 12.7%, 9.4%, 7.4% and 6.5% for one day, two days, three days and four days per week, respectively. The lowest number of visits was for six and seven days per week with 3.8% and 5.5%, respectively. The question highlights that approximately 40% of survey participants rarely visit central London while around 30% visit central London one to three days a week. It can also be noticed that 27% of people regularly visit between four to six days a week while 5.5% people visit central London on a daily basis (seven times a week) These visiting patterns show different groups of participants with different backgrounds and needs, representing central London visitors' diversity. The mean of the



participants' visits was 3.2 days per week.

Figure 6-2 Q2 - What is your MAIN Reason for the time you spend outdoors in central London? - Frequency

The second question classifies the survey participants' activity by asking them about the main reason for their activity while being outdoors within central London. This question helps to identify and recognise the main activity of central London visitors so that later on the researcher would be able to know if different activities within the street would influence the choice or preference of the suggested UGS alternative or not. Activities within the street varied as 38.8% were walking (walking to work/walking from bus or Underground station, walking home), while 28.8% were hanging around which covers meeting friends, sightseeing, dining and coffee shops, etc.. Tourism and shopping accounted for 6.4% of the activities followed by transportation (driving a car, riding a bus) with 4.8% and sports with 3.7%.

Other activities specified accounted for 11.2% representing 67 participants which, after analysis, described 14 mixed activities by participants who could not state the main reason for being outdoors and preferred to classify it as various activities between all choices. The findings showed that 26 participants out of the 67 were spending time outdoors, or going to meetings related to work. Nine people preferred to identify cycling separately as a mean of commuting, not sport. Five people specified that they live there. The remaining 13 participants cited a mix of different reasons for being within central London: social activism, climate protests, walking the dog or walking to parks, walking group activities, and one person identified that he does not spend time there because it is hot.

Overall, participants had a wide range of varied activities within the street and, based on their answers, almost 70% of them are doing activities which involve walking a great deal within central London streets which reflects the crowdedness and congestion within pedestrian walking spaces.

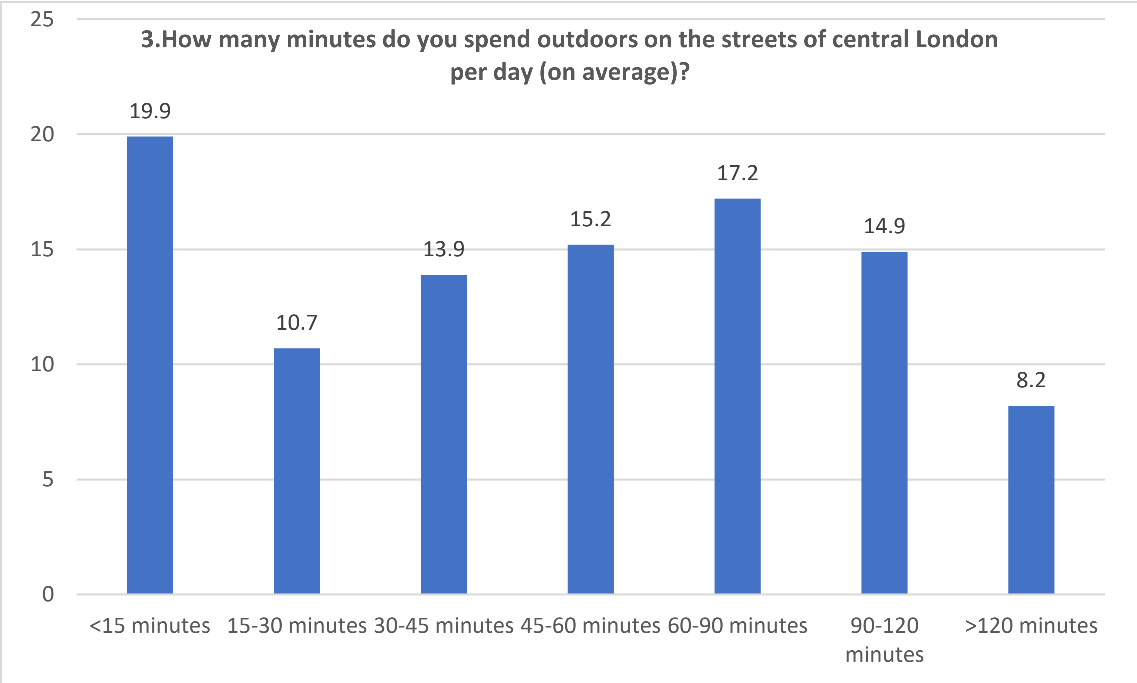


Figure 6-3 Q3 - 3.How many minutes do you spend outdoors on the streets of central London per day (on average)? - Frequency

The third question classifies the range of time participants spend outdoors within central London streets. This helped identify the range of time that ordinary people spend outdoors, and on the other hand, it also reflects the average time each participant spends based on their activities. Later on, this question was compared with question 12, which asks the same question relating to if the government applied one of the suggested UGS alternatives. Based on the participants' answers, the researcher was able to identify the influence of different UGS alternatives on time spent outdoors within central London.

The time spent outdoors shows a variance of minutes between 15 minutes or less and 120 minutes or more: 20% of participants indicated that they spend 15 minutes or less, followed by 17.2%, 15.2% and 14.9% representing 60-90 minutes, 45-60 minutes and 90-120 minutes, respectively. Following these, the average time from 30-45 minute accounted for 13.9% and 15-30 minutes accounted for 10.7%. Lastly, participants who spend more than 120 minutes represent 8.2%.

Overall, around 45% of participants spend less than 45 minutes, while 77% spends less than 90 minutes within central London streets. The mean of the time spent outdoors is 52.5 minutes which was later compared to measure if there would be a difference between current activity time within streets within central London's current situation and between future proposed UGS alternative situation in question 12.

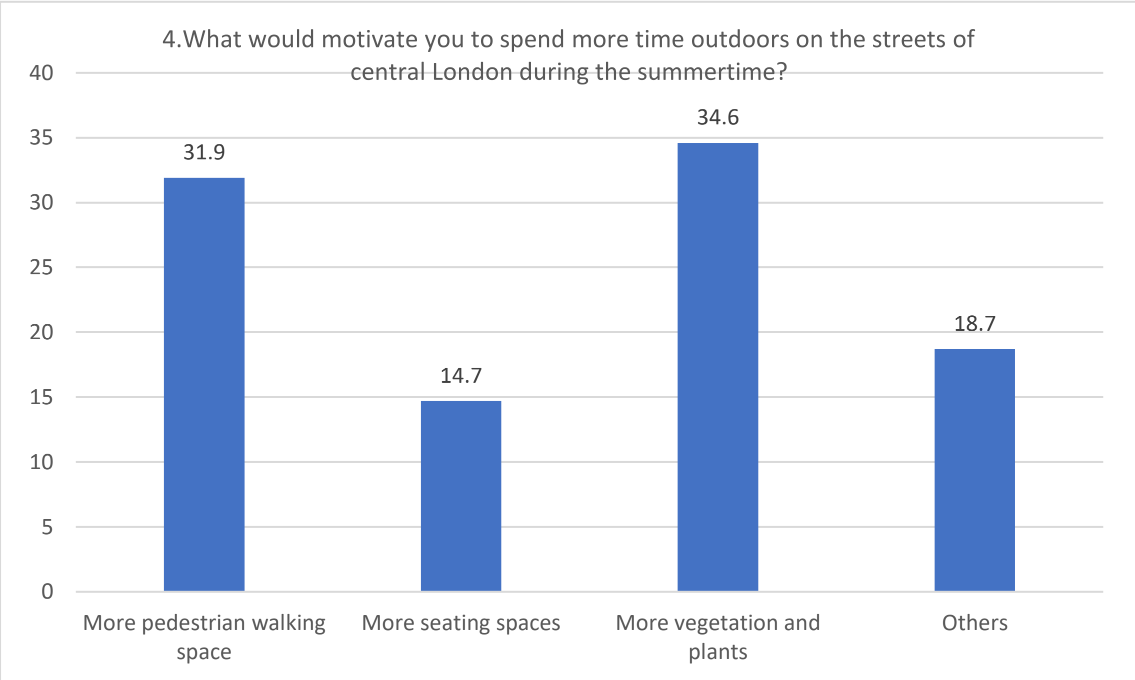


Figure 6-4 Q4 - What would motivate you to spend more time outdoors on the streets of central London during the summertime? - Frequency

The fourth question is directed more to identify participants' priority relating to outdoor street improvements during the summertime. Therefore, the questions assessed what the primary motivation was for participants to spend more time outdoors in summer within central London (more pedestrian walking space, more seating spaces, more vegetation and plants or other answers).

The highest answer was to introduce more vegetation and plants with 34.6%, followed by more pedestrian walking space with 32%, others with 18.7%, and more seating spaces with 14.7%. Other answers were chosen by 112 participants, including several motivations to spend more time during summer, which were mostly focusing on decreasing pollution, crowded streets, and traffic jams with 12, 6 and 14 participants respectively. In comparison, one of the main motivations for time spent outdoors is increasing cycling routes and lanes as stated by 25 participants.

On the other hand, 10 participants chose the option that all the answers together would be a great incentive for them to spend more time outdoors. More greenery parks and streets, nicer weather, less noise and more public toilets and parking spaces were chosen by four participants, each one individually. Around a further 20 participants chose different reasons as motivation; these included more outdoor activities (street galleries, social activities outdoors), wheelchair-friendly streets, rain shelters, less chaos and dirt, more trash bins, feeling safer, less crime and more police, more parking arrangements, cleaner air and carbon dioxide capture and shade.

Overall, vegetation and more pedestrian spaces accounted for 66.5% of the total choices which was confirmed after analysing other answers, which confirmed that most participants were motivated to spend more time outdoors by improving central London outdoor environment through increasing vegetation, decreasing pollution, less pollution, less crowding and cleaner air.

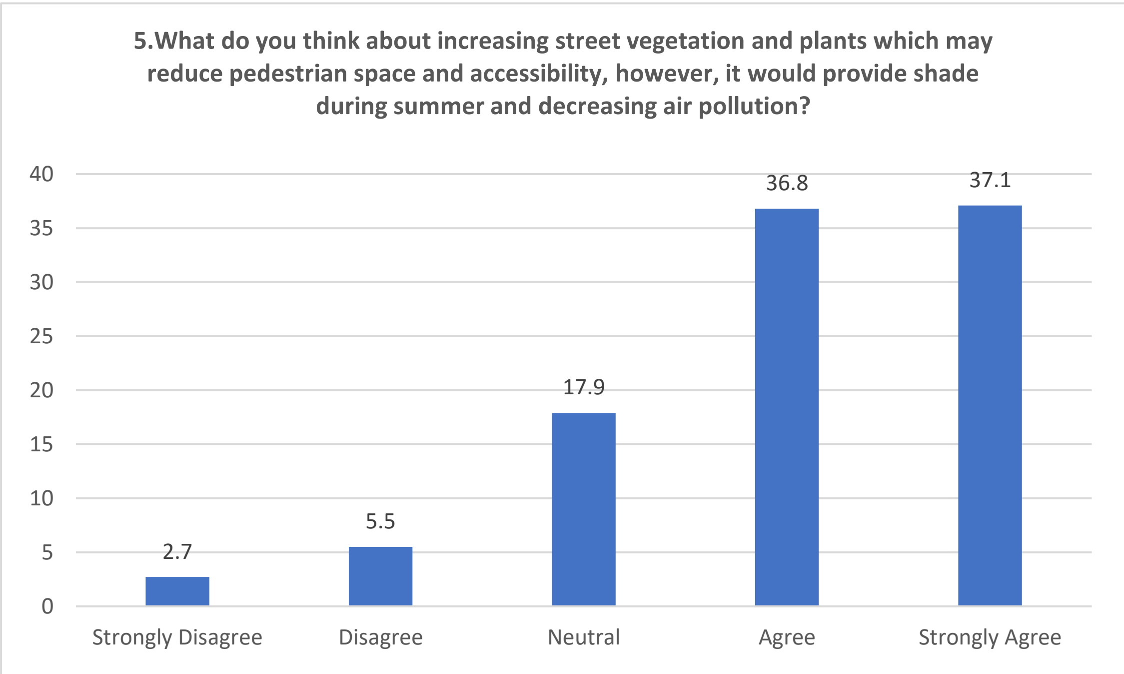


Figure 6-5 Q5 - What do you think about increasing street vegetation and plants which may reduce pedestrian space and accessibility, however, it would provide shade during summer and decreasing air pollution? - Frequency

The fifth question was mainly designed to check whether greenery and vegetation is a priority for participants, or whether it is a recommended not crucial choice. In order to check this, and validate the importance of the green and vegetation, and in order to avoid vegetation or green bias, this question asked about how supportive participants are for greenery against its drawbacks and limitations as reducing pedestrian space accessibility. The question was designed on a five-point Likert scale varying from 1 - Strongly Disagree to 5 - Strongly Agree. The answers were coded from 1 to 5.

The survey showed that numbers of participants who agree and strongly agree on increasing more street vegetation were similar with 36.8% and 37.1%, respectively. Then, 17.9% showed their neutrality towards more street vegetation while the least percentage for disagree and strongly disagree was 5.5% and 2.7%, respectively.

Overall, almost 74% agree on increasing street vegetation. The mean of the question on the Likert scale is 4, which represents agree. This response gives us a closer insight into participants' preference and their interest in vegetation; however; there are associated challenges. Question 5 response validates that question 4 was true and vice versa that both questions' responses confirm the massive interest in vegetation and green alternatives.

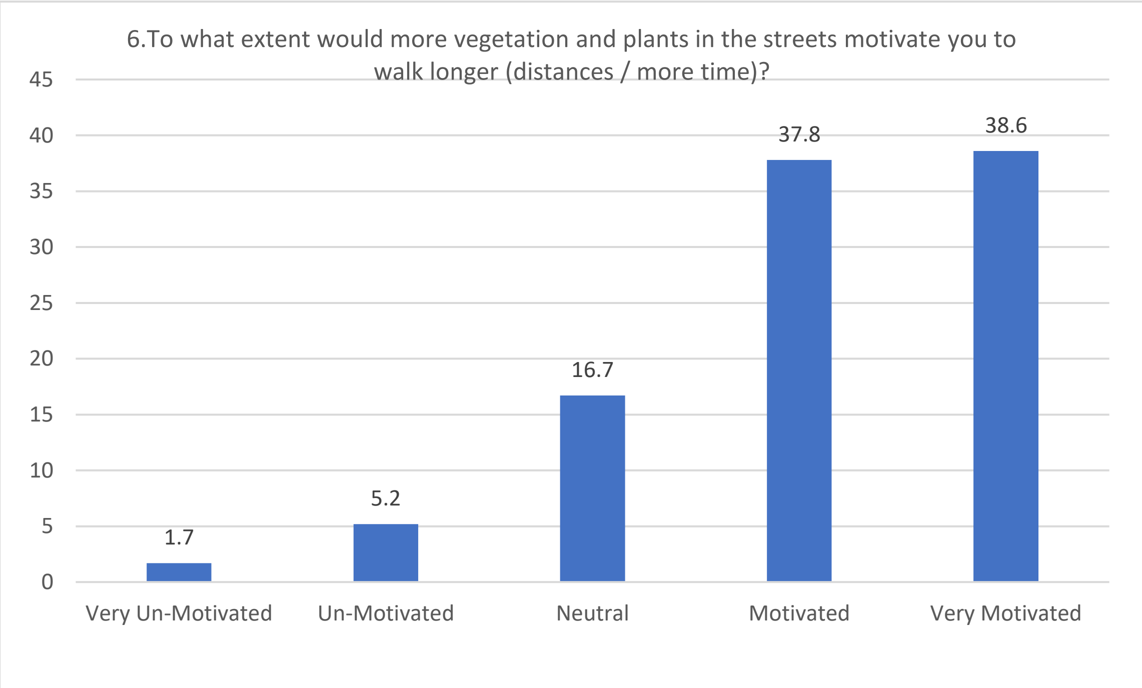


Figure 6-6 Q6 - To what extent more vegetation and plants in the streets would motivate you to walk longer (distances / more time)? - Frequency

Question 6 followed on from questions 4 and 5 in order to indicate, quantify and validate the importance of the UGS to central London visitors in order to avoid vegetation bias as well. The questions ask participants to what extent would more vegetation and plants in the streets motivate them to walk longer (distances/more time). Their answers reflected whether UGS alternative would have a positive or negative influence on their activity pattern outdoors where which walking is the common activity across different activities, and hence it related to all participants. The question was designed on a five-point Likert scale varying from 1 - Very un-Motivated to 5 - Very Motivated and the answers were coded from 1 to 5.

The survey illustrated that 37.8% and 38.6% represents the highest percentages for motivated and very motivated, respectively. The neutral choice was about 16.7%, followed by unmotivated and very unmotivated with 5% and 2%, respectively. Generally, motivated and very motivated choices represent 77% which reflects that participants will be highly motivated to walk a further distance or spend more time outdoors within the street. The mean of the choices is 4.1, which represents a motivated choice.

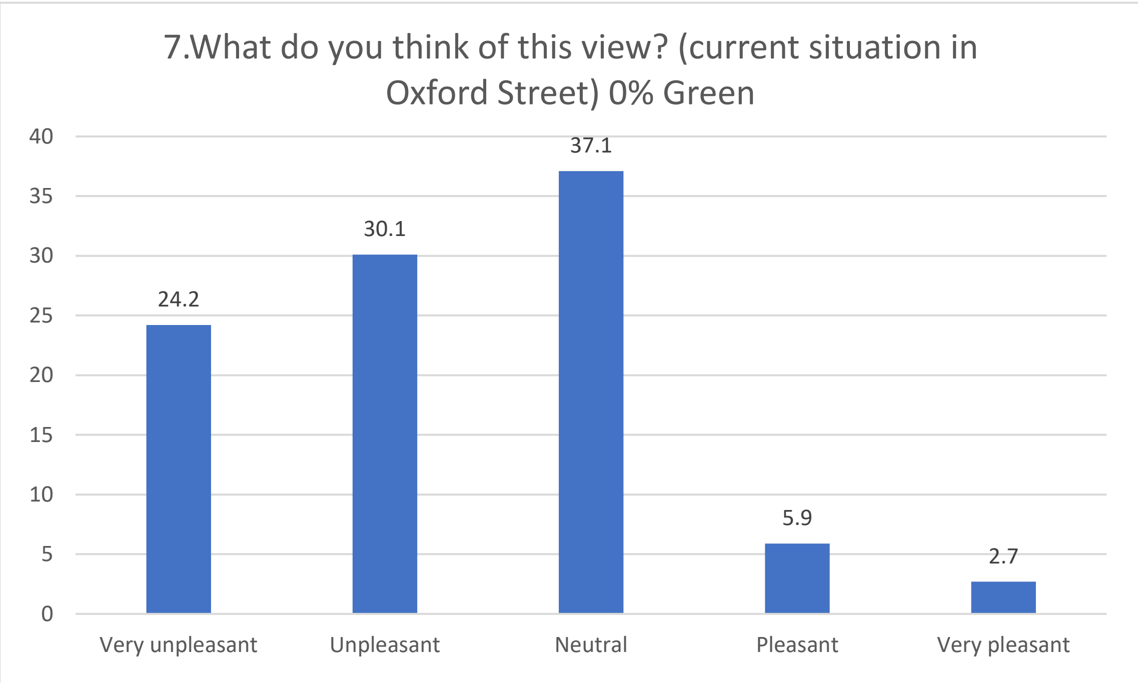


Figure 6-7 Q7- What do you think of this view? (current situation in Oxford Street) 0% Green – Frequency

Question 6 reflects the participants' positive influence towards more vegetation as it will increase their time and physical activity within the streets. This also validates participants’ interest in more vegetation and green areas whether on participants; street activity (walking more and spending more time outdoors) from question 6 or from the environmental activity from question 5 through providing shade during summer and decreasing air pollution and finally being a key motivation to spend more time outdoors in question 4.

Section two consists of five different illustrated pictures for Oxford Street. Question 7 represents the current case of Oxford Street with 0% green which is the present and actual scenario using a five-point Likertscale (5 points) from 1 -Very (extremely) unpleasant to 5 - Very (extremely) pleasant. The answers were coded from 1 to 5 with the suggested alternative or current case.

The highest chosen percentage was 37.1% for the current case scenario, followed by 30.1% and 24.2% of participants, representing neutral, unpleasant and very unpleasant, respectively, while pleasant and very pleasant presented 6% and 3%, correspondingly. Both very unpleasant and unpleasant represent 54.2% of total participants. The mean is 2.33, which represents an unpleasant view.

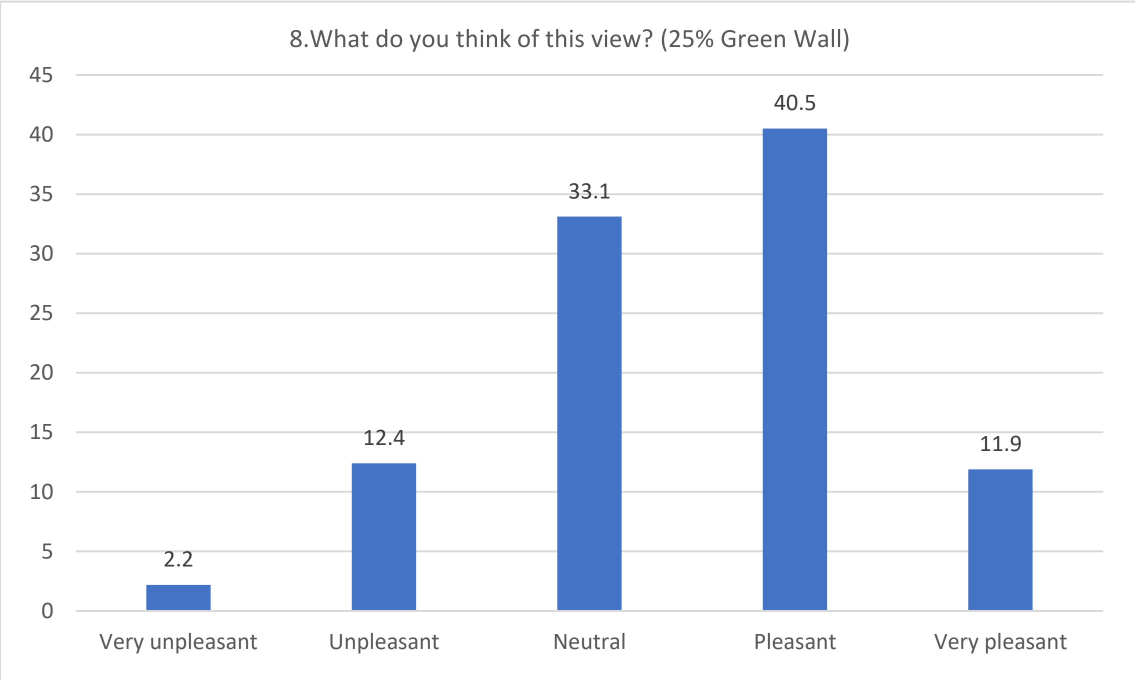


Figure 6-8 Q8 - What do you think of this view? (25% Green Wall)- Frequency

Question 8 shows a proposed UGS alternative for Oxford Street with 25% green wall coverage. It presents that 40.5% and 33.1% of participants have chosen that the 25% green wall has a pleasant view and a neutral view, respectively. While very unpleasant and unpleasant had similar values of 11.9% and 2.4% correspondingly and very unpleasant had 2% of the choices. Overall neutral and pleasant had 73.1% of participants' choices, and the mean of the choices was 3.4, representing the average between neutral and pleasant views.

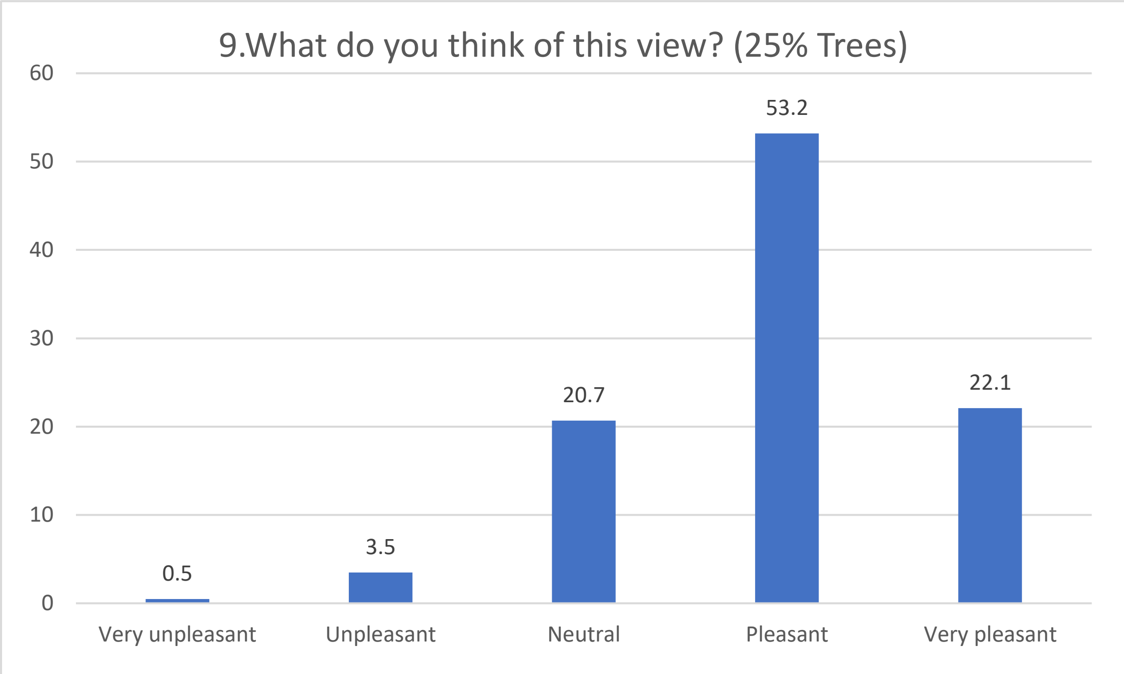


Figure 6-9 Q9 - What do you think of this view? (25% Trees) - Frequency

Question 9 represents a proposed UGS alternative for Oxford Street with 25% trees coverage. It presents that pleasant had the highest choice, with 53.2%, followed by 22.1% and 20.7% for very pleasant and neutral, respectively, while unpleasant and very unpleasant had 3.5% and 0.5%, correspondingly. In general, both pleasant and very pleasant represent 75.3% of participants' choices, and the mean of all participants; choices was 3.93, which represents pleasant.

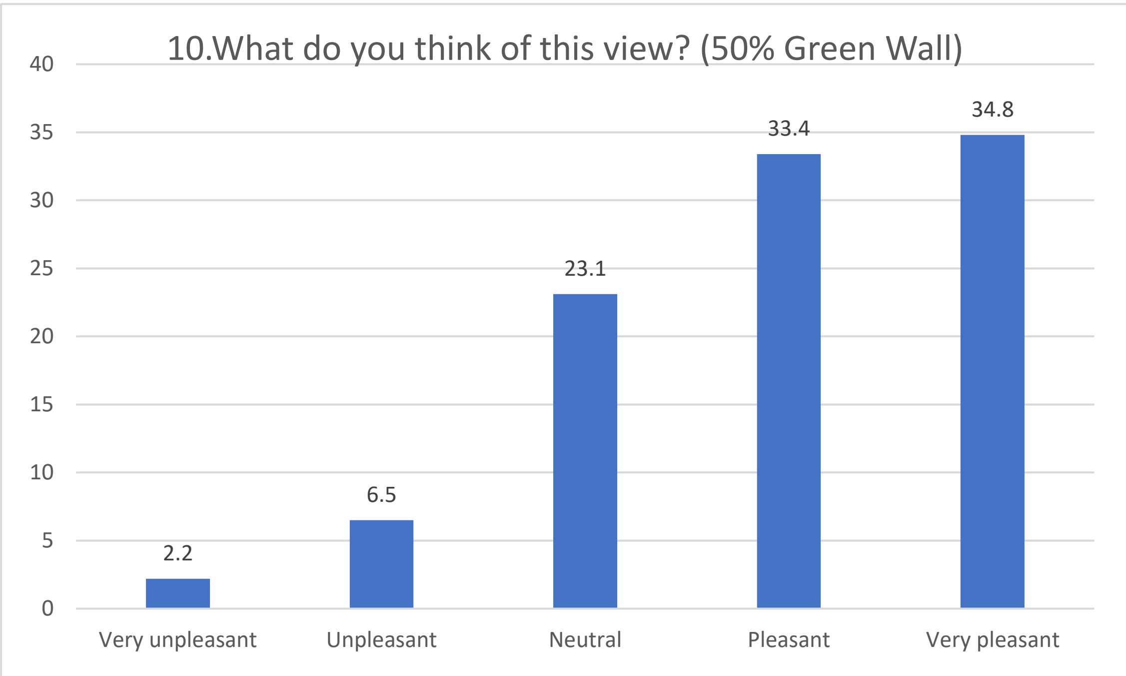


Figure 6-10 Q10 - What do you think of this view? (50% Green Wall) - Frequency

Question 10 signifies an optional UGS alternative for Oxford Street with 50% green wall coverage. It demonstrates that very pleasant had the highest choice, with 34.8%, followed by 33.8% and 23.1% for very pleasant and neutral, respectively, while unpleasant and very unpleasant had 6.5% and 2.2%, correspondingly. Overall, both pleasant and very pleasant represent 68.2% of participants' choice, and the mean of all participants' choices was 3.92, which represents pleasant.

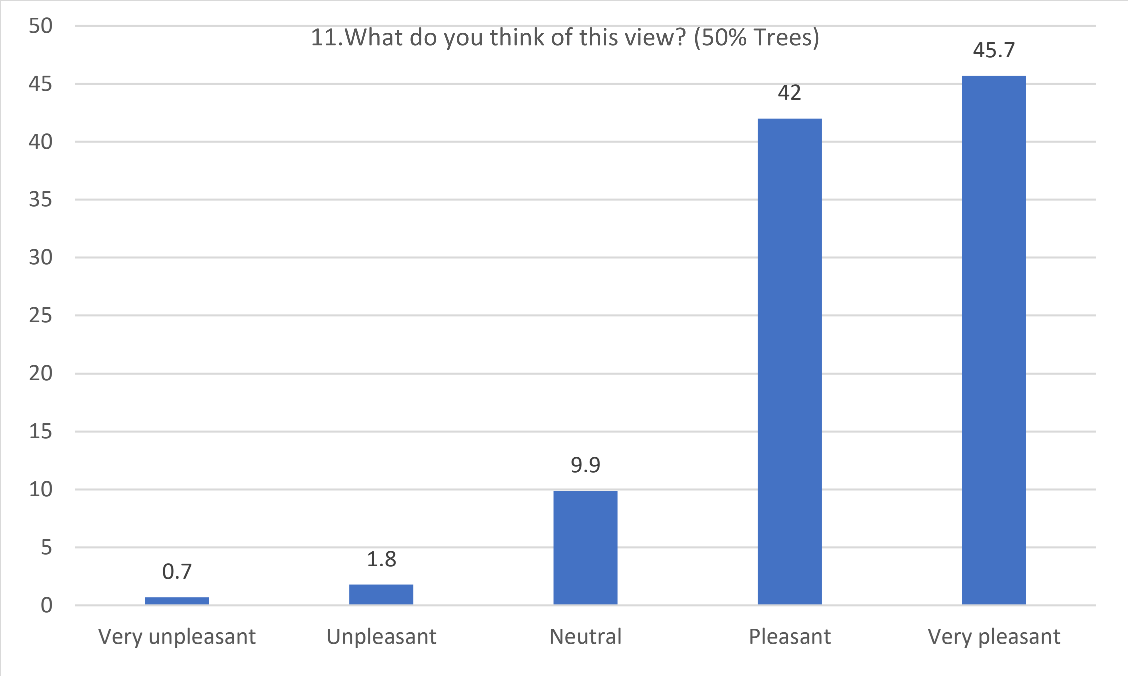


Figure 6-11 Q11 - What do you think of this view? (50% Trees) - Frequency

Question 11 represents a proposed UGS alternative for Oxford Street with 50% trees coverage. It illustrates that very pleasant had the highest choice, with 45.7%, followed by 42% and 9.9% for pleasant and neutral, individually while unpleasant and very unpleasant had 1.8% and 0.7% correspondingly. In general, both pleasant and very pleasant represent 87.7% of participants' choices, and the mean of all participants' choices was 4.3, which represents pleasant.

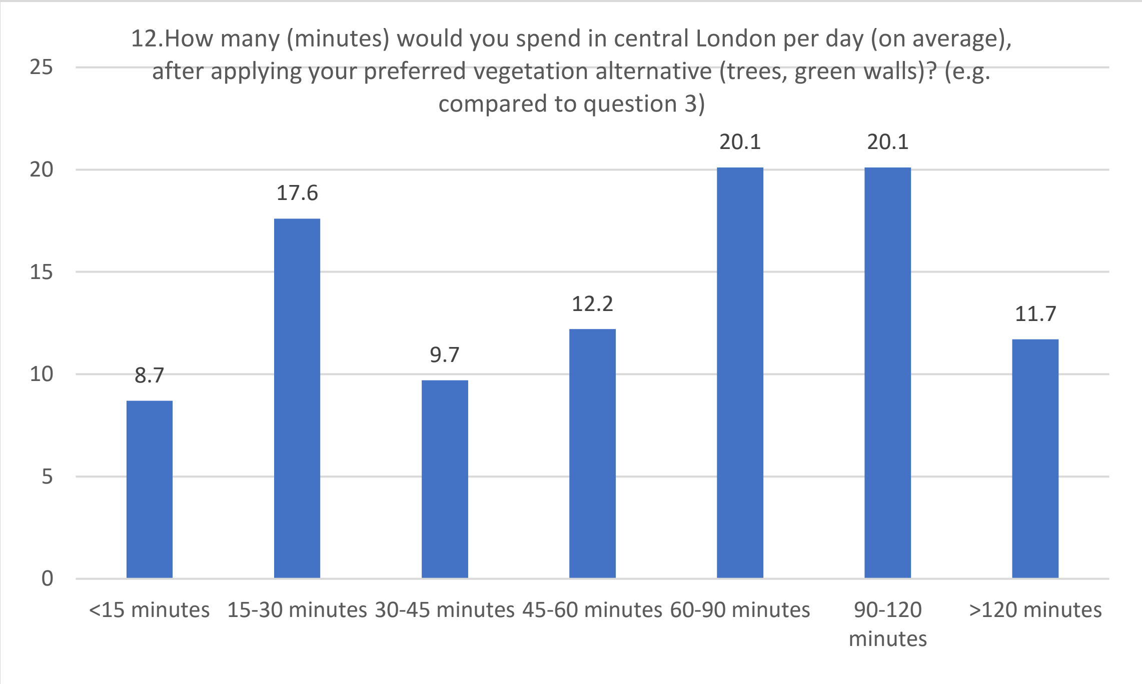


Figure 6-12 Q12 - How many (minutes) would you spend in central London per day (on average), after applying your preferred vegetation alternative (trees, green walls)? (e.g. compared to question 3) - Frequency

Question 12 classifies the range of time participants spend outdoors within central London streets after applying each participant's preferred alternative. This helped predict the range of time ordinary people will be spending outdoors after applying the UGS alternative and, on the other hand, it will also reflect the average time each participant spends based on their activities which could be easily compared to question 3 before applying UGS alternatives. Based on the participants' answers, the researcher was able to identify the predicted influence of different UGS alternatives on time spent outdoors within central London after applying UGS alternatives.

The time spent outdoors shows a similarity between 60-90 minutes and 9-120 minutes with 20.1%. They were followed by 15-30 minutes with 17.6% then 45-60 minutes and more than 120 minutes with 12.2% and 11.7%, respectively while time less than 15 minute and minutes between 30-45 minutes had a percentage of 8.7% and 9.7%, correspondingly.

Overall, around 40.2% of participants spend around 120 minutes, while 51.9% spends more than 60 minutes within central London streets. The mean of the time spent outdoors is 75 minutes, representing an increase of 30% more than their time before applying UGS alternatives. This also reflects that vegetation and UGS alternatives motivate people to spend more time outdoors.

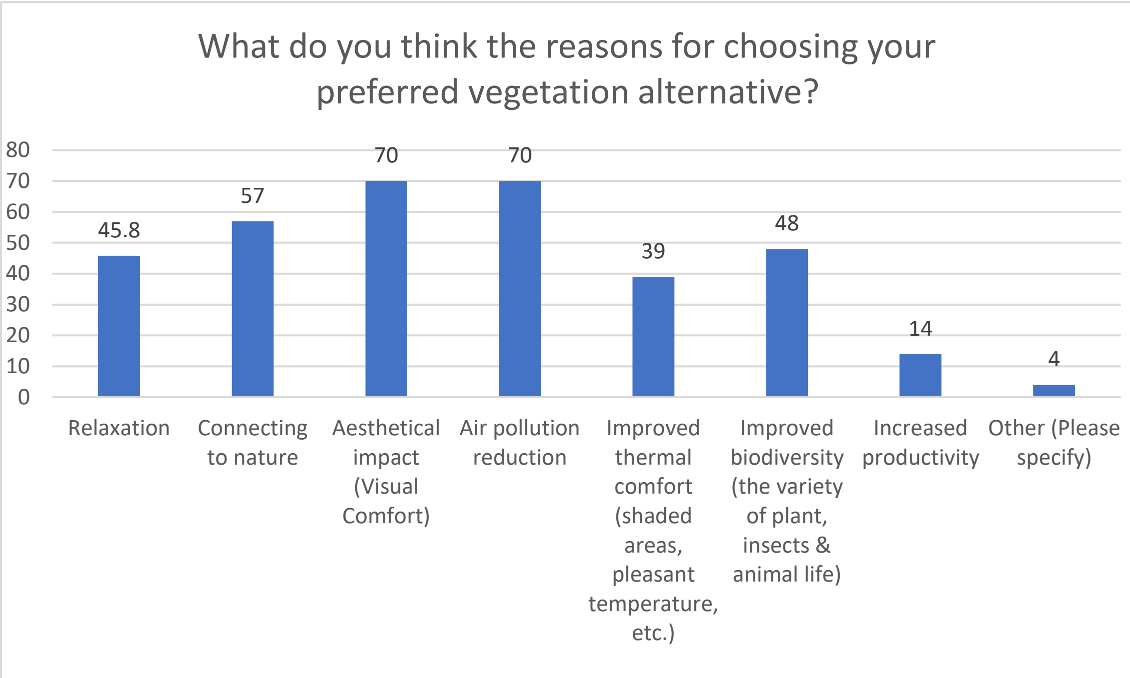


Figure 6-13 Q13 - about what do they think the reasons for choosing their preferred vegetation alternative - Frequency

Question 13 is a multiple-choice question which asks participants about what they think the reasons for choosing their preferred vegetation alternative above (trees, green walls) and they are allowed to choose multiple answers. This question is crucial to determine what the top priorities for participants for the UGS alternative are based on its multi-functional benefits. On the other hand, this question reflects what future research should be focusing on for more in-depth investigation concerning the public and their benefits from UGS since this research mainly focuses on thermal comfort and carbon dioxide sequestration.

Participants have chosen air pollution reduction and aesthetical impact (visual comfort) as the top priority with 70%, followed by feeling connected to nature, improved biodiversity (the variety of plants, insects and animal life) and relaxation with 57%, 48% and 45.8%, respectively. In fifth place is improved thermal comfort (shaded areas, pleasant temperature, etc.) with 39%, then increased productivity with 14%, and others with 4%.

The ‘other’ response by respondents was 4%, which represents 25 reasons which referred mainly to improved air quality, thermal comfort, mental wellness, and climate-resilient. Some participants indicated that it is more about the functions of those UGS alternatives, not their aesthetical values and that UGS should have free space to evolve and grow. Two respondents mentioned that UGS just make the space less ugly and more visually acceptable as it hides large buildings while three respondents indicated none of the above.

Surprisingly, the research focus, which is based on improved thermal performance ranked fifth with 39% while CO_2 sequestration was classified as one of the air pollution reduction strategies with 70%. Most UGS research mainly focused on environmental benefits (air pollution, thermal comfort levels), representing 109 out of 347.8. There are other factors which seem from the respondents' answers to be very crucial to them, such as aesthetical visual impact, connection to nature, relaxation, and increased productivity with 220 out of 347.8.

The third section within the survey contains more demographic and generic questions about survey participants and their choices and whether they would like to give further clarifications or not. Question 14 asks about respondents' gender in order to check this and whether they represent the community, or whether the sample is biased. The participants were mostly females, with 65% followed by males with 32% and others or prefer not to say with 3%.

Question 15 classifies participants age from 18 to 60+. The majority of participants were 26-40 years old with 45.7% followed by 40+, 50+ and 18-25% with 19.4%, 15.4% and 15.1%, respectively. The lowest percentage was for 60+ with 4.5%, while 80% of the participants are 40 years or less.

Participants were asked if they have any additional comments and, interestingly, 15% had additional comments which represent 88 comments; 20% of the survey participants – 119 - preferred to be contacted to receive the full survey results. The responses were classified into five classifications after analysis. One of them is motivating the researcher, and participants are excited about the change, and they should support the research and the work. The second group gave a further explanation for their answers within the survey which would explain their choices. The third group was classified as policy criticism, and request from the related authorities working on the project. The fourth group was identifying drawbacks and risks associated with UGS and how to avoid them while the fifth group was about the public suggestions and preferences about how and where to implement those UGSs from their perspectives.

The first group classification *–public suggestions and preferences* on the group work had 12 comments mainly wishing and requesting for pedestrianising the central London area and to make it more human-centred rather than vehicle-centric. Other members of the group advised having a holistic approach for greening not only through plants and vegetation but also through limiting pollution sources. Some comments have fancied a mix between trees and the living façade alternative, particularly for the biodiversity benefits while others suggested that parks should be connected through green corridors and rooftops should be converted into gardens. Comments also indicated that there are too many traffic lights instead of trees. On the other hand, people wanted a safer infrastructure, and UGS frequent maintenance is more important than placing plants and leaving them to die. Other participants indicated that the architecture needs to be changed, and the volume of buildings is huge, and UGS will help either hide the buildings or make the space more appealing.

The second category – *risks and drawbacks of UGS* – was identified by 18 survey participants who suggested that trees may take up spaces which will limit accessibility particularly for special needs visitors who already suffer from the crowded pavement. Participants pointed out that tree pollination could be challenging and tree volume could be too big. They stated that the related drawbacks were that the sky view and the horizon would be limited by the trees, which is an important part of being connected to nature, while trees make it harder for partially sighted visitors as it blocks the view and it also hides signs and shops and creates darker areas underneath.

One of the essential comments was that placing trees in a very congested pavement will make it more congested, increasing the problem, which is also risky during COVID-19. Other views see that placing more vegetation and greenery will not make much improvement without limiting the pollution source from all the vehicles. Decreasing pedestrian spaces will limit people from walking more and will motivate them to use other ways of transportation and again increase pollution levels and stress on public transport need.

The third category – *political disagreement* – was described in around 12 comments, mostly comparing London to other European cities such as Paris and Amsterdam. Amsterdam is referred to as a human-centric city and motivated people to cycle more than using vehicles while although Paris has lower green coverage, green exists everywhere which is due to the equal distribution of greenery across the city, unlike

London which has greenery in parks or at the city outskirts. Some people disagree with the Mayor's plan towards planning the denser city with more buildings rather than placing more open and green areas. At the same time, others see that green is not a priority for spending money as construction which would afford several benefits for people to live in and shops to open and bring further associated business benefits. Some views supported concrete greening areas in Vauxhall and wished it would be widely applied while others see that the TfL should depend on more renewable energies and sustainable transportation.

The fourth category – participants' comments on their answers within the survey – attracted nine responses. Some illustrated and explained that greenery would not change or influence their choice before or after applying suggested UGS as they are within central London for work so more greenery will not change the time spent outdoors within streets. Others said the same, but added that they might visit central London during the weekends if the UGS alternatives existed. One of the participants indicated that he suffers from agoraphobia (fear of open spaces).

The fifth classification – *motivational comments* – drew response from around eight participants who showed their deep interest in the work and government effort to place more greenery. They wished this to happen, wished the project luck, and hoped they would see it in reality. Some participants showed their interest in assisting the research team and working on the project if they can help.

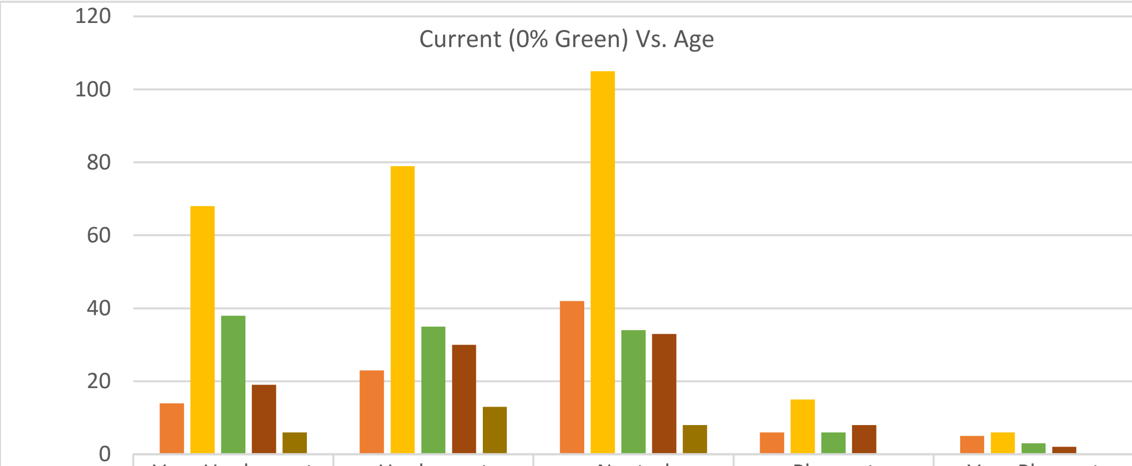
6.2.3 Questionnaire Survey Cross-tabulation analysis

Cross-tabulation is a significant and core part of survey analysis which is also referred to be as contingency table analysis or crosstabs. It is a statistical tool used for categorical analysis and distributes data finely. Categorical data include content whose relationships might be mutually exclusive. This quantitative research method helps to analyse the relationship between two or more variables. This would result in an analysis table with different rows and columns with percentages or codes in the correspondence axis. Data are usually collected and presented in numbers; nevertheless, numbers have no values unless they reveal something. Outcome survey reports are presented in a total combined form covering all survey respondents. Cross-tabulations simplify these data tables (frequency tables) that present the entire respondents' group results in order to examine relationships between these survey data results which could not be readily apparent when analysing the total survey response (frequency tables) (Ben Foley, 2018; Jane Treeza, 2019; Susan E. DeFranzo, 2020).

Since cross-tabulation is a mainframe statistical model that helps make an informed decision from overwhelming raw data that could carry similar results relating to research, it can identify correlations, patterns and trends between parameters. So, they are well represented and calculated through using advanced survey software with built-in analysis capabilities such as SPSS or JASP which can analyse the frequency of the favourite UGS alternative and break the results down by gender, age, number of street visits, etc. Subsequently, outcome tables can be presented graphically or visually through graphs and charts, among other tools.

Cross-tabulation offers data insights as it supports decreasing and highlighting the data sets into more manageable subgroups in addition to presenting deep insights. It would be challenging and prone to errors if frequency tables alone were used to achieve insights into the relationships between different categorical variables. Therefore, in analysing survey response data, cross-tabulation reports represent the relationship between two or more survey questions. A typical cross-tabulation table compared the two hypothetical variables “gender” with “Favourite UGS alternative”. Are gender and favourite UGS alternative independent? The table cells report the frequency counts and percentages for the respondents’ number in each cell (Ben Foley, 2018; Jane Treeza, 2019; Susan E. DeFranzo, 2020).

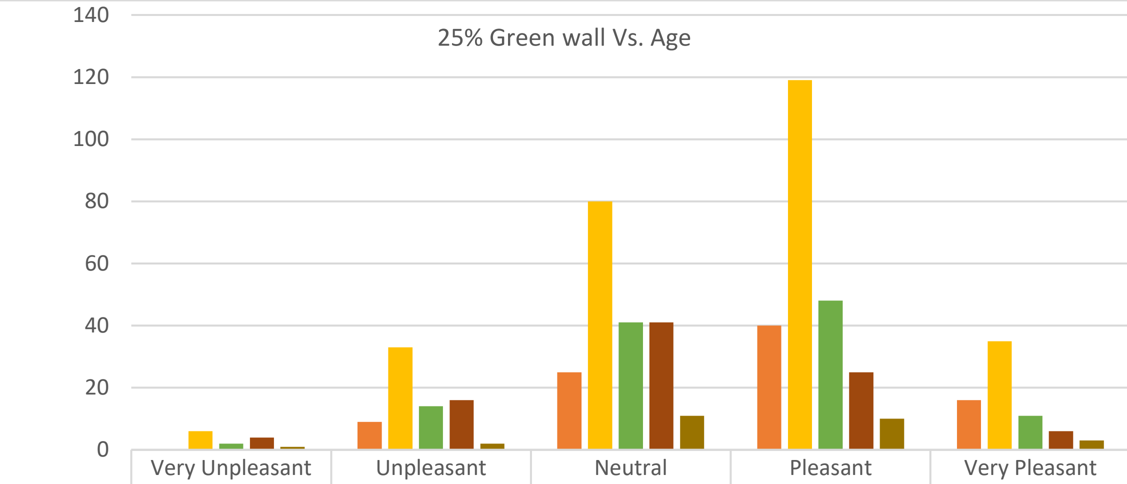
The cross-tabulation steps started to link and correlate the survey answers and the responses between different questions in order to gain a deeper insight and valued outputs to complete the overall aim and objectives of the research regarding applying the right UGS alternative and how that would reflect on pedestrians within streets. Therefore, most of the cross-tabulations used here have investigated participants' demographics relating to each suggested UGS alternative and how their activity will be influenced after applying one of the suggested UGSs to cross-tabulating questions before and after applying UGS systems.



	Very Unpleasant	Unpleasant	Neutral	Pleasant	Very Pleasant
18 - 25	14	23	42	6	5
26 - 40	68	79	105	15	6
41 - 50	38	35	34	6	3
51 - 60	19	30	33	8	2
60+	6	13	8	0	0

Figure 6-14 Cross-tabulation - Current (0% Green) Vs. Age

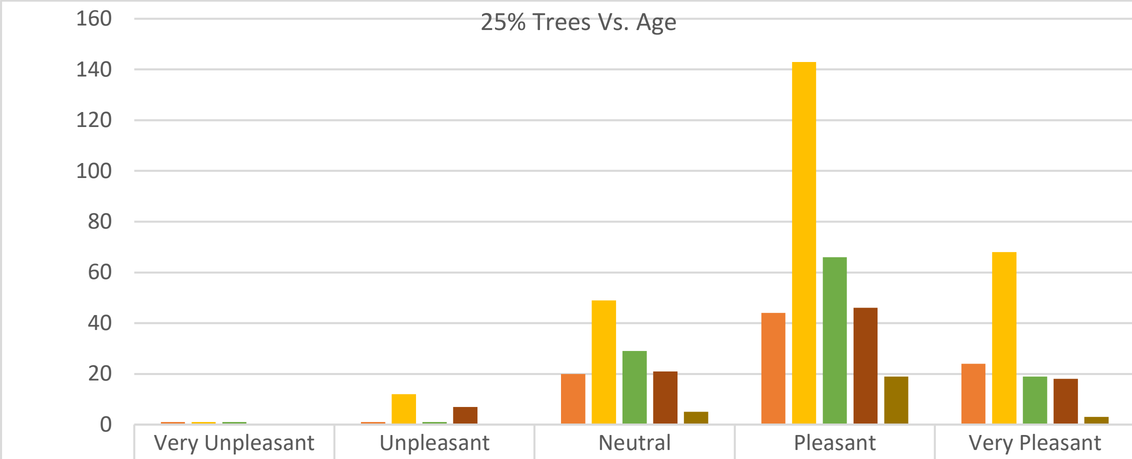
The first cross-tabulation relationship tried to address and spot if there was a difference or particular preference for survey participants based on their age group. The question wanted to know the participants' evaluation for the actual Oxford Street view, which is 0% green. Based on the cross-tabulation analysis, it was self-evident that similar users' patterns were noticed across the Likert scale as the mean varied between 2.1 and 2.6 which all represent unpleasant, reflecting that across different age groups, all participants agreed that the view is unpleasant.



	Very Unpleasant	Unpleasant	Neutral	Pleasant	Very Pleasant
18 - 25	0	9	25	40	16
26 - 40	6	33	80	119	35
41 - 50	2	14	41	48	11
51 - 60	4	16	41	25	6
60+	1	2	11	10	3

Figure 6-15 Cross-tabulation - 25% Green wall Vs. Age

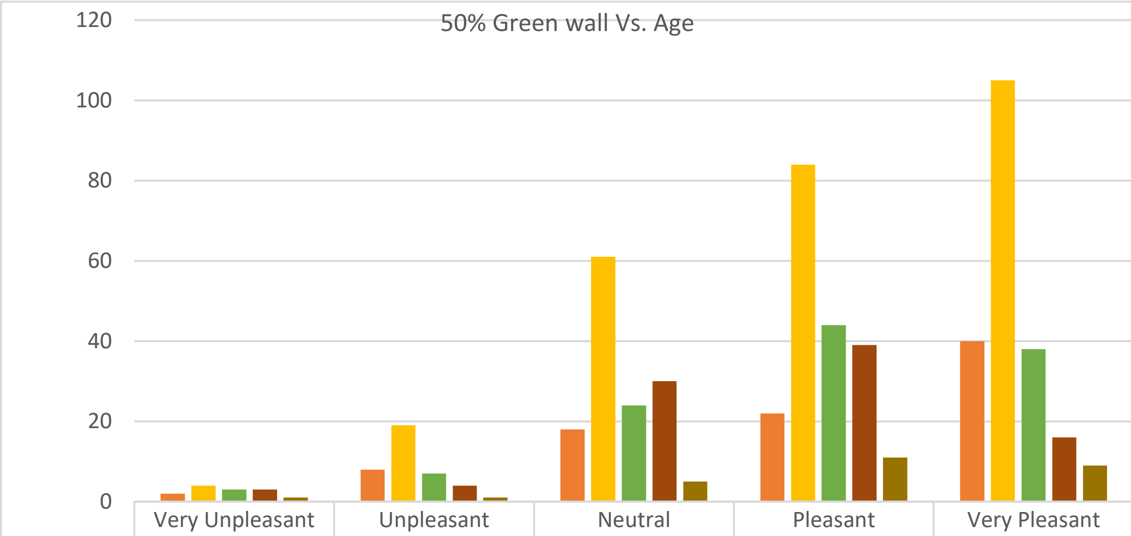
Similarly, this question focuses on participants' evaluation for 25% green wall and their age group. It was noticed that all different age groups have agreed that the 25% view is more appealing than 0% green and that has reflected on their evaluation. The average mean of ages varied between 3.1 and 3.7 across all age groups which represents neutral. The age group 18-25 had the highest mean of 3.7, while the lowest mean was 3.1 for ages 51-60.



	Very Unpleasant	Unpleasant	Neutral	Pleasant	Very Pleasant
18 - 25	1	1	20	44	24
26 - 40	1	12	49	143	68
41 - 50	1	1	29	66	19
51 - 60	0	7	21	46	18
60+	0	0	5	19	3

Figure 6-16 Cross-tabulation - 25% Trees Vs. Age

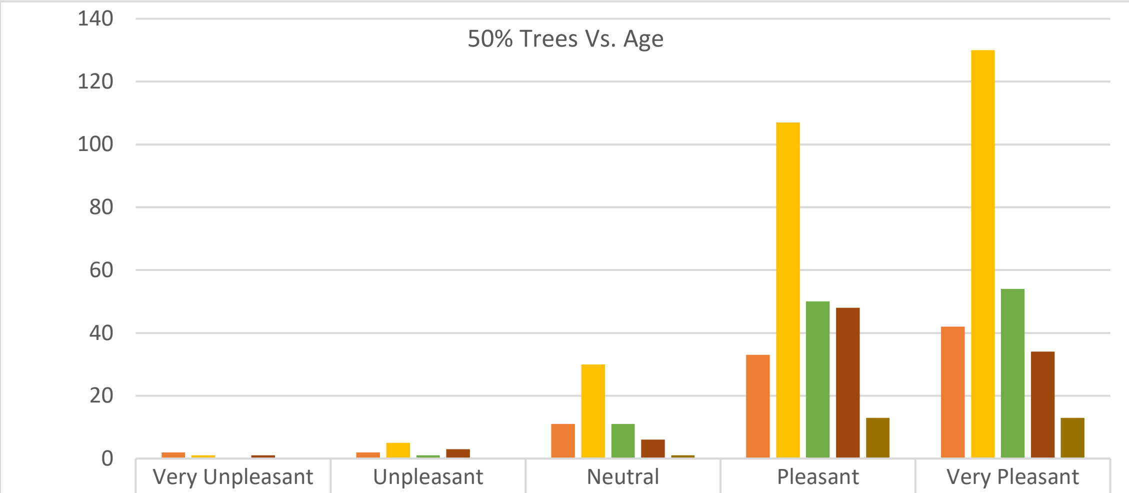
For 25% trees, cross-tabulation has revealed significant interest in participants' responses and evaluation as their evaluation on the Likert scale has moved towards pleasant, and very pleasant which shows that the majority have enjoyed the view. The average mean of age groups varied between 3.8 and 4, which reflects more agreement in the views and less variance. The mean of all age groups is 4, which is pleasant.



	Very Unpleasant	Unpleasant	Neutral	Pleasant	Very Pleasant
18 - 25	2	8	18	22	40
26 - 40	4	19	61	84	105
41 - 50	3	7	24	44	38
51 - 60	3	4	30	39	16
60+	1	1	5	11	9

Figure 6-17 Cross-tabulation - 50% Green Wall Vs. Age

Like previous cross-tabulations, this table reflects that different age groups showed interest with more green UGS applied to streets, where the green wall represents 50% of the spatial coverage. The mean of age group varied between 3.7 and 4, which overall represents pleasant. However, the percentage of green coverage increased from 25% for tree case to 50% green walls, and the average mean of responses between the two percentages was not impressive. Overall the mean of age groups was 4, which represents pleasant.



	Very Unpleasant	Unpleasant	Neutral	Pleasant	Very Pleasant
18 - 25	2	2	11	33	42
26 - 40	1	5	30	107	130
41 - 50	0	1	11	50	54
51 - 60	1	3	6	48	34
60+	0	0	1	13	13

Figure 6-18 Cross-tabulation - 50% Trees Vs. Age

Throughout different age groups, the majority of respondents have evaluated the 50% tree view as either pleasant or very pleasant, which reflects the great interest in higher greenery percentage, especially for trees. The average mean for 50% trees based on age groups was around 4.2 and 4.4, which represents pleasant and falls closer to very pleasant. Although the 51-60 age group has a mean of 4.2 for 50% trees. Its mean value was 3.7 for 50% green wall which reflects that the same percentage does not affect the choice, yet the type of green has a massive impact on the choice and evaluation of green and level of satisfaction. Across different age groups and their relation to different UGS alternatives, it was evident that the 51-60 age group had always had the lowest mean across all alternatives.

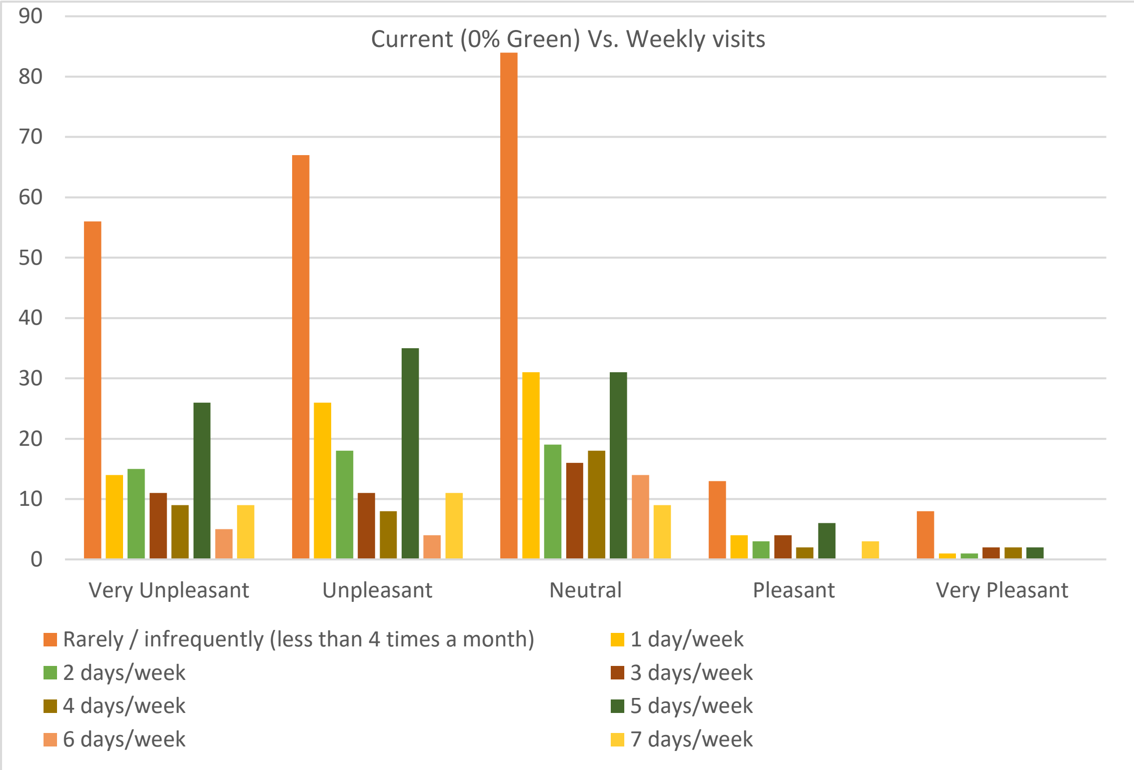


Figure 6-19 Cross-tabulation - Current (0% Green) Vs. Weekly visits

Cross-tabulation relationship tried to address and spot if there was a difference or particular preference for survey participants on different UGS alternatives based on their weekly street visits. The question was trying to know the participants' evaluation for the actual Oxford Street view which is 0% green based on their weekly visits. It was noticed that similar users' patterns were noticed across the Likert scale as the mean varied between 2.2 to 2.5 which all represent unpleasant reflecting that across different age groups, all participants agreed that the view is unpleasant and this cross-tabulation reflects that the number of visits does not massively influence participants' views.

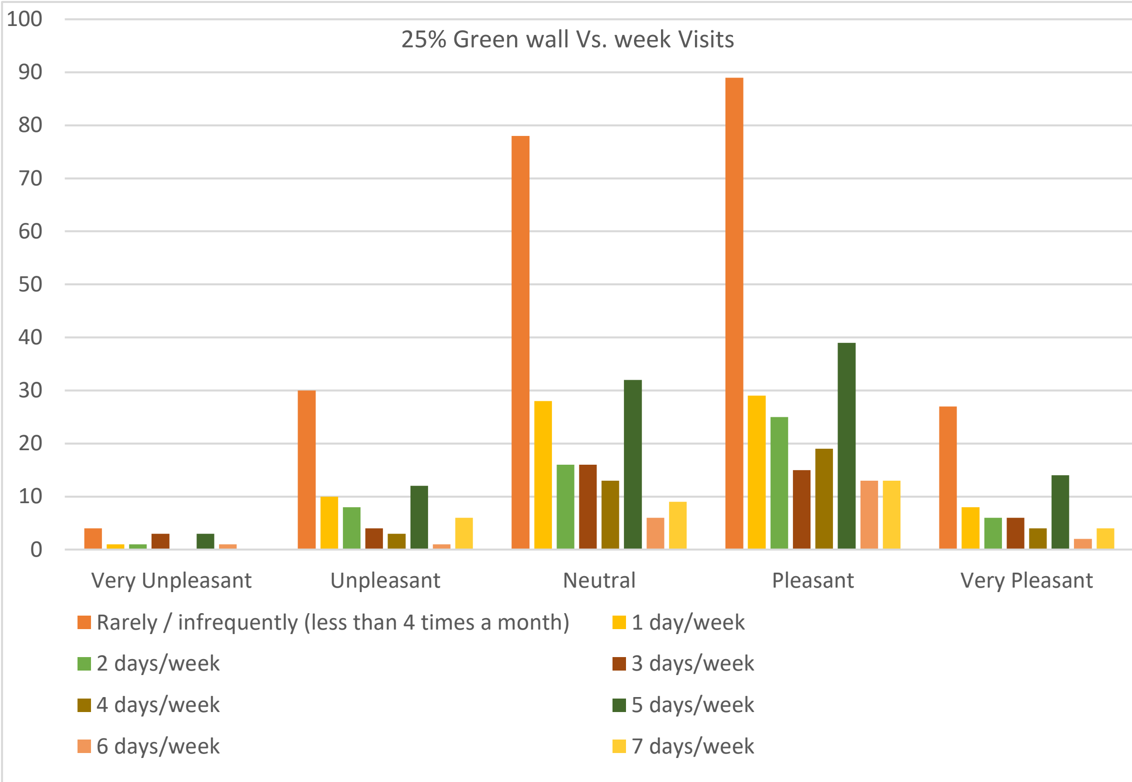


Figure 6-20 Cross-tabulation - 25% Green wall Vs. week Visits

Similarly, this question focuses on participants' evaluation for 25% green wall and their weekly street visits. It was noticed that all age groups have agreed that the 25% view is more appealing than 0% green and that has reflected on their evaluation. The average mean of week visits and the choice of 25% green wall varied between 3.4 and 3.6 which represents neutral. The overall number of weekly visits does not show a significant change in participants' perceptions as the whole sample seems to have a similar equivalent evaluation of 3.5 on average.

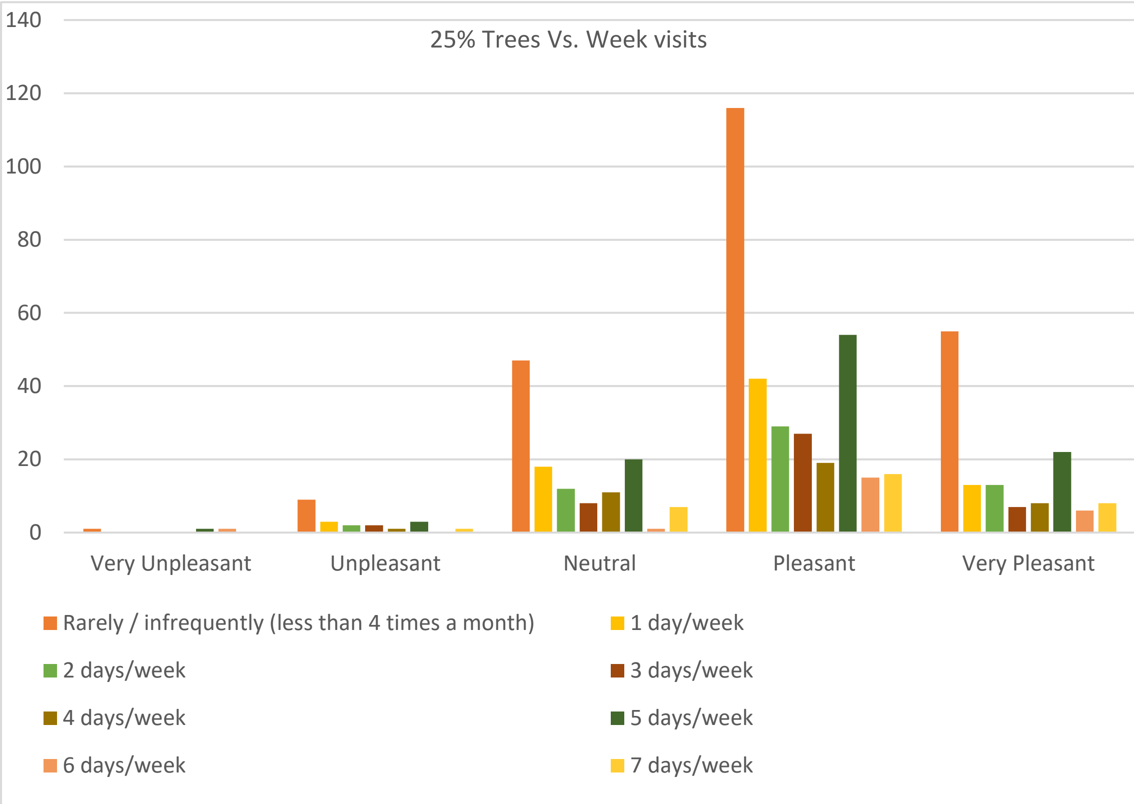


Figure 6-21 Cross-tabulation - 25% Trees Vs. Week visits

For 25% trees, cross-tabulation has revealed significant interest in participants' responses, and evaluation as their evaluation on the Likert scale has moved towards pleasant and very pleasant which shows that the majority have enjoyed the view, but that does not change or influence weekly visits. The average mean of 25% trees across weekly visits varied between 3.9 and 4.1 which reflects more agreement in the views and less variance, and it has nothing to do with the number of weekly visits since the mean of participants’ evaluation is almost identical.

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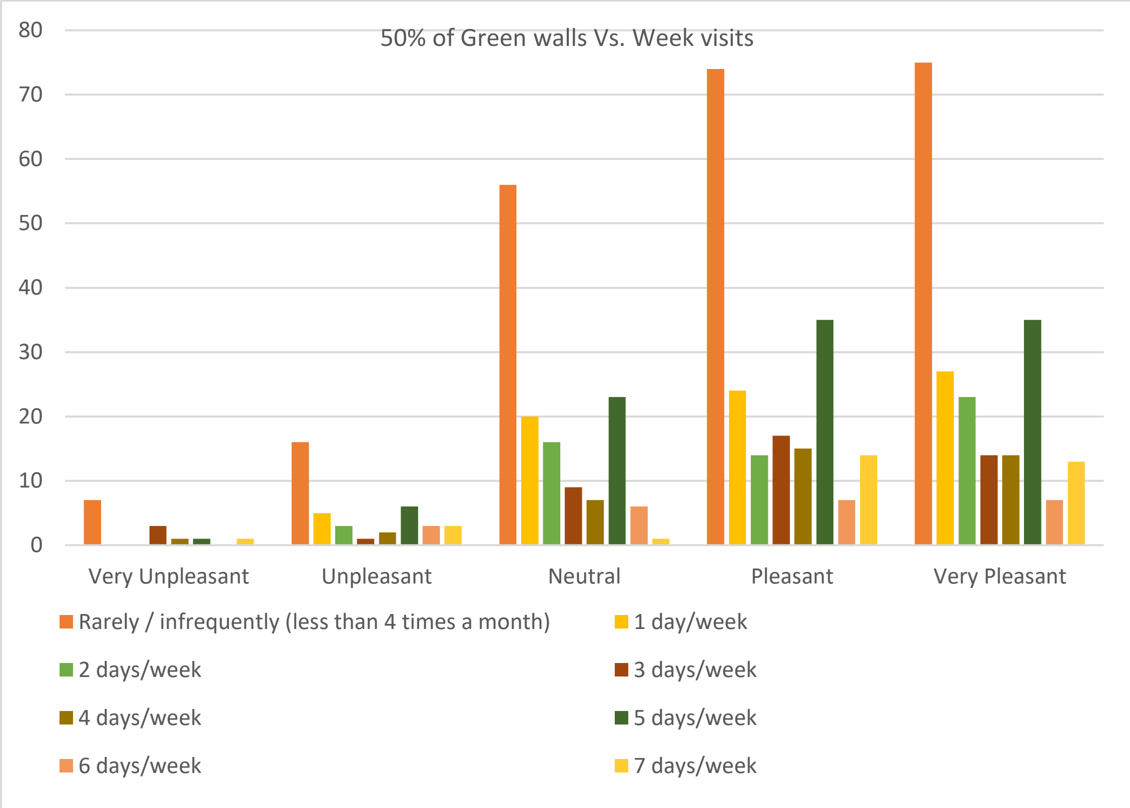


Figure 6-22 Cross-tabulation - 50% of Green walls Vs. Week visits

Like the previous cross-tabulations, this table reflects that different weekly visits showed interest with more green applied to streets where the green wall represents 50% of the spatial coverage. The mean of 50% green walls based on weekly street visits varied between 3.8 and 4.1, which overall represents pleasant. However, the percentage of green coverage increased from 25% for Tree to 50% alternative to green walls, the average mean of responses between the two percentages was not impressive. Overall, the mean of age groups was 4, which represents pleasant. On the other hand, the weekly visits are not influenced by the number of visits, and is mainly dependent on the view itself (the type of vegetation and its percentage).

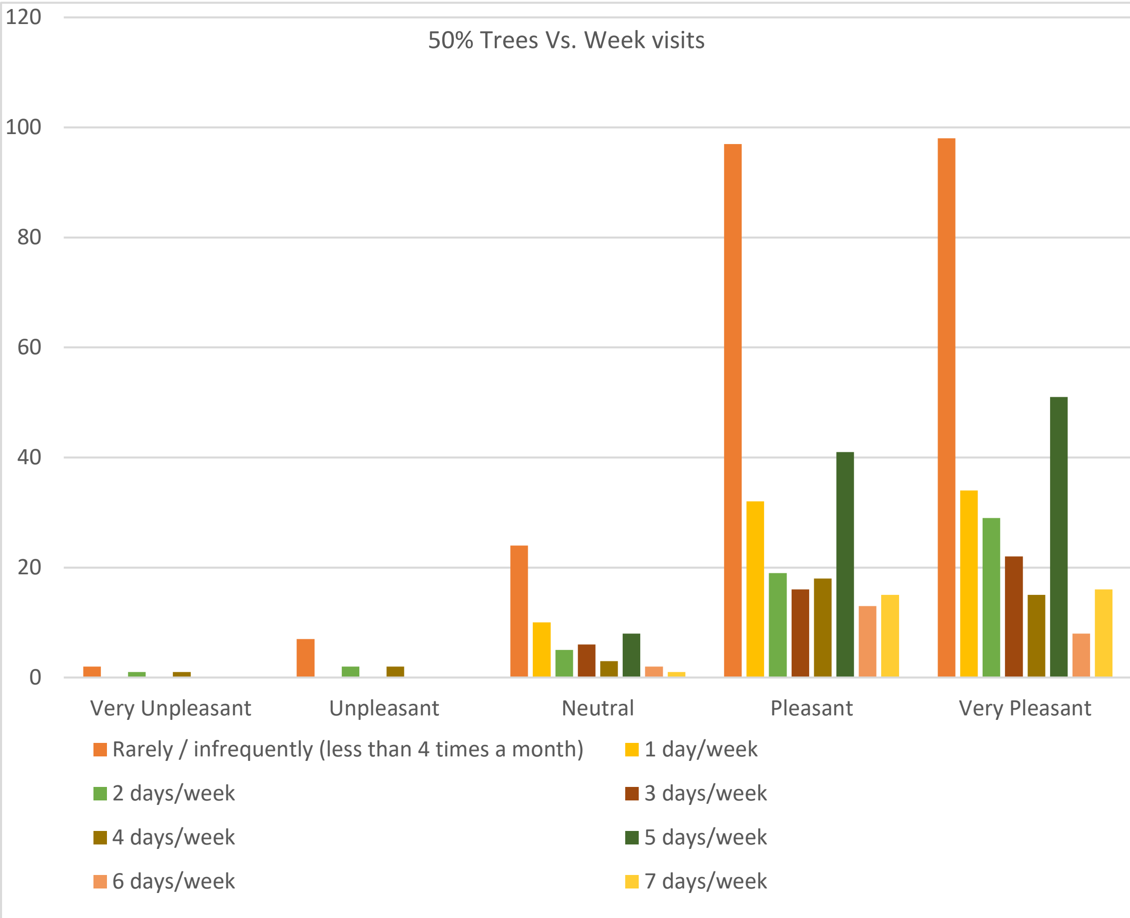
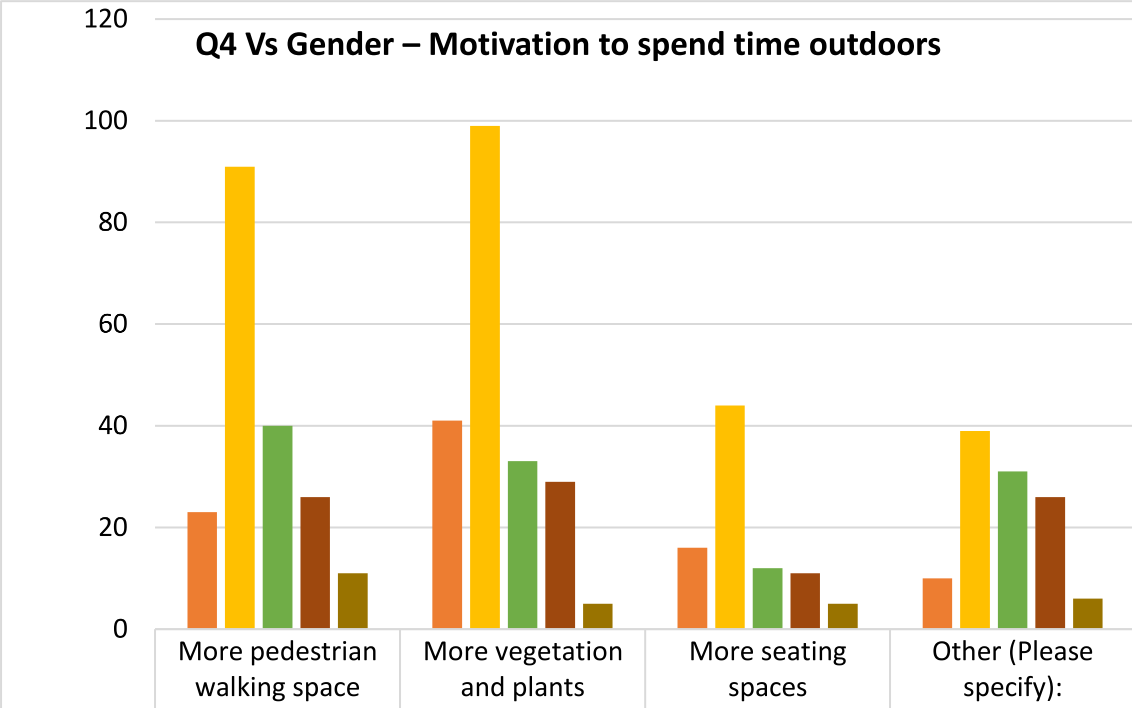


Figure 6-23 Cross-tabulation - 50% Trees Vs. Week visits

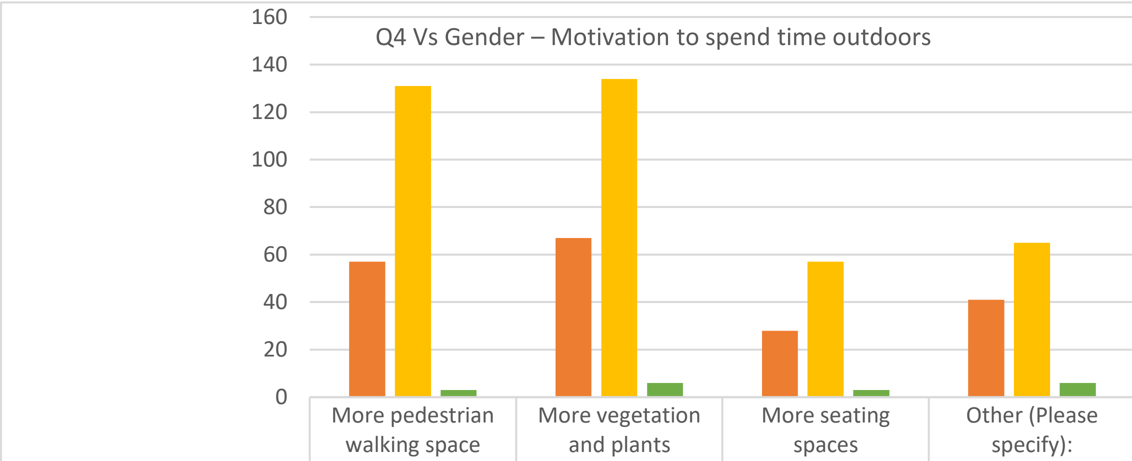
Throughout different weekly visits, the majority of participants have evaluated the 50% tree view as either pleasant or very pleasant, which reflects the great interest in higher greenery percentage, particularly for trees. The average mean of 50% trees based on weekly visits was around 4.1 and 4.5, which represents pleasant and falls closer to very pleasant. The cross-tabulation across different alternatives and weekly visits show that weekly visits do not have a massive influence on participants' choices.



	More pedestrian walking space	More vegetation and plants	More seating spaces	Other (Please specify):
18 - 25	23	41	16	10
26 - 40	91	99	44	39
41 - 50	40	33	12	31
51 - 60	26	29	11	26
60+	11	5	5	6

Figure 6-24 Cross-tabulation - motivations for spending more time outdoors in central London during summertime based on age groups

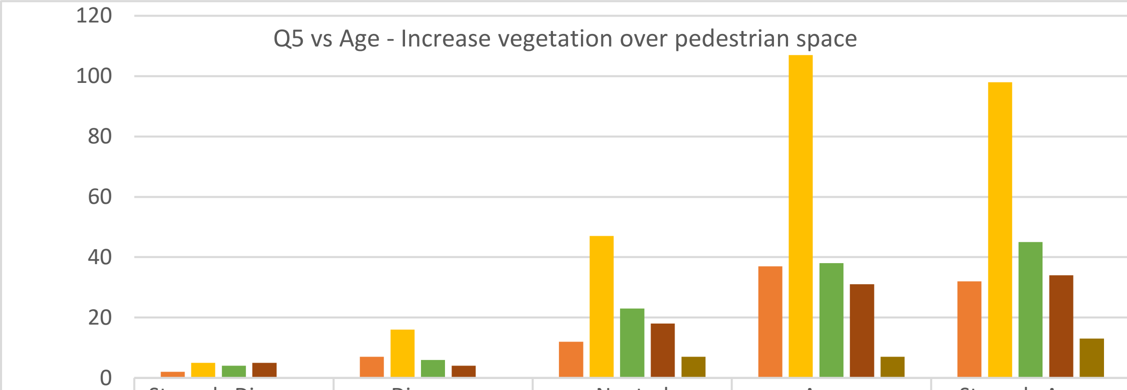
This crosstab was formatted in order to define the reasons and the motivations for spending more time outdoors in central London during summertime based on age groups. The graph reflects more information regarding older age groups 51+ and 60+, which prefer more pedestrian spaces due to their walkability limitations, and they find it harder to walk within small crowded streets. At the same time, younger age groups showed more interest in more vegetation. It is also worth mentioning that younger age groups of 18-25 and 26-40 had the highest choice for more vegetation and plants followed by more pedestrian spaces which reflects that each age group is facing the significant challenge of massive density and crowded streets.



	More pedestrian walking space	More vegetation and plants	More seating spaces	Other (Please specify):
Male	57	67	28	41
Female	131	134	57	65
Other / Prefer Not to say	3	6	3	6

Figure 6-25 Cross-tabulation - Q4 Vs Gender – Motivation to spend time outdoors

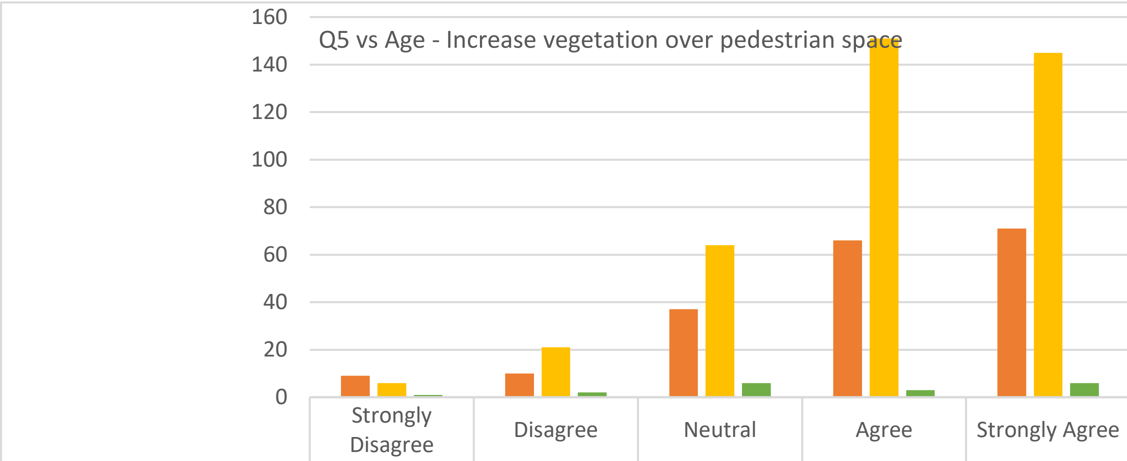
This crosstab was formatted in order to define the reasons and the motivations for spending more time outdoors in central London during summertime based on gender. It was interesting that for females both more vegetation and more pedestrian walking space were almost equal, while for men, they were a little more into more vegetation than pedestrian spaces. However, others (representing other generalities) had the highest choice of vegetation, yet their influence was not significant overall due to their low numbers. It is also worth noting that in their answers to the 'others' category (representing open answer) most of the people showed that they are motivated to have a mix between wider pedestrian space with more green which reflects the urgent need for both of them rather than picking one choice over the other.



	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
18 - 25	2	7	12	37	32
26 - 40	5	16	47	107	98
41 - 50	4	6	23	38	45
51 - 60	5	4	18	31	34
60+	0	0	7	7	13

Figure 6-26 Cross-tabulation - Q5 vs Age - Increase vegetation over pedestrian space

This cross-tabulation was ideally included to clarify the age relevance to placing vegetation and plants, which might reduce pedestrian space and how that will reflect on different age groups and their preferences. Across young age groups, most of the 18-25 and 26-40 participants mainly voted for agree or strongly agree while as age increases, the more the evaluation moves towards being more neutral, with the majority still agreeing on placing more vegetation. For ages 40+, 50+ and 60+, almost all three age groups supported more green, yet they tended towards slightly more neutral values. These values were reflected on the responses' mean values which varied between 3.9 and 4.2, and this shows that even among those aged 60+ the average was agree. This was also the case for the 41-50 and 51-60 age groups.

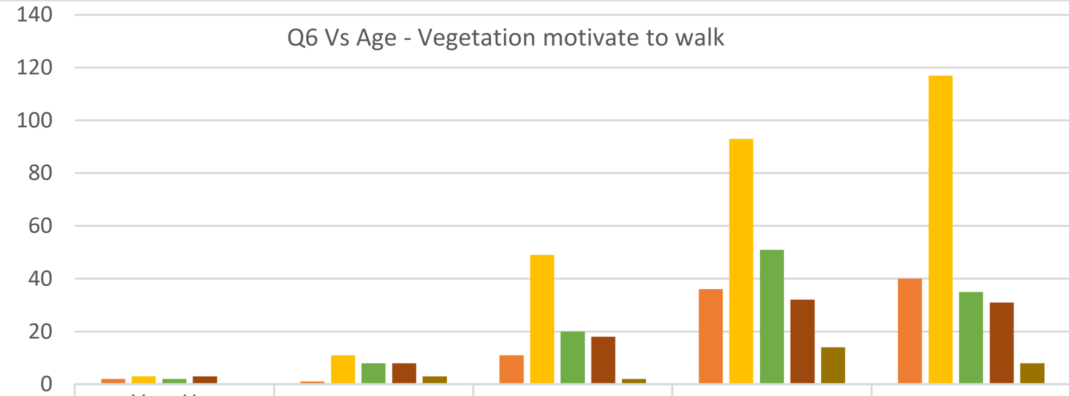


	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Male	9	10	37	66	71
Female	6	21	64	151	145
Other / Prefer Not to say	1	2	6	3	6

Figure 6-27 Cross-tabulation - Q5 vs Age - Increase vegetation over pedestrian space

The cross-tabulation was between placing trees and vegetation, which might decrease pedestrian space, and how gender choices reflect on that either with agreement or disagreement. The graph illustrates important agreement between gender motivation and support for more vegetation over pedestrian size which has been earlier asked. This gives a more in-depth insight into and background information about the motivation that vegetation and pedestrian spaces are important. In the previous questions, cross-tabulations were similarly selected with close percentages.

This questions clearly indicates that it is more important for pedestrians than the pedestrian space as, for both males and females, most of their numbers were either agreeing or strongly agreeing with more expansion of green over pedestrians' spaces which reflected on their mean values of 3.9 and 4.1 for males and females, respectively. It is worth mentioning that gender classified as others had a lower motivation and was more neutral rather than supporting the proposal of more vegetation; however, they have given higher percentage for vegetation than pedestrian space in the previous question.

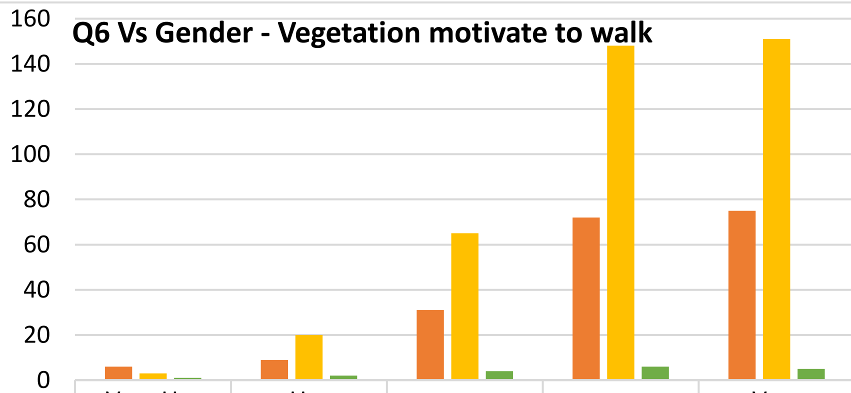


	Very Un-Motivated	Un-Motivated	Neutral	Motivated	Very Motivated
18 - 25	2	1	11	36	40
26 - 40	3	11	49	93	117
41 - 50	2	8	20	51	35
51 - 60	3	8	18	32	31
60+	0	3	2	14	8

Figure 6-28 Cross-tabulation - Q6 Vs Age - Vegetation motivate to walk

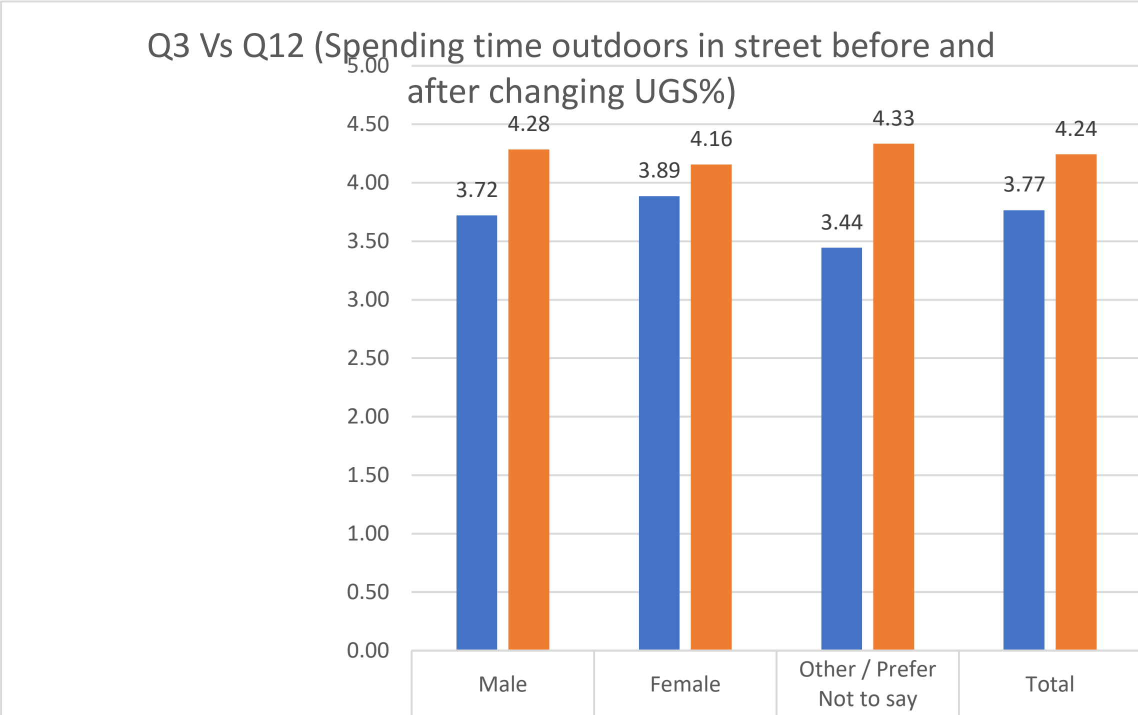
This graph represents the cross-tabulation between the age groups and how participants would be motivated to walk longer (distance or time) in streets with more vegetation. All of them had a similar preference of mean variation between 3.9 and 4.2 representing motivated on the Likert scale across different age groups. However, the younger ages showed more motivation to walk more, yet the difference was not high across different ages in the mean values.

Table 6-1 Cross-tabulation between motivation to walk more and gender



	Very Un-Motivated	Un-Motivated	Neutral	Motivated	Very Motivated
Male	6	9	31	72	75
Female	3	20	65	148	151
Other / Prefer Not to say	1	2	4	6	5

Similarly, the cross-tabulation between motivation to walk more and gender had similar outcomes across different genders, as shown in Figure 6-29. The mean value of males and females was 4 and 4.1, respectively representing motivation to walk either long-distance or for a long time. On the other hand, gender classified as others had lower motivation with 3.7 mean, which is closer to motivated than to neutral.



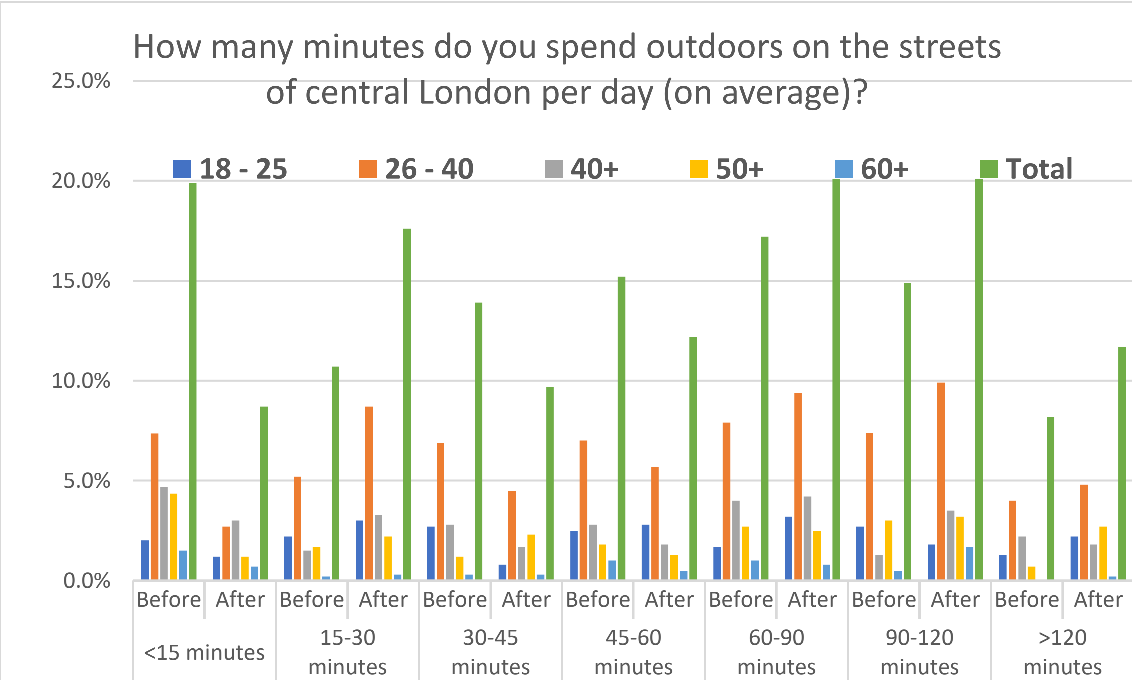
	Male	Female	Other / Prefer Not to say	Total
3.How many minutes do you spend outdoors on the streets of central London per day (on average)?	3.72	3.89	3.44	3.77
12.How many (minutes) would you spend in central London per day (on average), after applying your preferred vegetation alternative (trees, green walls)? (e.g. compared to question 3)	4.28	4.16	4.33	4.24

Figure 6-29 Cross-tabulation - Q3 Vs. Q12 – Average Time spent outdoors

This crosstab was implemented to compare similar questions; one of them asks about how long the participant usually spends outdoors within central London upon his/her visit and the other asks the same question after applying UGS alternative in order to quantify the difference if it existed in terms of time. The mean value before applying vegetation was 3.77, and after applying vegetation, it increased to 4.24, which reflects a 112% increase in the time spent outdoors after applying vegetation. The average means increased across different genders for male, female and others from 3.72 to 4.28 and from 3.89 to 4.16 and from 3.44 to 4.33, respectively.

On the other hand, the same comparison was carried for different age groups to identify how much vegetation would reflect age groups' time spent outdoors. For time spent more than 120 minutes, the average time spent from all time durations changed from 8.2% to become 11.7% with an increase of 3.5%. The average percentage of time spent for the time between 90-120 minutes has increased from 14.9% to 20.1% with an increase of 5.2%. For the time cluster from 6-90 minutes, the percentage has increased from 17.2% to 20.10% with an increase of 2.9% and for the timeframe of 15-30 minutes an increase of 6.9% took place to increase activity from 10.7% to 17.6%.

For shorter times such as 45-60 minutes, the number of participants decreased from 15.20% to 12.20% with a decrease in the number of -3% and similarly with time frame 30-45 minutes which decreased from 13.9% to 9.7% and for time frame less than 15 minutes decreased from 19.9% to 8.7% with a decrease of -11.2%. This clear decrease in time spent outdoors for time frames less than an hour was due to shifts in time frame activities of participants as, after applying more vegetation, participants in the survey



	<15 minutes		15-30 minutes		30-45 minutes		45-60 minutes		60-90 minutes		90-120 minutes		>120 minutes	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
18 - 25	2.0%	1.20%	2.20%	3.00%	2.70%	0.80%	2.50%	2.80%	1.70%	3.20%	2.70%	1.80%	1.30%	2.20%
26 - 40	7.4%	2.70%	5.20%	8.70%	6.90%	4.50%	7.00%	5.70%	7.90%	9.40%	7.40%	9.90%	4.00%	4.80%
40+	4.7%	3.00%	1.50%	3.30%	2.80%	1.70%	2.80%	1.80%	4.00%	4.20%	1.30%	3.50%	2.20%	1.80%
50+	4.3%	1.20%	1.70%	2.20%	1.20%	2.30%	1.80%	1.30%	2.70%	2.50%	3.00%	3.20%	0.70%	2.70%
60+	1.5%	0.70%	0.20%	0.30%	0.30%	0.30%	1.00%	0.50%	1.00%	0.80%	0.50%	1.70%	0.00%	0.20%
Total	19.9%	8.70%	10.70%	17.60%	13.90%	9.70%	15.20%	12.20%	17.20%	20.10%	14.90%	20.10%	8.20%	11.70%

Figure 6-30 Cross-tabulation - how much would vegetation reflect on age groups time spend outdoors

tended to spend more time outside, so they increased their time which decreased the number of people in lower time frame values.

6.2.4 Questionnaire Survey Descriptive Statistics

JASP software helped to carry out quantitative analysis resulting in measuring the frequency as a valid number or count of survey participants as shown in (Appendix F – Survey Analysis). While *mean* reflects the central tendency of participants' responses, *variance* reflects the difference between the average difference of all answers by participants, and the *range* indicates the highest range between extreme responses. The mood was used as a part of descriptive statistical analysis to clarify the difference between close answers, particularly between Q7, Q8, Q9, Q10 and Q11, which are mainly Likert-scale questions asking about different street UGS alternatives. Therefore, it would be helpful to reflect the minor differences.

The mean or average is probably the most commonly used method of describing the central tendency of responses. To compute the mean of responses, you add up all the values and divide by the number of participants for each required question separately. Therefore, each question mean was calculated through summing up all answers for each question and then dividing the total by the number of survey participants which is 598. The mean was chosen rather than the median for two reasons; first, to include all participants' answers without ignoring extreme ideas as outliers and second, to specify the average of all results and not only data centre which the middle responses of participants. The mean is easily understandable and presentable for non-experts, and it can be used to draw quick insights regarding responses.

Not all questions will have the same importance to know their responses' mean (such as Q2, Q4, Q14, Q15, Q16 and Q17), but it is essential to keep their existence within the question so as to see their values in other statistical analyses. The average mean of Q1 is 3.2, which represents that the average weekly visits of survey participants to central London is 3.2 days/week, while Q3 has a mean of 3.6 which reflects around 45 minutes as the average time spent outdoors by participants while in Q12 after applying participants, favourite vegetation, the mean changed to 4.4 which resembles 60 minutes. Meanwhile, 4 is the mean of Q5 reflecting that participants are motivated to increased street vegetation which might take space from pedestrians. In comparison, Q6 has a mean of 4.1 resembling that they would be motivated to walk a further distance or for a longer time with more green and vegetation.

Q7, Q8, Q9, Q10 and Q11 are a Likert-scale comparison between the current central London view and different UGS alternatives. Q2 has 2.3 mean which represents an unpleasant view while 25% LF in Q8 and 25% trees in Q9 has 3.5 (neutral – pleasant view) and 3.9 (pleasant) means, respectively. Q10 which is 50% LF and Q11 which refers to 50% trees) have means of 3.9 (pleasant) and 4.3 (very pleasant), respectively. Since means might not really reflect the accurate variations of responses, the mode was better able to reflect the difference and show the precise differences. The mean of Q7 was 3 (neutral view), Q8 and Q9 means were both 4 (pleasant view) while Q10 and Q11 means were both 5 (very pleasant view).

Variance is the amount of dispersion in a given data set as it measures how spread out a data set is. It is calculated by finding the deviation of each response in the data set from the mean and then squaring it. It could also be explained as the average of squared deviations from the mean. It helps in reflecting the degree of data set spread; the more spread the data are, the larger variance in reference to the mean (Satyam Kumar, 2017). The variance helped to mainly identify the Likert-scale questions as Q5, Q6, Q7, Q8, Q9, Q10 and Q11. The variance was 1 for Q5, Q7 and Q10 while it was 0.9 for Q6 and Q8 and was very low for Q9 and Q11 with 0.6 variance, which reflects that most of the participants had a similar preference for 25% and 50% trees' alternatives, while participants' choices varied more across Q7, Q8 and Q10.

The range is the difference between the largest and smallest responses. This is the simplest measure of statistical dispersion or "spread." It was included in the descriptive analysis in order to compare the difference between extreme answers and then reflect it on the variance which represents the discrepancy between responses in questions and that would help to relate the participants' variance from the questions' range. In other words, the range is the extreme limit (highest range) of responses' difference which the variance can be compared to. Overall, Q1, Q2, Q3, Q12, Q13, Q14, Q15, Q16 and Q17 reflect generic questions and demographics, so the variance was high, while Q5, Q6, Q7, Q8, Q9, Q10 and Q11 reflect to what extent the participant had different views.

Question Q13 was a multiple choice mainly asking: What do you think the reasons are for choosing your preferred vegetation alternative above (trees, green walls)? Participants were several answers to choose from; these were Relaxation (Q13.1), Connecting to nature (Q13.2), Aesthetical impact and visual comfort (Q13.3), Air pollution reduction (Q13.4), Improved thermal comfort (shaded areas, pleasant temperature, etc.) (Q13.5), Improved biodiversity (the variety of plant, insects and animal life) (Q13.6), Increased productivity (Q13.7), and Other (Please specify) (Q13.8).

Due to the multiple choice type of questions, it had to be included separately within JASP software. Each reason for choosing vegetation was given a special reference, such as Q13.1, Q13.2, etc. The statistical analysis helped to reflect the mean reflection on participants' most common reason for choosing vegetation, where the highest mean was for Q13.3 and Q13.4 which are Aesthetical comfort and Pollution reduction respectively, followed by Q13.2, Q13.1 and Q13.5 for means 1.6, 1.5 and 1.4, respectively. In comparison, Q13.6, Q13.7 and Q13.8 had the lowest mean across the question with 1. Variance and mode analysis were neglected due to the multi-choice nature of the question.

These descriptive statistics are for a single variable which was analysed previously as mean, variance, range and mode in case there are two variables, and it is required to define whether there is an association or relation or not. For instance, if one variable goes down, would the other variable go down as well? This association measure is used to illustrate how variables are related, which is widely known as the correlation coefficient.

The correlation coefficient (which is identified as the Pearson correlation coefficient) measures how well two variables are associated and related in a linear (straight line) method and is usually referred to as (r). (r) varies between -1 and +1. A value of $r = -1$ indicates that the two variables are negatively correlated; for instance, one variable goes up, the other goes down. Conversely, if $(r) = +1$ it indicates that the two variables are positively correlated, which means that both variables go in the same direction (both up for instance). Finally, if the value of $r = 0$, this indicates that the two variables are not linearly related (USA, 2020). Values between 0 and 0.3 (0 and −0.3) represent a weak positive (negative) linear relationship through a shaky linear rule while values between 0.3 and 0.7 (0.3 and −0.7) represent an average positive (negative) linear relationship through a fuzzy-firm linear rule. Finally, values between 0.7 and 1.0 (−0.7 and −1.0) indicate a strong positive (negative) linear relationship through a firm, linear rule (Ratner, 2009).

In order to determine whether the correlation between variables is noteworthy or significant, a comparison for the p-value is established to indicate the significance level. Usually, a significance level represented by α or alpha that equals 0.05 acts well. An α of 0.05 shows the probability of concluding that a correlation happens, while on the other hand, no correlation exists at 5%. The p-value confirms whether the correlation coefficient is significantly unequal from 0. A coefficient of 0 indicates that there is no linear relationship. If the p-value is less than or equal to the significance level, then it can be concluded that the correlation is different from 0 while if the p-value is greater than the significance level, then it cannot be concluded that the correlation is different from 0. If the P-value $\leq \alpha$: The correlation is statistically significant. On the contrary, if P-value $> \alpha$: The correlation is not statistically significant (Mihai Nica, 2019).

Usually, several quantitative variables (questions) are measured on each participant of a sample. Suppose we consider a couple of such (questions) variables, which reflects an interest to establish a relation to see if they are correlated or not and, if so, to what extent (Barbara Susan Dean, 2019). Therefore, the researcher utilised the JASP correlation heat map in order to define if there is a correlation or not. Later on, if there is a correlation, it will be identified numerically whether they i strong (0.5-1), average (0.3-0.5) and weak (0-0.3) correlations and their directions; that is, whether they are positive (increasing) or negative (decreasing) correlations (Goss-Sampson, 2018).

There are Pearson, Spearman and Kendall correlations. The Pearson product-moment correlation is one of the most widely used correlations in statistics. It is a measure of the relationship or correlation strength and the direction of a linear relationship between two variables. The Spearman correlation is depends on almost all the same assumptions as the Pearson correlation, yet it does not rely on normality, and the data can be ordinal too. So, it is a non-parametric test. The Kendall correlation is similar to the Spearman correlation in that it is non-parametric. Kendall is used within small samples or when there are many values with the same similar score or (ties). In general cases, Kendall's tau and Spearman's rank correlation coefficients are very similar and thus invariably lead to similar findings (Goss-Sampson, 2018). It may be used with ordinal or continuous data, and it is also a statistic of dependence between two variables. A discussion of correlation vs dependence can be found using it (David Sarmento, 2020).

6.2.5 Pearson's (r) Correlation analysis

JASP heatmap displays a correlation heatmap for Pearson, Spearman, and Kendall's tau separately and its design is symmetric along the diagonal. Blue colours represent positive correlation coefficients, while red colours represent the negative correlation coefficients. The saturation of colours represents the absolute value of the correlation coefficient. If "Flag significant correlations" is chosen through JASP, the significant correlations will be marked with $*p < 0.05$ if the correlation is significant at alpha=.05 level, **p < .01 if the correlation is significant at alpha=.01 level and ***p < .001 if the correlation is significant at alpha=.001 level (JASP, 2020).

As in Figure 0-2, the heatmap clearly showed a strong positive correlation between Q3 and Q12, with 0.75 representing a strong correlation between the number of minutes spent outdoors in central London before and after applying UGS alternatives. They were reflecting that with the increase with minutes spent before, the minutes spent after increase positively. At the same time, Q5 and Q6 had a strong correlation of 0.616 representing a positive correlation between the participants' acceptance for increasing more vegetation which might reduce pedestrian spaces and their time spent and distance walked outdoors within more vegetated spaces.

There was also an average positive correlation between several questions such as Q5 and Q11 with 0.32, which shows a correlation between agreeing on applying more vegetation and considering 50% trees coverage UGS alternative as very pleasant view. Q6 and Q4 had a correlation of 0.33, indicating that having more vegetation would motivate participants to spend more time outdoors and Q6, which is that participants would spend more time or walk a greater distance outdoors. Q8 and Q9 had a correlation of 0.47 reflecting that participants' choice for increased vegetation for 25% LF and 25% trees' increase has a positive correlation which is also represented in a positive correlation between Q8 (25% LF view) and Q10 (50% LF view). This is similar to a positive correlation between Q9 (25% trees view) and Q11 (50% trees view) with 0.43 and Q10 (50% LF view) and Q11 (50% trees view) with 0.31 positive correlation.

A weak positive correlation was noticed that varied between 0.1 and 0.28 across different question responses. The number of participants' daily visits per week (Q1) and the average minutes spent per day before (Q3) and after (Q12) vegetation were around 0.171 and 0.166, respectively. The number of the average time spent outdoors before vegetation (Q3) and identifying 25% LF as a pleasant view (Q8) was 0.12. A correlation was established between agreeing on placing more vegetation (Q5) and both 50% LF (Q10) as pleasant view and spending more average daily time after applying more vegetation (Q12) with 0.19 and 0.16. A correlation was found between participants' greater motivation to spend more time or distance outdoors (Q6), and all of the following questions as 25% trees view (Q9) and 50% LF view (Q10), more time spent outdoors Q12 and relaxation as the mean reason for vegetation (Q13.1) with a positive correlation of 0.11, 0.24, 0.28 and 0.25, respectively.

Q7 (current Oxford Street view) and both Q8 (25% LF view) and Q9 (25% trees view) had a similar positive correlation of 0.23. The correlation for Q8 and Q11 (50% trees) was 0.17 and Q9 (25% trees) had 0.20 correlation with Q10 (50% LF). Q10 had a correlation with the average time spent outdoors after applying more vegetation (Q12) with 0.13. Q13 (the main reason for UGS choice) had a positive correlation varying between 0.11 and 0.19 with Q5 (agreeing to place more vegetation), Q6 (more vegetation would motivate respondents to walk a longer distance or spend more time), and the main reasons were for relaxation, decreasing pollution, and aesthetical comfort.

On the other hand, there have not been any strong negative correlations between the survey questions; however, there were two average strong negative correlations. Q7 (current street view) had a negative correlation with both Q5 (motivation to increase more vegetation) and Q6 (motivation to spend more time or distance outdoors) which are -0.26 and -0.33, respectively. There is a negative correlation between Q15 (participants' age) and all of Q1 (weekly visits), Q3 (average minutes outdoors), Q6 (motivation to spend more time outdoors), and Q8 (25% LF view) with negative correlations of -0.11, -0.10, -0.11 and -0.14, respectively.

6.3 Conclusion

An online survey was conducted to collect pedestrians' responses to gather their feedback and perceptions on their preferred alternatives, and further questions were asked regarding how different urban green systems would influence their activities within central London. Through the online survey, participants showed their interest to increase street vegetation over pedestrian spaces. Their preferred alternatives were 50% trees followed by the almost equal preference for 25% trees and 50% green walls.

On the other hand, survey participants are willing to spend 30% more time outdoors if more green was planted, while their most important reasons for choosing UGS was their aesthetical value and air pollution capabilities. That was followed by connecting to nature, then relaxation. Improving thermal comfort was ranked fifth followed by increasing biodiversity, and increasing productivity.

7 Chapter 7: Discussion

7.1 Introduction

This chapter carries out and discusses a more in-depth investigation of these research findings and related studies on the influence of different urban green systems on UHI and carbon dioxide from ENVI-met simulation, enriching the discussion of the findings from the questionnaire survey analysis and its similarity with other studies. Results from ENVI-met simulations for different UGS across 2018, the 2050s and the 2080s are deeply studied and explored to recommend the best UGS alternative in UHI reduction and carbon dioxide sequestration in different climatic scenario across different street orientation. Subsequently, the questionnaire survey responses, results and analysis were formulated to indicate human preferences by identifying the best UGS alternative based on the responses from the pedestrians of central London.

Based on the findings and results of ENVI-met simulation and questionnaire survey, an ideal UGS alternative is proposed for application within central London canyons due to its environmental and social well-being benefits. These findings were discussed and represented through a graphical photo illustration showing the ideal suggestions on which UGS alternative to apply, ideal UGS density in central London canyons, and how to apply it. These findings and recommendations were compared to the most recent plans submitted by the policymakers.

7.2 UGS influence on UHI; PTC findings across different climatic scenarios and literature

Over the three climatic scenarios, there have been similar trends and outcomes to previous research to support the UGS implementation within urban street canyons in order to mitigate heat island and compensate for the shortage of green spaces simultaneously. In addition this will increase thermal comfort which (Arabi, Shahidan and Kamal, 2015) advised in order to transfer the hottest city area to cooler one in addition to decreasing the pollution intensities from UHI. The Ws percentage has decreased from around 19.4% to 25% for different tree percentages across the three decades, which was similarly represented by (Arabi, Shahidan and Kamal, 2015)They showed that Ws decreased around 20%-80% for trees. Based on these points, it is worth mentioning that although trees decrease Ws, they do increase thermal comfort levels due to shading, which outweighs the limitations of decreasing Ws.

It is interesting for this research to explore the finding of applying different UGS with different covering percentages (25% and 50%) through a major plan of turning London into the biggest national park in the world by 2050. Similar plans and initiatives were found in the Greening Master Plan in Hong Kong, which set 20%-30% green coverage targets, while Toronto City, Canada has introduced a bylaw to apply 20%-60% green roofs on all new structures with areas exceeding 2,000 square metres (Zupancic, Westmacott and Bulthuis, 2015).

Street canyon orientation plays an essential role in specifying the variety in thermal comfort levels between different UGS interventions. It mainly depends on the amount of solar radiation received by the surfaces, the sky view factor, and the proximity of the UGI, which clarifies the narrow difference across the different UGS, particularly between 25% and 50% trees in NS canyons (due to building shade). Meanwhile, (Oke, 1980) showed that UGS's change, had a massive change on PTC levels in the EW canyon. The reduction in temperature reaching 1 K could be achieved if a third of the total land area is covered with greenery (Ng *et al.*, 2012). On the other hand, this study has confirmed a finding that the closer the canyons are to the NS orientation, the lower the Ta and MRT are, which is similarly found by (Bourbia and Awbi, 2004; Ali-Toudert and Mayer, 2007; Nasrollahi, Namazi and Taleghani, 2021).

Figure 5-22 PET different years 2018, the 2050s and the 2080s; it shows that, within this study, by applying 50% trees within central London during the 2080s for the worst thermally oriented street canyon (East-West), the thermal comfort achieved is equivalent to the thermal environment and temperature of the same street in 2018 without greening, which is 62 years difference while applying 25% of trees for the same canyon in the 2050s will improve the thermal environment and increase thermal comfort levels to achieve 2050s temperature without greening which is 30 years difference. Similar studies, such as Gill (2006) found, found that adding 10% more trees to Manchester City, the UK will eliminate UHI and climate change equivalent to Manchester city climate in the 1990s. Furthermore, a recent study by (Wang *et al.*, 2020) showed that increasing adding grove and street trees as a green cover to 10% could be the best adaptation strategy to eliminate overheating in Guangzhou, China.

(Shahidan, 2011) reported that the PTC under shaded areas such as trees and self-shaded buildings on urban canyons (such as North-South canyons) has PTC nearby "neutral" cases compared to those under extreme solar radiation gain in East West canyons. Shahidan also declared that tree densities and quantities have an essential role in providing noteworthy temperature reduction on an urban scale, particularly if combined with high albedo materials. (Ayyad and Sharples, 2017) confirmed research findings that Tmrt highly influences PET values; therefore, using green vegetation as a shading device would significantly lower Tmrt and hence PET, leading to increased thermal comfort levels which was similarly confirmed by (Teshnehdel *et al.*, 2020). On the other hand, it was noticed that street canyon orientation change has a highly significant influence on the wind speed, which was found in an in-depth study by (Ayyad and Sharples, 2020).

Vegetation type, location in the canyon and its percentage amount are more effective within higher temperatures and lower humidity which can be easily noticed within the changes of 2018, the 2050s and the 2080s. This was similarly found in a study by (Perini and Magliocco, 2014). Trees showed maximum lowering temperature while LF showed increase in humidity with less influence on temperature levels. PTC levels increase with the increase of tree percentages, particularly within the future climatic scenarios of the 2050s and the 2080s. On the other hand, the location of UGS plays an essential role in determining its effect intensity at which ground UGS as trees has a massive influence on PTC compared to LF which is applied on walls. However, LF, high albedo materials and green roofs are more effective at the building scale through decreasing the cooling and heating loads (Perini and Magliocco, 2014).

A similar study was carried by (Zölch *et al.*, 2016) during a typical heat day for the current (2016) and future climatic scenarios (scenario A1B for 2030–2060) for Munich, Germany. It simulates different UGS interventions (trees, living facades, green roofs) to the base case scenario for the urban neighbourhood (street sidewalks, on parking lots, and in courtyards) with 0% green at 3 pm. This study tried to achieve two vegetation scenarios (realistic and maximum greening scenarios). Maximum vegetation scenario for each alternative was achieved through planting trees on sidewalks and in courtyards, greening flat roofed buildings, and greening two-thirds of facades.

The aforementioned futuristic study located in Bavaria, Germany found a parallel results pattern to the London 2050 case. At which 22% (realistic tree coverage) and 34% (maximum tree coverage had a PET reduction of 10%-13% compared to their base case scenario. While in London, the PET reduction varied between 9% and 21% for 25% trees, and 50% for EW canyons and 5% for NW canyons. On the other hand, for the PET reductions across each study, base case year 2018 for London and 2016 for Bavaria State, the PET reduction between different trees percentage was 4%-7% in Bavaria. At the same time, it was around 5% in the NS orientation and between 11% and 14% in the EW canyons in London. Across both studies, some significant differences should be noted as difference in cities, climatic data, and greenery percentage applied, yet the finding patterns showed a similar flow. However, these findings differed from a study by (Emmanuel and Loconsole, 2015) who stated that an increase of 20% green cover leads to a reduction in temperature up to one third or half of the expected extra-urban heat island effect in 2050 which was not approached in EW canyon with a saving of 9% for 25% tree coverage for PET values.

However, the researcher found that both LF percentages do not influence PET, although it slightly increases RH In their case study, (Zölch *et al.*, 2016) found that their LF had a PET reduction 5%-10%, but that is only closer to the building walls, while when pedestrians are more than two metres away from the building, there are no effects on PTC and PET which was found by the researcher in the London case which his thermal receptors were set five metres away from the building. That reflects the importance of LF coverage in isolating buildings and improving their thermal performance (U. Mazzali *et al.*, 2013) rather than PTC. On the other hand, Zolch and colleagues' study and that of

(Zupancic, Westmacott and Bulthuis, 2015) confirmed this researcher's literature review findings that green roofs do not influence PTC even in future climate scenarios Alexandri and his colleagues (Alexandri, 2005; Alexandri, Jones and Doussis, 2005; Alexandri and Jones, 2006, 2008) have clearly explained and investigated the influence of both living facades and green roofs on UHI and PTC, which confirmed that GR does not influence thermal comfort levels in the street levels, yet it influences GR thermal comfort at roof level, while LF influences the climate near the façade itself. Even though achieving the UGS coverage of 30% to 50% is recommended by the findings from the literature review in order to reach a wide UGS diversity such as mixing living facades and connected green corridors. These thermal improvement benefits are directly related to the UGS type, size, quality, and density.

However, denser tree alternatives decrease wind speed, yet its thermal reduction benefits outweigh its windspeed reduction disadvantage, which was similarly found by (Zupancic, Westmacott and Bulthuis, 2015).On the other hand, higher albedo pavement increased the mean radiant temperature. However, it decreased surface temperature which resulted from a massive increase in thermal stress which was found by (Huttner, 2012) who attested that a higher albedo results in more incoming solar radiation and then reflected to the street canyon, leading to a higher radiative temperature within the canyon. That was different from (Shahidan, 2011) findings which identified that high albedo materials within canyons decrease temperature and mitigate UHI in tropical climates.

7.3 UGS influence on Carbon Dioxide (CO_2) findings across different climatic scenarios and literature

One of the leading greenhouse gases is CO_2 which is contributes to almost 50% of climate change. There are two strategies to reduce it; the first is by controlling CO_2 emission sources which most of the reduction methods are working on it by limiting energy use and the industrial process that emits massive volumes of CO_2. The second strategy is improving CO_2 sequestration through using green systems and forest areas for that which also helps in landscaping, ecosystem and recreation (Lee and Kwon, 2018). One-third of the world's land is available land for increasing the world's forest cover without touching existing cities or agriculture. However, that is being diminished with time even if global warming is limited to 1.5°C since it is predicted that, by 2050, the available forest restoration area might be reduced by one fifth because it would be too warm for some tropical forests (J. F. Bastin *et al.*, 2019).

Urban forest refers to the inclusion of all green systems (street trees and tree parks clusters, gardens, any green spaces whether they are nurseries, rooftops or riparian (river/seafront) corridors) within the urban area. Four per cent of the world's land area is occupied by urban areas which could accommodate 121 billion trees (Crowther *et al.*, 2015; Endreny, 2018). However, green systems (trees, green walls, etc.) are not the critical solution to offset the CO_2 because the space which is required to plant and place green systems if applicable would be massive, and would not leave any space for anything else on the planet's landmass to have any other activity (Boysen *et al.*, 2017).

Five trees are required to be planted each year to offset an average car covering a distance of 10,000 miles/year which is emitting five tonnes of CO_2/year, which is also equivalent to the emissions from a one-way flight between London, the UK and Sydney, Australia. These emissions were calculated based on the native broadleaf tree within the UK where, during the lifetime of one tree, it can sequestrate up to one tonne of CO_2 during its life (100 years) (Grantham, 2015). Thus, there is an urgent need plant green systems, including trees, which will not be feasible or applicable because the whole world land has to be covered by green systems then(Grantham, 2015).

Within the past 100 years, global warming accelerated up to 1.3◦C, and the global surface temperature has also increased by 0.74◦C. Should this global surface temperature increase by 1.5-2.5oC, this will lead to the extinction of 10% to 40% of both animals and plants (Lee and Kwon, 2018). Half of the carbon emissions are naturally sequestrated by vegetation (mainly forests) since 1750 while the ocean sequestrates the rest by creating a buffer against climate change. However, it negatively influences the sea life by increasing CO_2 concentrations within seawater, leading to acidification (Brack, 2019).

Deforestation has a tremendous negative influence on climate change as it leads to the releasing of all CO_2 emissions from soil and plants within the forest. CO_2 is estimated to be 861 ± 66 Gt carbon concentrated as follows:, 44% in soil, 42% in biomass, 8% in deadwood and 5% in the litter, while geographically the storage of this CO_2 is mainly divided as follows: 55% in tropical forests, 32% in boreal forests and 14% in temperate forests (Brack, 2019).

There are five sources for the gross global tree cover loss between 2001-20015 which are ((i) commodity-driven deforestation by 27%, (ii) forestry 26%, (iii) agriculture shifting 24%, (iv) wildfires 23%, and (v) urbanisation by 0.6%) (Philip G. Curtis et al, 2018). Seventy eight per cent of carbon emissions are created from cities (Aminzadeh and Khansefid, 2010; Prachi Ugle, Sankara Rao and T V Ramachandra, 2010). The International Energy Agency (IEA) approximations showed that, in 2006, urban areas energy production shared 71 % of energy-related greenhouse gas emissions, which are predicted to reach 76% by 2030. In addition, urban areas turn out to be the point sources for greenhouse gases (CO_2, Ozone O3, methane (CH4)) volatile organic compounds (nitrous oxide (NO), nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), nitric acid (HNO3), and other organic acids (Schramm, 2012).

This study did not show massive savings in CO_2 which reflects that CO_2 sequestration as a part of air pollution mitigation strategies is insufficient for achieving climate change reduction targets for CO_2. Moreover, CO_2 offsetting through UGS is relatively small compared to city emissions. Thus, UGS initiatives should be integrated as a part of wider policies and plans to limit air pollution and CO_2 emissions based on (Zupancic, Westmacott and Bulthuis, 2015).

A different study by Rajagopalan and Andamon (2018) showed a relationship between greenery, CO_2 sequestration, the temperature at which the case with less greenery has recorded higher CO_2 concentration and temperature, recording a peak of 37.50 °C temperature reading and 670 PPM CO_2. On the other hand, the street fully covered with greenery has recorded lower CO_2 levels and temperature with a peak of 32.5°C and 420 PPM. This might be due to several reasons such as the type of trees, pollution concentration, and wind direction. For instance, lower temperature decreases the chemical properties of CO_2 and hence lowers concentration at the human level (Afshari, 2017).

Although CO_2 improvements from UGS might not be high saving both 850 people's lives and 670,000 incidences of acute respiratory symptoms in the USA could be approached by only a 1% improvement in air quality from trees through a study by (Nowak *et al.*, 2014).

Overall, CO_2 contributes to almost 50% of climate change and it can be either controlled through limiting emission resources or improving UGS planting which is already being diminished by one fifth in some forests as it is too warm. On the other hand, the available land for planting is only one-third of the world (J. F. Bastin *et al.*, 2019).

7.4 Pedestrians' UGS preference discussion across the literature

This survey results reflect the pedestrians' need for a more walkable, pedestrian-friendly city that agrees with the wide definition of walkability as a built environment friendliness level offered to pedestrians. This friendliness level has features such as safety, comfort, visual attractiveness, and connectivity which provide a friendly environment that intends to encourage and motivate walking. A connected, compact urban environment should reduce the travel distance between different destinations and facilitate walking as a means of transport to reach walkable environments. These findings agree with a study in the UAE by Al-Sabbgh (2019) which found that pedestrians' walking patterns are related to microclimate and outdoor space adjustments (visual comfort, sun, shade, wind, etc.). Based on these outdoor settings' improvements, people will be encouraged to walk more outdoors and to extend their time and walkability outside.

The survey affords evidence of a consistent demand for more UGS. Respondents revealed pedestrian preferences at which the available UGS coverage in their streets is lower than required. This was similarly illustrated in a questionnaire survey study by (Arvanitidis *et al.*, 2009), while another survey by (Kothencz *et al.*, 2017) confirmed that the aesthetical values of UGS while implementing them is an important component of the action since nature perception is a strong predictor of pedestrians' levels of satisfaction with UGS.

A questionnaire survey study by (Lee and Kim, 2015) in Seoul, Korea describes citizens' attitudes towards urban parks and green spaces when they were questioned about the main reasons for their park visits. Interestingly, most of the people (25.8%) go there for relaxation and walking, followed by meeting friends (16.2%), then enjoying nature (14.4%). This similarly could happen within central London streets if more green is applied, as the current study suggests, by the 2050s and the 2080s. Furthermore, another question has been answered regarding the top roles of green space in parks, which has found that 30% agree that parks provide leisure space. This was followed by three roles which are similar to the top three roles for street benefits in the current survey; these are giving mental stability (18.5%), reducing air pollution (17.6%), and making scenery beautiful (12.8%). It was astonishing however that these findings come from urban parks' value, but they are similar to the findings of the researcher's survey about UGS benefits within streets.

The aforementioned study by (Lee and Kim, 2015) reflects the average Likert scores for an opinion on methods to expand parks and green spaces and it has astonishing similarity to the researcher's findings in the UGS within central London. Lee and Kim found that expanding pedestrian paths ranked 3.65 on the Likert scale followed by expanding bicycle paths with 3.59, applying more green through greening rooftops and walls of the buildings and fences with 3.55, and expanding natural parks in forest areas with 3.54. A similar finding was noticed in the current research where the researcher compared different priorities for pavements and pedestrians spaces within central London streets. Most participants have chosen more vegetation 32% and more pedestrian space (35%) followed by another open ended answer (19%) and more sitting areas (15%).

On the other hand, a study by (Beaney, 2009) which investigates green spaces in the urban environment as uses, perceptions and experiences of Sheffield City has conducted a survey and found that that the main activities undertaken and reasons for visiting green spaces are: 59% of people visit green spaces for walking followed by 55% for sitting and relaxing while 46% walk for transport and 25% visit these spaces to meet and socialize. As a mode of travel, 87% of the survey participants are on foot. The time which was taken by people to visit the green space was less than five minutes for 50% of them and less than 10 minutes for 80% of them, which confirms the findings of Lee and Kim (2015). The length of stay in local green space has astonishing indications; for instance, 37.6% pass-through green space only, followed by 27.8% who spend 30-60 minutes, followed by 21.6% who spend less than 30 minutes in these spaces. Furthermore, 68% of people visit green space alone, 37% of them visit with friends, and 37% visit with their partners. A total of 70% of people visit green space monthly on average.

The GLA calculated the economic value provided by London's parks through quantifying the benefits of parks for the public services, residents, and businesses based on present values evaluated over a period of 30 years. These benefits from the parks were either recreational, mental health, physical health, residential property, Carbon dioxide sequestration, temperature reduction. The total value of £91 billion that parks in London benefitted from was divided into £56 billion to residential property, £17 billion for recreation, £11 billion for physical health, and £7billion for mental health. For environmental benefits, such as CO_2 sequestration, £0.3 billion was saved by parks and £0.6 billion was from temperature reduction (*Natural capital accounts for public green space in London*, 2017).

That reflects that however different the environments, cultures, needs, community and type of urban spaces are, all humans have similar needs and priorities. More attention should be devoted to the UGS increase in the neighbourhood-level within densely populated areas in urban centres (Shi *et al.*, 2020).It is also worth mentioning that the main reason for frequently going to the park is that it is closer to home and usually people spend less than an hour there. That confirms that if London streets become greener, people would be motivated to walk more and hence compensate for the shortage of parks around homes, turning London into the biggest national park in the world by 2050 as per the Mayor of London's plan. These findings are confirmed through a study by (Märit Jansson, 2014) who found that it was repeatedly described in the literature, that UGS qualities and values are linked to proximity to where people commute, live and work.

7.5 Questionaire Survey, Computer Simulations and Literature Discussion

LSDC (2020) has suggested that GI work should be completed in collaborations with the local communities who use the spaces as pedestrians, local residents and workers in order to take ownership of these plans in addition to assisting in designing UGS and providing rich comment and criticism. That would ensure that public spaces are tailored to particular frequent users and not generic in order to reach the best UGS alternative for pedestrians. This approach was followed by the researcher while designing and distributing a questionnaire survey to fit with Londoners' needs, which has successfully found interesting responses similar to other research and surveys.

A discussion, argument and consistent triangulation between computer simulation results and questionnaire survey responses were developed. This will enrich and enhance policy and help decision-makers to make the most appropriate decision regarding applying UGS in central London through providing them with reality findings from pedestrians' responses and questionnaire survey.

Through ENVI-met Computer simulations, the best UGS alternative to mitigate UHI and CO_2 sequestration was 50% trees in the EW canyon orientation and 25% trees in the NS canyon orientation. That was similar across different years investigated; however, the thermal improvements increase with the increase of years due to climate change. In terms of CO_2 sequestration, trees were the best-performing alternative in sequestrating

CO_2. For LF with its different percentages, it did not have a noticeable influence on PTC while HPA had a negative impact on PTC through reflecting solar radiation back to pedestrians (acting as a second source of heat radiation) and, hence, increasing thermal stress.

In 2020, The Mayor of London planned to increase tree canopy cover in London streets by 10% of current levels by 2050, to achieve 23% as a part of urban forest land. That validates the constant and urgent need for UGS in London streets, particularly in areas of low canopy cover (LUFB, 2020).

In order to link these findings to humans and their wellbeing, a link should have been created to investigate the pedestrians' preference and favourite alternative across different UGS with different densities. Specifying pedestrian preferences helps specify the most precise and appropriate UGS not only for its thermal comfort and CO_2 reductions which is tangible environmental aspects but also from the human and wellbeing perspective, which is usually intangible. Therefore, based on the ENVI-met simulations and questionnaire survey responses, further findings were explored.

Within the questionnaire survey, many respondents wished to see a mix between trees and living facades which was neither included in the survey nor explored in the ENVI-met simulation to discover its environmental thermal improvement and CO_2 reductions. Through investigating what the top priority and benefits were for pedestrians from UGS, the top choice was for air pollution reduction and visual comfort (aesthetical value), that was followed by connecting to nature then relaxation. In the fifth place, was improved thermal comfort which was the core of the research investigation. Through the survey, the researcher was able to identify the top priority for central London visitors and we could understand that climate change influence on thermal comfort levels is not a priority for them; on the contrary, air pollution, aesthetical values and connecting to nature are very important for them.

Even though air pollution was one of the interests which UGS can influence, the researcher has excluded pollutant dispersion since it will be time-consuming and will need more time than available to this research study to look at different pollutant dispersion in addition to thermal comfort levels and CO_2 sequestration. But based on the survey responses and interests, if the researcher had more time, he would have investigated both air pollution reduction through ENVI-met software in addition to evaluating the aesthetical visual comfort levels and connection to nature values to pedestrians within central London.

One of the key findings of the survey is that 35% of pedestrians are motivated to walk more within central London through having more green space. 32% cited more pedestrian walking spaces, and around 19% wanted a mix between more pedestrian walking spaces and more vegetation and plants. These responses indicate the urgent need to find an alternative for UGS which does not take space away from pedestrians and at the same time affords thermal improvement outdoors besides its aesthetical value as a part of vegetation which could be lawns (grass). However, that might affect the function of the street being walkable; for example, it may become muddy during the winter. However, it could be aesthetically integrated into pavements without affecting the walkability function of the pavement. Although this research suggested HPA, it was not improving thermal comfort and it does not have high aesthetical value and, hence, it was excluded from the survey.

It is also worth mentioning that if vegetation and greenery were applied within streets that might take space away from pedestrians, and the average survey responses agreed with that. This survey question was validated through correlating and checking the mean of survey participants who are willing to spend time in central London streets after applying vegetation which found that the average of survey responses is willing to spend 30% more time within streets once vegetation or a UGS alternative is placed.

7.6 Urban Green Systems design proposals

Based on the questionnaire survey, computer simulations and literature discussion and findings, a suggested photo illustration representing sections, elevations, layouts and 3D view for canyons is presented. These artwork illustrations are proposed to demonstrate methods of UGS applications in London streets. The following pictures represent photoshopped pictures for London canyons at the current situation (base case) and the suggested ideal UGS alternative based on environmental benefits, visual comfort and aesthetical value, and other safety measurements such as cycling lanes.

The suggested UGS alternative environmental benefits are represented by reducing the UHI effect and carbon dioxide sequestration, while from its aesthetical perspective, responses from the survey have suggested that people would like to see a mixture between trees and living facades and since the aesthetical value is one of the top priorities within their responses, it was hard to ignore their responses regarding the aesthetical value and visual comfort through mixing LF and trees; however, LF does not achieve a noticeable environmental improvement.

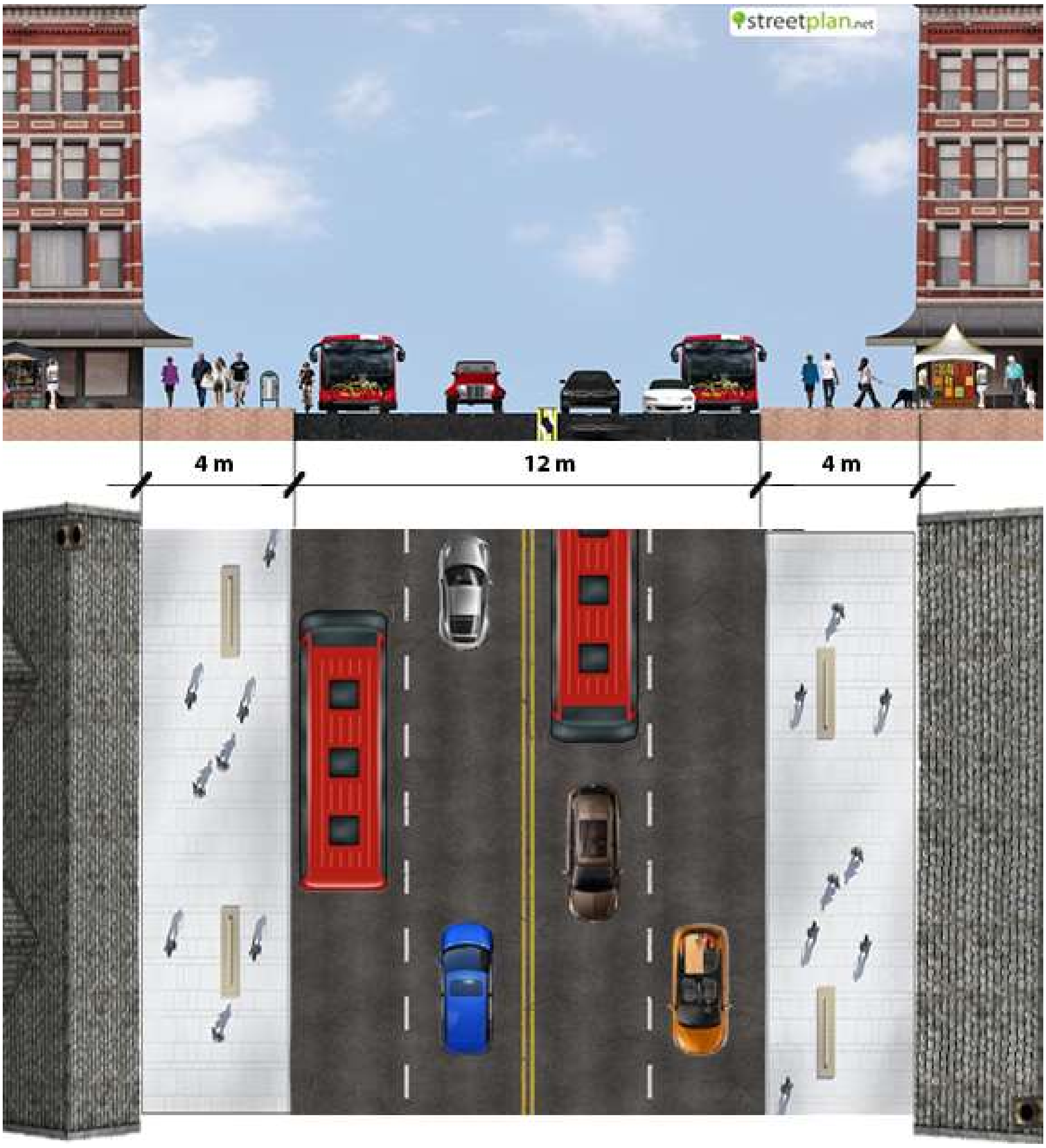


Figure 7-1 Street Base Case, on top is street section, while in bottom is street Elevation (Author)

Figure 7-1 represents a typical canyon in central London, which is a two-car lane in each direction without trees or a cycling lane. While in Figure 7-2, a suggested proposal for Central London streets with few changes to the base case. For instance, there is a clear (1 meter) lane for cyclists on both sides in the suggested alternative, London Plane trees with covering density of 50% of the street canyon area, and a 25% LF coverage on buildings. On the other hand, car lane was reduced from 12 meters to 8 meters and the extra 4 meters were added to pedestrian pavement with 1 meter each side and 1 meter for cycling lane. One of the observations across the street canyon within central London is that it has a small pavement width in the middle of the two-street direction where some street furniture is placed such as (traffic lights, pedestrian crossings, streetlights and signs, among others. This pavement is appearing near the street intersections and disappears across the rest of the street sometimes. Although the pedestrian pavements and traffic ways do not have an accurate measurement, they are usually the average width across the beginning and the end of the street. For the car roadway, sometimes it narrows and widens across the same street, yet the presented proposal illustrates a wider typical canyon, while during narrow street canyons, buses and cars are usually merged into one wide lane instead of two as presented.

The EW street canyon with 50% trees coverage and 25% LF, which does not appear clearly through the plans in Figure 7-1 and Figure 7-2 as it fits very close to the building skin. The North-South canyon has 25% of trees with 25% LF as it does not need a higher percentage of UGS coverage. However, this proposal in both figures is ideal for central London canyons, as the UGS benefits increase with the increase of pedestrian numbers and the importance of the street.

Surprisingly, similar plans were found for greening central London; for instance, The Crown Estate and Westminster City Council are working with Westminster City Council, TfL and the GLA to deliver interim plans for Regent Street, to support creating a greener, more accessible, and safer West End (Crown State and Westminster Council, 2020; PHE, 2020). These plans aim to reduce congestion and vehicle movements vital in reducing traffic to a single lane in each direction on Regent Street. These plans were considered to resolve the consistent need for more pavement space, and sustainable tree planting and greenery are also being introduced to benefit biodiversity and air quality on Regent Street, to support social distancing during the COVID-19 pandemic.

Figure 7-2 Street 50% Trees with 25% Living Facade, on top is street section, while in bottom is street Elevation (Author)

On the other hand, the Crown State has introduced tree planting and green to enhance our visitors' experience and improve biodiversity by planting London Plane trees. However, the suggested Crown State plan did not include an ideal green percentage as a density based on canyon orientation and where to locate it. These plans, objectives and methods of application in central London were very interesting as they have validated and confirmed the findings and recommendations of this research and its methods of applications, which reflects the adequate and accurate findings and quality of research.

Based on (LSE-Cities and GLA, 2017; PHE, 2018), over 90% of high street visitors walk as a transport method to visit their high streets since high streets are walkable, local destinations and essential points of connectivity. However, 18% of London is officially publicly accessible green space; individuals who live in the deprived city centre and inner-city areas have five times less access to a good quality green space (PHE, 2018). That reflects the inequality of UGS distribution due to parks being disproportionately located in richer neighbourhoods while 21% of London houses have no garden, compared with 12% of Great Britain (LSDC, 2020). The amount of accessible green space per person is less than the goal area on a football field (six-yard box) (Paul de Zylva, Chris Gordon-Smith and Mike Childs, 2020; Paul de-Zylva, 2020).

Park closures due to overcrowding due to COVID-19 has disproportionately impacted poorer communities and black, Asian and minority ethnic groups, as these communities typically share less space and have less access to public parks and private gardens (Paul de-Zylva, 2020). Therefore, the (GLA, 2019) is a long-term mission for highstreets and town centres as part of major regeneration and restructuring schemes that consider solar radiation, street orientation, natural light, shading, and flooding proactive climatic response in high streets and town centres.

That long-term mission aims to benefit from mitigating UHI by creating green spaces and planting more trees in and around high streets and town centres and introducing more shaded areas. An aesthetical value and functional benefits are maximised by redesigning highstreets and town centres by reducing traffic lanes, introducing bicycle lanes isolated from traffic, and planting trees. These functions and benefits were illustrated in Figure 7-2.

It is worth mentioning that the researcher similarly designed the GLA proposal in Figure 7-3 and in (Appendix I – London Illustrations by researcher by the researcher based on Research findings and Discussion) as a research recommendation for best UGS alternative based on Oxford Street observations from a functional perspective, while computer simulations using ENVI-met have given the best UGS alternative from the environmental perspective through mitigating UHI and carbon dioxide sequestration. Finally, the questionnaire survey helped to determine the human preference regarding the best UGS alternative for pedestrians. The GLA proposal is slightly different from the research proposal in terms of placing a parking bay alternated with cycle parking located between cycling lane and roadside, and that may be due to having a wide street. On the other hand, (PHE, 2018; GLA, 2019; Crown State and Westminster Council, 2020) did not specify greening densities and percentage, size of trees, and orientation in their suggested proposals this research has investigated.

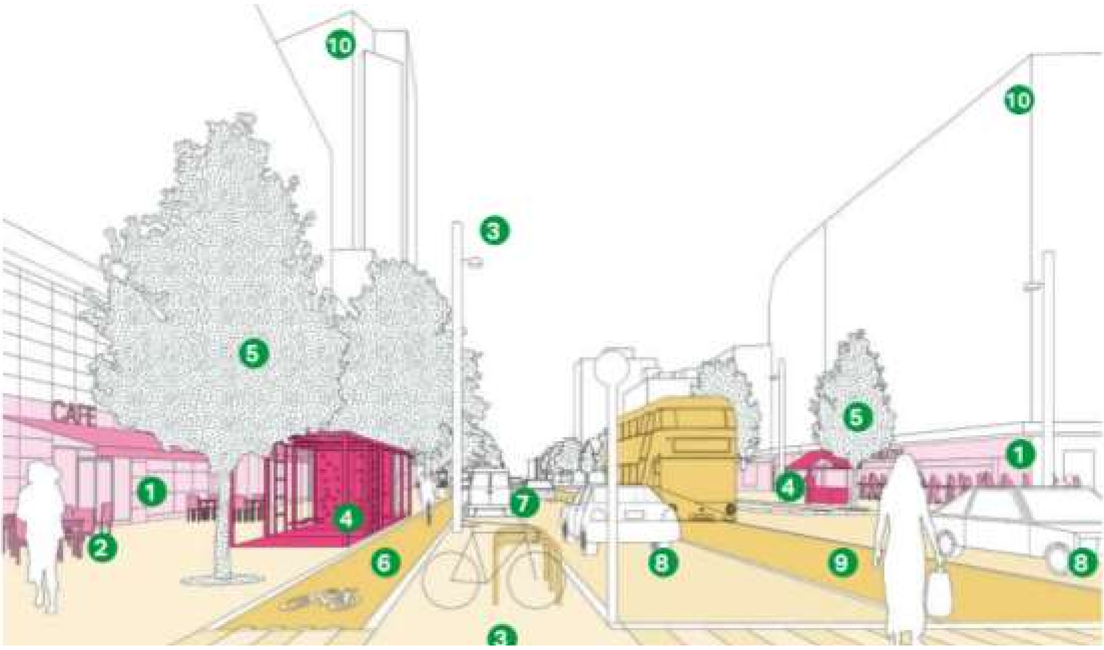


Figure 7-3 Long-term mission for highstreets and town centres by the GLA (GLA, 2019)

Current street standards (TDAG, 2020a) advised planting more trees due to their importance for climate change adaptation and mitigation and better mental wellbeing. That confirms the consistency and alignment between research findings across the environmental benefits of UGS through adaptation and mitigating UHI and carbon dioxide reduction and specifying the human perception of pedestrians from the survey responses who declared the need for UGS due to its mental wellness and connecting people to nature.

7.6.1 Urban Green Systems design proposals justification based on Covid-19

Green spaces have been enormously influential during the COVID-19 lockdown, and their visits have increased 160% (LSDC, 2020) primarily because green spaces are considered as one of the last open places during the pandemic which indicates how essential these spaces are in addition to their new benefit of being less isolated (Meredith Whitten, 2020). Almost half (44%) of Londoners have stated visiting green spaces more frequently since the lockdown, which is higher than the national average by one third (35%). Forty-six per cent (46%) of Londoners felt more connected with their community during lockdown while 43% stated they felt just as connected as before, and 8% of

Londoners felt less connected. Further, 54% of Londoners appreciate green spaces more since the lockdown and social distancing measures were imposed, while 59% are more conscious of the GS benefits, particularly for mental health and wellbeing (CPRE, 2020).

Sixty-two per cent (62%) of Londoners believe that improving, enhancing and protecting green spaces should be a top priority after the social distancing and lockdown. Over 80% of the UK public request that the government prioritise wellbeing over GDP during the pandemic, while 60% of the public request that this remains after COVID-19 has subsided (LSDC, 2020).

Studies by (RTPI, 2020; TDAG, 2020b) illustrated the importance of green spaces, particularly within the COVID-19 pandemic since restrictions and lockdowns which are required to reduce the spread of COVID-19 in addition to insufficient access to open space – either public or private – will exacerbate physical and mental health problems which are already costing the NHS £1.4billion a year. In turn, these influences decrease and weaken the social and physical resilience of communities and reduce economic activities. However, on the other hand, we should consider social distancing by not reducing the pavement space due to street furniture and UGS as trees that might limit and congest the pavement walkability, especially during and after COVID-19 (Isabelle Fraser, 2020; West-Berkshire Council, 2020). Therefore, expanding the footway (pavement) would be a must to avoid any risks.

This study compares current and withdrawn street design practices based on street design standards (TDAG, 2020a). Findings showed that prioritising streets to be human-centric is based on a hierarchy priority for pedestrians, then cyclists, public transport, specialist service vehicles, and private vehicles rather than vehicles as in the withdrawn street design practices. Several survey participants identified and mentioned this as one of their core needs within streets, in addition to the request of increasing tree coverage with a wider footway and creating safe cycling lanes. Consequently, it would be applicable to make this shift in vehicle lanes through reducing it (merging two lanes into a one-lane road) and adding the space for cycling lanes and pavements due to the national shift to work from home during the pandemic. which leads to the creation of opportunities and improve safety to introduce green infrastructure interventions such as trees (LUC, 2020).

LUC (2020) has confirmed that well-connected local green spaces matter more than ever throughout the COVID-19 pandemic, particularly after observing high pressure and densities by parks' visitors, highlighting the shortage of green space in our cities.

Since connecting green spaces would create a network of green lungs and natural spaces through urban areas not just gardens and parks, but also trees, green walls and green roofs, this GI strategy's connection would improve the quantity, quality and connectivity of UGS within urban areas, which would lead to making them more attractive, safer and afford a higher quality of life.

Figure 7-4 Regent street base case (Crown State and Westminster Council, 2020)

Figure 7-5 Regent street (EW orientation) proposal with 50% Trees and 25%LF (edited by Author)

7.7 Conclusion

Through discussing the findings of this research from ENVI-met simulations and comparing it to other research findings, and then comparing the questionnaire survey results and findings with related research, a suggested ideal UGS alternative was proposed and illustrated through graphical pictures. Surprisingly, recent plans by policymakers in London such as Westminster, TfL, and GLA reflected the same ideas and findings of this research, such as applying more greens, cycling lanes and narrow car lanes; however, they did not include detailed information as the accurate percentage of tree coverage or its location, and they have only specified the type of trees as London Plane trees, which was the same type used in this research.

8 Chapter 8: Conclusion and Future Research

8.1 Introduction

This chapter draws out conclusions and outcomes using urban green systems as an approach for future climate change adaptation in London across 2018, 2050 and 2080 in terms of urban heat island mitigation and carbon sequestration within different canyon orientations central London.

Outline outcomes and concluded points on each component of urban green systems besides climate change mitigation levels are presented In addition recommendations, limitations, and direction for further studies are stated, and contributions to knowledge are set out. This was concluded through literature reviews, computer simulations using ENVI-met software, and online surveys.

Within this chapter, findings are addressed regarding different UGS settings in central London based on street canyon orientation in each case year (2018, 2050 and 2080) to achieve the best pedestrian thermal comfort and more carbon sequestration levels through urban green systems and how these would influence pedestrians' activities within the street based on pedestrians' preferences.

Subsequently, based on the findings across the literature, computer simulations, questionnaire survey, recommendations, limitations and future research studies are presented and discussed.

8.2 Conclusion

This research was undertaken in an effort to find critical justification for the UGS as approach to mitigate and adapt to future climate changes. It aimed to provide one or more solutions that could be applied within street canyons to motivate pedestrians to walk more during the summer season. The purpose of this was to encourage the individuals to depend less on public transport, improve their quality of life, increase biodiversity, increase visual comfort satisfaction and connecting to nature in addition to decreasing thermal stress within their built environment. The Mayor of London set these goals within his plan to make London the biggest national park in the world by 2050, the Healthy Street Initiative by the TfL, and Walkable London by Zaha Hadid.

An extensive process of simulation analysis and questionnaire survey was executed to investigate PTC in order to improve the overall microclimatic conditions without the need for massive change by applying different UGS interventions such as trees, living façade, and high albedo pavement with different densities (25% and 50%) in different canyon orientations within central London (North-South and East-West). It was hypothesised that improving pedestrians' thermal comfort during their journeys to central London would encourage them to walk for longer distances and over more extended periods during the summer.

This study is presented in three stages. Stage 1 presents reviewed theoretical work and similar research carried out in the related fields of climate change and its influence on the UK and urban environment. The following section of stage 1 focused on identifying climate change adaptation and mitigation strategies focusing on UGS and its broad definitions and benefits. Due to the multi-functionality of UGS, this research focused on its benefits for thermal comfort and CO_2 sequestration. Stage 2 reviews ENVI-met simulation, the questionnaire survey and their analysis that were used to investigate PTC from environmental, physiological and psychological aspects.

Subsequently, stage 3 tests all alternatives and analyses the findings from the applied methods in order to provide fully descriptive and quantitative findings of the most appropriate UGS intervention, where it should be applied and with the right density not only from an environmental perspective (thermal comfort and CO_2 reduction), but from physiological and psychological preferences based on the survey outcomes. The outcomes and findings add distinctive knowledge for the decision makers, urban designers and planners in the UK context about the impact of the built environment on pedestrians' preferences, comfort levels, and influence on the human behaviours and activities within the streets.

Recent research findings and recommendations illustrated in the discussion chapter were similar to the most recent and updated similar and related articles and also reflected recommendations from experts and policymakers that validated and confirmed the results of this research.

8.2.1 Underlying reasons for CO2 sequestration and UHI effect and how to mitigate it, particularly in current and future climate scenarios

A relationship between UGS and UHI mitigation in the current climate scenarios of summer 2018 and future climatic scenarios of the 2050s and the 2080s is being established in numerical methods. Despite UGSs' multi-functionality, to the best of the author's knowledge, there are no existing specific guidelines or recommendations based on numerical data concerning how UGSs would influence PTC in London so it can be used as a strategy for climate change mitigation. Thus, the present research has tried to address this knowledge gap in this field in order to determine the best factors that affect pedestrian thermal comfort. The research assessed whether increasing UGS percentage would be most likely to increase the PTC or whether that would not be the case. Furthermore, the location and the UGS placement are more vital and responsible for increasing PTC.

Climate change is taking place very fast, reflecting on climate and the natural environment, causing temperatures to rise, warming oceans, decreased snow cover, sea-level rise and more flooding, and ocean acidification. These will also lead to more frequent heatwaves, droughts and sea-level rise, which will cause the climate to shift, whereby London will have a climate similar to Barcelona by the 2050s. Climate change will affect London; the temperature will get warmer (between 4.4°C and 7.8°C), humidity will get drier (-2.8% to -13.1%), and wind speed will increase around 200% more for both the 2050s and the 2080s scenarios respectively. The UK climate future in the twenty-first century is classified into three scenarios representing different slices of the century (near, mid, end) of the decade which are represented in the following years - the 2020s, the 2050s and the 2080s respectively. Each year of them has three carbon emission scenarios of the following probability –(10%, 50% and 90%, respectively.

London's climate will be like that of Barcelona by the 2050s due to climate shifts. However, the 47% of UGS coverage in London is not an accurate representation of UGS in central London which has UGS coverage of almost 0.1% in its streets. In comparison, Treepedia software reflects that the green view factor average across the whole of London is 12.7%. This reflects the uneven distribution of UGS across London, which i mainly exists in the green belt (outside the inner city where it is most needed) or in the big parks.

Benefits and influences of UGS on urban heat islands in future climate change have not been addressed much in the literature to date. UHI during the summer is higher than in the winter and the difference during the night time is more than during the day, but the temperature is much higher during the daytime. Most VGS studies within a temperate climate were focusing on UHI and biodiversity, followed by air quality and hydrological benefits and carbon sequestration. At the same time, only a few of them looked at their influence on planning and infrastructure, energy performance and economic aspect. The "multi-functionality of green spaces as "open green spaces, green roofs, green walls, etc." was thoroughly explored within this research with the main focus on combating UHI effect, carbon sequestration and providing climate refugees.

Canyon geometry, orientation wind speed, sky view factor and global solar radiation play critical roles for UHI intensity, especially during the daytime, while deep narrow canyons, densification and building factors are usually more important for night time UHI.

PET was a more precise way to indicate thermal stress and thermal comfort rather than Ta alone since it considers the effect of several variables, such as Ta, Tmrt, Ts, Ws, RH, solar radiance on human skin. However, 47% of London is green; yet almost all London city centre streets, especially the research area covering mainly Oxford in addition to being near Regent, James, Baker, Duke, Marylebone streets, have nearly 0% green.

8.2.2 When and how the built environment may benefit from UGS in a temperate climate such as the UK

This study delivers experiential evidence that adaptation and mitigation to climate change is essential to provide habitable cities in the future. In fact, the simulation results illustrate that PET values, and therefore heat stress, are already very high in densely built-up areas as central London within the summer seasons.

UGS implementation within London city centre would be different in terms of the season (summer, winter, spring and autumn), year (2018, 2050 and 2080), the type of UGS itself, its percentage, and where it is applied; and that would be based on street orientation. Where North-South streets do not need much vegetation as East-West streets that is mainly due to solar radiation received and the canyon geometry (building to street height) at which buildings' height within central London canyons limit the sunlight rays that reach street level due to building shading.

For Tr percentages in PET, it could be concluded that with cooler temperatures across the variation of years, seasons and days, similar savings in Tr percentages were found based on S1 and S2 comparison where S1 was a well-oriented canyon with low direct sun hours. Trees lower Ws slightly, but this does not influence thermal comfort as Ws is already too low. However, they work better in higher solar radiance and poorly-oriented streets. Increasing LF and trees' percentages increased RH, particularly for the LF case.

Vegetation type, location in the canyon and its percentage amount is more effective within higher temperatures and lower humidity which can be easily noticed within the changes in2018, the 2050s and the 2080s. Trees showed maximum lowering temperature while LF showed an increase in humidity with less influence on temperature levels.

This research focused on the average summer season (21 June-21 September), unlike other research which showed extreme heat stress conditions or worst-case scenarios. Therefore, the research findings regarding trees could be more beneficial within harsh and extreme heatwaves which will be more frequent in the future. On the other hand, this study findings due to climate change could be worse in terms of meteorological data for each year, leading to more pessimistic scenarios.

8.2.3 The potential of lowering the urban heat island effect and CO_2 reduction through different types of UGS

From a quantitative approach, decreasing temperature within the street canyon is shown when the building envelope is covered by vegetation. Significantly, the hotter the weather is the higher climate mitigation, and improvements can be shown, especially the higher the solar radiation is. The saved energy and canyon temperature could be decreased when it is covered by vegetation.

The vegetation usage on poorly oriented high dense canyons can compensate for their poor design and orientation particularly in high emission scenarios than in lower emission scenarios. This becomes more evident in the 2080s followed by the 2050s and 2018sdue to its higher UHI effect while if it has been applied to the whole city scale, much improvement for the urban heat island effect could be reached and lowered on a large scale.

For the North-South street in 2018, applying high albedo surfaces for pavements would barely change pedestrian thermal comfort through reducing PET by -0.21°C which was due to its high effect on lowering the surface temperature while its reflectivity had increased Tmrt. In the case of other vegetation percentages, PET improved by -0.35°C to -1.05°C while for the EW canyon which has a very high thermal stress compared to the NS one, HPA increased thermal stress by +1.3°C due to its high Tmrt, while trees lowered PET by -3.08°C and -5.84°C for 25% trees and 50% trees, respectively. For LF 25% and LF 50%, a reduction of -1.17°C and -0.09°C, respectively, were found as a Tr, which is almost negligible for LF 50%.

High albedo pavement type shows a significant reduction on surface temperature while it has increased the Tmrt as well due to its reflection ability; thus, it is not efficient to place it as its thermal improvement is not beneficial enough. PPD has been lowered in all UGS alternatives even in the HPA case which had higher PET before, while it increased by 25% in the LF case up to 67.6% in the EW canyon. This might be because PMV and PPD do not take solar radiation and Ws into consideration while considering pedestrians' humidity and activity, and their clothing.

For the 2050s, the overall temperature rises by around 3°C which leads to an urgent request for climate change mitigation and adaptation systems, taking into consideration that the NS canyon which was not a priority canyon for applying UGS in 2018, has become more crucial and not a choice for applying UGS to increase PTC with 25% trees, while for the EW canyon, not less than 50% trees become a must due to high solar radiation and temperatures.

For the NS canyon 25% and 50% trees had similar thermal improvement due to lack of direct solar radiation where both saw around a -2°C decrease in PET, while for the EW canyons 25% and 50% LF have a negligible effect on PET. HPA has increased heat stress in both NS and EW canyons as it reflects solar radiation back, which reflects that the position of placing the UGS alternative is a crucial factor in its efficiency and practicality. For EW, 25% and 50% trees saved up to 2.8°C and 6°C (10 and 20% improvement in PET) respectively; nevertheless, an insignificant improvement was found of 0.04°C and 0.19°C for 25% and 50% LF, respectively.

The 2080s had a similar pattern to 2050 in terms of UGS practicality and efficiency in different canyons, yet it shows more importance as the heat stress increases, where HPA in NS has increased PET 5°C more and 10°C more in EW canyons. Meanwhile 25% and 50% LF have negligible influence and both trees' percentages slightly improved PET by 2°C maximum in the NS canyon causing thermal improvement to jump significantly in the EW orientation by -4°C reduction for 25% tress and -9°C for 50% trees, which represents improvements of almost 20% and 25%, correspondingly.

Shading is the most significant purpose of UGS for heat stress adaptation and mitigation, followed by both evapotranspiration and ventilation. This reflects the massive thermal improvement for tress more than that caused by LF and HPA, which cannot provide shade. On the other hand, buildings' shade plays an important role in NS orientation as it blocks GSR, thus providing shadow and lowering the need for UGS.

Although CO_2 contributes to almost 50% of climate change, it did not benefit from massive improvements from different UGS interventions as PTC across the different years and different canyon orientations. This was due to the limited capabilities of UGSs as trees and green walls at which the amount of produced CO_2 is huge compared to the amount sequestrated. Overall, CO_2 reduction from UGS was small relative to city-based emissions and increasing UGS alone is insufficient for achieving future and current climatic goals.

In order to absorb CO_2 concentrations which are emitted, the whole world should be covered with greens, which is not feasible. On the other hand, it was found that diminishing CO_2 should be through limiting its sources and emitters not by increasing UGS. In addition, CO_2 is a global effect and not a local effect which confirms that it should be targeted on a global scale, not only within canyons within limited urban scale and neighbourhoods. From this study, the trees had the highest CO_2 sequestration by saving PPM while LF within the ENVI-met software had a limitation that it was not able to calculate CO_2 sequestration by living façade. In reality the primary source of CO_2 sequestration is the oceans through algae and that is leading to its acidification, not land UGSs, which is worth mentioning as well.

The CO_2 sequestration percentages from trees were between 0.7% and 1.2% for both 25% and 50% trees, respectively, which represents 4-5 PPM out of 420PPM. At the same time, the CO_2 concentrations increased within canyons from 410 PPM to 423 PPM due to the chemical and physical properties of carbon dioxide, which made the concentration denser and trapped within canyons. On the other hand, CO_2 concentration decreased with the increase of temperature within the same environment, which is evident in that, in the 2050s and the 2080s, the temperature increases and hence the CO_2 slightly decreases. There are other reasons for UGSs to have an influence on CO_2 sequestration such as the tree or LF age (young, mature, old), climate and weather (sunny, cloudy) which all impact on leaf stomata, irrigation and maintenance. All these factors have a massive influence on the efficiency of the UGS alternative and its efficiency on CO_2 sequestration.

8.2.4 The human perception of different UGS alternatives and how it would influence their street activity

Since human behaviour is variable and consequently hard to predict, it is not likely to produce totally accurate predictions. Nevertheless, it provided the author of this thesis with a more profound understanding of the relations across various variables, which helped in shaping an additional, comprehensive perception of different UGS interventions and their influence on pedestrians' activities and walking patterns in London.

Some of the survey findings have explored pedestrian activities within central London streets, time spent, number of visits, and reason for visits. Subsequently, it has given a closer insight into the significance and the pedestrians' motivation to spend more time outdoors if UGSs were applied even they have some trade-offs such as taking up space, associated maintenance associated, and others. Furthermore, different UGS interventions (trees and LF) were presented with different densities (25% and 50%) in order to specify the pedestrian's degree of visual satisfaction with their view and their preference compared to the current base case with 0% green. Last, different questions in the survey investigated the pedestrian time change after applying their preferred UGS alternative and how it would reflect on their street activity and the time spent outdoors.

The survey outcomes highlighted and revealed the most significant explanatory reasons and motivations for pedestrians to spend more time or walk a longer distance outdoors based on UGS alternatives. These outcomes have been achieved through creating cross-tabulation and correlations between questions in order to reveal some of the unpredicted and unobserved relationships between different questions and factors. Therefore, using these analyses in generating comprehensive, detailed information will be informative for policymakers and urban planners to improve UGS quantity and quality within London.

8.2.4.1 Questionnaire Survey Frequency

The survey frequency analysis classified the survey into four sections: the first section showed a variety of different participants with different street activities (walking, shopping, hanging around, etc.) within different week visiting intervals (such as one, two, three or more days per week) and with different spent time outdoors. Most people were interested in more vegetation and more pedestrian space; however, although they need more pedestrian space, participants strongly agreed with replacing pedestrian space with greenery such as trees, and they have reflected that on their activity as well, showing that they are willing to walk or spend more time outdoors if there is more green.

Within the second section, participants showed moderate satisfaction with the current central London view and, with the increase with a greener percentage from 0% green to 25% to 50% green, the participants mean satisfaction increases. In comparison, responses show that 25% trees have almost equivalent satisfaction and preference value for 50% living façade, which reflects that more green coverage does not always represent more satisfaction and also the type of UGS has an impact on satisfaction. Overall trees, especially with 50% coverage, attracted higher satisfaction from the participants.

Subsequently, participants indicated that they are more interested in spending 30% more time within the streets after applying the UGS alternative than their usual time patterns. Participants revealed that their top priorities for choosing the UGS alternative were due to its benefit for air pollution and aesthetical view followed by connecting to nature, then relaxation and thermal comfort, while the lowest ranked priority was for increasing productivity. This reflects that thermal comfort in summer is not one of their top priorities compared to other UGS benefits. This is a direction that is worth exploring for future researchers, with a focus on aesthetical comfort and pollution levels.

Participants' demographics show that almost twice as many women as men participated in the survey, and about 61% of the sample was less than 40 years old. When asked for further comments, participants made a wide range of comments from political, human and, and environmental perspectives as well as some criticisms. Participants showed a wide knowledge about UGS and have given feedback which varied between positive and negative on policymakers and how to apply UGS and what they are willing to have in London.

8.2.4.2 Questionnaire Survey Cross-tabulation

Overall, cross-tabulation has brought a deeper quantitative understanding of the findings from the survey based on frequency, sample, and participants' interests. This helped make the survey responses more precise and tailored for the research objective in identifying pedestrian preference for UGS alternatives, what the appropriate percentage of UGS to be applied is, and what the expected activity pattern would be outdoors after applying it.

Across different age groups and genders, the UGS preference and bias did not change as all participants had similar preference with similar mean values which reflects that all of them are motivated to see more green. However, their preference is more for trees than green walls. Even the percentage of GW was 50% which is higher than 25% trees; participants' preference was more trees with a lower percentage, while 50% of trees had the highest mean value. This means that the type of UGS is more important than the percentage of UGS coverage.

A cross-tabulation was carried out between week visits and different UGS alternatives. Across all of the UGS alternatives, the number of central London weekly visits did not influence UGS alternative choice, and a similar pattern to gender and age choices' mean values have confirmed that UGS alternative choice does not have a relation or influence on participants weekly. Subsequently, two questions investigated the pedestrians' priorities (vegetation, more pedestrian spaces, more seating area or others) across different age groups and genders. No difference was noticed as the responses had similar patterns to the overall preference; however, cross-tabulation showed that females had a similar numerical equivalence for more vegetation and more pedestrian space. However, more vegetation was preferred slightly more than more pedestrian space; responses reflected the importance of implementing more green in addition to wider pedestrian space, or at least without limiting their street walkability.

For the other question regarding how participants feel towards more vegetation which would take up pedestrian space in summer, participants showed more motivation for more vegetation over pedestrian space, even for females who had previously chosen an equal choice of vegetation and pedestrian space, who subsequently chose vegetation as a priority compared to pedestrian space. On the other hand, older age groups 51-60 and 60+ were more neutral/unbiased (neither motivated nor non-motivated) towards more vegetation against pedestrian space.

Furthermore, a cross tabulation was carried out between age, gender and a question regarding whether more vegetation would motivate participants to walk a further distance or for a longer time. A very high percentage showed motivation to walk a further distance or for a longer time with an average mean of 4 representing motivated. Following that, a comparison between the average time spent by the participant before applying UGS (the current case scenario) and after applying one of the suggested UGS alternatives was carried out. The results confirmed that most of the participants are willing to walk a further distance or for a longer time.

8.2.4.3 Questionnaire Survey correlations

There is a strong positive correlation between time spent before and after applying vegetation and a strong positive correlation between agreeing on increasing street vegetation and participants' motivation to walk a further distance or for a longer time within more vegetated streets. There was also an average positive correlation between agreeing on applying more street vegetation and all UGS alternatives, especially for higher vegetation coverage 50% trees and 50% LF. A positive correlation has always been found between the low (25%) and high (50%) UGS alternatives.

8.3 Research limitations

Multiple research methods that were chosen to cover the gaps of knowledge that were determined prior have been challenging, through different levels. These methods relied in large part on computer simulations and an online survey with fixed subjects and data, and real-time measurements, which were taken and validated by the researcher. An extensive effort was made to overcome the financial and human resources limitations without compromising the credibility or the flow of the research process.

The COVID-19 pandemic had an influence on the research, particularly within the survey phase. This led to changes in the standard research process due to the current circumstances of constraints to approaching the survey sample due to social distancing requirements. The, researcher reformatted the whole survey based on a different sample and data collection methods instead of face-to-face to be completely online. However, although the researcher was flexible, the human interaction constraints and the restrictions have reflected on the research time and led to cancelling the facial emotional analysis which the researcher intended to carry out, but it was eliminated due to avoiding physical interactions as shown in Appendix J - Physiological and Emotional Analysis.

COVID-19 might have influenced the survey participants as the survey was collected during the lockdown when nearly everyone had to work from home. This made it challenging for participants to recall their activity within the street; how they felt, their daily pattern, and so on. Some survey participants even indicated that COVID-19 might reflect on their UGS choice as, within central London's congested streets, planning further UGS might take more space and hence will increase the congestion which is not advised during the COVID-19 pandemic.

Within survey analysis, several participants have requested a mix of living façade and trees which was not presented in any of the illustrations which mainly focused on one form of UGS with a consistent density of either 25% or 50%.

8.3.1 Methodological limitations

This research explored how cool pavements, green walls, and trees influence the urban heat island effects and mean radiant temperature in London city. The methodology developed was a sequence of simulated environments in order to achieve and analyse the information, with physical monitoring. Some simulations might be insignificant or have no real influence on the process, UHI, has all helped significantly to achieve a wider overview and a better understanding of the procedure and the outcomes.

The simulated environments might be limited due to their size, function, scale and physical models' materials. Due to time constraints, it was not possible to use different UGS types with different changes, such as foliage leaf thickness, type of green wall was used as green façade, intensive green roofs, and basic street trees, to name a few.

Therefore, the most common practice was used in order to avoid multiple trial and error simulations. In addition to all of these changes, each simulation took three to four days on average to run, which is time-consuming and it was hard to make any changes while the simulation was running, particularly running it in different climatic scenarios. At the same time, it was only possible to compare the current case in 2018 through the physical model and validate it through simulation (ENVI-met) as a validation and calibration method while the other futuristic scenarios – the 2050s and the 2080s – were predicted through computer simulations only.

8.3.2 ENVI-met software limitations

The main methodology part relied on ENVI-met modelling software which usually included some form of simplification and abstraction of the real world, leading models to be an approximation of the truth.

North-South (NS) and East-West (EW) canyons have the same or nearly similar output measurements for thermal comfort across years, yet this is not the case in reality which is clearer on maps as the East-West has some spots or points which are higher in temperature measurements (more thermal stress), but within the average of the street, these cannot be distinguished or noticed, especially when the UGS alternative is applied within the whole canyon and not within specific spots or points; otherwise, measurements would be biased.

However, it is already known that nocturnal UHI is higher than daytime UHI, yet due to the low temperature and the absence of GSR, the comfort levels during the night are higher. This research focused on daytime UHI and did not study the nocturnal UHI. During the daytime, there is intensive continuous heat stress as long as the sun emits solar radiation, and hence there was an urgent need for UHI mitigation scenarios during the daytime rather than during the night-time hours.

ENVI-met software helped represent PTC in a scientific way through showing PET differences across different alternatives, reflecting the physical improvements. However, it did not represent what human beings feel in terms of the psychological (mental and emotional) improvement based on seeing and interacting with nature in reality. For instance, would seeing more trees or green walls in the streets make them more thermally comfortable even if there is a physical, thermal improvement?

ENVI-met software might have some limitations as for VGS as LF does not have an influence on CO_2 sequestration as it considers VGS as a non-liveable urban system, unlike trees which are considered as a liveable urban system which uses a photosynthesis process and grows with time. Wind speed and direction was not constant within actual measurements which is also reasonable as usually measurements are being taken across a longer duration then the average wind speed and most dominant wind directions are being identified. In software simulation, the dominant wind direction and wind speed are easily identified.

The research mainly focused on UHI and CO_2 sequestration within central London; however it did not take national parks (Hyde Park, Kew Gardens, etc.) and pockets gardens and other surrounding green areas into consideration. This was due to focusing on the general case of London in general, particularly because central London had less than 1% green area within its streets at the time of the research.

Due to the lack of information and data about expected CO_2 emissions in the 2050s and the 2080s even by the MET office, the researcher used the same CO_2 PPM in the three decades. This was because there was no exact number or even a rough estimation of what would be the CO_2 PPM in the air which could be easily noticed that the UK withdrew from the Paris Climate Accord as it cannot meet the future targets in lowering Carbon emissions.

Regardless of UGS multi-benefits, its implementation in policy and planning faces many challenges, including involving various policymakers, overcoming institutional and technical barriers, resolving conflicts of people's need within limited pedestrian spaces and finally the running costs and regular maintenance for the suggested intervention. However the researcher held several meetings with policymakers, frequent street visitors, and experts, and this study does not suggest that the modelled scenarios can be integrated directly into the application but rather that they can serve as an assessment of the adaptation potential of UGI in specific settings.

The research findings focused on SUHI in order to assess different levels of UGS influence on PTC, while some of these alternatives might have an influence on night-time SUHI; on the other hand, UGS might influence different UHI levels tov varying degrees, which was not included in this study.

The research findings did not include the influence of placing different UGS alternatives, especially trees, on air pollution concentrations and air pollution particles dispersion. The researcher tried to identify the least disadvantage for trees trapping air pollution through shifting trees from both pavements sides so as not to be on the same parallel lines.

This research looked at the thermal benefits and CO_2 reduction of UGS alternatives at the human scale (1.5 metres) while it did not reflect that on the whole urban neighbourhood at the canopy level and boundary level at which their total reduction of different UGS percentages – either 25% or 50% – might have a different influence. Trees and vegetation species vary in their cooling capacity and cooling mechanisms which was not considered within this study as the researcher's primary objective was to use the local trees and local LF plants that easily fit within the UK climate and streets. On the other hand, both deciduous trees and deciduous LF influence during winter were not taken into consideration during winter when leaves fall. Applying UGS-related costs and time such as site preparation, planning, plant production, stewardship, planting, monitoring, outreach and administration are significant, but these were not quantified in terms of how long each alternative would take to be applied, or each alternative cost and financial turnover. Correspondingly, the economic benefit of reducing UHI and sequestrate CO2 is not identified. There are many possible research and scientific areas regarding UGS types and their influence on climate and air pollution mitigation overlap. This happens while comparing the effects of UGS types and scales, and where and how to apply them. This is due to the wide heterogeneity of the topic disciplines and foci which have multiple -related inputs.

Given the research's limitations discussed above, it is strongly believed that the methods used, the number of subjects, and the instruments selected for data collection and analysis create a satisfactory balance between the feasibility and generality of the outcomes.

8.4 Research recommendation

It is advised to prioritise EW canyons as they are receiving more solar radiation. For the NS canyon it is advised to either be left as it is at the current situation for 2018 with 0%, or apply low vegetation percentage with maximum of 25% trees, due to the lack of solar radiation as a result of building self-shading on the street canyon.

Shifted trees achieve better thermal comfort performance as its distribution is avoiding shade overlapping and increasing distributing the shade across the urban canyon, especially with the sun path change. In addition, parallel lined trees would create a semi-connected crown which will block air pollution underneath and decrease the dispersion, thus, shifting trees is more recommended.

After simulating different urban green system alternatives with different percentages across different years, the most appropriate UGS with the most appropriate percentage was used in each canyon orientation across each year which was 25% trees for the NS canyon, and 50% trees for the EW canyon. How these trees are placed should be shifted, to avoid shade overlapping or trapping pollutants underneath the trees' crowns.

and that for the whole investigated years as the most performing alternative to increase PTC.

HPA could be an appropriate alternative for climate mitigation and adaption if it was placed on building roofs as it will reflect solar radiation back leading to decreased solar radiation and hence increased thermal comfort at the canopy level instead of at the pedestrian street canyon level.

Even though the efficiency, multi-functionality and benefits of UGS were proven within this research to mitigate UHI and increase PTC and sequestrate CO_2 across different years, this does not halt climate change as it will keep on taking place and changing due to increasing temperature levels, which reflects and confirms that UGS is just a mitigation method, but will not reverse the changes. UGS benefits are maximised when it affords shade for urban canyons, while its CO_2 sequestration levels depend on the used UGS, of which trees are the most efficient. However trees are not beneficial or noticeable on a small scale since CO_2 sequestration requires a large number of trees (forming a dense forest) to see a difference in CO_2 levels.

The significance of thermal improvements and CO_2 sequestration is maximised with the used effective strategies which are more beneficial when placed in the right locations with the right percentage and time as this is a challenge on a global scale, not a controlled small urban scale challenge. Moreover, mitigation strategies should be implemented and applied within the physical scale, urban scale and policy scale to complement each other which will lead to massive improvements. It was crucial to link UGS benefits in order to avoid any collapsing or contradiction benefits which could happen incase of placing large amount of trees within street canyons, could lead to trapping air pollution which then contradict with the benefit Trees' offer. These could happen through linking Environmental thermal benefits with Air pollution such as CO_2 sequestration in order to maximise the benefits of used UGS intervention with a broad view for its benefits. Therefore, when UGS can be applied within streets, side effects as trapping air pollutant could be avoided when placing trees, reducing pedestrian spaces on pavements could be avoided by using LF for instance or applying HPA.

There is a scarcity of available space for establishing UGS within urban canyons due to the high density of urban space in central London and the high cost of urban land. But through using green roofs, the hottest areas of a city can be mitigated either through using cool roofs (high albedo paintings and materials) or using green roofs to maximise the benefits to include mitigating air pollution, improving the management of rainwater run-off and increasing biodiversity.

For policymakers and expert urban planners, the results suggest practical protocols for the strategic placement and selection of different UGS interventions in central London, so as to mitigate UHI and increase CO_2 sequestration through prioritising the hottest canyons (EW) with lower wind speed, then applying trees with the most appropriate percentage. Further alternatives can then be used such as placing LF in southern building elevations, and placing green and cool roofs on the roof levels. The analytical framework followed herein may be used as a guideline for similar case studies of similar context and similar climatic zones.

Choice of the right tree species should be based on physical properties as leaf area index, density, crown radius, density, and branching arrangement. The chosen tree species should be available within the climate context in order to achieve more effective and better thermal improvement and CO_2 reduction. Planting healthy young trees in advance to be fully grown by the 2050s and the 2080s would be the best option as, within warmer climates and through climate shifting and climate change, trees will age faster and die faster due to the frequent photosynthesis process they will be going through.

Connecting scattered small and medium parks together through urban corridors (vegetated street canyons) will maximise cooling effects rather than just having one wide central park as that will break up the micro effects of the urban form than can cause cooler and hotter pockets.

It is advised to apply a combination of trees and living façade in the streets. On the other hand, the applied UGS alternative should be aesthetically appealing as it is one of the most important values and benefits for pedestrians.

It is preferable to apply a UGS alternative without affecting or limiting the pedestrian space.

8.5 Future research

Based on the survey responses, pedestrians within central London are mainly looking for aesthetical, visual comfort and air pollution reduction benefits equally as their top priority and reasons for choosing UGS. Since it was not explored in this research and, to the best of the researcher's knowledge, not explored within the UK context, both are is two of the critical aspects to be explored in future research. However, the researcher plans to explore the aesthetical benefits through facial emotional analysis of face recordings, which was postponed due to COVID-19. Connecting to nature and relaxation are the second and third reasons for a pedestrian to choose UGS as their top benefits, which was not investigated in this research. This reflects the multi-functionality of UGS and that pedestrians are looking more to mental and visual comfort, which are non-materialistic. This reflects the urgent need to quantify these benefits in future research.

Several responses from the survey suggested decreasing and limiting vehicular access to central London and replacing the car lanes with more cycling lanes to make it more human-centric rather than mechanical-centric; this would eventually make central London more pedestrianised. Therefore, it is essential to explore further challenges related to this decision and how that would influence different visitors' activities and perceptions.

The survey analysis reflected that central London pedestrians intend to spend 30% more time in the streets with more green, but a more in-depth investigation is required to see their activity pattern and how that would benefit the commercial and economic perspectives.

There is a requirement to explore the connections and associations between the different UGS and broad UHI levels (such as SUHI, CUHI, BUHI). It would be interesting to explore the thermal benefits of UGS on the canopy level (building roofs) as green roofs and cool roofs and how they will influence the boundary UHI. On the other hand, it would be helpful to investigate the benefits of shading units instead of trees and how they would limit solar gain and hence increase thermal comfort levels.

It is advised to compare the rest of the mitigation strategies and their influence on UHI in general and pedestrian thermal comfort at the local scale to UGSs, which is investigated in this research. These mitigation strategies could be cool building envelopes, water bodies and canyon shading systems. It would also be interesting to project urban thermal improvement on buildings in order to see the influence of these mitigating strategies on buildings with different canyons and how that would reduce energy consumption in buildings.

Since UGSs were applied during the average of the hot season (21 June-21 September) which means it is the expected average temperature within climate change, It is clear that during real warm heat stress days which will have more frequent heatwaves during the 2050s and the 2080s, the benefits of UGSs can be exploited and maximised, particularly as the world's population increases. Therefore, investigating warmer and extreme weather conditions during the hot season reflects the maximum thermal benefits of UGS.

It would be beneficial to determine the PTC based on seeing and visualising more UGS coverage within the streets even though they might not lead to thermal improvement. This would help the intangible values of UGS and their improvement to PTC apart from the thermally measured values. For instance, LF does not make many improvements to PET, and thus not to PTC either. However, the pedestrian might show that they are thermally comfortable when they are located in streets with high LF densities. There was a massive reduction in thermal stress leading to an increase in thermal comfort levels in addition to a slight reduction in CO_2 reduction, so physical, psychological, economic and social benefits need to be explained in order to study if a relationship exists from reduced heat and CO_2 associated with UGS. For instance, research could investigate the relationship between different UGSs within central London neighbourhood and health benefits.

Several participants in the survey showed their interest in seeing a combined mixture of trees and living façade in streets. Therefore, it would be interesting to look at the combined thermal and air pollution reduction benefits for these.

LF does not have a significant difference on UHI as most of the solar radiation falls on urban street canyons and not the buildings, particularly in the EW canyon orientation. Despite the humidity increase from LF increase, it is worth checking how that would reflect on building insulations and how LF would influence canyons where more solar radiation falls on building walls than on the street canyon itself.

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Appendix A – ENVI-met windows

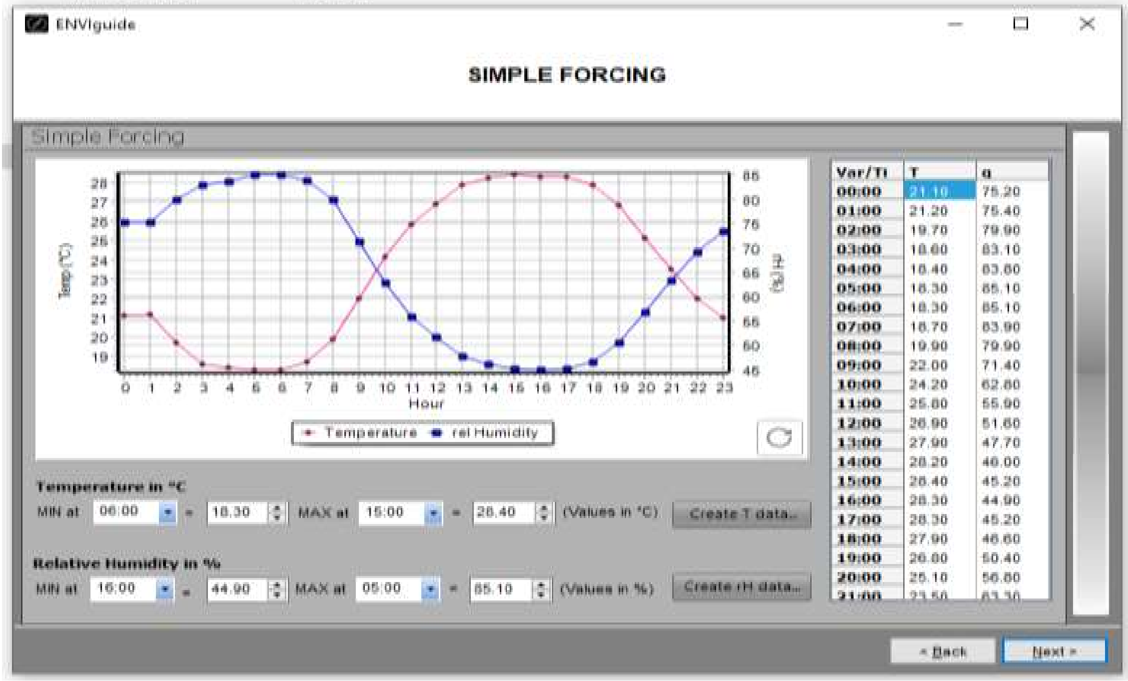


Figure 0-2 ENVI-Guide

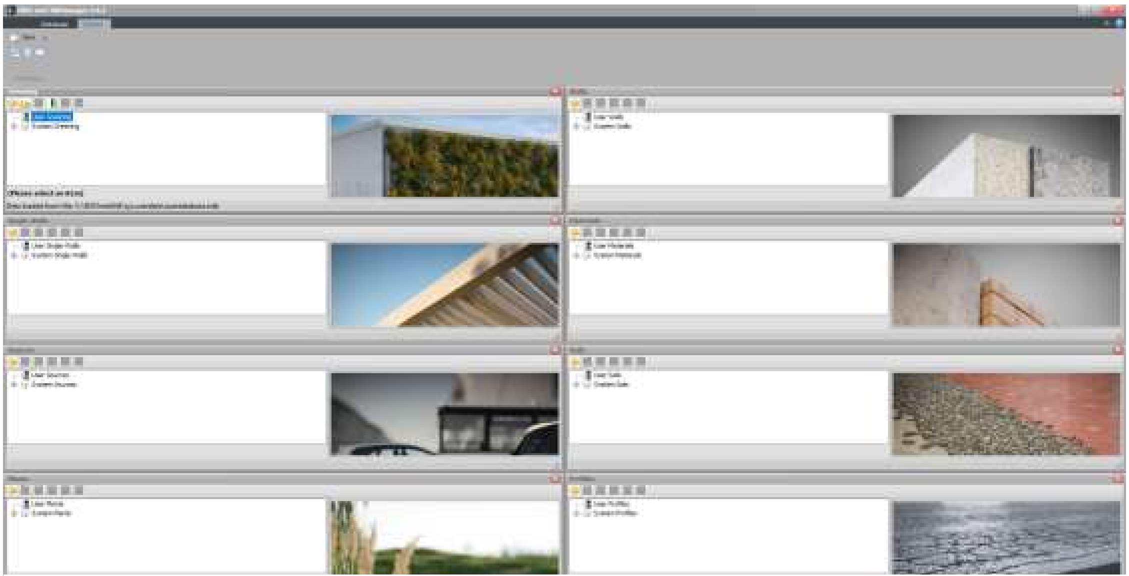


Figure 0-1 Data Base Manger

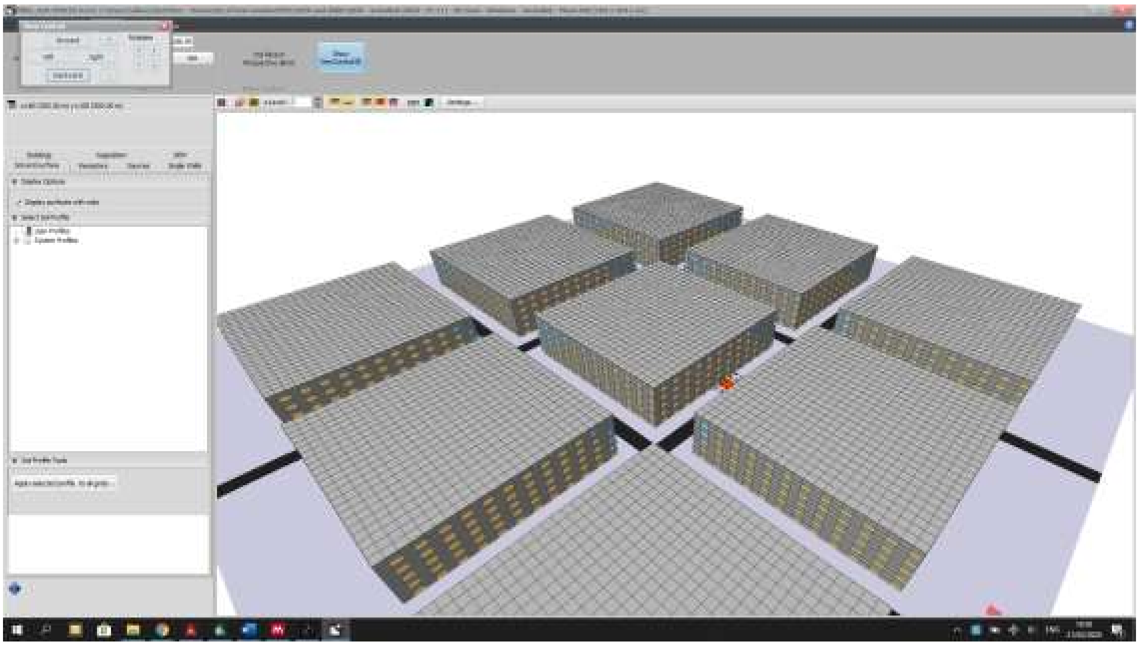


Figure 0-4 Spaces file

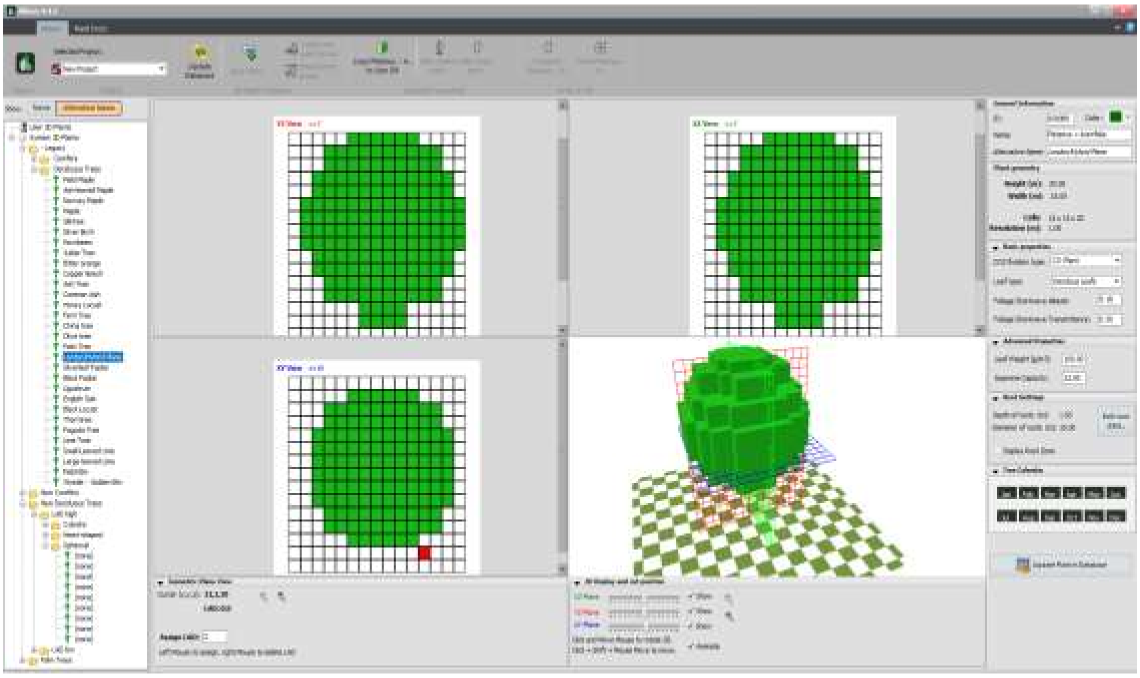


Figure 0-3 Albero window for tree modifications

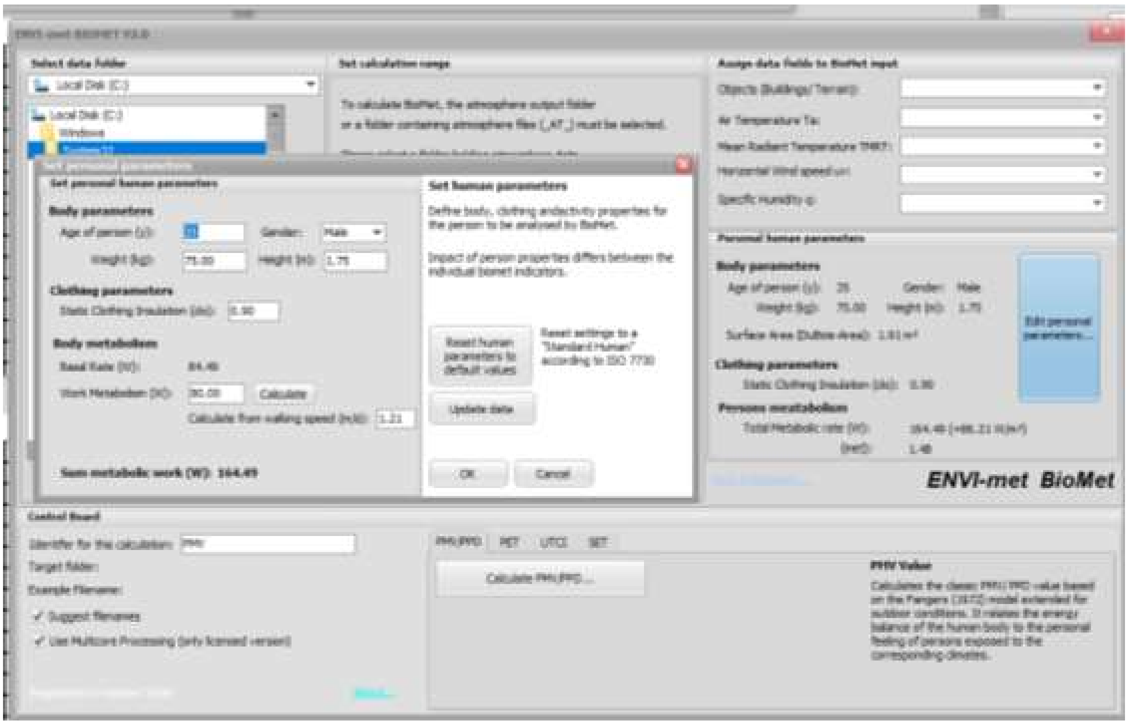


Figure 0-5 BioMet window for different thermal comfort parameters

Appendix B – Questionnaire Survey Design And Questions

PhD Survey - Mayor of London's Plan to make London the greenest city in the world

Note: All questions for activities before COVID-19

[illegible]

[illegible]

* [illegible]

* 1. How often do you visit central London?

(Oxford street, Regent Street, Piccadilly and Bond Street, Paddington and St. Marylebone, SOHO, Covent Garden, Knightsbridge, Mayfair, London Victoria, London Charing Cross, Camden, China town, etc.)

- Rarely / Infrequently (less than 4 times a month)
- 1 day/week
- 2 days/week
- 3 days/week
- 4 days/week
- 5 days/week
- 6 days/week
- 7 days/week

* 2. What is your MAIN Reason for the time you spend outdoors in central London?

- Walking / walking to work / walking from bus or Underground station / walking home
- Tourism
- Transportation (Driving a car, riding a bus)
- Sports (cycling, running, etc.)
- Shopping
- Hanging around (meeting friends, sightseeing, dinning and coffe shop, etc.)
- Other (Please specify)

* 3. How many minutes do you spend outdoors on the streets of central London per day (on average)?

- <15 minutes
- 15–30 minutes
- 30–45 minutes
- 45–60 minutes
- 60–90 minutes
- 90–120 minutes
- >120 minutes

* 4. What would motivate you to spend more time outdoors on the streets of central London during the summer time?

- More pedestrian walking space
- More vegetation and plants
- More seating spaces
- Other (Please specify)

* 5. What do you think about increasing street vegetation and plants which may reduce pedestrian space and accessibility, however it would provide shade during summer and decreasing air pollution?

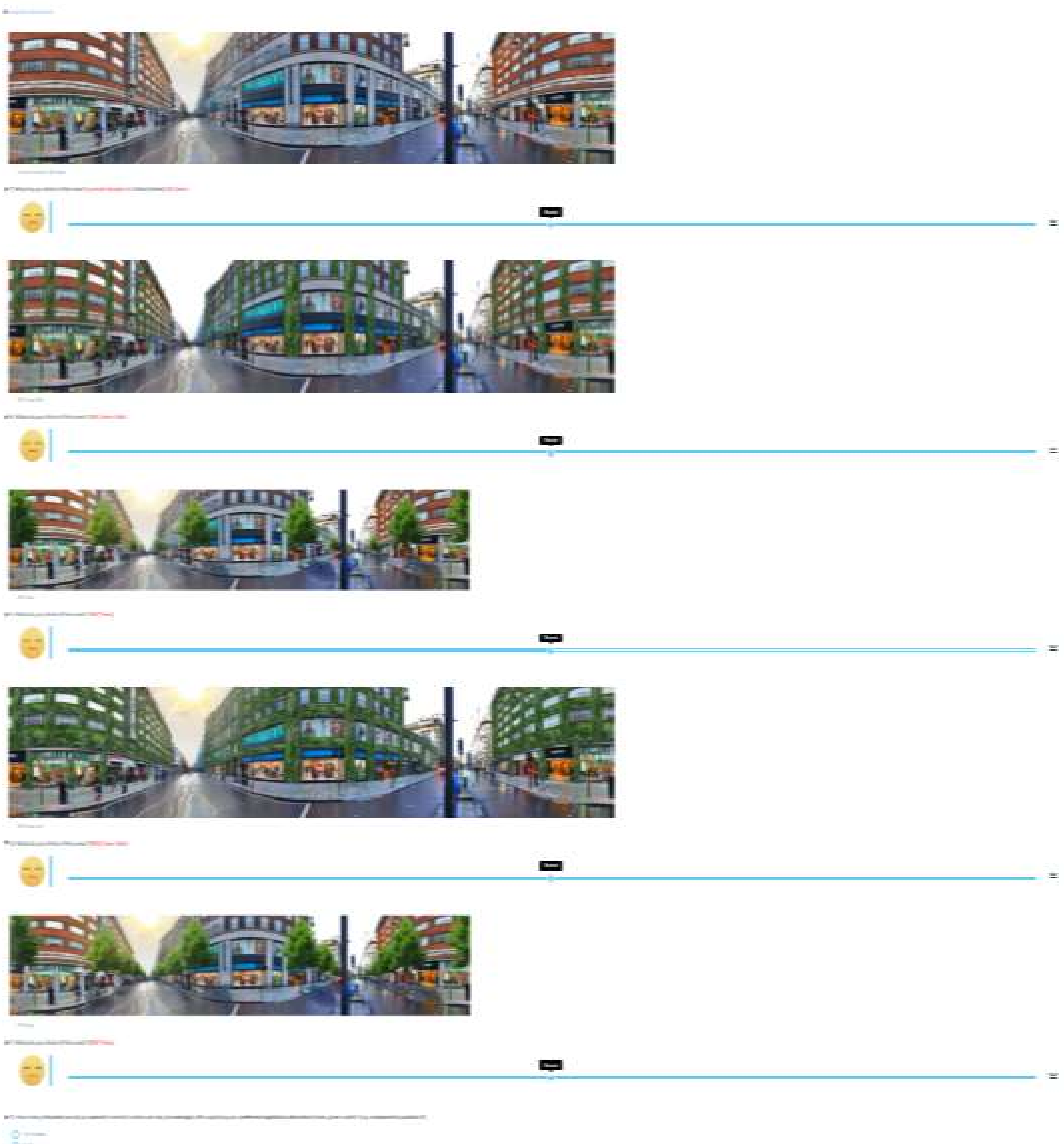
Neutral

Clear

* 6. To what extent would more vegetation and plants in the streets motivate you to walk longer (distances / more time)?

Neutral

Clear



* 12. How many **(minutes)** would you **spend** in central London per day **(on average)**, **after** applying your **preferred vegetation alternative** (trees, green walls)? (e.g. **compared to question 3**)

- ◯ <15 minutes
- ◯ 15-30 minutes
- ◯ 30-45 minutes
- ◯ 45-60 minutes
- ◯ 60-90 minutes
- ◯ 90-120 minutes
- ◯ >120 minutes

* 13. What do you think the **reasons** for choosing your **preferred vegetation alternative** above (trees, green walls)?
(you can choose more than one answer)

- ☐ Relaxation
- ☐ Connecting to nature
- ☐ Aesthetical impact (Visual Comfort)
- ☐ Air pollution reduction
- ☐ Improved thermal comfort (shaded areas, pleasant temperature, etc.)
- ☐ Improved biodiversity (the variety of plant, insects & animal life)
- ☐ Increased productivity
- ☐ Other (Please specify)

* 14. Gender

◯ Male ◯ Female ◯ Other / Prefer Not to say

* 15. Age

◯ 18 - 25 ◯ 26 - 40 ◯ 40+
◯ 50+ ◯ 60+

* 16. Any Additional Comments

- ◯ No
- ◯ Yes, (Please specify)

* 17. Would you like to receive the full survey results?

- ◯ No
- ◯ Yes, please write your (Email, phone number, etc.)

Appendix C – Ethical Application and Approval

Ethics ETH1920-0142: Mr Hashem Mohamed Hany Taher

(Medium risk)

Date 03 Feb 2020

Researcher Mr Hashem Mohamed Hany Taher

Student ID 1630377

Project Using Urban Green Systems as an Approach for Future Climate Change Adaptation in London

School Architecture, Computing & Engineering

Ethics application

1. Project details

1.1. Title of proposed research project

Using Urban Green Systems as an Approach for Future Climate Change Adaptation in London

1.2. UEL Researchers

Mr Hashem Mohamed Hany Taher

Start date of project for which ethical approval is being sought

07 May 2020

Anticipated end date of project for which ethical approval is being sought

22 Jan 2021

If this project is part of a wider research, please provide the RRDE, SREC, CREB or NHS research ethics approval number.

If this project is part of a wider research study, please state the start and end dates of the wider study.

1.7. Where will the research take place?

London

2. Aims and methodology

2.1. Aims and objectives of the project

The research focuses on significant environmental benefits of urban green systems (UGS) as trees, living façade and high albedo materials for mitigating Urban Air Pollution and Urban Heat Island effect (UHI). The aim of this study is to investigate quantitatively the impact of UGS on climate change adaptation and mitigation in current and future climate scenarios 2050 and 2080 through determining its influence on UHI.

Review the underlying reasons for UHI effect and how to mitigate it particularly in future climate scenarios.

The Objectives were mainly focusing on Investigating when and how the built environment may benefit from UGS in the UK. Then develop and analyse a simulated and basic real prototype urban model to study UHI effect mitigation in an urban canyon through UGS.

Evaluate the developed model to measure the potential of lowering urban heat island effect through different types of UGS by 2018, 2050s and the 2080s.

Demonstrate potential UHI mitigation effect within the canyon urban scale, by utilising UGS for climate change adaption, through collected data from the real base case in the simulation.

2.2. Methodology, data analysis and recruitment for the project

The research methodology employed by the researcher is a mixed-method research methodology including qualitative and quantitative methods. The quantitative analysis would be used as simulations are illustrations of the characteristics and features of a real-time state. ENVI-MET Simulation is distinguished from static representation and numerical predictive modelling through focusing on dynamic relationships of urban green systems (UGS) as trees, living façade and high albedo materials and Urban Heat Island effect (UHI) effect (Deming and Swaffield, 2011). While analysing the methods to use for this thesis the impact of UGS on urban canyons to determine the influence on UHI, a computer simulation was carried out to determine and imagine the urban impact and influence through applying UGS on buildings, within the urban street canyon. The strategies used in the research include: explore, forecast, testing, and learning (Deming and Swaffield, 2011). These simulation scenarios are addressed to assess the impact of UHI on current and future climate scenarios by 2018, 2050 and 2080. Which is finally illustrating quantitatively the mitigation level and improvement to our future climate from different UGS alternatives (trees, living facade and high pavement albedo).

On another hand, The survey is a research method to be employed as it has been widely used to analyse statistical relationships between pedestrian thermal comfort and social and aesthetical variables in several relevant studies. The structured questionnaire survey utilises phenomenology qualitative method where the focus is more directed to individual experience which will contain includes questions with expected formats of answers such as numbers, rating scale, different pictures for comparison and choosing the best preference of UGS and the pedestrian top priority for their walking. It is divided into four sections as following (Evaluating pedestrians' activities within the street, Evaluating UGS importance, choosing the best alternative for them and finally basic information about pedestrians). It aims to collect quantitative data with standardized means. The survey is structured (pre-designed questionnaire) with closed format/ended questions of multiple choices including (other) option where pedestrians can include their own reason/choice/preference and a label scale format (from 1 to 5). It aims to collect quantitative data with standardized means. k.

This survey is being carried out with the aim of exploring and analysing the pedestrian preference of different urban green system (UGS) alternatives (trees, green wall) with different percentages in Oxford street. The survey is divided into 4 sections and organised from Generic questions about (Pedestrians activities' in Oxford Street), followed by more specific questions about UGS (Evaluate the Green Street-scape importance), then to more specific evaluation for the preferred UGS alternative (Evaluating the Proposed Green Street-scape in Oxford street). This survey will be based on proposed UGS alternatives within ENVI-MET simulation in order to check the pedestrian perception and preference for which UGS percentage (25% and 50%) and which UGS typo (trees,

green wall). This alternative would be illustrated by graphics in order to assist pedestrians to pick their favourite alternative.

Since this questionnaire survey is one of the core research methods to be employed to answer the research question, since it has been widely used to analyse statistical relationships between thermal comfort outdoors and urban green systems, and their variables (percentage of UGS, type, etc.) in numerous relevant studies. This method has been widely used to investigate implications between outdoor thermal comfort and UGS (Lin et al., 2014; Kangur, 2015; Sarkar et al., 2015; Lhomme- duchadeuil, 2018).

(Further data analysis and data collection details are clarified in Data collection word file application) that will include survey question, illustrated pictures).

The video recordings for Facial emotional analysis for survey participants was illuminated due to Coronavirus circumstances, which also limited the survey participants sample size and selection which will be explained in the survey recruitment section.

Is the data accessed, collected or generated of a sensitive nature?

No

If yes, please provide details. Please ensure that all data of a sensitive nature is handled carefully and stored appropriately.

About your project

Is the research project funded?

No

Does the project involve external collaborators?

No

Does the project involve human participants?

Yes

Does the project involve non-human animals?

No

If yes, where is the research project taking place?

Does your project involve access to, or use of, material (including internet use) covered by the Terrorism Act (2006) and / or Counter-Terrorism and Border Security Act (2019) or which could be classified as security sensitive?

No

Does the project involve secondary research using or analysing an existing data set?

No

Does the project raise ethical issues that may impact on the natural environment over and above that of normal daily activity?

No

Does the research involve data collected online or via social media?

No

If yes, please provide details.

Will the research project take place overseas?

No

Will the researcher or research team be responsible for the security of all data collected in connection with the proposed research?

Yes

Does your research project require third-party permission?

No

If yes, please provide details.

Does your research project involve any circumstances where the professional judgement of you and/or the team is likely to be influenced by personal, institutional, financial or commercial interests?

No

If yes, please provide details.

Recruitment

Are the research participants able to give informed consent (in written or verbal form)?

Yes

If no, is this because they are perceived to lack mental capacity or because they are vulnerable?

Not applicable

If the participants are perceived to lack mental capacity, please provide the reason(s).

Further details

If the participants are perceived to be vulnerable, please provide details of the vulnerability.

Does the research involve children or young people under the age of 16?

No

6.1.6 If yes, are the children or young people able to give informed assent?

If no, is this because they are perceived to lack mental capacity or because they are vulnerable?

Not applicable

If the participants are perceived to lack mental capacity, please provide the reason(s).

Further details

If the participants are perceived to be vulnerable, please provide details of the vulnerability.

6.2. How will participants be recruited?

The data collection will be carried out in collaboration with the PhD researcher supervisors instead of Marks and Spencer (M&S) Oxford street and Transport for London (TfL) and the Greater London Authority (GLA). This is due to COVID-19 limitations and priorities for working online for these firms and thus, the researcher and his supervisor will try to share the online survey with their connections and people who might be interested.

On another hand, the researcher has modified the survey to fit central London in order to include wider participants within the survey sample instead of focusing on Oxford street only in the previous one, which was going to be depending on the distributed online survey by M&S and the TfL, which is changed at the moment.

The questionnaire will be created online via google sheets and emailed to research close and extended circle connection as the interested parties, colleagues and friends who are visiting central London and would be motivated to fill the survey during the current situation. This convenience sample is chosen as it is mainly easier to reach people and invited people to fill the survey most probably will not mind to fill it, compared to other online approaching methods.

Instead of focusing on people who work within Oxford street (M&S and the TfL, etc.) researcher has expanded the infrequent visitors within the survey to gather a wider sample and more variety of sample selection, in order to be able to see whether that would influence pedestrians choices (on which Urban green system they would choose, like trees, green walls) within London.

The data collection will be carried out in collaboration with Marks and Spencer (M&S) Oxford street and Transport for London (TfL) and the Greater London Authority (GLA). The researcher participated in the preliminary consulting stage with the TFL and the GLA. Both the GLA has been working on Mayor of London Plan to make London the greenest city in the world by 2050s in parallel with Healthy streets plan by the TFL.

Both projects seek to motivate pedestrians and Londoners to walk more through improving levels of comfort within streets which my PhD is seeking through improving thermal and aesthetical levels for pedestrians through using different UGSs. The research objectives, methodology, future benefits and incentives have been introduced to the GLA & TfL in order to establish the research collaboration.

6.4. How many participants are being sought for the project?

(Oppenheim, 1992) Declared that sample accuracy is more important than the sample size, while the sample size is more important for statistical group differences. Thus, the process of selecting participants (sampling selection) is very focused on Westminster Borough visitors as they would be the most people who have a direct relationship to proposed UGS changes so the targeted participants will be the one who is regularly visiting, working, or exercise within Westminster Borough.

The questionnaire survey schedule would be starting at the nearest time in order to maximize the number of survey participants and then having more database to be analysed. The maximum number for survey takers for the online survey is 200 person, however, if the researcher reached around 100 participants that would be satisfactory for the research to proceed to the analysis stage.

How long will participants be required for the project?

The survey will take less than 3 minutes to be completed.

Will the participants be remunerated for their contribution?

No

If yes, please specify monetary value of cash or giftcard / vouchers.

DBS

Do you require Disclosure Barring Service clearance (DBS) to conduct the research project?

No

Is your DBS clearance valid for the duration of the research project?

Yes

If you have current DBS clearance, please provide your DBS certificate number.

Not applicable

Medical

Is your project a clinical trial and / or involves the administration of drugs, substances or agents, placebos or medical devices?

No

If yes, please provide clarification as to why your project does not fall under the Medicines for Human Use (Clinical Trials) Regulations (2004) or Medical Devices Regulations (2002) or any subsequent amendments to the regulations.

Does your project involve the collecting, testing or storing of human tissue / DNA including organs, plasma, serum, saliva, urine, hair, nails or any other associated material? No

If yes, please provide clarification as to why your project does not fall under the Human Tissue Act (2004).

Risk

Does the project have the potential to cause physical or psychological harm or offence to participants and / or researchers?

No

If yes, please provide details of the risk or harm explaining how this will be minimised.

Please complete and upload a risk assessment form.

Does the project involve potential hazards and / or emotional discomfort / distress?

No

If yes, provide an outline of support, feedback or debriefing protocol.

9.3. Provide an outline of any measures you have in place in the event of an adverse event or reaction or unexpected outcome, the potential impact on the project and, if applicable, the participants.

Not Applicable

Anonymisation

Will the participants be anonymised at source?

Yes

If yes, please provide details of how the data will be anonymised.

Completing Online survey with no form of personal identification requests

Are participants' responses anonymised or are an anonymised sample?

Yes

If yes, please provide details of how the data will be anonymised.

Anonymous online survey

Are the samples and data de-identified?

No

If yes, please provide details of how the data will be anonymised.

Please provide details of data transcription.

The collected data will be stored and viewed privately by the researcher himself only

If applicable, will all members of the research team know how the code links the data to the individual participant?

N/A

10.5.1. If no, in the event of a researcher's absence please specify the process should access to the research data be required.

Will participants be anonymised in publications that arise from the research?

Yes

If no, please provide details.

Will participants have the option of being identified in the study and dissemination of research findings and / or publication?

No

If yes, please provide details.

Data security

Will the researcher or research team be responsible for the security of all data collected in connection with the proposed research?

Yes

If no, please provide details.

Will the research data be stored safely on a password protected computer?

Yes

If no, please provide details.

Will the research data be stored on a UEL data managed device?

Yes

If no, please specify where the electronic data will be stored and how the data will be kept secure.

Will you keep research data, codes and identifying information in a separate location?

No

If yes, please explain how you will store the research data.

Will the raw data be shared with individuals outside of the research team?

No

If yes, please specify the names, positions and their relationship to the research. Name

Position

Relationship to research

Will participants be audio and/or video recorded?
No

If yes, please explain how you will transfer, store and, where relevant, dispose of audio and/or video recordings.

If audio and/or video recordings will be retained, please provide details and state how long the recordings will be kept.

Will you retain hard copies of the data?
No

If yes, please provide details of how the data will be transported safely and, where relevant, undergo secure disposal.

Will the research data be encrypted and transferred inside of European Economic Area (EEA)?
Yes

If no, provide details of where the research data will be stored and measures in place to keep the data secure.

16.10. How long will the research data that details personal identifiers be stored?
Until the research ends on 21/01/2022

Dissemination

Will the results be disseminated?
Yes

If yes, how will the results of the research be reported and disseminated?
Dissertation / Thesis Peer reviewed journal Internal report Conference presentation
Written feedback to research participants
Presentation to participants or relevant community groups Books or chapters

If you selected other, please provide further details.

If the results of the research will not be reported and disseminated, please provide a reason.

20. Attachments

Generate your Participant Information Sheet and Consent form using answers provided in your ethics approval application. The Word files generated can be edited. Then upload your final files before submitting your application.

20.1. Upload any additional files to support your application which have not already been uploaded within your application.

University of East London

Dear Hashem Mohamed Hany

Application ID: ETH1920-0142

Project title: Using Urban Green Systems as an Approach for Future Climate Change Adaptation in London

Lead researcher: Mr Hashem Mohamed Hany Taher

Your application to University Research Ethics Sub-Committee was considered on the 7th of May 2020.

The decision is: **Approved**

- *In view of the COVID-19 pandemic, the University Research Ethics Sub-Committee (URES) has taken the decision that all postgraduate research student and staff research projects that include face-to-face participant interactions, should cease to use this method of data collection, for example, in person participant interviews or focus groups. Researchers must consider if they can adapt their research project to conduct participant interactions remotely. The University supports Microsoft Teams for remote work. New research projects and continuing research projects must not recruit participants using face-to-face interactions and all data collection should occur remotely. These regulations should be followed on your research until national restrictions regarding Covid-19 are lifted. For further information please visit the Public Health website page https://www.gov.uk/government/organisations/public-health-england*

The Committee's response is based on the protocol described in the application form and supporting documentation.

Your project has received ethical approval for 2 years from the approval date.

If you have any questions regarding this application please contact your supervisor or the secretary for the University Research Ethics Sub-Committee.

Approval has been given for the submitted application only and the research must be conducted accordingly.

Should you wish to make any changes in connection with this research project you must complete 'An application for approval of an amendment to an existing application'.

The approval of the proposed research applies to the following research site.

Research site: London

Principal Investigator / Local Collaborator: Mr Hashem Mohamed Hany Taher

Approval is given on the understanding that the UEL Code of Practice for Research and the Code of Practice for Research Ethics is adhered to.□□

Any adverse events or reactions that occur in connection with this research project should be reported using the University's form for Reporting an Adverse/Serious Adverse Event/Reaction.

The University will periodically audit a random sample of approved applications for ethical approval, to ensure that the research projects are conducted in compliance with the consent given by the Research Ethics Committee and to the highest standards of rigour and integrity.

Please note, it is your responsibility to retain this letter for your records.

Questionnaire cover letter (heading) and distribution

This questionnaire is the empirical study for a PhD thesis about Using Urban Green Systems as an Approach for Future Climate Change Adaptation in London; the main researcher is Hashem Taher who is working on Mayor of London Plan to be the greenest city in the world by 2050s and Healthy streets with the TfL, who is studying for the PhD degree in the School of Architecture, Computing and Engineering, University of East London. The purpose of this survey is to define the most appropriate UGS alternative for Oxford street and its influence on Pedestrians thermal comfort and walkability. Reassuring anonymity for survey respondents and giving them a choice to complete it or withdraw at any stage. In addition to asking the interviewers about any unclear question, and feel free to add their worthy comments.

The survey will be online based or a web survey. These surveys are managed over the Internet through interactive screen forms. Expected participants may receive an electronic mail invitation for contributing in the survey with a link to an online website (SOGOSURVEY), where the survey would be completed. These surveys are very economical as they are very cheap to manage, survey outcomes are instantly recorded and updated in an online database, giving the ability to several respondents to submit their survey at the same time and the survey can be easily adjusted whenever needed. Nevertheless, if the survey website is not protected by a password or designed to prevent multiple submissions, the responses can be easily compromised, which is not happening in the secured (SOGOSURVEY) website. Usually, researchers prefer dual survey distribution mood as (mail survey, online survey), allowing respondents to select their preferred method of response and in order to guarantee more response rate (Anol Bhattacherjee, 2012).

Therefore, the survey distribution was done entirely through the internet. This sort of distribution was chosen so that respondents could fill the survey in a comfortable environment. This effects on a variety of factors dealing with the instant perception that might possibly bias the access to generally held opinions, beliefs and perception about thermal and aesthetical comfort. To make certain each questionnaire survey was completely completed, each item had to be responded to before going to the next page.

A short message sent in advance to the targeted respondents asking their participation in a forthcoming survey can prepare them in advance and improve their tendency to respond. The message should state the purpose and significance of the study, mode of data collection online survey, and appreciation for their cooperation and how it would reflect on the city (Anol Bhattacherjee, 2012)(Anol Bhattacherjee, 2012).

The distributed message through emails is totally different from WhatsApp and Facebook messages and posts as within emails; it was a formal and direct message regarding researcher identification, research title, aim and objectives and how long would the research take (3minutes). While the Facebook and WhatsApp messages and posts were quite more friendly in order to attract more attention and response for people at which it started with introducing current challenges due to COVID19 on my research, and it will take them 3 minutes if they are happy to participate and how that will help my research.

The message includes that "Dear all my PhD has affected negatively due to COVID 19 and definitely a lot of you as well. So, your 3 minutes completing my Survey will help me a lot.

PhD Survey - Mayor of London's Plan to make London the greenest city in the world

I am a PhD student at the University of East London (UEL) working on the Mayor of London's Plan to make London the greenest city in the world by 2050s. I won the 3MT competition 2019 as the top PhD research at the UEL school of (Architecture, Computing and Engineering). My PhD research is supported by GLA (Greater London Authority) and the TFL (Transport for London).

https://survey.SoGoSurvey.com/r/XFOVT2

Survey expected to take (2-3 minutes)

I would appreciate your kind response

Your survey is about your normal daily pattern before COVID-19

Appendix D – Professional Meetings, collaboration and Discussion for Presenting the PhD to Investors and Decision Makers

Transport Adaptation Steering Group
27 January 2020, 13:00
Mott MacDonald, 10 Fleet Place, London EC4M 7RB

Agenda

13:00	Welcome and introductions (Richard McGreevy, Chair)
13:05	Notes and actions from last meeting – October 2019
13:10	Changes to habitats and species and implications for lineside management (Mark Broadmeadow, Forestry Commission)
13:40	TCFD implementation for infrastructure (Charles Allison, ERM)
14:10	TfL adaptation plans (Sarah Turner, TfL)
14:35	Break
14:45	The influence of urban green systems on the UHI in London (Hashem Taher, University of East London)
15:15	Updates from the group
15:50	AOB
16:00	Close

Date	Second Party	Activity
Thu 02/08/2018 10:00 - 11:00	**GLA (Peter Massini)**	**Green walls and buildings – PhD Meeting**
Wed 03/10/2018 14:00 - 14:30	**Old Oak Park Development (Dan Epstein)**	**Green Infrastructure for London Future Climate Scenarios 2050 & 2080 (PhD)**
Thu 22/11/2018 15:30 - 16:30	**TfL (Charles Snead)**	**potential collaboration**
Fri 23/11/2018 11:00 - 12:00	**Barking Riverside Development**	**Barking Riverside: Initial meeting**
Fri 18/01/2019 09:00 - 14:00	**Newton Fund**	**BRE Visit & project presentation**
Mon 03/06/2019 09:30 - 10:30	**Mark & Spencer (Zoe Monteford)**	**Marble Arch - Air quality monitoring site vist**
Wed 10/07/2019 10:00 - 11:00	**Building Research Establishment (BRE)**	**Biophilic conference**
Fri 12/07/2019 11:00 - 12:00	**Building Research Establishment (BRE) , Flavie Lowers & Cambridge University (Mark Allen)**	**UEL & Cambridge university Project discussion regarding BRE**
Mon 15/07/2019 12:30 - 13:30	**Building Research Establishment (BRE) , Flavie Lowers & Cambridge University (Mark Allen)**	**UEL & Cambridge university Project discussion regarding BRE**
Tue 29/10/2019 17:00 - 17:30	**Trees for Cities**	**PhD project discussion**
Wed 20/11/2019 10:30 - 11:30	**Transport for London**	**GI and urban heat**
Tue 03/12/2019 14:00 - 15:00	**London Tree Officers (LTOA) Criag Ruddick**	**LTOA: London the Greenest City in the World 2050 - PhD**
Mon 27/01/2020 13:00 - 16:00	**Transport for London**	**Transport Adaptation Steering Group**
Thu 22/10/2020 14:00 - 15:30	**Transport for London**	**Green Infrastructure Steering Group Meeting**

10 December 2018 (Early Research Questions & Investigation)

Hello Hashem,
Thanks for sending this through. It was interesting to read and has raised a lot of questions with us (see the attached pdf with comments).

Obviously, this is still early days and there's a lot of work you'll be doing over the next weeks and months to refine your research proposal. I think the two main points for us are:

· policy context: there's a need for a more thorough consideration of London policy in this field as part of your literature review

· methodology: we would like to see greater detail and clarification of your methodology – at the moment, you seem to want to measure a lot of related things, but the framework for measurement (i.e. the questions you're hoping to answer through your research) isn't very clear to us, and so it's hard for us to judge whether your findings will be useful for future TfL / GLA decision-making. Having the right controls will also be critical to ensure your findings can be extrapolated city-wide

For us, interesting research areas include:

· local: using the modelling software to test various levels of different green infrastructure provision on some London streets to see what kind of local temperature reductions might be achievable in theory and which interventions would be most effective – this would give us a sense of whether we could ever hope to achieve a meaningful benefit at the street scale

· regional: using the modelling software to test whether lining all of London's major roads with mature trees would have any impact on London's overall temperature (probably not, but this would still be useful to know)

· behavioural: whether greening a street actually encourages active travel and why (e.g. is it just because greenery is attractive, or because of the cooling effect; would cool roofs actually be more effective at encouraging active travel, etc.)?

Please do get in touch if you'd like to discuss any of our feedback. This week's looking very busy for me, but next week's much freer.

Thanks again and best wishes,

Katherine

31 January 2019 (Central London Canyon geometry and details)

Hi Katherin,

I have a couple of questions for you and Charles regarding the greenery percentage:

I have noticed that most of Central London street canyons are not vegetated with trees or there are some trees with a very low percentage, which means also that the 47% is not applied to them. Thus, while simulating different canyons I should choose a rational percentage for vegetating these canyons with trees, green walls and trees for instance at the beginning.
Do you agree with me for choosing 25% at the beginning and 47% as a percentage for current case and we can add more percentage for ambitious greening factor !? OR would you recommend to use 0% greening, 25% and 47% ?

3. Regarding Mayor's plan, he wants to make london 50% green at least, then what is the ambitious goal which is supposed to be much higher than the actual goal (47%) because while simulating both cases, there would not be huge difference between them!?

The Mayor's >50% green cover target applies across the whole of London, and so recognises that some areas will be greener / less green than others (this is normal for a city). As a result, it's probably not the best approach to use the >50% target as a threshold for your research.

In terms of on-the-ground research, it's probably best to just find some relatively grey canyons to compare with some relatively green canyons but that otherwise share similar characteristics (e.g. building height, spacing between buildings, etc.).

In terms of modelling, it's probably best to model a range of scenarios to determine which ones have the biggest impacts on temperature. For example, if there's an S-shaped curve for temperature and tree canopy cover, at what point does the curve level off (beyond which it'd make only negligible changes to temperature). Or if the relationship is linear, what's the optimum tree canopy coverage? Or is it more effective to have a combination of trees and green roofs? This is important for us to understand, because of the costs involved with greening.

4. Regarding canyons, do you have a map where extreme hot/warm conditions are happening? I have found map for pollution levels, is there something similar for the UHI and heat stress?

London's urban heat island map for a warm summer can be found here: https://data.london.gov.uk/dataset/london-s-urban-heat-island and for an average summer here: https://data.london.gov.uk/dataset/london-s-urban-heat-island---average-summer and an exploration of mortality risk from high temperatures can be found here: https://data.london.gov.uk/dataset/mortality-risk-from-high-temperatures-in-london--triple-jeopardy-mapping-

5. Where I can find more information regarding streets canyons within central London as " Average/approximate height of the canyons, canyon width, canyon length, etc."

So far as I know, there's no such thing as a street canyon classification system – partly because I'm not sure there's a formal definition of a street canyon (e.g. with thresholds). You'd have to use a combination of e.g. UKMap, OS MasterMap, LiDAR, etc. and set the criteria that you think will identify street canyons, and then cross-reference this with other datasets (e.g. the GLA's tree cover map / green cover map) to identify canyons with the specific characteristics you're interested in.

4 February 2020 (Survey comments and feedback from the TfL)
Hi Hashem,

Thanks for this. I just wanted to clarify what you need from us. Did you mean to ask us for a letter of support for the distribution of your survey to our employees at Oxford Street tube stations, i.e. Oxford Circus, Bond Street & Tottenham Court Road? If so, please could you send a template / example that we can modify?

We don't have any other employees on Oxford Street that I'm aware of, and we unfortunately don't have the resources to distribute your survey to members of the public / retail employees along Oxford Street. How do you intend to reach them, seeing as they're a key target audience?

Looking at the survey, I have some suggestions you may / may not want to take on board:

In general

· The survey needs a blurb at the top explaining its purpose and how the answers will be used.

· The radio buttons need an explanation of what the numbers mean, e.g. is 1 very necessary / supportive, or is 5 very necessary / supportive?

Section 1

· It might be worth adding in a question at the beginning if the participant is a regular or casual visitor to Oxford Street, i.e. do they work there most / every day or are they there for a one-off shopping trip? The answer to your current Q.1. will be very different for the two groups – casual visitors may spend a few hours there on one day, but not visit again for weeks, which isn't really picked up in your answer options.

· Q.2. needs to be a bit more specific – there may be multiple answers for the same person and the same visit (e.g. for a casual visitor, they'll be taking transport to/from Oxford Street and walking along the street and shopping, and maybe hanging around in a cafe. And are you talking about the current visit, or averaged over e.g. a week?

· Q.3. needs to be more specific – are you talking about outside, and about any street or Oxford Street in particular? I can imagine many people would say in response to the way the question is currently phrased, 'air conditioning', as they'll be thinking about the shops, rather than the pavements! Using the word 'outside' may help with this. I suspect other options are likely to come up frequently, e.g. reduced air pollution, reduced traffic noise, etc.

Section 2

· Q.1. needs to specify what metric you're trying to improve through greening. At the moment, Oxford Street is one of London's busiest, and so by that measure most successful, streets – clearly greening is not essential for that and could even reduce busyness by taking up space on the pavement that would otherwise be used by pedestrians. But it is essential to improve pedestrian comfort, though to what extent it improves in comparison with e.g. reducing traffic, is another question that may well be worth exploring (e.g. by participants ranking different environmental interventions to see how high greening comes up the list of priorities).

· Q.2. is misleading. Of course almost everyone is going to support street greening ;-) But you need to state what the disadvantages are to get an accurate picture of public opinion. For example, explaining that greening can take up space on the pavement and costs local authorities money in maintenance, leaves on pavements in wet weather can be a slip hazard, etc.

· Q.3. seems to be about London in general, rather than Oxford Street specifically? This can be a bit confusing unless this is clearly stated. For example, more greenery might not encourage more people to walk more along Oxford Street because most people already walk along it. Whereas more greenery along low-footfall roads could encourage more pedestrians to use them.

Section 3

· Perhaps rather than 'how satisfying', you could ask 'how welcoming', or 'how attractive'? Satisfying is an unusual word in this context.

· Q.6. What do you mean by 'your favourite alternative'? Do you mean an alternative shopping centre to Oxford Street, e.g. Westfield, local high street, etc.? And this would only really apply to visitors, not to retail / TfL employees. And for some visitors it might not apply at all – tourists, for example see Oxford Street as a destination in its own right (Selfridges, etc.) and so wouldn't consider anything else to be an alternative.

· Q.7. I think the answers to this need a bit more thought. Most people will never say 'increased biodiversity' or 'increased productivity' as a reason for visiting a different shopping centre! They're more likely to say, it's more convenient from work / home, it's less busy, there's more parking, there're more shops I need / like, etc. I don't think you'll get very reliable results to this question as it stands.

· Q.9. (should be Q.8.) To ask this, you first need to identify whether people actually know about and use 'green streets' – have you defined what these are? And comparing green streets to parks is misleading – many parks don't just provide greenery, they provide other services that streets, no matter how green, just can't, e.g. playgrounds, recreational facilities, gardens, ponds, etc. So you're not comparing like-with-like. You'd probably be better off asking something like, if you had a choice to walk 5 minutes longer along a tree-lined street, or 5 minutes shorter along a street with no trees, which would you tend to do on average? Of course, the answer to this will change depending on the purpose of the journey – for example, I suspect that for commutes, most people will pick the shortest route, just to get home more quickly! So you need to be very specific.

Section 4

· Gender: Please check very carefully with your ethics advisor about the options you should be providing for this question – many people are non-binary, which you are excluding by only giving Male and Female as options, or will not wish to give an answer

· Age: If you're not including children in this survey (sensible, given the ethics involved), there's no need to have Other as an option, as you've got all the ages covered. My only suggestion would be to add in 60+ and 70+ as options.

· Employer: Presumably, not everyone you survey will be working on Oxford Street? May be worth adding in options for e.g. tourist, etc.

· Disabilities: Please check with your ethics advisor about the options you should be providing for this question and how they should be phrased. Apart from the sensitivities involved, we probably also want to find out about e.g. mobility issues and have the option not to give

I hope these comments are helpful. Please do get in touch if you have any questions about them. I think the results of the survey could be really eye-opening – the questions just need a bit of finessing to allow that to happen!

Best wishes,

Katherine

Appendix E – Publications

Biophilic Office project, Biophilia and Outdoor Thermal Comfort

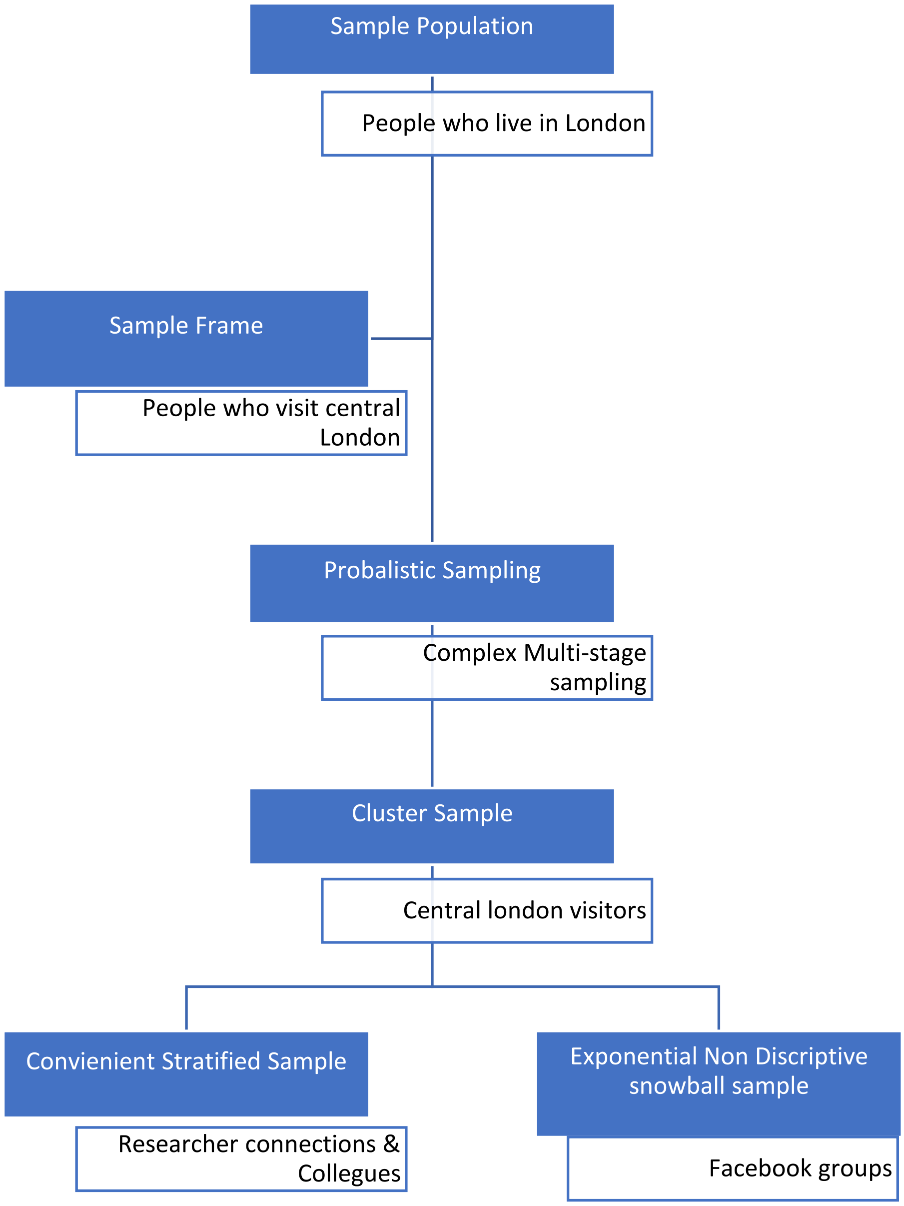
August 2019

Building Research Establishment (BRE), Biophilic Office Project

The Influence of Urban Green Systems (trees, living facade, albedo) on the Urban Heat Island Effect in Central London 2018
September 2019 IOP Conference Series Earth and Environmental Science 329 Follow journal
DOI: 10.1088/1755-1315/329/1/012046
Conference: Sustainable Built Environment Conference 2019 Wales: Policy to Practice At: Cardiff, UK Volume: 329
License CC BY 3.0

A state of the art review of the impact of Vertical Greenery Systems (VGS) on the energy performance of buildings in temperate climates
September 2018
Conference: Second International Conference for Sustainable Design of the Built Environment: Research in Practice At: The Crystal, London

Appendix F – Survey Analysis



Descriptive Statistics

In order to describe the basic and elementary data features of a study, descriptive statistics are required. They illustrate summaries about the sample measure, size, means in a simple presentable way which would help to draw statistical outcomes. The descriptive analysis, combined with graphical analysis, form the basis of quantitative analysis in a virtually presented way. Since in the research study, there are many measures and outputs from the large sample size, descriptive statistics simplifies the large data amounts in a manageable form, through reducing these large data outputs into a simpler summary (William M.K. Trochim, 2020). The four major types of descriptive statistics to characterize data through Descriptive statistics are frequency, central tendency, dispersion or variation and position measure (Pritha Bhandari, 2020).

Measures of Frequency (Count, Percent, Frequency), which shows how often something happens and using it when it is required to present how often a response is given. While measures of Central Tendency as (Mean, Median, and Mode), it is useful in locating the response distribution by many *points in order to u*se it when you want to show how an average or most commonly indicated response lays. There are measures of Dispersion or Variation as (Range, Variance, Standard Deviation) which identifies the spread of responses by stating intervals as Ranges (High/Low points), Variance or Standard Deviation (shows the difference between observed response and mean).

They are used when it is required to show how "spread out" the data are. It is also helpful to know when the data are so spread out that it affects the mean. Measures of responses positions as (Percentile Ranks, Quartile Ranks) which reflects how responses fall in relation to one another. This depends on standardized scores and which is used it is required to compare scores to a normalized score as a national norm. On the other hand, the mode is the response that has the most significant frequency, which reflects the response which has the most of answers. Even though it is not used commonly, it is helpful when the margin differences are rare or when the differences are non-numerical. The prototypical example of something is usually the mode.

JASP represent Jeffrey's Amazing Statistics Program in recognition of the pioneer of Bayesian inference Sir Harold Jeffreys. It is a free multi-platform open-source statistics software package which is developed and continually updated, and the used version within this research is 0.14 by researchers at the University of Amsterdam. This software is a free, open-source programme which covers and computes both advanced and standard statistical analysis with the main emphasis on supporting a user-friendly interface. Unlike too many statistical packages, JASP delivers a simple drag and drop interface, menus which are easily accessed, intuitive analysis with real-time computation and finally displaying all results either numerically or graphically.

All tables and graphs are illustrated in a format which could be saved independently or copied directly. Tables could be exported from JASP in LaTeX format as well (Goss-Sampson, 2018). Through using JASP software analysis, survey output data has been exported to excel sheet in order to import it to JASP software to carry on further analysis and statistics. Therefore, questions in the survey have been referred to numbers to be easily placed in a table at which question 1 in the survey is referred to (Q1), question 2 is (Q2), and so on.

Q1 - How often do you visit central London?

Q2 - What is your MAIN Reason for the time you spend outdoors in central London?

Q3 - How many minutes do you spend outdoors on the streets of central London per day (on average)?

Q4 - What would motivate you to spend more time outdoors on the streets of central London during the summertime?

Q5 - What do you think about increasing street vegetation and plants which may reduce pedestrian space and accessibility; however, it would provide shade during summer and decreasing air pollution?

Q6 - To what extent more vegetation and plants in the streets would motivate you to walk longer (distances / more time)?

Q7 - What do you think of this view? (current situation in Oxford Street) 0% Green

Q8 - What do you think of this view? (25% Green Wall)

Q9 - What do you think of this view? (25% Trees)

Q10 - What do you think of this view? (50% Green Wall)

Q11 - What do you think of this view? (50% Trees)

Q12 - How many (minutes) would you spend in central London per day (on average), after applying your preferred vegetation alternative (trees, green walls)? (e.g. compared to question 3)

Q13 - What do you think the reasons for choosing your preferred vegetation alternative above (trees, green walls)?

Q14 – Gender?

Q15 – Age?

Q16 – Any additional comments?

Q17 – Would you like to receive survey results?

Descriptive Statistics table results

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q14	Q15	Q16	Q17
Valid	598	598	598	598	598	598	598	598	598	598	598	598	598	598	598	598
Mean	3.2	3.6	3.6	2.2	4.0	4.1	2.3	3.5	3.9	3.9	4.3	4.4	1.7	2.5	1.1	1.2
Mode	[a] 1.0	1.0	1.0	2.0	5.0	5.0	3.0	4.0	4.0	5.0	5.0	4.0	2.0	2.0	1.0	1.0
Variance	5.4	5.9	3.8	1.2	1.0	0.9	1.0	0.9	0.6	1.0	0.6	3.4	0.3	1.1	0.1	0.2
Range	7.0	6.0	6.0	3.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	6.0	2.0	4.0	1.0	1.0

[a] More than one mode exists, only the first is reported

Table 0-1 Descriptive Statistics results (mean, Mode, Variance, Range)

Descriptive Statistics

	Q13.1	Q13.2	Q13.3	Q13.4	Q13.5	Q13.6	Q13.7	Q13.8
Valid	**598**	**598**	**598**	**598**	**598**	**598**	**598**	**598**
Mean	**1.5**	**1.6**	**1.7**	**1.7**	**1.4**	**1.0**	**1.1**	**1.0**
Mode	**1.0**	**2.0**	**2.0**	**2.0**	**1.0**	**1.0**	**1.0**	**1.0**
Variance	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.0**	**0.1**	**4.0e -2**

Table 0-2 Descriptive Statistics for Q13 (Mean, Mode, Variance)

Cross Tabulation

	Current (0% Green) Vs age				
Age	**18 - 25**	**26 - 40**	**41 - 50**	**51 - 60**	**60+**
Mean	2.6	2.3	2.1	2.4	2.1

Figure 0-1 Cross tab - Current (0% Green) Vs. Age

	25% Green wall Vs. Age				
	18 - 25	**26 - 40**	**41 - 50**	**51 - 60**	**60+**
Mean	3.7	3.5	3.4	3.1	3.4

	25% Trees Vs. Age				
	18 - 25	**26 - 40**	**41 - 50**	**51 - 60**	**60+**
Mean	4.0	4.0	3.9	3.8	3.9

	50% Green Wall Vs. Age				
	18 - 25	**26 - 40**	**41 - 50**	**51 - 60**	**60+**
Mean	4.0	4.0	3.9	3.7	4.0

	50% Trees Vs. Age				
	18 - 25	**26 - 40**	**41 - 50**	**51 - 60**	**60+**
Mean	4.2	4.3	4.4	4.2	4.4

	Current (0% Green) Vs Number of street daily visits per week							
	Rarely / infrequently (less than 4 times a month)	**1 day/week**	**2 days/week**	**3 days/week**	**4 days/week**	**5 days/week**	**6 days/week**	**7 days/week**
Mean	**2.3**	**2.4**	**2.2**	**2.4**	**2.5**	**2.2**	**2.4**	**2.2**

	Rarely / infrequently (less than 4 times a month)	**1 day/week**	**2 days/week**	**3 days/week**	**4 days/week**	**5 days/week**	**6 days/week**	**7 days/week**
Mean	3.5	3.4	3.5	3.4	3.6	3.5	3.6	3.5

	Q9							
	Rarely / infrequently (less than 4 times a month)	1 day/week	2 days/week	3 days/week	4 days/week	5 days/week	6 days/week	7 days/week
Mean	3.9	3.9	3.9	3.9	3.9	3.9	4.1	4.0

Q10

	Rarely / infrequently (less than 4 times a month)	1 day/week	2 days/week	3 days/week	4 days/week	5 days/week	6 days/week	7 days/week
Valid	228	76	56	44	39	100	23	32
Mean	3.9	4.0	4.0	3.9	4.0	4.0	3.8	4.1

	Q11							
	Rarely / infrequently (less than 4 times a month)	1 day/week	2 days/week	3 days/week	4 days/week	5 days/week	6 days/week	7 days/week
Mean	4.2	4.3	4.3	4.4	4.1	4.4	4.3	4.5

	Q5				
	18 - 25	26 - 40	41 - 50	51 - 60	60+
Mean	**4.0**	**4.0**	**4.0**	**3.9**	**4.2**

	Q5		
	Male	Female	Other / Prefer Not to say
Mean	3.9	4.1	3.6

	Q6				
	18 - 25	26 - 40	41 - 50	51 - 60	60+
Mean	4.2	4.1	3.9	3.9	4.0

	Q6		
	Male	**Female**	**Other / Prefer Not to say**
Mean	**4.0**	**4.1**	**3.7**

Pearson's (r) Correlation heatmap

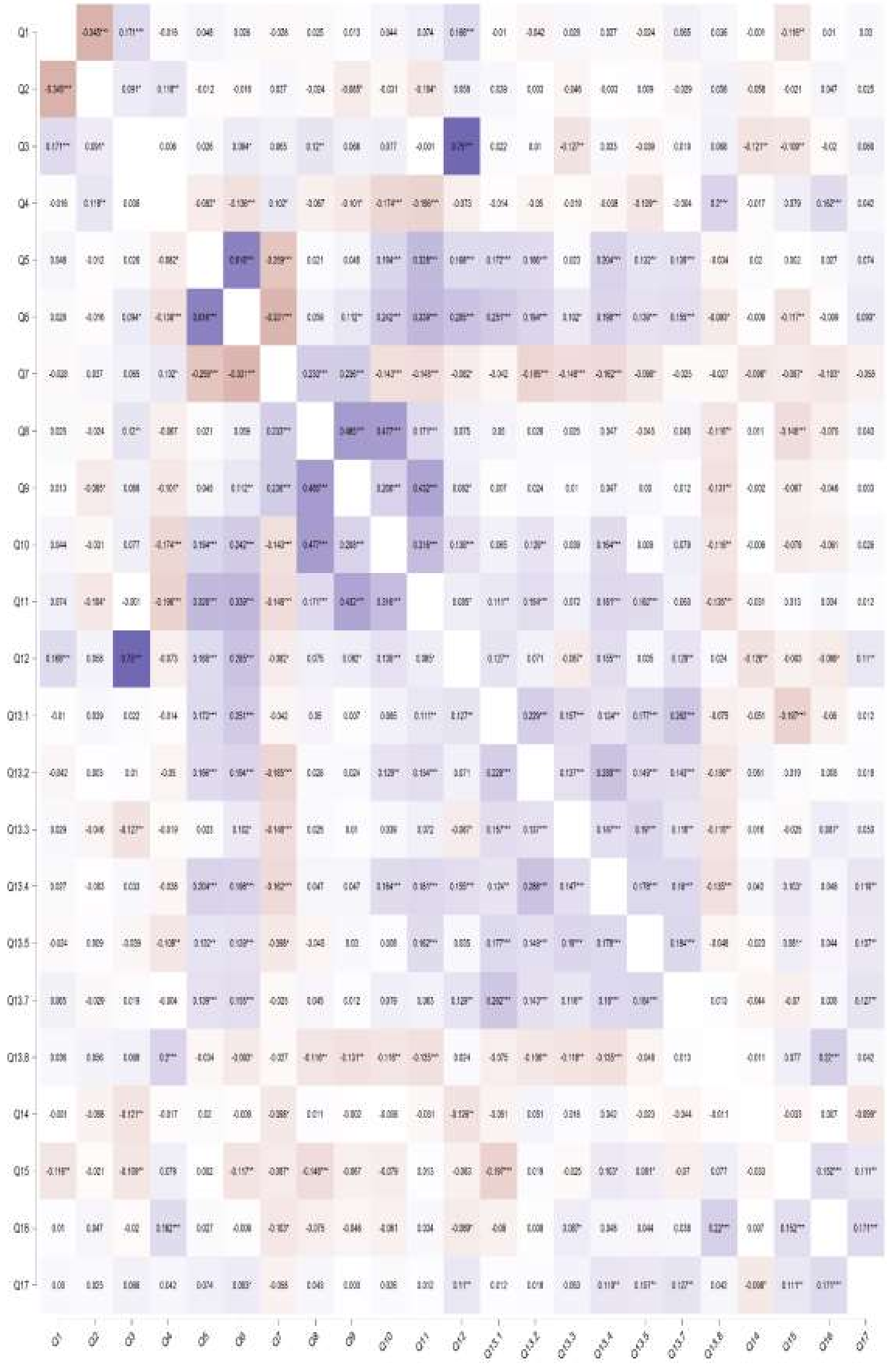
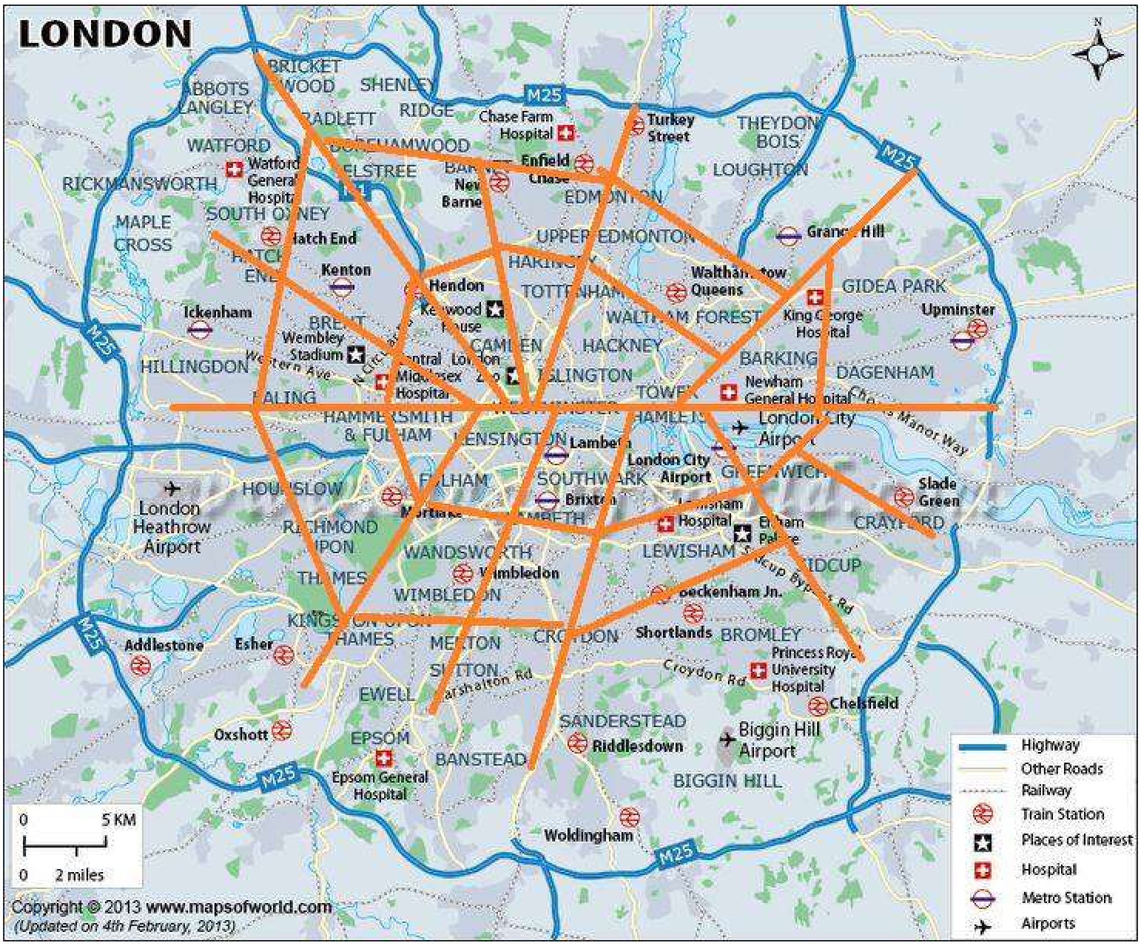


Figure 0-2 Pearson's r heatmap

Appendix G – Survey participants graphical illustrations

The following illustration is quoted from Tony Franklin, who made his precious comment among other valuable comments on a Facebook page (Stop Killing Cyclists).

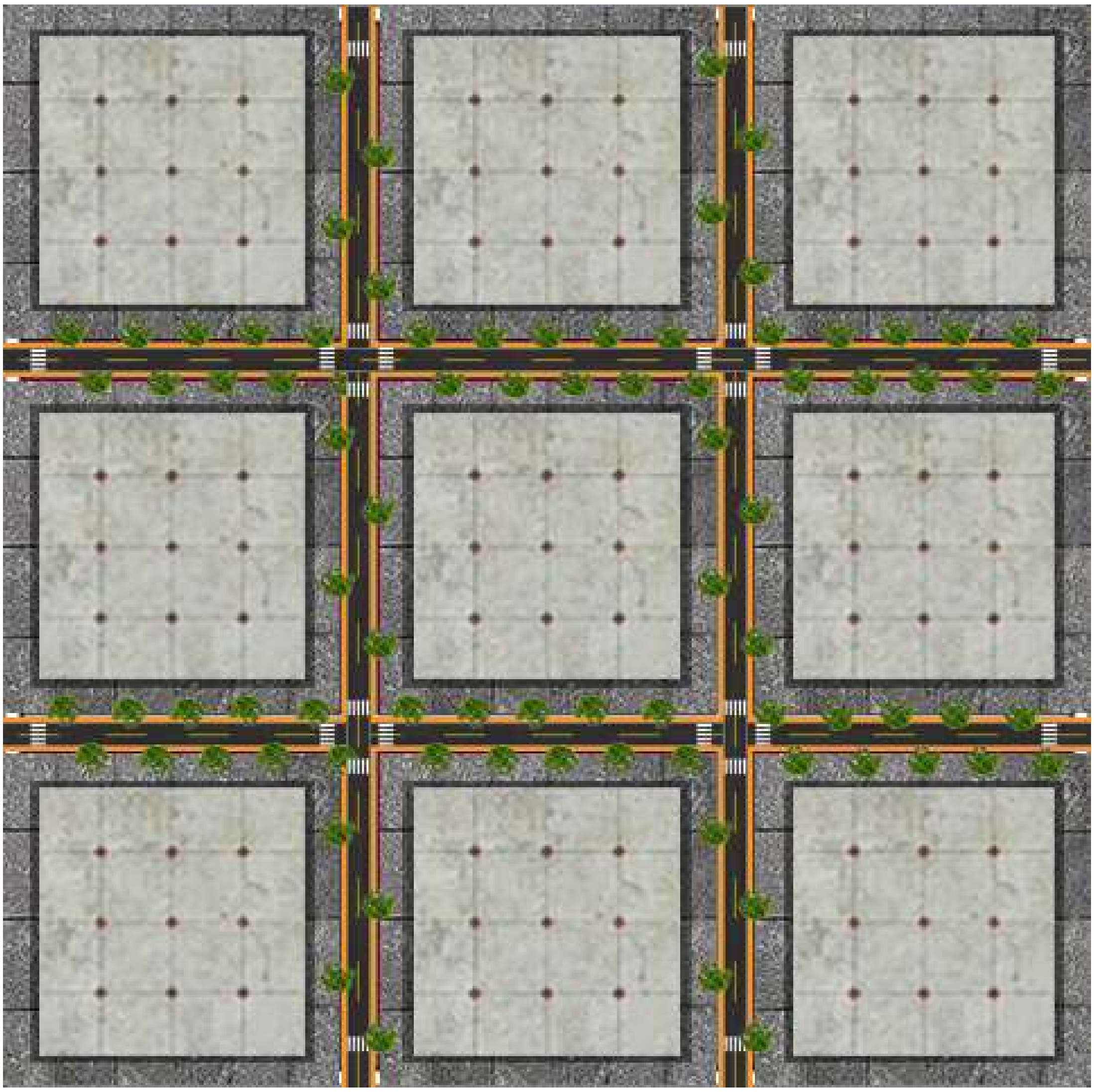


Mr Franklin represented his graphical illustration saying that “The picture below illustrates a basic starter to have an 8 metre wide highway connecting all parts of London. 4m wide in each direction, no access from streets by motor vehicles onto the highways. Knock down properties if need be, shut down roads to motors to accommodate a proper highway that could transport millions every day. it would still cost less than Crossrail and take months not decades. Cost benefit ratio is massive. Wide lanes allow cyclists of all types to use it at the same time from 4-year olds to seniors, sporting cyclists, people needing modified cycles and any other type. Segregated lanes that are currently being pushed are utterly useless, they have no attraction to a large portion of people who might want to cycle or cycle already. I've cycled on the so called 'superhighways' in London and they are dangerous and simply too narrow for proper safe cycling for large numbers, they're restrictive in access/egress, circuitous (desire lines are massively important) and don't join up to the places people need to travel to. If you don't stop up roads to motors, don't remove parking both in the residential, retail, business, industrial etc, don't make motoring massively more difficult than you can put as many cycle lanes in as you like it won't make much of a dent. You only need look at Paris to see how 'building' cycle lanes has failed to get much uptake of cycling. their 6-year plan fell flat on its face, modal share has not changed from 2014 and their target of 15% modal share is a pipe dream. Them fudging cyclist numbers by doing counts on a day they knew had public transport strikes and a cycle race thus closed roads fools no-one. Even in the Netherlands cycling is going down despite more cycle infra investment, more car ownership, more driving, why, because they build lovely wide roads for motorists that go everywhere so make driving easy".

Appendix H – Survey Demographics

Participants Number	**Gender**			**Age**				
598	**Male**	**Female**	**Others**	**18-25**	**26-40**	**40+**	**50+**	**60+**
Percentage (%)	**32**	**65**	**3**	**15**	**46**	**19**	**15**	**5**

Appendix I – London Illustrations by researcher by the researcher based on Research findings and Discussion



A proposal for street layout after applying 50% trees in EW street canyons and 25% trees in NS canyons and green walls across all canyons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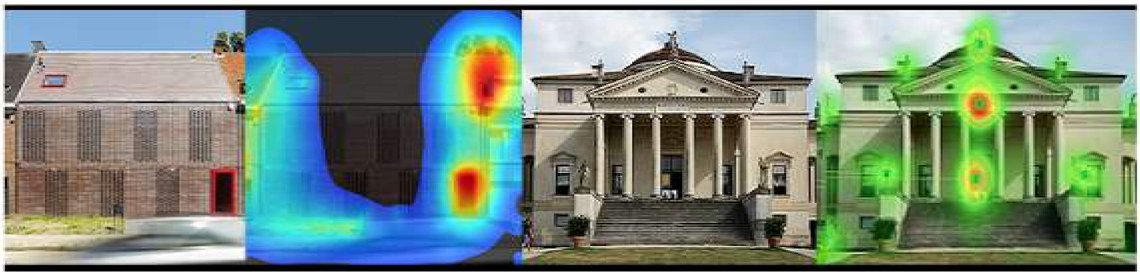
Proposal for London street with trees and green walls by Marshalls who explored the future of the UK's building environments and how they can adopt more urban greenery to create eco-friendly cities. This proposal was created similar to the researcher proposal who suggested a mix between trees and green walls for Londoners. This picture was edited by the researcher (including cycling lanes, one lane for traffic for each direction) to complete the full view of making London Greener.

Appendix J - Physiological and Emotional Analysis

Physiological and Emotional Analysis

Biometric tools as electroencephalogram which measures brain waves; facial expression analysis software that follows our expressions changes; and eye-tracking, which helps us to record unconscious eye movements, are increasing massively in all concepts, ideas and product development nowadays, beyond the psychology departments or medical labs where you they were originally were used in (Ann Sussman and Janice M. Ward, 2017). Thus, there is an increasingly use high-tech tools to understand hidden human behaviours, and then the designers would be able to design their products to meet users' needs and requirements.



There was a deep interesting study carried out using four pilot studies on how we look at buildings in 2015 which utilised these previous technologies in order to understand how architecture influence people and it also helps us to predict human responses (what they are looking at the first time, where they like and which not). This was represented through Visual Attention software which creates heat maps that glow brightest at points which people look most, and visual sequence diagrams, (above right), predicting the sequence people will likely look at details within pictures. Eye tracking tools record how long a the individual spends while observing or reviewing at an object and their viewing patterns, not their positive or negative emotional responses (Hollander, Sussman and Carr, 2018). This study declared that humans ignore blank facades, fixing design drives explorations, and people look for people all the time within pictures (Ann Sussman and Janice M. Ward, 2017; Lingchuan Meng, 2019).

Professor Colin Ellard, run a research on how fascination for how streetscapes impact us within a book (Places of the Heart: The Psychogeography of Everyday Life) which described how the physical surroundings would influence everything we do, as investigating how buildings and street layouts influence our brains, bodies, stress levels, and overall health (Ann Sussman and Janice M. Ward, 2016).

For instance, trying to collect information about the experience of urban pedestrians to understand the influence of buildings on their behaviour, in case we're seeing and interacting with only the bottom a building, how we are going to optimize the building façade and change its materials? Which parts either for street or buildings are getting more attention? With eye and screen tracking we would be able to measure that.

These technologies and studies helped us to integrate more different specialisation of different fields in order to understand human preferences and human perception which reflects a different perspective of human science either within architecture, urban and city planning and their influence on human factor.

Physiological and Emotional Analysis Softwares

Thus, within outdoor urban spaces, the discomfort factors due to microclimatic changes would have the major impact on peoples environmental (thermal aspects) and social condition (behavioural aspects). Hence, exploring, quantifying and assessing these conditions requires not only innovative computational tools and methods, but the investigation of new sources of information as well (ClimateFlux, 2020).

For urban planning, this new technological era means we can record how people see and feel about their surroundings and environments, not as machines, but as creatures who cares for nature connection which is also affected and limited by anxieties. Thus, through the latest technological software, we would be able to collect actual world, real-time data about emotional behaviours in the built environment and to definitively answer constant questions such as why people enjoy walking through miles of a dense urban settings more than others and to which extent (Ann Sussman and Janice M. Ward, 2016).

Nowadays, it's possible with affordable new software tools, we can track subconscious predispositions and use quantifiable to explain the human reaction to an existing case or predict reaction to a new alternatives or proposals for proposed cases. Urban Planning will be developed in a quantifiable and trackable in the 20th century.

What this research is looking at is using screen tracking and facial emotional analysis in order to investigate the instant subconscious response and behaviour of people towards different urban scenes to inform the design of the built environment.

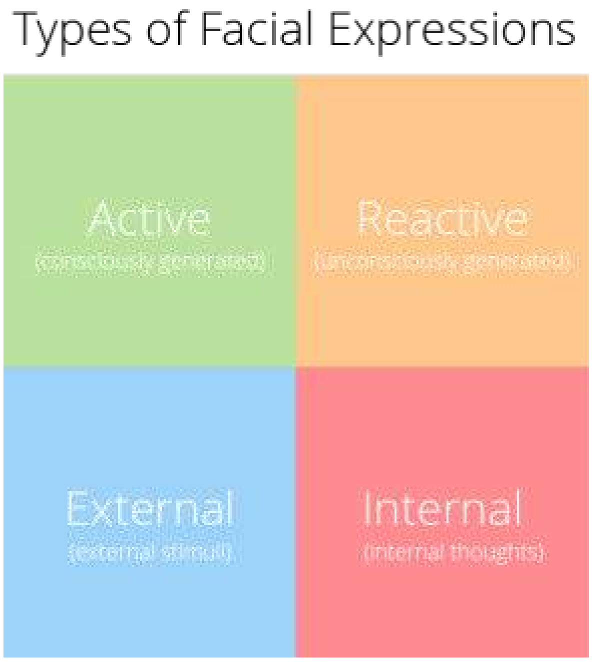
Emotions or Feelings

Almost all of us consider emotions and feelings are pretty much the same at which the two words reflect the same meaning as a synonym although they depend on each other's, they are different from each other's. Usually people get a feeling when they face an emotional experience and conscious thoughts, however, emotions describe physiological states and are generated subconsciously (iMotions, 2015b)

Types of Facial Emotional Expressions

The human face has 43 muscles controlled by 2 facial nerves linked to the front of the head, and these muscles have no other visible purpose than to transport emotional information to others using these muscles (Jessica Wilson, 2017).

The average of facial expression is around 0.67 – 4 seconds. In addition to researchers classifications for emotions to 7 core emotions (happiness, sadness, surprise, fear, anger, disgust and contempt). Each has its own muscles movements features for instances happiness is linked o raised cheeks and lip corners pulled up while sadness is linked to inner brows raised, brows lowered and lip corners depressed (Elvira Fischer, 2018).



(Jessica Wilson, 2017).

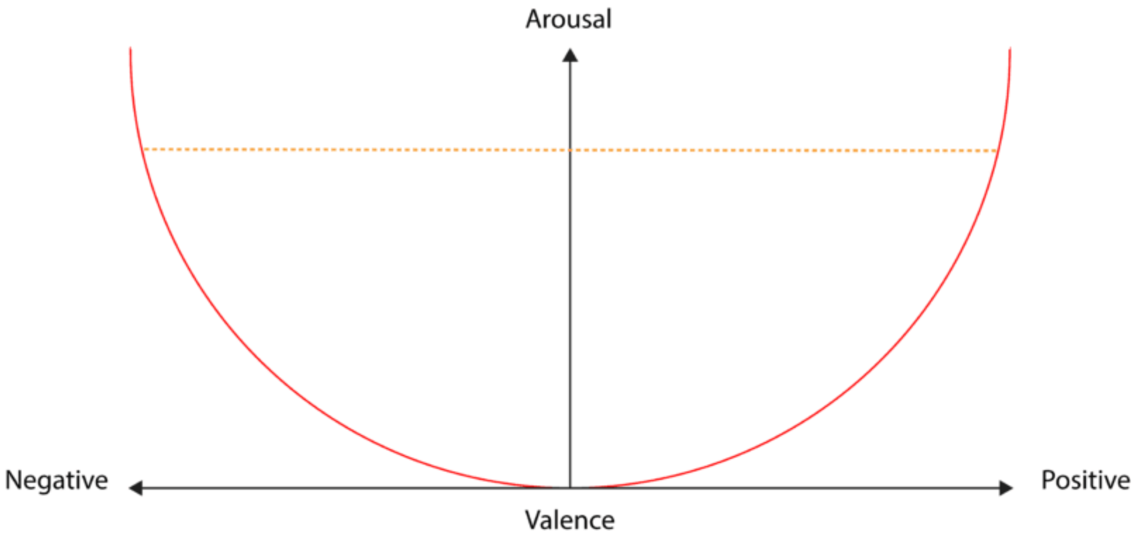
We can change our facial expressions as an actor, while reactively as laughing to a funny joke. Facial expressions can be stimulated by external factors as tasting a drink or food, and finally internal emotional expression as thinking about food while you are on diet (Jessica Wilson, 2017). Based on these, it was easily identified the different type of facial emotional expressions and the emotions the human face reflecting.

Facial Emotional Analysis

Coherently, there would be recorded video for a sample only who will voluntarily accept their faces being recorded, It is expected that this sample will be quite small compared to workers numbers as participants might not like to share their facial expressions being recorded. Taking into consideration that it is a very time consuming to analyse the facial emotional analysis for all the sample after recording their facial expressions while completing the online survey.

Time spent while checking each UGS alternative picture and his screen tracking on what the person who fills the application is mainly looking at precisely (green, street) in order to specify the most appropriate UGS alternative from the human perspective which was similarly investigated by (Jiang, Chang and Sullivan, 2014; Suppakittpaisarn et al., 2019). At this phase, VR glasses might be used to give participants better understanding and views of proposed alternatives and their proposed visualisation in reality.

Facial expressions allow researchers to observe participants' emotional states. Through a camera-based facial recorder and automatic emotion detection software have numerous benefits for instance you don’t have to attach or link participants with any wires, just analyzing their facial emotional outcome as a reflection from what they are seeing (iMotions, 2015c)Facial expression analysis is important for measuring and calculating emotions and emotional valence, which is a extra abstract measure of the negativity or positivity of the emotional expression. For instance, the emotional state of “happiness” most probably has a just positive valence (“Yay, I won a prize!”), whereas the emotional state “surprise” can comprise both positive (“Oh, a gift card!”) and negative (“Oh, an accident!”) aspects.



(iMotions, 2015c)

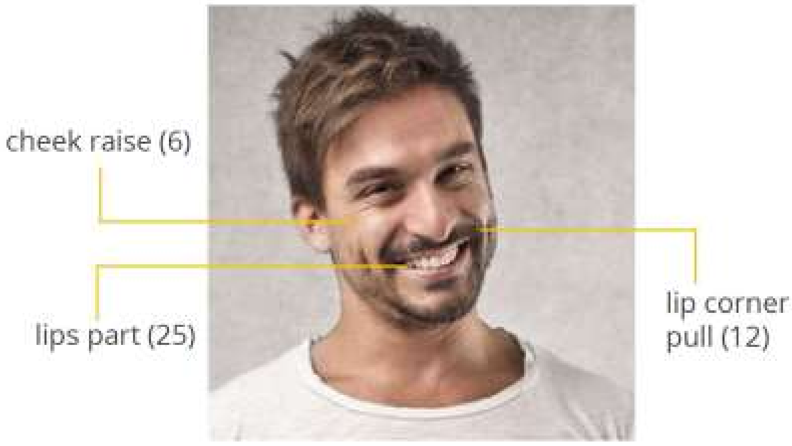
As Steve Jobs said, “The broader one's understanding of the human experience, the better design we will have”.

Both the facial emotional analysis and the online survey would strongly represent the human factor and human participation on different UGS alternatives, which would finally lead to guiding designers and policymakers into integrating the most applicable UGS alternative with the most appropriate percentage.

Facial Emotional Analysis Techniques mechanism

In general, facial muscles movement due to emotional reaction can be recorded and analysed in three different methods which are The Facial Action Coding System (FACS), Facial Electromyography (fEMG) and Automatic facial expression analysis (iMotions, 2016).

The Facial Action Coding System (FACS), it follows facial expression based on anatomic features at which each individual face muscle is linked an action unit (AU1, AU2, etc). Despite it shows the muscles movments, it does not read emotions as it is a measurement or indication system for facial muscles movments It is mainly relaying on visible changes in facial muscles and tissues and it collects the score or number of moved muscles.



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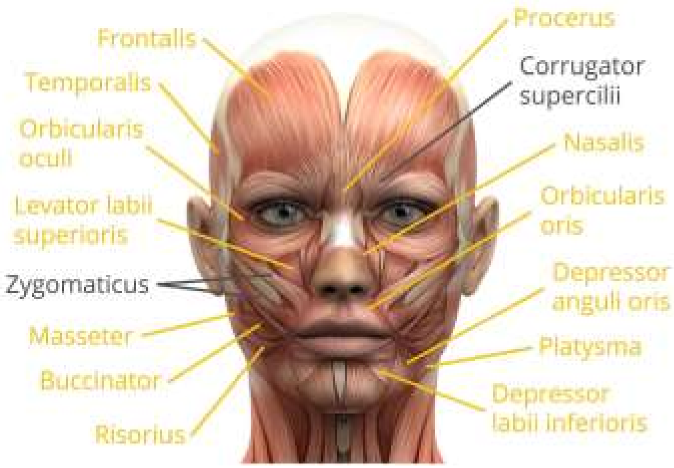
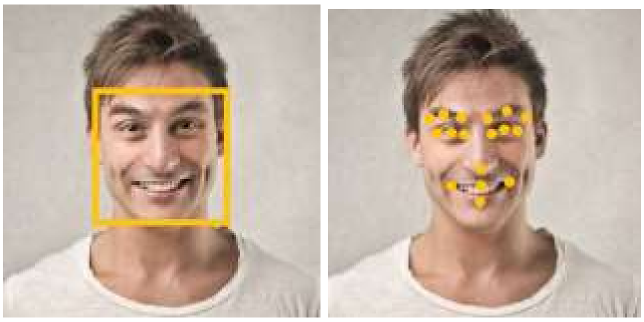
Facial Electromyography (fEMG)uses electrodes to be attached to the skin surface to amplify any tiny electrical impulses for faces around eyebrows, cheekbones and mouth. For instance Drawing the eyebrow downward near the face centre, the corrugator supercilii is a pyramidal muscle close to the eyebrow, generally active when stating negative emotions such as suffering. While The zygomaticus extends from each cheekbone to the corners of the mouth, usually associated with positive emotions as smiling



Automatic facial expression analysis is, reflects a computer-based Algorithms instantly detect faces, code facial expressions, and recognize emotional conditions. It goes through three stages while recording a video which are facial detection, then Facial landmark detection and registration and finally Facial expression and emotion classification



Compared to FACS or fEMG, automatic facial expression analysis doesn't require specialized high-class equipment, electrodes, cables, or amplifiers.

Screen Tracking

Screen tracking is an impressive way of determining visual attention. However, it can be utilised for many different aspects and applications with research, its main aim and goal is to specify and indicate where exactly participants look at (top of picture, down, right left, which colours grapped their attention, which items, which component of the photo illustration. In addition to analysing the reasons behind that through specifying whether their curiosity and interest or driven by provoking stimuli that draw their attention

It aims to predict where individuals will look in pre-attentive processing, the first few seconds they take in a visual illustration scene, before their conscious brain can act and that would demonstrate how expressively these human hidden behaviours influence our experience of a specific environment.

Eye tracking or screen tracking records visual resting points which is called fixations, and the rapid movements between them which is called saccades, which both can give understanding into what features of an image immediately grabs individuals attention. This technology is generally used today to measure the usefulness and effectiveness for designs, marketing, advertising and medical disciplines (Justin Hollander et al., no date). With screen (or eye) tracking researchers are able to explore how participants will visually evaluate and choose across different visual alternatives, for how long (as in duration) they focus on specific areas (fixation time) and how frequent they look at that certain area (fixation count). Based on the resulted statistics it would be possible to draw areas of interest (AOI), which are user-defined choices of one or many alternatives, areas within their choices, revealing their attention results (iMotions, 2015a).

Why it is better to use both Screen Tracking with Facial Expressions (Limitations of single usage of one of them)

Screen or eye tracking tools records the duration the individual spends looking at an object, not their emotional response whether it is positive or negative. Therefore, For that critical information, researchers combine screen or eye tracking with other biometrics as facial emotional analysis. Eye or screen tracking tools are powerful because they help us ‘see’ our hidden inner judgment for our surroundings which are determined unconsciously, or ‘pre-attentively.’ Which will help to predict the success of a design alternative before it’s construction or applying into action. In addition to main objectives, facial emotional expressions are also affected by mentalization, memories, opinions and views, thus, combining screen tracking and facial expressions is influential combination that helps researchers to easily get much more data, evidence and information about a human reaction to a certain stimulus.

Neither screen trackers nor facial recording requires biosensors which have to be attached to the body, which allow researchers to get understandings in real-world test scenarios To maximize the analytic power of facial emotional expression analysis, researchers might combine valence (the quality of the emotion) with arousal (the strength of the emotion). Fascinatingly, arousal can be predictable from measuring human dilation, so this is just another purpose to combine facial capture and screen tracking as you can extract and combine many more metrics for a higher levels of validation (iMotions, 2015c). The importance of linking both Eye or screen tracking tools will increase when the emotions are not clear due to the lack of interaction of receptors (participants) as photo or video illustrations might not be stimulating enough of their facial muscles or emotions especially if it is not linked to one of the key reasons of life (food, drink, life or death) or violence images for instance as well since these factors might have larger influence on participants reactions.

Conclusion of Facial emotional analysis software limitations

However facial emotional analysis software is very beneficial to understand the facial emotional reactions associated with different UGS alternatives with different percentages within Oxford street, yet it was not clearly able to show massive change with different pictures or different percentages due to different reasons as the following:

Facial muscles reactions usually need a massive action so they can reflect this action with an obvious reaction and the more sensitive and touching the heart or stimulate human emotions it is, the more facial reaction would appear. Thus, in this study, it has slightly shown unaddressed points, analysis and consideration which is usually were unsaid before or during previous studies, yet it is important to mention or study or indicate these emotions or reactions. Facial emotional reactions could be compound or mixed due to the diversity of human emotions or complexity of human reactions and feelings towards the different environment. Thus, the software could show similar or different emotions for the same picture. These limitations require integrating more facial emotional analysis software in order to give a deeper view as screen tracking,